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DISTRIBUIÇÃO: ***Associações Distritais*** **e Clubes**

ASSUNTO: Formação: Balanço do Exercício 2004/2008

Juntamos em anexo o Balanço relativo ao Exercício 2004/2008, no que diz respeito ao sector da Formação.

João Paulo Vilas - Boas
Vice - Presidente

Balanço do exercício 2004/2008 do Sector de Formação da FPN

Precipitaram-se vertiginosamente os últimos quatro anos, durante os quais, mediante proposta da Associação Portuguesa de Técnicos de Natação (APTN), desempenhei as funções de Vice-presidente da FPN para a Formação. No início do nosso mandato submeti à apreciação dos meus colegas de Direcção e à família da natação, uma "declaração de intenções" para o período de exercício que se avizinhava. Hoje, terminado o mesmo, chegou a hora do balanço.
Confrontando-nos com o documento inicial, julgamos que o Sector de Formação da FPN tem matéria de que se orgulhar, mas também outra relativamente à qual reconhecemos ter sido excessivamente optimistas. Umas e outras não deixarão de ser, por certo, matéria e experiência relevante para os responsáveis que nos sucederem. Que possam realizar melhor trabalho neste domínio e que a nossa experiência e os trilhos que abrimos os possam ajudar, é o que desejamos.
Comecemos o nosso balanço pela positiva!

1. Orgulhamo-nos de ter reorganizado o Sector de Formação, permitindo ultrapassar as actividades de gestão corrente e lançar novas iniciativas e conceitos. Neste domínio destacamos:

1.1. A efectiva implementação do Plano Nacional de Formação, formalmente escorado sob propostas regionais que impunham a existência de planos regionais de formação. A este nível conseguimos articular procedimentos num quadro estratégico nacional coerente, nutrido pela avaliação semestral do rendimento regional e nacional, e lançar o hábito de definir estratégias de remediação, que passaram quase sempre pelo lançamento e redistribuição de novas iniciativas;

1.2. A normalização, estratificação e harmonização das taxas do Sector de Formação, lançando estratégias de reforço orçamental baseadas no justo valor retributivo do exercício administrativo, nomeadamente através de emolumentos administrativos;

1.3. A criação de uma Bolsa Nacional de Formadores, através da qual se certifica internamente a qualificação dos formadores que prestam serviço ao Sector, bem como elenca e disponibiliza um inventário de profissionais credíveis e disponíveis para as iniciativas das Associações, dos Clubes e, inclusivamente, de pessoas individuais;

2. Orgulhamo-nos de ter estendido o conceito de Formação aos diferentes agentes desportivos e não exclusivamente aos técnicos desportivos e árbitros, conferindo-lhe uma abrangência mais consentânea com a importância dos contributos de cada um e reforçando o potencial de crescimento da natação imputável a cada qual. Neste particular, sublinhamos o lançamento de acções de formação para diversos públicos-alvo, relevantes para o progresso da modalidade, nomeadamente: (i) ex-praticantes; (ii) praticantes de alta competição em actividade; (iii) praticantes *Masters* em actividade; (iv) potenciais praticantes em formação; (v) formadores; (vi) médicos e paramédicos; (vii) dirigentes; (viii) administrativos, (ix) técnicos de piscinas e (x) pais:

2.1. No caso particular dos ex-praticantes, lançamos uma formação integrada (de técnico, de árbitro e de dirigente) que tem merecido os mais elogiosos comentários de diferentes sectores, não apenas pelos méritos explícitos, mas também, e sobretudo, pelo carácter exemplar que a caracteriza, na esteira das perspectivas enunciadas a este respeito pelo Senhor Presidente do Comité Olímpico

Internacional. De facto, procura-se com esta formação, a um tempo, reaproximar e fidelizar os antigos praticantes à modalidade, elevando a probabilidade de darem continuidade benévola ou profissional à sua ligação e expressão plena ao seu grande conhecimento dela, bem como proporcionar uma alternativa profissional a quem tanto se dedicou à modalidade;

2.2. Aos praticantes de alta competição procuramos proporcionar formação complementar em domínios nucleares como a psicologia, a nutrição, as ajudas ergogénicas e o doping, a profilaxia de lesões, o controlo e avaliação do treino, etc., reforçando os vectores aparentemente menos prioritários da educação desportiva tradicionalmente proporcionada no clube, mas de extrema importância para o quotidiano, para a longevidade desportiva e para o desempenho do praticante;

2.3. Aos *Masters*, tradicionalmente menos enquadrados tecnicamente, procurou-se proporcionar-lhes formação técnica propriamente dita, potenciando a sua capacidade para se auto-treinarem, mas valorizando sempre o enorme prazer e voluntarismo que emprestam à sua prática e procurando fazer com que o próprio perfil da formação proporcionada se aproximasse da forma como os sujeitos se dedicam à modalidade;

2.4. Os jovens potenciais praticantes, sobretudo das modalidades emergentes e/ou inexistentes (Pólo Aquático, Sincronizada e Saltos), mas também da Natação Pura, foram objecto de programas de formação particulares, desenvolvidos em contexto dos Programas de Desenvolvimento Desportivo (PDD) do Instituto de Desporto de Portugal (IDP). Tratou-se de programas de investimento prioritário do IDP, da FPN e do Sector de Formação, que mobilizaram milhares de crianças e que poderão constituir uma iniciativa âncora fundamental para a promoção e salvaguarda do futuro das modalidades. Complementarmente, a gestão da imagem e da marca dos PDD foi muito conseguido, constituindo estes algumas das iniciativas mais procuradas pelas Associações e pelos Clubes;

2.5. A este nível (PDD), os esforços desenvolvidos na formação de formadores foram excepcionais, tendo-se materializado em diversas acções práticas e na edição de um manual emblemático, de que nos orgulhamos profundamente;

2.6. A oferta de formação da FPN estendeu-se também ao sector médico, paramédico e de apoio técnico ao treino, com múltiplas acções, nem sempre tão procuradas como gostaríamos, mas sempre de elevada qualidade. O recurso a profissionais altamente qualificados, experientes e de reconhecida competência nos espaços académico e desportivo foi, a este nível, uma preocupação central. O leque de ofertas estendeu-se também ao apoio psicológico ao treino, área onde fomos particularmente insistentes, cientes que estamos de que o culto das competências psicológicas e, de entre estas, da motivação e da perseverança, constituirão vectores axiais do desenvolvimento desportivo da natação nacional;

2.7. A formação para dirigentes desportivos foi também insistentemente implementada, numa parceria excelente com a APOGESD (Associação Portuguesa de Gestão Desportiva), que veio permitir lançar fundamentos de formação em Gestão Desportiva de carácter quase-profissionalizante entre os dirigentes benévolos, que esperadamente contribuirá para o reforço da sua capacidade de intervenção e de sustentação das condições de prática dos seus praticantes. Complementarmente lançámos múltiplas acções de formação dedicadas a plataformas de suporte informático de gestão do clube (*Splash TeamManager*) e da competição (*Splash MeetManager*), bem como do *FPNSystem*, requerido para a gestão da participação competitiva dos praticantes;

2.8. A formação conferida no domínio informático, restrito ou mais geral, foi estendida também aos funcionários administrativos da própria FPN. Formação complementar dedicada aos administrativos da FPN em domínios carenciados de competências foi também proporcionada;

2.9. No que respeita à formação de técnicos de piscinas e espaços aquáticos, muito procurada agora como no passado, foi seriamente consolidada através do reforço da excelente relação de cooperação estabelecida com o Instituto Politécnico do Porto, através, sobretudo, da iniciativa e da generosidade do Senhor Engº Vitorino Beleza. Concretizando mais aprofundadamente esta relação, foi preparada a protocolarização da certificação profissional no domínio com a FPN como par;

2.10. Finalmente, orgulhamo-nos profundamente de termos ousado intervir numa comunidade essencial para o futuro da modalidade: os pais e as famílias dos nadadores. Pretendida como uma formação de largo espectro e despretensiosa no seu conceito, procurou-se desta forma desmontar comportamentos tantas vezes inadequados e valorizar outros, absolutamente decisivos para o sucesso da modalidade. Ao mesmo tempo procurou-se consciencializar os pais para a natureza e exigências do treino e para a sua variação ao longo da carreira do nadador. Procurou-se revalorizar o sucesso, estende-lo a mais do que ao campeão e procurou-se alimentá-lo através de um mais consequente labor "invisível", em casa, desde a mesa até ao sono, passando pelas conversas e pela afirmação de valores verdadeiramente compatíveis com o melhor espírito desportivo. Esta foi, talvez, das áreas de maior sucesso do nosso exercício.

3. Orgulhamo-nos de ter dado passos consistentes no domínio da formação de técnicos e árbitros, especialmente no que respeita: (i) à diversificação da oferta de formação; (ii) ao lançamento de novas rotinas; (iii) à uniformização terminológica em treino e ao lançamento das bases de um Plano de Carreira Nacional; (iv) à reestruturação de cursos e revisão curricular dos cursos e (v) à concepção de um Sistema Nacional de Graduação Profissional de Técnicos de Natação:

3.1. Apesar da diversificação da oferta de formação ter acontecido sobretudo no que respeita aos técnicos - e não tanto aos árbitros -, ela não deixou de ser um facto e, sobretudo, um facto que viabiliza um alargamento de horizontes e do mercado de trabalho dos mesmos. Concomitantemente, esta diversificação correu baseada na participação de formadores de elevada craveira nacional e internacional e estendeu-se, para além das mais comuns e ortodoxas, a áreas como a Natação em Águas Abertas, o Socorrismo e Salvamento Aquático, Natação Desportiva de Salvamento, Actividades Aquáticas Não Competitivas (Hidroginástica, Natação para Bebés, ATSO) e Natação Terapêutica e Natação Desportiva Adaptada (em articulação com a Federação Portuguesa de Desporto Adaptado);

3.2. Uma das novas rotinas implementadas durante o presente mandato consistiu na organização de acções de formação concomitantemente à realização dos diversos Campeonatos Nacionais. Trata-se, porém, de um hábito não completamente consolidado, não tanto no domínio organizativo – onde se espera que, de futuro, cada candidato a uma organização nacional passe a incluir *ab initio* o respectivo projecto de acção de formação no programa do evento -, mas sobretudo no domínio da participação dos técnicos. De facto, ao contrário do que acontece nas grandes competições europeias e mundiais, onde as acções de formação para técnicos são normalmente organizadas e sempre muito concorridas pelos treinadores presentes (treinadores de nível de selecção, leia-se…), nas acções nacionais foram normalmente muito poucos os técnicos presentes, apesar da diversidade, oportunidade e novidade dos temas, bem como da qualidade dos prelectores convidados. Isto talvez se tenha devido a falta de tempo, ou de interesse, mas pensamos que se trata sobretudo de uma questão de hábito e de cultura - de cultura de formação, que às vezes parece escapar aos nossos técnicos (a menor presença nos Congressos da APTN ainda se pode justificar pelos custos associados, mas durante os Campeonatos Nacionais os treinadores não se vêm obrigados a grandes deslocações, a pagamentos de alojamento e, muito menos, a pagamento de inscrição). Esperamos que a luta agora iniciada possa prolongar-se no tempo e dar espaço a uma necessária transformação de mentalidades neste domínio, muito a exemplo do que já aconteceu na Natação Adaptada, onde as acções muito bem sucedidas que fomos levados a organizar mostraram uma vontade insaciável de aprender. Se assim for, o apoio que proporcionamos a vários técnicos nacionais para participarem em congressos internacionais será uma iniciativa a reforçar e a valorizar no futuro; caso contrário importará que a FPN se interrogue acerca da propriedade desse esforço, se muitas vezes a oferta nacional é menosprezada (deverá "pagar o justo pelo pecador"?);

3.3. Novas rotinas foram também tentadas através das iniciativas de uniformização e harmonização terminológica em matéria de treino desportivo, bem como no que respeita à conceptualização do Plano de Carreira subjacente à formação do nadador nacional. Em ambos os casos e em estreita articulação com o

Departamento Técnico, lançamos acções nacionais de formação/debate que conduziram à convergência para uma plataforma terminológica comum que facilite a mobilidade de nadadores entre técnicos, nomeadamente quando ao serviço de selecções nacionais, bem como para um Plano de Carreira do Nadador Nacional, que não deixará de contribuir para uma mais conseguida e harmonizada estruturação das cargas ao longo da carreira desportiva, obstando ao abandono precoce e favorecendo a maximização do rendimento desportivo no momento mais oportuno para o efeito;

3.4. No que diz respeito à reestruturação dos cursos de formação de treinadores e árbitros, o trabalho desenvolvido centrou-se sobretudo nos domínios da revisão curricular, já realizada para o Curso Elementar de Arbitragem e para o Curso de Árbitro Nacional (através do Conselho Nacional de Arbitragem), e de 1º e 2º níveis de formação de técnicos, bem como na concepção de um novo figurino para os últimos. Nestes (2º Nível) passou a considerar-se um tronco comum de formação e um tronco vocacional (Ensino, Natação Pura, Pólo Aquático, Natação Sincronizada), que pode ser cursado cumulativamente pelo mesmo treinador, e que permite promover formação não deficitária de treinadores para os sectores mais carenciados (Pólo Aquático e Sincronizada), curiosamente aqueles onde a procura é também menor e as mais das vezes insuficiente para justificar a organização de um curso completo;

3.5. Por último (mas, como se compreenderá, não o menos importante), neste mandato foi possível concretizar um modelo para a implementação de um Sistema Nacional de Graduação Profissional de Técnicos de Natação (SNGPTN). Tratou-se, de facto, da primeira tarefa que concretizámos (a concepção do modelo), e cuja implementação efectiva foi adiada para a segunda metade do mandato devido a razões estratégicas. Porém, no início dessa segunda metade, o IDP mostrou-se interessado no conceito e propôs-nos que o desenvolvêssemos para suportar o modelo nacional a generalizar a todas as modalidades desportivas. Assumimos e concretizámos também essa tarefa no início de 2007, tendo o primeiro projecto de Decreto-Lei sido concluído em Junho pelos Serviços Jurídicos da Secretaria de Estado da Juventude e Desporto (SEJD). Decidimos, então, aguardar pela sua publicação, bem como pela da restante regulamentação (então e ainda iminente…), ao invés de implementar o sistema restrito, que implicaria a duplicação de custos de processamento. Todavia, quando, depois, propusemos à Assembleia Geral (AG) da FPN a aprovação do novo Regulamento do Sector de Formação, harmonizado com o restante quadro regulamentar da FPN, admitimos avançar mesmo unilateralmente neste processo, pressupondo poderem continuar a verificar-se atrasos maiores por parte do Governo. Para tal requeremos o apoio massivo da AG, o qual não se veio a verificar por toda a nova regulamentação proposta pela Direcção ter sido retirada de discussão e adiada para debate posterior. Esperamos, naturalmente, que o trabalho que realizámos - e que continuamos junto do IDP e da SEJD - chegue a bom porto, permitindo que o próximo mandato possa implementar o SNGPTN;

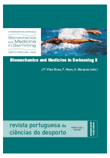
4. Orgulhamo-nos de ter contribuído decididamente para a construção da memória colectiva da modalidade, fundamentalmente através de duas iniciativas:

4.1. Através do encerramento das “gerações papel” dos rankings nacionais de natação pura, que não eram publicados desde 2003/04. Concretizámos a edição desse e de mais dois, até viabilizarmos a sua produção electrónica on-line;

4.2. Através do lançamento da Histórias dos 100 Anos de Campeonatos Nacionais de Natação, cujo primeiro volume foi lançado já em 2008 e cujo segundo e último volume está previsto para publicação em Dezembro;

5. Orgulhamo-nos também de ter proporcionado à família da natação nacional, mas sobretudo aos técnicos, médicos e paramédicos, a possibilidade de participarem a custos excepcionalmente reduzidos, no mais importante congresso mundial consagrado à natação, especialmente no que à sua expressão científica e à fundamentação da prática diz respeito. Tratou-se, efectivamente, de uma oportunidade formativa ímpar, dificilmente replicável no futuro, onde uma elite de “conhecedores” da natação mundial foi trazida até junto dos profissionais

portugueses. De facto, em Junho de 2006, em co-organização com a Universidade do Porto, Faculdade de Desporto, a FPN organizou o *Xth International Symposium Biomechanics and Medicine in Swimming*, evento que se realiza de 4 em 4 anos sob os auspícios do *Steering Group Swimming* da *World Comission for Science in Sport* (UNESCO), que reúne a generalidade da comunidade científica congregada em torno da natação e onde se apresentam todos os mais recentes progressos operados no domínio do conhecimento da natação e do nadador, desde 1970. Foram quase 400 participantes, de quase 40 países, que puderam assistir a mais de uma centena de novos contributos para o progresso do conhecimento da natação, a maioria dos quais plasmados na obra:



Vilas-Boas, J.P.; Alves, F.; Marques, A. (eds). *Biomechanics and Medicine in Swimming X. Portuguese Journal of Sport Sciences,* 6 (Suppl.2), 2006. Universidade do Porto, Faculdade de Desporto, Porto.
Estando já esgotado, segue em anexo PDF um exemplar do livro.

6. Orgulhamo-nos ainda de ter deixado um legado de nova regulamentação específica do Sector de Formação, harmonizada com todo o restante quadro regulamentar da FPN, incluindo o próprio Sistema Nacional de Graduação Profissional de Técnicos de Natação que, por isso, poderá ser agora implementado em qualquer momento.

Naturalmente que, se julgamos ter matéria de que nos orgulharmos, também noutros aspectos ficámos claramente aquém das nossas próprias expectativas e intenções. Gostaríamos de ter intervencionado mais o domínio da formação de árbitros, mas pensamos que as várias conversas tidas a esse respeito com o Senhor Presidente do Conselho Nacional de Arbitragem deixaram semente perene. Gostaríamos também de ter alargado o domínio das acções de formação pensadas para os elementos "auxiliares" da equipa técnica (médicos, paramédicos, psicólogos, etc.) e, sobretudo, para os nadadores. Neste particular, pensamos que, no futuro, uma mais sistemática articulação do Sector de Formação com outros sectores da FPN poderá render os melhores dividendos no reforço da formação proporcionada pela FPN aos seus nadadores (da formação aos *Masters*, passando pela alta competição e pelas Selecções Nacionais).
O ponto menos conseguido de entre os que seleccionámos como vectores estratégicos foi, porém, o da documentação. Havíamos decidido lançar a produção e publicação dos Manuais de Formação FPN, os quais constituiriam mais valia editorial *per se*, ao mesmo tempo que sustentariam os cursos de formação. Apesar de ter sido uma tarefa classificada como urgente e de interesse formativo e financeiro, a iniciativa acabou por "aderir" ao cronograma do Sistema Nacional de Formação de Técnicos de Natação e ser sistematicamente adiada. Pensamos que esta deverá ser uma prioridade do Sector de Formação no futuro próximo e constitui, seguramente, o maior insucesso desta gestão do pelouro. Os múltiplos suportes iconográficos digitais das acções de formação que disponibilizámos, alguns em formato de CD dedicado, os livros que publicámos e a gestão do espaço "Formação" do *website* FPN que realizámos, que incluiu a disponibilização das melhores comunicações dos Congressos da APTN, não nos retiram a mágoa de não ter conseguido progredir neste objectivo.
Por último, não queremos deixar de referir o insucesso relativo que assumimos no que respeita ao objectivo de articular transversalmente a formação com outras iniciativas da FPN. Pretendia-se que a existência de um possível Ranking Nacional de Clubes, que transcendesse em muito a lógica desportiva estrita vertida na Taça de Portugal ou no Campeonato Nacional de Clubes, e que incluísse um conjunto de factores de valorização que não estritamente desportivos, onde se incluísse a formação alcançada e procurada continuamente pelos seus quadros (de técnicos a dirigentes e funcionários). Pretendia-se também que a formação alcançada e procurada fosse considerada na política de atribuição de incentivos e regalias, bem como no que respeita ao convite para integrar equipas nacionais, quer por técnicos, quer por outros agentes. Pretendeu-se ainda que estes valores integrassem a lógica subjacente à Matriz de Apoio Regional que suporta a atribuição de verbas pela FPN às Associações. Qualquer destas iniciativas não foi conseguida, mas esperamos que se mantenham como germinais das futuras opções da FPN.

Depois de iniciar este documento redigindo-o na primeira pessoa do singular, não quero deixar escapar esta oportunidade sem regressar àquela forma, apesar de assumidamente menos canónica, para publicamente enaltecer e agradecer a dedicação, profissionalismo e competência dos profissionais que me rodearam, muito em especial da Dra. Isabel Ribeiro, do Prof. Doutor Ricardo Fernandes e do Dr. Bruno Freitas. Sem eles e sem os demais do *staff* benévolo e profissional da FPN e das Associações, o pouco que conseguimos não teria sido possível.

Muito obrigado!

J. Paulo Vilas-Boas

Vice-Presidente

X[th] INTERNATIONAL SYMPOSIUM

Biomechanics and Medicine in Swimming

PORTO > PORTUGAL > 2006

Biomechanics and Medicine in Swimming X

J.P. Vilas-Boas, F. Alves, A. Marques (eds.)

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U.PORTO
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COMITÉ OLÍMPICO DE PORTUGAL

FCT Fundação para a Ciência e a Tecnologia
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A RPCD tem o apoio da FCT
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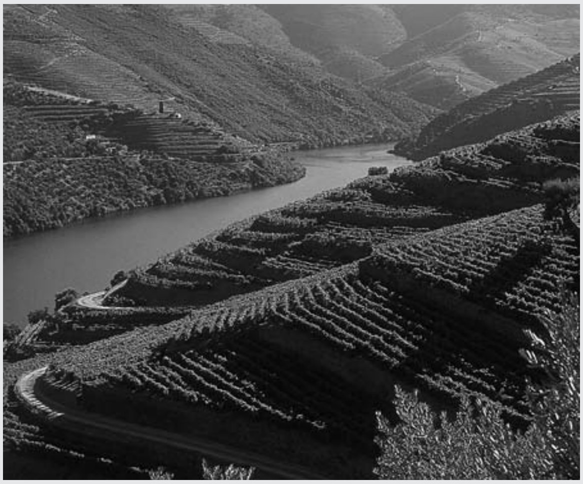
Tecnologia, Inovação do Quadro
Comunitário de Apoio III

Dear participants of BMS2006

Jorge Bento
Director of the Portuguese Journal of Sport Sciences

Certainly you already heard about us. Not in a direct way, but rather through a product that travels around the world. I am referring to the Port wine. The persons who cultivate grapes it in the slopes of the Douro River call this wine ‘generous’.
Certainly there are reasons for that designation. Homer said that the wine cheers the man heart, thus taking him out from a state of sadness. In the altar of the Christians mass, the wine is a symbol of a miracle that raises us to God. And, in the table of men, the wine celebrates health and fraternity. Therefore wine is indeed generous.
Generous is also the attitude that leads you to participate in this congress. To share knowledge, to exchange and widen perspectives and points of view, to animate and deepen the reflections and discussions, are acts full of human generosity. Therefore, we classify as generous your stay at our Faculty, and our town.
We feel very honoured and gratified with your visit. We will seek to correspond to your generosity with the warmth of our esteem and gratitude. The bread and wine that we will eat and drink together in the forthcoming days will establish the approach. We want that at the end of congress, when you return home, you also feel that distance does not exist and that we all stand closer together. This is our purpose, this is our dream. Welcome!



X^th INTERNATIONAL SYMPOSIUM

Biomechanics and Medicine in Swimming

PORTO > PORTUGAL > June 21 to 24, 2006

A coach-friendly scientific congress on the road to Beijing 2008.

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Preface

J. Paulo Vilas-Boas, Francisco Alves, António Marques

Since 1970, the swimming science world has been moving and growing rapidly on a quick pathway, catalysed by the successive editions of the International Symposium on Biomechanics and Medicine in Swimming. Held worldwide, the Symposium has provided the swimming science community with some of the most outstanding books and collections of contributions that, unlike the "publish or perish" maxim of some modern scientists, have become more sought after and more valued by this particular community, than the high impact peer reviewed journals.
The Symposium was started in Brussels, by the effort of Léon Lewillie, the great figure of science, creativity and ethics, the personality to be honoured during this edition of BMS. Then, crossing the Atlantic, to Alberta, Canada, the meeting explored one of the most productive continents on swimming science and sport of the last century, to return immediately to Europe, namely to Central Europe, to Amsterdam and Bielefeld, both icons of knowledge, scientific growth, and sport excellence. A journey into the United Kingdom (Liverpool) was then more than justified, mainly for the opportunity of visiting a city with historically strong relationships with water and the sea, but also with culture, modernity, and hard work. Leaving Europe again, the option was, once more, America, and the United States. The visit to Atlanta was certainly a tribute both to the soon to be held Olympic Games and to one of the most productive periods of Swimming Science in the United States. After this, Symposium returned to the old continent through the north of Europe (Jyväskylä, Finland), confirming one of the most organized centres on sport sciences worldwide. Following this, the meeting moved progressively to the south…to France (Saint Étienne) and, finally, to Porto, Portugal. Was this the road of wine? Not only! And we are now looking forward to an ambitious move to the East, as well as to a visit to Africa, Latin America, and Oceania, the latter being one of the core regions of swimming sport nowadays.

Almost all the Biomechanics and Medicine in Swimming Editions have been marked, in terms of history of swimming science: Brussels promoted a paradigmatic revolution in swimming propulsion, kinematic referenciation of propulsive actions, and EMG analysis of muscular recruitment. Four years later, the "how-is-the-movement approach" gave place to more integrative Biophysical approaches: active drag, energy cost, efficiency and EMG, then shared the attention of delegates. 1978 brought new developments in the aerofoil approach to swimming propulsion, with some of its core papers on that subject as well as on active and passive drag relationship and assessment methods. In Amsterdam, new integrative approaches stood out in the programme, making it possible to reach, in Bielefeld, the first high point regarding relevant contributions from coaches, probably because in the same year, in Madrid, just before the World Championships, the First World Swimming Coaches Congress was celebrated. The Liverpool Symposium was marked by the prolific scientific production on Swimming from Colorado Springs, but once again it was Leuven which took home the Archimedes Award, with the promising young scientist Véronique Colman following Luc van Tilborgh's example of the previous edition. This was the period of the emphasised utility of the evaluation and advice programs for swimmers and coaches, based on protocols integrating several areas of expertise: from anthropometry to physiology, through biomechanics to psychology. The Poolside Demonstration was, at that meeting, absolutely astonishing, with the appearance of both the MAD-System, and the aquatic EMG system of J.P. Clarys and co-workers. Atlanta was a good but relatively small conference, especially innovative through the introduction of "pure and hard" world top level coach for discussions with the community of swimming scientists, in a particularly difficult period with outstanding performances clouded by suspicions of doping. In 1998, the meeting of Jyväskylä stressed the mostly relevant progresses of the Japanese scientific swimming community, opening doors for the last event: the Saint Étienne symposium, very eclectic, and once again envisaging a more and more "coach-friendly approach" so traditional in the view of its chairman, one of the physicians and physiologists who is most passionate about the training process.

And here we meet again, this time in Porto, Portugal. Rather strangely, some may think; but it's possible to find a reasonable motive: this is not a leading country in swimming sport (far from it, in fact) nor in swimming science, but we are improving, and struggling as hard as possible. Moreover, this is one of the countries in the world where we can find one of the largest percentages of highly educated swimming coaches, with a very high number of university educated professionals in Sport Sciences and Physical Education, as well as MSc (top level coaching), and PhDs. If from this we can not draw any other conclusions than rather speculative ones about the importance of an university education for swimming coaches, we can at least assume that that coexistence is possible, and that a bridge between coaching practice and swimming research can be built on a basis of convergence of efforts. Both the Chairman and Vice-chairman of this Symposium are university teachers and researchers, but have also been coaches participating in the highest level competitions in the world; always at the "Portuguese level" of performance, we admit, but also with the "Portuguese synthesis", with the universities, the clubs, the swimmers, and the coaches, working close together. This, we think, will be the fertile ground for the future growth of practice conditions to beat the outstanding level of current swimming records, more easily attained in countries with other genetic, demographic and sociological backgrounds, which may favour swimming excellence, but undoubtedly where knowledge, practice, feeling, and experimentation can move together, hand in hand.

This edition aimed to be a "coach friendly" symposium, the first of this series to declare this purpose explicitly, but we will be more than satisfied if we can contribute to the above-stated need for cooperation. That was the reason why the Portuguese Swimming Federation, the Swimming Association of the North of Portugal, the Portuguese Swimming Coaches Association, and the University of Porto were pooled together, under the patronage of the Portuguese Olympic Committee, and the support of most of the other public Portuguese Universities with Sport Sciences programs.

The participants will find in this event contributions ranging from the most sophisticated pure scientific approaches, based on models and simulations, to some very practical problem-solving essays; from very detailed issues, to whole system perspectives. Nevertheless, all of them are certainly scientifically and intellectually stimulant to engage fruitful discussions and projects which will certainly interest both scientists and coaches, and guarantee progress for our swimmers, the true leitmotiv of our work.

A few last words to deeply acknowledge the hosting and supporting institutions of this Xth BMS Symposium, all the sponsors, co-workers (scientifically, and organizationally speaking), and participants and a very special thanks to the reviewers of the book, the hardworking and cooperative members of the Scientific Committee:

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To finish, one word for two colleagues, two fantastic professionals without whose effort this book would not have been possible, especially within the timetable we have imposed on ourselves: Susana Soares who managed to get together all the pieces of the puzzle along with people's wishes, rhythms and idiosyncrasies, interfacing authors, reviewers, and editors, but really supporting the existence of Biomechanics and Medicine in Swimming X, and Armando Vilas Boas who gave format, character, and life to this book.
We thank them both!

MEMORIAM
Prof. Dr. Léon Lewillie

JAN SWAMMERDAM, DUCHENNE DE BOULOGNE…LEON LEWILLIE… OR HOW THE STUDY OF MOVEMENT BECAME A MULTI-DISCIPLINARY SCIENCE.

Jan Pieter Clarys

Vrije Universiteit Brussel
Experimental Anatomy

Swammerdam was a biologist, anatomist, chemist, doctor and explorer. In 1658 he showed the Duke of Tuscany how to stimulate a nerve with scissors to make it contract - an experiment that could be repeated at will. These experiments and this demonstration took place 129 years before the similar experiments for which Galvani always receives the credit (1).

Duchenne (de Boulogne), a better-known figure, was a doctor, therapist, physiologist, engineer and inventor. He was the first to introduce electrical stimulation, and he invented and developed various prostheses and orthoses (Duchenne de Boulogne, 1872). All this took place more than a century before the development and marketing of the FES.

Léon Lewillie also researched movement, not through the eyes of a doctor but through the eyes of a kinesiologist, inventor, physical educationalist, ergonomist, biomechanic, physiologist, electro-physiologist and historian. Léon Lewillie was at the same time a philosopher, a humanist and a sportsman at the highest level.

To quote Simon Bouisset (2)*: "Il est vrai que Léon à été bien plus que le premier président de la Société de Biomécanique Française, le premier président du "Workinggroup of Biomechanics in Sport of UNESCO et le premier président de la commission mondiale de Biomécanique en Natation du (CIEPS/ICSSPE).*

Il a été en raison de la qualité de ses travaux scientifiques parmi les premiers à avoir été significative dans le domaine de la Biomécanique du Sport et de la Natation en particulier.

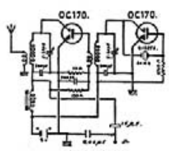
Il a eu non seulement l'initiative du premier congrès de la Société Française mais c'est lui qui a concrétisé le premier Symposium de Biomécanique en Natation à Bruxelles en 1970.

Il nous a donné une autre dimension de l'étude du mouvement."

Léon Lewillie was born in the Brussels district of Ixelles in 1925 and died at the age of 76. He graduated in Physical Education, qualified as a teacher and subsequently took his doctorate. He also studied kinesiatrics, initially working as a biometrics assistant, and was appointed professor of the theory and history of physical education for courses in the 'analysis of movement and the biomechanics of locomotion and sporting activities' 'physical activity in the workplace' and 'physiology applied to physical exercise'.

It is no easy task to summarise Professor Lewillie's career. A modest man, he frequently concealed his own sporting achievements. This club president, whose interests focused on the general development of the disciplines practiced within the Belgian swimming league, became a registered member in 1938.

He rapidly entered the world of competition and won the Belgium 200 metres free style championship. His commitment to these events during the occupation is evidence of his determination to assert the value of sport in socially and politically difficult times.
He rapidly developed the idea that longevity in water sports was achieved through practising a variety of different disciplines, and this he demonstrated personally, becoming the only Belgian to win the water polo championships over a forty-year interval – at the age of 16, at schoolboy level, and again at the age of 56, not as a veteran but in a division 3 team. It was not until ten years later that he competed at the Masters swimming championships.
But Léon Lewillie lived several lives. Not only did he co-found the Biomechanics Society, he was also a co-founder of the Sports Biomechanics Working Party (ICSSPE, UNESCO), and co-founder of the International Society of Biomechanics (ISB) and the International Society of Electrophysiological Kinesiology (ISEK). Above all, Léon Lewillie was a versatile scientist with a very varied output.
Léon Lewillie the **inventor** gave us the first remote pulse rate transmission device. "The equipment should be as light and unobtrusive as possible, so the use of transistors was obviously appropriate. The transmitter consists of a quartz-driven oscillator stage and a final stage sending via a telescopic car radio antenna." (5, see diagram).



This was in 1961, and the system was never improved or marketed. Twenty years later, the 'sport tester' based entirely on the principles described by Lewillie was a huge success.
He also designed a radio transmission system making it possible to measure amplified EMG signals, and another system for the remote recording of respiration. Right from the start, electromyography was clearly the instrument of choice for this research. However, for Lewillie two conditions were necessary for its effective use: a very compact device, and an understanding of the relationship between the electromyogram and other biomechanic parameters. Miniaturised technologies led to storage and telemetry systems that could be used in the field without risk of interfering with movement.
This was during the years between 1965 and 1968. The telemetry system has been copied, improved and marketed by others, but not by Léon Lewillie. Twenty years later, there were still several EMG telemetric systems on the market, and K2 and TEEM systems enjoyed great success as portable respiratory measurement systems.
Léon Lewillie **the physiologist** started out in 1959 with his doctorate entitled "Changes in the oxygen coefficient during increasingly intense physical activities", although he had already been working for eight years with professors Delanne and Segers on physiological and statistical aspects of several tests of speed and racing aptitude on young people aged between 12 and 18. He also studied the comparative state of preparedness of young people in different sporting disciplines, and the relationship between the clinical examination of these young people and their fitness for physical exertion in terms of the impact of acute hypoxia on the heart rate and arterial pressure.
In the early 1960s he set about researching the changes occurring in the mechanisms for adapting to rest and effort under the influence of drugs given to young sportsmen and women. He studied practically all the drugs used of the time period.
Meanwhile, Léon Lewillie had never turned his back on his original university qualification in physical education, though his approach was philosophical and rarely practical - although titles like "Effects of training and fatigue on motor systems in the sportsman" or "Swimming performance and the result of a compromise between two contradictory requirements" might lead us to imagine otherwise. Léon Lewillie liked to philosophise about "swimming for all", "sport in the media" or even "sports leisure and wine". He often quoted Giraudoux: '"Man is not an animal destined by life for the knacker's yard", or "Often the sportsman dies at the same age as the man who doesn't do any sport. But the one has lived in a state of preservation, and the other in a state of life".

In the early 1980s, Léon Lewillie worked for a short period as **an ergonomist** on two projects for the European Commission. One was a study of impact in road accidents, the other on biomechanical and musculo-skeletal problems caused by loading various types of car boot.

There remain the three most important Léon Lewillies: the **biomechanic**, the **historian** and the **electro-kinesiologist**.

The biomechanicist loved simple things. His first interest was the definition of movement in images, using light trails, stroboscopy and a camera. Analysis in a single plane enabled him to study a large number of movements, and where three-dimensional analysis was necessary he achieved this by using two cameras and a calculator. Later he turned to automatic film analysis and on-line systems with a television camera.

Light traces, combined with stroboscopy, remain for a long time his preferred method, resulting in analyses of different swimming styles, including the particular swimming style required in water polo, as well as the various movements made by sportsmen, factory workers and persons with disabilities. He was never interested in major biomechanical calculations or formulae, or in simulation and modelling. He was fanatically opposed to the 'science salesmen', who arrived with complex and sophisticated equipment dictating the method of measurement and analysis, as a result of which scientists were no longer the masters of their own experiments and ideas. Neither did he ever regard himself as a biomechanic. His colleagues gave him that label; he always called himself a 'kinesiologist'.

Then there was Léon Lewillie **the historian**. Of course he was responsible for the 'history of physical education' course, but he was not satisfied with the literature by Butler (1930), Diem (1931) and Strobel (1936), nor with the reports of the International Society for the History of Physical Education and Sport (HISPA), though he never failed to attend the society's congress, and he loved presenting his research results there. He frequently spent weeks and sometimes months in the cellars and antiquarian sections of the most important libraries in Belgium. His research, publications and presentations were on themes such as 'Professional sport in the Greek world', 'Swimming across the centuries', 'The history of scientific measurement', 'Scientific research in sport and physical education', and the works of Duchenne de Boulogne, Marey, Von Humboldt and Galvani. Inevitably, he also researched the history of electromyography.

In short, the history of sport and certain aspects of scientific research were a major interest in Lewillie's career. In 1982 he published *'Le sport dans l'art belge de l'éque romaine à nos jours*' (Lewillie-Noel 1982) in a de luxe edition illustrated with a hundred works by Belgian artists, providing a very personal overview of the history of sport in Belgium – an unequalled work and, so far, unique of its kind.

Table 1. Number of peer-reviewed publications specifically concerned with EMG and sport.

Swimming:	33*	Rowing:	3	Bowling:	1
Cycling:	22*	Judo:	3*	Cricket:	1
Running:	17*	Archery:	2	Fin swimming:	1
Skiing:	13*	Windsurfing:	2	Handball:	1
Tennis:	8	Volleyball:	2	Rifle shooting:	1
Gymnastics:	8	Baseball:	3	Sailing:	1
Weightlifting:	7	Water polo:	2	Skiff:	1
Triple/high/long jump:	5	Javelin:	2*	Shot putt:	1
Golf	5	Kayak:	2	Softball:	1
Speed skating:	4	Badminton:	1	Synchro swimming:	1
Soccer:	3	Basketball:	1	Wrestling:	1

** not included in the table: windsurfing 1 (Clarys et al, 1986a, in Dutch); judo 3 (Miura et al, 1970; Ikai and Asami, 1963; Takahashi et al, 1971 in Japanese); swimming 2 (Lewillie, 1967 in French; Kipke, 1966 in German); cycling 1 (Monod, 1963 in French); weightlifting 2 (Ono, 1962 in Japanese; Lukachev 1970 in Russian); javelin 2 (Salchenko and Smirnov, 1982 in Russian; Tanner, 1982); skiing 1 (Schaff and Hauser, 1987, in German).*

However, the best-known Léon Lewillie was the **electromyo-kinesiologist**. This is easily explained. He worked with electromyography techniques, but as his main interest was in the description of movement and its applications in sport and ergonomics, he had no wish to be an electro-physiologist. As he did not really regard himself as a biomechanic either, he called himself 'the schizophrenic of EMG'. His EMG work in the field of water sports and his own techniques for recording muscular work via telemetry are known throughout the world. "The study of the movements of a swimmer largely depend on the limits posed by water to the use of current investigation techniques. Laboratory measurements are by and large unsatisfactory; in this activity, where human performance stands at barely a tenth of what can be achieved on dry land, the resistance of the ambient environment has enormous importance".

For Léon Lewillie, the analysis of movement required a qualitative and quantitative understanding of muscle action. From its first applications, electromyography was clearly the best available tool for this research. However, two conditions had to be fulfilled to enable it to be used effectively: a very compact device, and an understanding of the relationship between the electromyogram and other biomechanic parameters.

It is thanks to Lewillie that the use of EMG in sport has almost become a scientific discipline in itself, and it is no surprise that the table below reveals the existence of so many studies focusing specifically on EMG and swimming.

Léon Lewillie may be thought of primarily as an inventor, but he also constantly combines effectiveness with simplicity. A striking example of this was the electrodes that he used in these "dynamic" and "ballistic" movement studies. Normal electrodes could not be held in a suitably fixed position during movement; he needed electrodes that were firmly embedded in the skin. Most of these EMG studies were carried out using the little metal rasps used for mending punctures on bicycle tyres, a technique that more than halved the number of artefacts appearing. Many other researchers since then have used (and improved) these "rasp" electrodes.

Lastly there is Léon Lewillie the man of the world, active in many fields… a member of the Belgian resistance organisation, the 'Armée Blanche'; a free mason since the war, and a master mason for many years; an experienced specialised oenologist; but above all a man, teacher, professor, father, brother, fellow team-worker, scientist, president and fine friend: all in all, a very great man.

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SWIMMING BIOMECHANICS

INVITED CONTRIBUTION

FUNDAMENTAL HYDRODYNAMICS OF SWIMMING PROPULSION.

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The purpose will be to describe the different methods applied in swimming research to visualize and understand water movements around the propulsive limbs and their application to improving swimming technique. A compilation of flow visualization methods applied in human swimming research is presented. Simple propulsive actions will be analyzed combining the kinematic analysis with the flow visualization: underwater undulatory swimming and sculling propulsion. The analysis of vortices generated and 3D analysis of the pulling path seems the most adequate method to develop a new understanding of swimming propulsion. The development of flexible and portable laser systems such as the recently incorporating fiber optics and fiberscopes, will enable the applicability of PIV in real swimming conditions to quantify the wake momentum and vorticity. New and attractive ideas are emerging: the possible use by the swimmer to his advantage of the vorticity if it is produced by an external source, such as the environment, another swimmer or the re-use of his own vortices during the stroke or after the turn will be topics for research in the near future.

Key Words: wake, sculling, undulatory, flow visualization, Strouhal number.

INTRODUCTION

The study of human swimming propulsion is one of the more complex areas of interest in sport biomechanics. Over the past decades, research in swimming biomechanics has evolved from the observation subject's kinematics to a basic flow dynamics approach, following the line of the scientists working on this subject in experimental biology (20, 56). As Dickinson stated (20) "at its most fundamental level, locomotion is deceptively simple, an organism exerts a force on the external environment and through Newton's laws, accelerate in the opposite direction", but the dynamics of force application are not as simple as they might at first appear, specially during swimming or flying where the force is applied to a fluid. In fact, it results from the complex three-dimensional interaction between a stationary fluid and a moving body with soft boundaries. The hydrodynamics of this phenomenon are yet not clear. The muscle contraction flexes or extends a particular joint, moving the limb though the water. The water previously occupied the limb's volume; the subsequent position required the displacement of its particles. At very slow limb displacement, the water particles will occupy steadily and in an orderly way, but at higher limb velocities the water is moving unsteadily, generating a turbulent wake behind. This subject was analyzed by Counsilman (18), who considered that "eddy resistance is more important than frontal resistance and that, at least theoretically, more propulsion is derived from the back of the hand than from the front of it".

In an ideal situation the hand is fixed in the water (no displacement and zero velocity) and the net shoulder muscles contraction produces a full body displacement forward of the swimmer's body (for example using the MAD system); there is no interaction between the hand and the water around it. In a real situation the hand interacts with the water and its velocity is increased. But increasing the backward velocity of the hand alone will not produce the desired forward velocity (similar to a caterpillar paddlewheel); a combination of curvilinear hand movements (up-down, left-right and backward) will produce the desired effect on body velocity (46). The propulsive force is a vector addition of lift (L) and drag (D) forces generated by the hand and they are proportional to velocity squared (see eq. 1,2)

$$\boldsymbol{L = 1/2\ \rho\ u^2\ C_L\ S} \qquad \text{(Eq. 1)}$$

$$\boldsymbol{D = 1/2\ \rho\ u^2\ C_D\ S} \qquad \text{(Eq. 2)}$$

Where $\boldsymbol{u}$ is the relative velocity with respect to the fluid (m/s), $\boldsymbol{S}$ is the hand's surface area (m^2), ρ is the water density (kg/m^3), $\boldsymbol{C_L}$ is the lift coefficient and $\boldsymbol{C_D}$ is the drag coefficient. The values of these coefficients are characteristic of the object tested and are a function of the angle of attack (α) and the sweep-back angle (ψ) as Schleihauf (44, 45) and Berger (7, 37) investigated. Maximum values of $\boldsymbol{C_L}$ (about 0.8-1.0) are obtained between 35º and 45º-attack angle, and maximum values of $\boldsymbol{C_D}$ (about 1.3) are obtained at 90º. The values of $\boldsymbol{C_L}$ and $\boldsymbol{C_D}$ are more similar when all possibilities of sweep-back (different "leading edges" orientations of the hand) angles are considered. This indirect method of propulsive force calculation is based on the proper knowledge of the hand position and its velocity in a three-dimensional reference system (water volume) and in conditions of extreme accuracy the coefficients can be calculated (26, 37) and the water refraction controlled in order to apply adapted DLT methods (25). Considering these limitations some index characteristic have been defined in the 3D pulling path (47):

a) Diagonality index: the average angle of the negative hand line motion and the forward direction at the points of first, second and third maximal resultant force production (57);

b) Scull index or lift-drag index: the average ratio of lift and drag forces ($\boldsymbol{C_L / C_D}$) at the three greatest occurrences of resultant force (57);

c) Force distribution index: is the average location of the three greatest resultant forces expressed as a percentage of the total duration of the underwater phase of the arm pull (57).

A similar approach was used by Sanders (43) to obtain the propulsive forces alternative vertical breaststroke kicking applied by the water-polo goalkeepers.

Under this methodology four basic hand propulsive movements were defined (31, 32): Downsweep, insweep, upsweep and outsweep. Each stroke was therefore composed of a combination of these movements. For example, breaststroke is composed of outsweep and insweep.

The previous paragraphs based the understanding of swimming propulsion on steady-state flow mechanics that has left many questions unanswered. Some trials observing the flow behaviour around the swimmer's body lead us to try to apply unsteady mechanisms of force production to resolve them. However, such approach needs to analyze the flow behaviour around the propulsive limbs to identify the phenomena, a difficult task in a swimming pool, but quite common in fluid dynamic laboratories.

The traditional semantic classification of the propulsive forces in terms of drag and lift is not relevant when applying a non-

steady hydrodynamic analysis and it is probably more useful to investigate the momentum and the vorticity or their respective scalar indicators the energy and the enstrophy applied by the swimmers limbs on the water.
Our purpose will be to describe the different methods applied in swimming research to visualize and understand water movements around the propulsive limbs and their application to improving swimming technique.

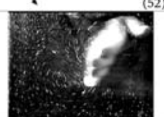
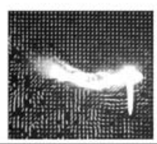
OBSERVING WATER MOVEMENTS

During aquatic locomotion forces are exerted by the body and limbs against the surrounding water, which is not fixed in position but instead yields in response to the action of propulsive surfaces (27). Colwin (12, 13) and Ungerechts (54) suggested new ways of analysing the swimming propulsive movements based on the observation of water around the propulsive limbs. All bodies (including propulsive limbs) displacing water will create vortices (rotating water masses) in their wakes; they carry a fairly high momentum, which can transfer a strong propulsive impulse to the body (55). As Bixler (9) stated when an object accelerates, decelerates, or changes its shape or orientation as it moves through a fluid, the flow will be unsteady. Thus, the resulting pressure field exerted by the fluid on the body's surface, responsible for the propulsion, will be again unsteady, varying differently with both time and position. In this conditions the propulsive drag and lift forces developed by a swimmer's hand at a given time are dependant not only upon the velocity at that time, but also the acceleration at that time and the acceleration history of the hand prior to that time. Under these criteria the calculated $\boldsymbol{D}$ need to be updated in unsteady flow conditions, for example, through a quasi-steady approach (9):

$$D = 1/2\ \rho\, u^2\, C_D\, S + k\, \rho\, \forall\, a \qquad \text{(Eq. 3)}$$

Where: k is the added mass coefficient, $\forall$ is the characteristic volume of the body on which k is based and a is the instantaneous acceleration at time t. The first term is equation 2, which is the drag due to steady state motion. The more water that is "grabbed" by the swimmer's hands the larger the added mass and the larger the propulsive drag. Such quasi-steady model theory is of common practice when investigating fluid forces on structures (49).
Based on the observation of flow movements it is possible to measure the total locomotor force (in fishes). It is calculated by dividing the fluid momentum of the vortex ring (or rings) shed over a fin beat cycle by the duration of the fin beat. The momentum of each vortex ring is itself calculated as the product of the water density, the area of the vortex ring and the mean ring circulation (27). The described procedure, simple in essence but complex in its applicability in human motion, encourages us to apply sophisticated methods of flow measurement such as Particle Image Velocimetry (P.I.V.). This methodology broadly used in fish propulsion studies has been recently applied in human swimming in a very controlled situation (2, 35). Nevertheless, we must improve the methods used to visualize the flow around the swimmer's limbs before applying this advanced methodology.
A compilation of flow visualization methods applied in human swimming research is presented in Table 1. The capabilities and limitations of each method are very different and are adapted to research conditions: laboratory (small water tanks), swimming flume or swimming pool. Under very controlled conditions it is relatively easy to observe and measure water movements; however in real swimming the observations are more complex and less accurate, as it is only possible to analyze the problem in a qualitative and descriptive way at the moment.
The approach developed in Tsukuba University is a first trial to apply PIV in freestyle swimming. A sophisticated swimming flume, a tool similar to that the applied in fish swimming research, is being used. The flume is filled with small close-to-buoyant particles. A laser light sheet within the working area illuminates a horizontal plane, parallel to the water surface. The arm pull action of the swimmer enables his hand to cross the illuminated slice of the flow during the insweep and outsweep. A triggered high-speed camera records the illuminated plane while the hand crosses this specific zone, so that it is possible to observe the hand displacement and water particles movements. Pairs of consecutive images from the video sequences are then input into a cross-correlation processing algorithm, which takes a small, user-defined area of the image and calculates the direction and magnitude of each particle's velocity within that region. This yields a single velocity vector representing the average flow within that small area. Repeating this analysis at each location, a map of velocity vectors can be calculated that provides a snapshot of wake structure and strength (27, 35, 49) [see figure 1.7].

Table 1. Flow visualization methods applied in swimming research (PIV listed bellow is not a flow visualization technique but a mechanism one).

Method	Description	Authors	Sample Picture
1. Natural or spontaneous bubbles	As a result of accidental air entrapment (16)	Colwin (12-16) Ungerescht (54)	
2. Tuft	Observing the direction and motion of the tufts made of thread or lod of an appropriate length and material (36)	Hay (24), Ferrell (22), Toussaint (51), Nakayama (36)	 (52)
3. Reflective particles	Particles of solid tracer are distributed uniformly in the fluid (36)	Arellano (1) Redondo (40)	
4. Injected bubbles and bubbles wall (Path line method)	Fluid tracer (air) is injected continuously into the flow though fine tubes or holes (36)	Arellano (1, 3, 4)	
5. Coloured dye	Fluid tracer (dye) is injected continuously into the flow though fine tubes or holes (36)	Colman (11) Persyn (38)	
6. Sodium Fluoresceinate powder	The flow is visualized using a chemical reaction between the fluid and surface substance (36)	Colman (10)	See figures in this book section (10)
7. PIV	A picture capturing movements of tracer particle is analyzed through some optical and /or mathematical procedure to get velocity information (36)	Arellano (2) Matssuchi (35)	

As Colwin (16) stated "vortices are the muscles and sinews of propulsion, and the activity, seen here in the flow field, represents a history of the swimmer's propulsion". The application of injected bubble enables us to observe the wake produced by a swimmer after the propulsive limb movements; this history tells us about the efficiency of the energy transfer mechanism between the swimmer and the water and his control of propulsive actions. Swimmers of different levels generate very different wakes during simple and complex aquatic movements. In some cases, better swimmers generate bigger vortices that rotate quicker and are kept stationary in the water after the swimmer's stroke or kick, enhancing more efficient energy transfer mechanisms. Simple propulsive actions will be analyzed combining the kinematic analysis with the flow visualization: underwater undulatory swimming and sculling propulsion.

UNDERWATER UNDULATORY SWIMMING

At certain Reynolds numbers, when a wake is generated, a double row of vortices is visualized. Their characteristics depend on the situation of the immersed body, stationary (like a hand following a rectilinear path) or oscillating (like a fish tail). The vortex street shed from stationary bodies produces drag and a staggered Kárman vortex street. An oscillating tail or foil produces a vortex trail shed where the sense of each vortex in the trail is opposite to that of the Kárman 'natural' shedding case (see figure 2); it can be considered as 'thrust-type' trails as the induced momentum produces thrust upon the disturbing body initiating the trail (58).

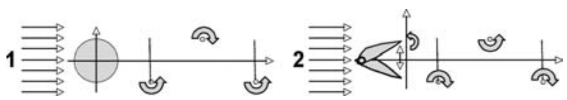


Figure 2. 1. A vortex street shed from a stationary body that produces drag. 2. A vortex trail shed produced by an oscillating foil that produces thrust. Adapted from Weihs (58).

When a fish undulates and propels itself with its tail fin, it produces a water displacement that can be observed: wake vortices. Every vortex generated after each stroke has a different rotation (clockwise or anti-clockwise), producing a jet of water undulating between vortices and flows in the direction opposite to the swimming direction (56). What makes the high efficiency and high thrust of a foil is the manner in which the vortices are arranged behind the foil, the oscillating tail is a more efficient method of propulsion than a classical propeller (42). Before starting to study complex strokes such as the freestyle-pulling path, we decided to begin with underwater undulatory swimming (UUS). The UUS is fully underwater (wave drag can be considered negligible), the body is extended horizontally with the arms stationary, legs and body movements can be considered symmetrical and displacement is obtained with leg and body propulsive undulations or oscillations.

The Strouhal number is a dimensionless number, representing the ratio of unsteady and steady motion (23). Strouhal number (***St***) can be defined by the equation:

$$\boldsymbol{St = A_{p\text{-}p} f / U} \qquad \text{(Eq. 4)}$$

Where $A_{p\text{-}p}$ is the tail-beat peak-to-peak amplitude (the distance from the peak of the tail fluke upstroke to the peak of the tail fluke downstroke), f is the tail-beat frequency and U is the mean body velocity. It can be interpreted as well as a reduced frequency, providing a ratio between the momentum caused by the tail oscillation and that due the forward motion of the swimmer. It is then an estimate of the relevance of the unsteadiness in the fluid-body interaction to the overall fluid structure. In our previous studies (4, 5) swimmers with less experience obtained values higher than 1, while top performers obtained values around 0,80. These values are far from the results of efficient water animals (between 0,25 and 0,35 (53)). The practical use of this number is to play with its variables in order to bring its value closer to the more efficient range without decreasing the swimmer's speed, in this case with modifications in frequency and amplitude values. In that sense, it appears to be part of an indicator of the efficiency in the aforementioned energy transfer mechanism. Parameters such as the timing of the change of direction of the tail (acceleration-deceleration), the tail's curvature and its performance in generating circulation or the synchronization between vorticity creation and tail, knees and hip motion appear to be linked to the obtained performance for a given thrust.

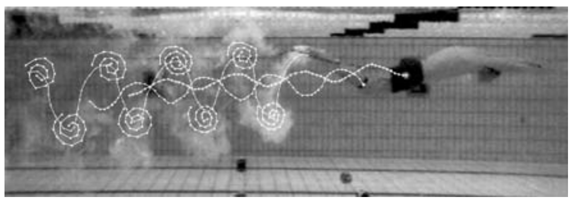


Figure 3. Spiral drawing representing the size and rotation direction of the vortices generated after each change in the kick movement. Some authors have suggested the thrusting impulse is a reaction to the jet stream away from the body, moving between the counter-rotating vortices (28, 53, 59). The trajectories represent hip, knee and big toe. The vortices drawn represented an instant after the change of direction in the big toe trajectory. All the traces were performed with the computer programme GraphClick v2.8.1 (Arizona Software).

The combination of the body landmarks kinematics and flow visualization demonstrated in UUS:

a) A wake of counter-rotation vortices is clearly observed after kick-up and down (see figure 3)

b) The feet leave the vortex behind after each change in their trajectory, maintaining their rotation for several seconds while its size is expanding (see figure 3)

c) The vortex wake pushes a hypothesised jet stream (see figure 3)

To think that the vortex creation *is not related* to the forward displacement of the swimmer's body seems unrealistic considering the controlled circumstances of the UUS displacement studied. The analysis of undulatory displacement of the body land-marks using Fourier analysis demonstrated in UUS a coordinated sequence and increase of amplitude and peak vertical velocities from shoulder to feet. The body landmarks are phases of a simple sinusoid oscillation with very rhythmical motion. The high mean velocities of centre of mass (about 2 m/s) measured in top swimmers are obtained with smaller ranges of c.m. velocities than we expected (about 0,4 m/s) and similar ranges to the most continuous stroke: freestyle (33). In spite of the limits recently imposed by the FINA regulations the applicability of this stroke in the underwater phase of the starts and turns is clear (17, 34).

THE SECRETS OF SCULLING

Another basic propulsive movement is horizontal scull. This short propulsive action of the hand is applied specially in synchro swimming or water-polo (goal-keeper) to keep some part of the body out of the water stationary and high and in the insweep phase (bending the elbow) of all the competitive swimming strokes (6). It is characterised by an important application of hydrodynamic lift force (6, 45). The basic movement is performed using a trajectory similar to an ellipse in the front view and an elliptical-figure eight trajectory in the horizontal plane (see figure 4).

Figure 4: Trajectory and plane position during a cycle of vertical sculling movement (50 Hz). It can be observed the changes in the attack angle, leading edge and trailing edge (sweep back angles) every half stroke (stroke reversal).

The analysis of this movement under the steady or quasy-steady theories would lead us to find that the continuity of propulsive force application could be stopped during the stroke reversal actions. This phenomenon has been analysed by biologists that studied the insects and birds flight finding that the conventional mechanisms (steady) simply do not provide enough lift for a flying insect to stay in the air (8). Delayed stall, rotational lift and wake recapture represent three distinct, yet interactive, mechanisms of unsteady lift generation which are necessary for flying insects to achieve the flight forces needed to support their weight and carry loads (21). An advance in biofoil rotation not only generates circulatory forces at the end of each stroke, it also increases the strength of the wake and ensures that the wing has the proper orientation to use the shed vorticity for generating positive lift at the start of the next stroke (21). It can be hypothesized that sculling actions observed in the figure 4 use the previously mentioned mechanisms. The movement is composed by four kinematic portions: two translational phases (insweep and outsweep), when the hands move through the water with efficient angle of attack (about 40º), and two rotational phases (pronation and supination), when the hands rapidly rotate and reverse direction. The *delayed stall* can be an addition to the forces generated during the hand translation with high angles of attack. Our observations demonstrated that big vortex is generated and de-attached after the start of each translational phase. During the stroke reversal and based in the *rotational circulation* mechanism (a specific application of the Magnus effect) it is necessary an early hand flip, before reversing the direction, then the leading edge rotates backward relative to translation and should produce an upward component of lift. Depending on the timing of the referred stroke reversal one can expect *cumulative Wagner effect* acting in attenuating the generated lift (19). One additional lift force can be obtained with the *wake capture*. The hand benefits from the shed vorticity of the previous stroke. If rotation precedes stroke reversal, the hand intercepts its own wake so as to generate positive lift. It is possible to argue in this case the swimmer's ability to extract energy from its own wake. What is also possible provided a sufficiently high Strouhal number is achieved is to produce wakes consisting on maximum backwards momentum vortices, as is frequent in animal swimming (29, 30). Using particle tracking on the wake of a hand stroke it is possible to delimit the regions of positive (anticlockwise) and negative (clockwise) vorticity on the plane of the laser sheet used. It is also possible to apply unsteady Kutta-Joukovsky theory to relate pressure and velocity measurements as discussed in Redondo et al. (39-42).

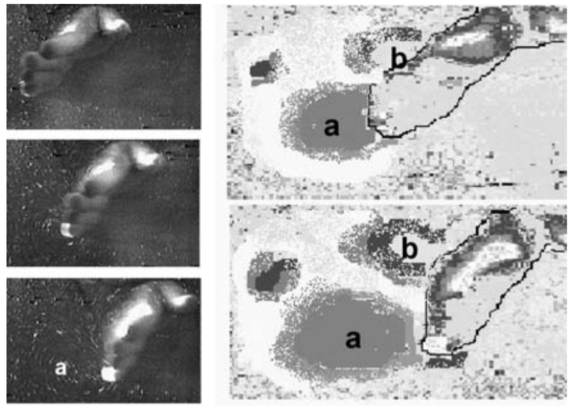


Figure 5: Trajectories of the seeded particles in an experimental tank as a hand stroke is performed. A vertical plane of laser light is used to film the wake at (50 Hz) left. Two maps of the vorticity are shown in the right images showing the shedding of positive (blue-b-) and negative (red-a-) vortices.

Hand drag coefficients obtained experimentally at different water speeds were related to the Reynolds number (Re) and compared with those obtained by Schleihauf, (45, 46), for a wide range of angles and speeds, which included the turbulent wake transition. The drag coefficient decreases when the Reynolds numbers increase near the transition with values of the drag and lift coefficients from 20º to 90º-sweep angle when Re is high [9.4×10^4] (39). The detailed analysis of velocity and vorticity balances in the wakes of swimmers limbs is still at large but figure 5 shows the strong dipole structure produced by a hand stroke (40).

CONCLUSIONS

The analysis of vortices generated and 3D analysis of the pulling path seems the most adequate method to develop a new understanding of swimming propulsion. The development of flexible and portable laser systems such as the recently incorporating fiber optics and fiberscopes, will enable the applicability of PIV in real swimming conditions to quantify the wake momentum and vorticity.

What may be obtained using an integral balance of the momentum and vorticity of swimmers wakes is the feedback necessary to obtain maximum propulsion, irrespectively if it is due to drag or lift projections of the limbs. This is clearly maximized when minimal balances of vorticity, which occur when coherent structures do not spread sideways, are coupled with maximum momentum and minimal energy. This is not an easy balance as demonstrated by a single vertical wake by Linden and Turner (30). For the simpler underwater undulatory swimming analysis on the Strouhal number on swimmers (4) shows that humans are still far from fish and dolphins, that obtain maximum propulsion at about St= 0.2-0.4, (50).

New and attractive ideas are emerging: the possible use by the swimmer to his advantage of the vorticity if it is produced by an external source, such as the environment (48), another swimmer or the re-use of his own vortices during the stroke or after the turn will be topics for research in the near future.

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INVITED CONTRIBUTION

ANALYSIS OF SWIMMING TECHNIQUE: STATE OF THE ART: APPLICATIONS AND IMPLICATIONS.

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INTRODUCTION
Methods of analysing motion have advanced greatly in recent years due to improvement in technology as well as application of scientific approaches. Methods of analysis may involve video based techniques from which kinematics and kinetics can be derived or direct measurement of velocity and force using various velocities and force transducing devices. At the Centre for Aquatics Research and Education (CARE) we have developed methods based predominantly on analysis of video. Analysis based on video ranges from qualitative analysis without quantification of variables, to three-dimensional analysis of kinematics and kinetics from digitised body landmarks from several cameras.
The purpose of this paper is to present video-based methods of collecting data, analysing data, and presenting results for different levels of analysis including qualitative analysis and simple quantitative analysis for immediate feedback, two-dimensional (2D) and three-dimensional (3D) quantitative analysis of kinematics, and deriving forces from the whole body centre of mass. Examples of specific applications and implications are described.

STATE OF THE ART FACILITIES AND EQUIPMENT
In 2000 a six lane 25m swimming pool was planned to accommodate research in aquatics, education and training in aquatics in the Department of Physical Education Sport and Leisure

Studies, and to serve some of the aquatics recreational needs of students and staff of the University of Edinburgh. Fortunately, research was recognised as a priority and considerable flexibility was afforded in designing the facility to accommodate research.

Lighting
The pool room has no windows. This ensures that lighting is consistent and there are no 'shafts' of light affecting the quality of the video recordings. Lighting is supplied by large lights with colour temperature resembling natural white light. Large reflectors are located strategically to disseminate the light evenly to maximise video quality and reduce shadow effects. Three levels of lighting are available with the maximum setting (1000 Lux) used when video recording.

Cameras and camera housings
Up to eight three chip high resolution JVC KY32 CCD 'gen-locked' cameras operating at 50 fields per second record motion simultaneously. Up to three cameras can be used for capturing the motion from above-water perspectives and up to six can be used to capture the below-water motion. Currently three are deployed above water and five below water.
Limitations regarding the dimensions of the building meant that pits or corridors for housing cameras to obtain below-water views were not possible. To overcome this limitation, camera housings were recessed into the walls at six locations – on each of the side walls at 12.5m (for analysis of mid-pool technique) and at 2.5m (for starts and turns) and in the end wall between lanes 1 and 2 and between lanes 5 and 6 (for front views). Although this was a pioneering and problematic exercise it has created some advantages. The cameras are actually in the water and therefore the light rays do not pass through thick glass. This eliminates distortion and the effects of changing angles of the camera axis to the glass when panning and tilting. Kwon (6) has shown that distortion is greater the closer the camera is to the glass. Therefore, depending on the structure of the viewing windows, reduction of distortion when cameras are placed outside the pool is often at the expense of the range through which the camera can pan. The housings at the University of Edinburgh pool have been designed to maximise the angle of pan possible. This means, for example, that the mid pool camera can be panned to track a swimmer through the whole 25m lap. The cameras remain permanently in the water in a constant state of readiness for recording. They can be removed readily for annual servicing which includes replacing the waterproofing 'o rings' of the cameras and pan and tilt motors.
The cables carrying signals to and from the cameras were laid during construction of the pool and are therefore invisible and unobtrusive. In addition to remote electronic control of pan and tilt, camera height can be adjusted readily from the pool deck by a mechanical winding mechanism. Clear perspex covers protect the cameras from swimmers and swimmers from the cameras. These can be removed easily when production quality recordings are required and when distortion free quantitative 2D and 3D analyses are required. It has been found that the quality of the recordings is not affected by the covers for qualitative analysis.
In addition to the six underwater cameras, three above water cameras are supplied by cables that are extendable to any part of the pool deck from three different locations. Camera mountings are located at four elevated positions on the side walls of the swimming hall. A long camera boom provides flexibility in obtaining specific views, for example from directly above a swimmer. The boom runs on rails beside the pool so that a particular perspective of a swimmer can be maintained throughout a swim. The boom is also useful for suspending EMG electrodes for various types of aquatic research including research in hydrotherapy, and for collection of expired air.

Remote control of camera functions and data collection
The nine cables terminate in an air conditioned control room that has a window looking out to the pool. The cables interface to a control system enabling simultaneous 'gen-locked' recording at 50 fields per second. The computer system comprises a control computer and nine storage computers, each of which is dedicated to one camera. The control software (Cameron Communications Ltd) allows any combination of cameras to be used and the recording time to be set. The software allows the user to select any view for display on a control room monitor either in split screen or full screen of a camera selected using the software. The shutter speed, focus, zoom, and gain of each camera are set independently and can be stored to avoid unnecessary repetition and wastage of time between testing sessions. Data are compressed during collection and stored as 'AVI' files.

Playback
Following recording, the AVI files can then be replayed immediately by standard video players such as Windows Media Player, the playback software developed by Cameron Communications, and by qualitative analysis software such as Dartfish. The software by Cameron Communications facilitates quick selection of camera views from a 'playback library' for playback as one camera view, two synchronised views of the same swim, or comparative views of two separate swims. Control features of the software include a slider bar for rapidly locating the section of interest, two speeds of slow motion, single frame advance, pause, and zoom.

Poolside display
The control room is linked by hidden cable to a an air-conditioned poolside compartment housing six 27" monitors for live feedback of any combination of views and two 42" plasma screens for software control and digital playback. Typically, coaches and analysts observe the performance live by watching any of the selected camera views and together with swimmers observe the performance on one of the plasma screens immediately after the swim. With the recent introduction of a remote mouse and keyboard, recording and playback can be controlled on poolside by analysts or coaches.

Concurrent downloading of AVI files to CDROM or DVD and analysis stations
Concurrent with collecting data and providing immediate poolside feedback, recorded AVI files can be downloaded onto CDROM or DVD. The files on the control computer and hard discs for each camera are accessible from a network of five analysis stations in the building. Two of these analysis stations are offices while the others are research laboratories. This means that material for coaches and athletes to take home for further scrutiny can be available very soon after completion of the testing session.

QUALITATIVE ANALYSIS AND SIMPLE QUANTITATIVE ANALYSIS FOR IMMEDIATE FEEDBACK

Various programs provide immediate feedback to swimmers and coaches. Other centres, for example, the Centre for Aquatics Research (CAR) at the University of Granada, and the Katholieke Universiteit Leuven, have developed sophisticated automated reporting systems. Several portable systems for quantifying fractional times of race sections including mid-pool, turns and starts of all swimmers in a competition have been developed, for example, the 'Australian' system by Mason and Cossor at the Australian Institute of Sport, and the system by Arellano developed at The University of Granada. One of the impressive features of these systems is their ability to calibrate distances across all pool lanes so that all swimmers in a race can be analysed.

Rather than analysing the race data of several swimmers in a competition setting, the CARE system specialises in high quality detailed analysis of individual swimmers swimming at coach-selected paces in a single lane. The advantages of the system include:

— Simultaneous synchronised views from several cameras including below-water mid-pool, below-water end-pool (turn) at 2m from the wall, front/rear view, and three above views including one directly above the swimmer using the boom camera.

— Zooming to maximise the image size to increase the ease and effectiveness of qualitative analysis and to increase the accuracy of measurements. This also facilitates high quality stills ('snapshots') with text or graphic overlays for qualitative analysis.

— The underwater views enable qualitative analysis of stroking technique and postures in both mid-pool and starts and turns, streamlining and glide trajectories.

— Panning on any one camera. When swimming continuous laps the mid-pool below-water camera is usually panned. When analysing turns and starts the end-pool below-water camera is often panned.

— The ability to measure kinematics associated with particular events not observable from above views. These include time and distance from the end wall at the instant of commencing kicking following turns and starts, speeds at wall exit, commencement of kicking, and surfacing.

— The ability to measure 2D angles with camera axes perpendicular to reference planes including the vertical plane along the line of the swimming direction from the below-water mid-pool and end-pool cameras and above-water boom camera; the vertical plane perpendicular to the direction of motion using the front/rear view underwater camera and above-water boom camera; and the horizontal plane using the above-water boom camera.

Variables routinely measured in the service programs, for example, for the swimmers of the Scottish Institute of Sport are shown in Table 1.

Table 1. Variables routinely measured for quick feedback.

Phase	Variable	View
	Race parameters: stroke length; stroke frequency; speed,	mid U/W
	stroke index:	
	Times	
Mid-Pool	pull time	mid U-W
	recovery time	mid U-W
	Angles at events (hand entry, hand exit, max, min):	
	trunk to horizontal	
	hip in vertical plane	mid U-W
	knee in vertical plane	mid U-W
	shoulder roll to horizontal	mid U-W
	arm angle to line of travel	front U-W
	Trunk angle to line of travel	boom A-W
	Thigh angle to line of travel	boom A-W
	Hip angle in horizontal plane	boom A-W
		boom A-W
	Times	
	time in (from 7.5m to fist wall contact)	end U-W
	hand contact time	end U-W
	foot contact time	end U-W
Turns	time out (from last wall contact to 15m)	mid U-W or boom
	time commence kick (from last contact)	A-W
	time surface (from last contact to head breaking surface)	end/mid U-W
	total time	
	Angles	
	hip, knee, and trunk to horizontal at first contact	
	hip, knee, and trunk to horizontal at max knee flexion	end U-W
	hip, knee, and trunk to horizontal at max last contact	end U-W
	hip, knee, thigh and trunk to horizontal at surfacing	
	Distances	end U-W
	distance from wall at commence kick	
	distance from wall at surfacing	end/mid U-W
		end U-W
		end/mid U-W
	Times	
	block time (from gun to last contact)	boom
Starts	flight time (from last contact to head entry	boom
	glide time (from head entry to fist kick)	end U-W
	kick time (from first kick to head surface)	end U-W
	swim time (from head surface to 15m)	boom
	total time (gun to 15m)	
	Angles	
	hip, knee, and trunk to horizontal at gun	boom
	hip, knee, and trunk to horizontal at max knee flexion	boom
	hip, knee, and trunk to horizontal at last contact	
	hip, knee, thigh and trunk to horizontal at head entry	boom
	hip, knee, thigh and trunk to horizontal at foot entry	boom
	Distances	
	distance from wall at head entry	end U-W
	distance from wall at commence kick	
	distance from wall at surfacing	end U-W
		end U-W
		end/mid U-W

TWO-DIMENSIONAL (2D) AND THREE-DIMENSIONAL (3D) QUANTITATIVE ANALYSIS FOR RESEARCH

Staff and postgraduate students at CARE regularly conduct 2D and 3D data collection and analysis. 2D approaches include quantification of passive drag and added mass from digitised video data of subjects performing inclined glides, and quantification of movement rhythms and inter-joint coordination in various modes of swimming. 3D approaches are being used to quantify body roll and changes in temporal and spatial movement patterns across conditions such as swim speeds, stages of a simulated race, and preferred race distance.

Most studies in swimming have been limited to 2D analysis techniques. However, except in the case of distinctly planar

swimming skills such as dolphin kicking and flutter kicking without body roll, 2D analysis does not enable accurate quantification of swimming skills because the motion of body parts is not confined to planes perpendicular to the camera axes. In previous 2D studies bilateral symmetry has been assumed. It is preferable not to assume bilateral symmetry as it has been shown that swimmers' techniques are not symmetrical (1). Also, there are asymmetries in the anthropometric characteristics (12). For this reason, most of the quantitiative research conducted at CARE employs 3D data collection and analysis methods.
A three dimensional calibration frame (Figure 1, 2) 1.5 m in length, 1.5 m high and 1 m wide as described in detail by Psycharakis et al. (2005) was constructed to accurately calibrate the 3D space using the direct linear transformation (DLT) method.

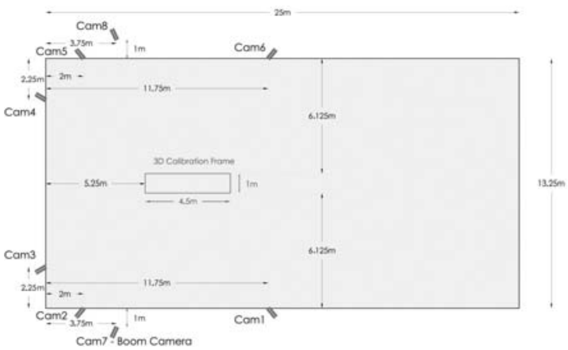

Figure 1. Position of the calibration frame relative to the cameras.

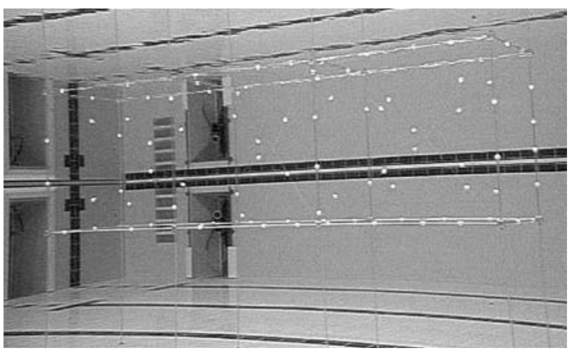

Figure 2. Underwater view of the calibration frame.

Flexural stiffness and orthogonal axes were ensured by using 12mm aluminium tubing and triangulation by wires. The locations of the centres of the 92 (46 above and 46 below water) 3cm diameter polystyrene spheres were then determined to within 1mm using surveying techniques.
Tests of the calibration procedures for a set of 30 digitised points yielded mean RMS errors of 3.9mm, 3.8mm and 4.8mm for the X, Y and Z axes respectively. Considering the volume of the calibrated space (6.75m^3), the errors in this study were similar or lower than those reported in studies by Payton et al (8) and Coleman and Rankin (2). The reliabilities indicated by repeated digitisations of one marker were ±0.4mm, ±0.5mm and ±0.4 mm, for the X, Y and Z axes respectively.
The APAS system is used for digitising the landmarks in each camera view and determing the 3D locations using the DLT algebraic equations arising from the digitised coordinates of the calibration markers. Above and below water 3D coordinates resulting from separate DLT transformations of above and below-water landmarks are then merged using a MATLAB program to produce continuous time series for each landmark. Variables of interest for each study are then determined using bespoke MATLAB programs and sub-routines. These typically include linear and angular kinematics with respect to inertial and internal frames of reference.

DERIVING FORCES FROM THE WHOLE BODY CENTRE OF MASS

It is well established that the accuracy of kinematics and kinetics derived from position-time data using a rigid-link human body model is dependent on the accuracy of estimating the segment masses, segment centre of mass locations relative to the segment endpoints and, in the case of angular momentum and angular kinetics, segment moments of inertia. These are collectively referred to as body segment parameter (BSP) data. The accuracy of segment centre of mass position also affects the accuracy of angular momentum and whole body angular kinetics due to its influence on the remote terms.
BSP data may be obtained from various sources that may be categorized as cadaver studies, immersion studies, direct measurement techniques, and mathematical models (11). The methods vary in the extent to which they take into account individual characteristics and therefore vary in the accuracy of the BSP data and consequent calculated values of kinematics and kinetics. For example, Miller and Nissinen (7) found large discrepancies between ground reaction forces derived from whole body centres of mass digitized from cine film and ground reaction forces measured directly from a force platform. BSP data were identified as contributing to those errors.
The Elliptical Zone method developed by Jenson (5) is a mathematical modeling technique to determine BSP data of each body segment of individual subjects. The method applies the assumption of Weinbach (13) that cross sections of the body segments can be modeled accurately as ellipses. Dempster (4) found that this assumption yielded very small errors with the exception of the shoulders. Using BSP data obtained by the elliptical zone method Sanders et al. (1991) found that the low frequency parts of the ground reaction forces of drop jumps derived from digitized high speed video were within 3% of those obtained directly from a force platform. Wicke and Lopers (14) found that the volumes of several body segments and the whole body can be measured accurately using the elliptical zone method.
Although the elliptical zone method appears to offer the advantage of providing accurate BSP data for any individual, its use has not become common. Proponents of the method typically project photographic slides of the front and side views of the subject onto a large digitizing table such as a PCD Model ZAE 3B (5) and Calcomp 9100 (10). A cursor is moved along the edges of body segments to obtain the diameters of the ellipses required for input to the ZONE program that then calculates the BSP data. Therefore, application of the method has been limited by the availability of digitizing tables and data collection programs compatible with the digitizing device.

Recently, researchers at CARE (3) have developed a PC version of Jensen's 'elliptical zone' digitising program to yield accurate body segment parameter data. The software has several features designed to maximise the accuracy of the BSP data and its ease of use. Images of the calibration rods and body segments can be zoomed prior to digitising or tracing. A user can 'undo' mistakes and continue from the last correct entry. The body segments can be outlined easily using a laser mouse with the segment zoomed. If the outline is not as desired it can be redone. The elliptical cylinders are generated and displayed automatically. Figure 3 illustrates examples of the traced outlines from which the diameters of the elliptical zones are determined.

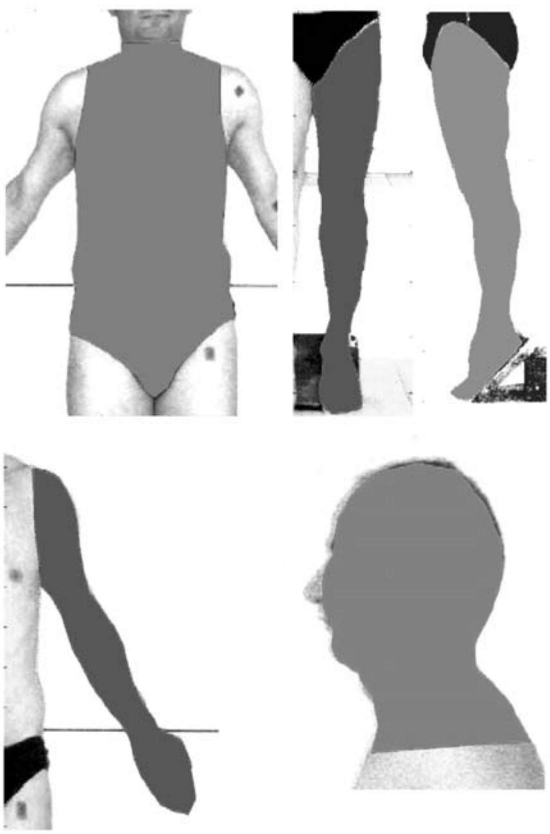

Figure 3. Examples of the outlines of body segments obtained by tracing the image with the mouse.

CONCLUSION
This paper described how 'state of the art' video equipment and video-based methods are being applied to assist analysis and research in swimming at the Centre for Aquatics Research and Education. Applications ranging from qualitative analysis for immediate feedback to 3D analysis to advance knowledge of how performance is optimized were presented.

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EFFECTS OF FATIGUE ON THE KINEMATIC HANDS SYMMETRY IN FREESTYLE.

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The purpose of this study was to investigate the effects of an exhaustive test on the symmetry of right and left hands trajectories. Eight male international swimmers performed 25 m in

1/2 tethered swimming at maximal velocity to calculate power before and after an exhaustive test of 4*50m freestyle. Right and left fingertips were digitised frame by frame from underwater views (50Hz). The trajectories were characterised by different points in the frontal plane (O), (I) and the sagittal plane (F),(D) et (B) to calculate the symmetry index (SI) based on the differences right-left coordinates. The spatial symmetry and the temporal asymmetry observed for all the points was maintained after the exhaustive test. The stable spatial symmetry with fatigue could be related to the high level of the population. The temporal asymmetry was not associated to the breathing side or to the dominant hand and could reflect the individual force-time patterns within the stroke.

Key Words: freestyle, fatigue, kinematic, symmetry.

INTRODUCTION

Symmetry can be defined as an exact correspondence between opposite halves of a figure or a form, whereas asymmetry is any deviation from this “ideal” structure (5). During walking, Robinson *et al*. (1987) determined a symmetry index (SI) to evaluate the gait symmetry before and after chiropractic manipulation on patients. For Herzog *et al*. (1989) acceptable symmetry in walking corresponded to SI lower to ± 10%. Goble *et al*. (2003) observed a decrease of kinematic and forces asymmetry with the increase of walking velocity. In running, Karamanidis *et al*. (2003) confirmed the symmetry of the gait. All these studies involved the lower limbs movements during terrestrial locomotion.. During swimming, the propulsion were principally generated by the upper limbs. Front crawl is characterised by alternative right and left arms strokes associated to a varying number of kicks (11). Symmetry in swimming was recently investigated by Haffner and Cappaert (1999) who reported symmetry on angular values of the upper limb for international swimmers. Cappaert and Van Heest (1999) concluded that the symmetry of the studied parameters reflected the most efficient stroke and thus characterised the best swimmers.

Other studies underlined right and left differences for the body roll angle (2), (4), (10), stroke duration with greater values for the breathing side (1), (16) when Goldfuss and Nelson (1971) and Potts *et al.* (2002) have reported strength and power imbalance between both arms in competitive swimmers.

In regard to these previous results obtained in fresh conditions, the aim of the study was to investigate the effects of an exhaustive test on the symmetry of the right-left hand trajectories.

METHODS

Eight voluntary male international swimmers participated in this study (age: 22.5 ± 2.3 yr, height 1.87 ± 0.07 m and weight 79.0 ± 6.5 kg). Five swimmers were characterised by a unilateral breathing pattern (right-sided) whereas the three other presented bilateral breathing pattern. After a standardised 1200 m swim warm-up, each swimmer performed 25 m in semi-tethered swimming at maximal velocity to obtain maximal swimming power (P) before (pre) and after (post) an exhaustive test of 4*50m in freestyle.

A swimming ergometer, fixed on the start area of the pool, was used to collect instantaneous force (f) and instantaneous velocity (v) in semi-tethered swimming, the swimmer being attached by a cable-pulley system to a powder brake (Lenz). Two digital video cameras (Panasonic WV-CP454E, 50hz) were used to record the underwater frontal and sagittal views.

The right and left fingertips, were digitised frame-by-frame according to Schleihauf’s software (Kinematic Analysis) over a stabilised portion of 5s in the middle part of the 25 m power test. The smoothed 3-D trajectories were characterised by different points in the frontal and sagittal plane (Figure 1). Each point was characterised by its temporal and spatial coordinates. To avoid any cumulative effect of the temporal parameters, the temporal coordinate for each point was calculated by subtracting the temporal coordinate of the previous point on the same axis ($t_n = T_n - T_{n-1}$ (s))

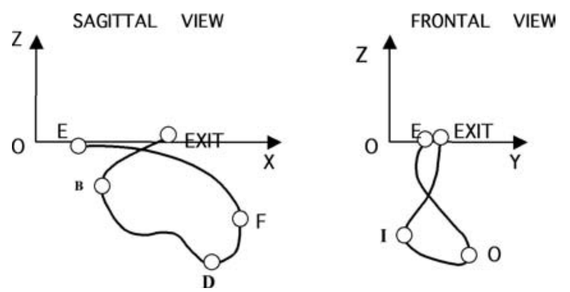

Figure 1. Characteristic points of the fingertip trajectory on the x-antero-posterior axis: F (maximal forward coordinate), B (maximal backward coordinate), on y-transversal axis: O (maximal outward), I (maximal inward), and on z-vertical axis: D (maximal depth).

According to Robinson et *al.* (1987), the symmetry index (SI) was calculated for each point

$$SI = \frac{X_R - X_L}{\frac{1}{2}(X_R + X_L)} \times 100$$

where X_R and X_L corresponded to the right and left coordinates. A negative SI indicated a right dominant side and a positive value a left one. Acceptable symmetry corresponded to SI lower to ± 10% (8).

The mean absolute SI, standard deviation (*s*) were calculated. Data from the left and right sides were compared through a non-parametric Wilcoxon test ($p<0.05$).

RESULTS

Results indicated that the maintain of the spatial symmetry (SI<10%) after the exhaustive test (figure 2A) with a temporal asymmetry (2B) was not significantly modified. Great individual variations were observed for the temporal asymmetry with right or left dominance depending on the subject and the point (figure 3).

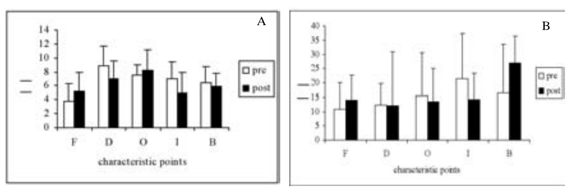

Figure 2. Mean absolute spatial SI (A) and temporal SI (B) of the characteristic points.

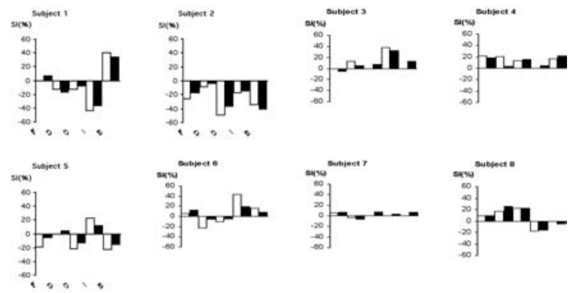

Figure 3. Individual temporal SI (%) for all the characteristic points.

Each subject presented a left or right dominance depending on the point excepted for subject 2 for which a left dominance was observed for all the points (figure 3). Whatever the subject and the point, the left or right dominance remained unchanged in fatigue condition.

DISCUSSION

The swimmers presented a spatial symmetry either in pre or post conditions. This was in the same way of the symmetry on angular values of the upper limb observed by Haffner and Cappaert (1999) in eight international swimmers. The stable symmetry reflected a strong pattern not affected by the fatigue condition as mentioned by Rodacki et al (2001). The present results on spatial symmetry highlighted the top level of the studied swimmers. Conversely, hands trajectories presented strong temporal asymmetry not modified with fatigue. This stable asymmetry appeared to be not related to the dominant hand and/or to the side breathing contrary to several authors who concluded that breathing have an influence on stroke duration and body roll angle (1), (4), (16) and on strength and power imbalance between arms (6), (12). The temporal asymmetry could reflect the individual intra-cycle force-time pattern in regard to previous results indicating differences among subjects in force-time pattern during the arm stroke (11), (15). These authors suggested that swimming propulsion is rather produced by impulse (force by time) than by high average force. Thus, it seems plausible that the observed temporal variability could reflect the variability of impulse distribution during the arm stroke.

CONCLUSIONS

The stable spatial symmetry and temporal asymmetry characterised the top level studied swimmers. The intra-cycle temporal variations suggested to study the force-time pattern to detect a possible effect of fatigue on impulse production within the stroke.

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FRONT CRAWL KINEMATIC: BREATHING AND PACE ACUTE EFFECTS

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The aim of this study was to verify the effects of breathing and no breathing and pace on stroke length (SL) and rate (SR) and swimming velocity (SV). Ten sprinter males performed 6 front crawl trials of 25 m (rest interval: 1min30s). SL, SR and SV were measured under two breathing conditions: breathing to the preferred side every cycle (B) and no breathing (NB), and three paces representatives of: warm up pace, 1500 m freestyle race pace, and 50 m freestyle race pace. Each trial was filmed

with a motion analysis system (60 Hz) from sagital view. A reflective marker was fixed to the swimmer's right wrist to quantify SL and SR. SV was obtained by the SL and SR product. Under NB conditions, SR and SV increased independent of the pace. The increase of pace was related to decrease of SL and increase of SR and of SV, whatever the breathing condition.

Key Words: breathing, stroke length, stroke rate, swimming velocity.

INTRODUCTION

Mean stroke length (SL) and rate (SR) and mean stroke velocity (SV) are objectives criteria and useful performance evaluation factors which are used by coaches and swimmers. It is recognized that SL is a good propulsive efficiency indicator and can be used to evaluate progress in the technique level (8). SR is dependent of the spent time in each stroke phase: propulsion and recovery. Product of SL and SR is the SV, in a given distance (7), not considering propulsive affects of push-off from the start and turnings. It has been demonstrated that increased SV is achieved by a combination of increasing SR and decreasing SL (4, 5, 7) and that a given swimmer swims faster in short term by increasing SR and that the same swimmer improves the maximum swimming speed in long term by increasing the SL (11). This negative relation between SR and SL seems to be an ability to adjust SV learned as part of training for competition (5). Swimmer body position is a very important factor when drag and propulsive forces are well thought-out (2). Alterations in body position could reflect in SL, SR and SV. To decrease possible negatives effects of the breathing motion, swimmers are oriented to keep head aligned with the longitudinal body axes, even during breathing motion (1). Although a correlation between the breathing movement and the performance has not been previously found (9), competitive swimmers usually breathe less frequently in short term events (e.g. 50 m freestyle).

Considering that swimming kinematics can be modified under different swimming condition (e.g. breathing and different paces) (5), the aims of this study were to verify (a) breathing and no breathing effect and (b) different paces on SL, SR and SV among 50 m freestyle swimmers.

METHODS

Ten 50 m front crawl male specialists (age: 20.7 ± 2.4 yr.; total body mass: 77.4 ± 5.1 kg; height: 184.5 ± 7.8 cm; upper limbs span: 193.5 ± 5.2 cm; 50 m freestyle mean best time: 23.5 ± 0.66 s) participated in this study. Subjects performed 6 front crawl trials of 25 m with a rest interval of 1min30s, in a 25 meters pool. SL, SR and SV were measured under two breathing conditions: breathing to the preferred side every cycle (B) and no breathing (NB), and three paces representatives of: warm up pace (P1), 1500 m freestyle race pace (P2), and 50 m freestyle race pace (P3). Each trial was filmed with a motion analysis system (60 Hz) from sagital view. A reflective marker was fixed to the swimmer's right wrist to quantify SL and SR, after digitalizing (only the first frame, when the wrist appeared in the surface of the water was used, in three consecutives cycles). A 2 m frame was used to calibrate linear distance in the beginning, in the center and in the end of the screen field (12 m) (there was a variation of 2.2% in the number of pixels corresponding to 2 m from the center to the extremes of the screen). SV was obtained by the SL and SR product. Statistical analysis was made with repeated measures ANOVA in a mixed 2x3 model (breathing and pace conditions). To verify main effects a Bonferroni post-hoc test was used (significant level of 0.05). Software SPSS 12.0 was used.

RESULTS

Table 1 presents mean and standard deviation of SV.

Table 1. Mean ± standard deviation of SV; n = 10. B = breathing; NB = no breathing; P1 = warm up pace; P2 =1500 m freestyle race pace; P3 = 50 m freestyle race pace.

	BP1	BP2	BP3	NBP1	NBP2	NBP3
SV ($m \cdot s^{-1}$)	1.21 ± 0.07	1.45 ± 0.06	1.86 ± 0.08	1.32 ± 0.10	1.60 ± 0,08	1.91 ± 0.07

No-breathing, independent of the pace, could increase SV [$F(2, 18) = 41.8$; $p < 0.001$; $\eta^2 = 0.823$]. As expected, increased pacing has caused an increased SV values, independent of the breathing condition, [$F(2, 18) = 250.4$; $p < 0.001$; $\eta^2 = 0.965$]. Approximately 96% of the SV variance can be explained by the different paces. No significant interaction between breathing condition and pacing was found [$F(2, 18) = 1.44$; $p = 0.263$; $\eta^2 = 0.138$].

Figure 1 presents mean and standard deviation of stroke rate by trials.

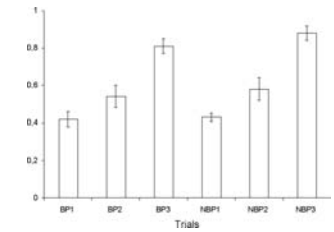

Figure 1. Mean ± standard deviation of stroke rate n = 10. B = breathing; NB = no breathing; P1 = warm up pace; P2 =1500 m freestyle race pace; P3 = 50 m freestyle race pace.

No breathing, independent of the pace, has caused increased SR values [$F(1, 90) = 13.03$; $p = 0.006$; $\eta^2 = 0.592$]. Under both, breathing and no-breathing, conditions, SR increased with the increasing pace [$F(2, 18) = 366.9$; $p < 0.001$; $\eta^2 = 0.976$]. Interaction between breathing and pace was significant [$F(2, 18) = 14.6$; $p < 0.001$; $\eta^2 = 0.619$]. Approximately 97% of the SR variance can be explained by the different paces.

Figure 2 presents mean and standard deviation of stroke length by trials.

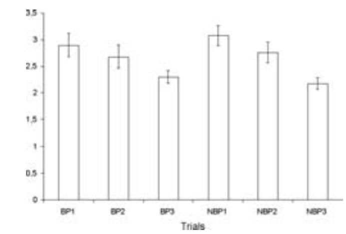

Figure 2. Mean ± standard deviation of stroke length n = 10. B = breathing; NB = no breathing; P1 = warm up pace; P2 =1500 m freestyle race pace; P3 = 50 m freestyle race pace.

Breathing condition did not cause any change in SL [$F(1, 9) = 0.045$; $p = 0.836$; $\eta^2 = 0.005$]. Under both, breathing and no-breathing, conditions, SL increased with the increasing pace [$F(2, 18) = 178.8$; $p < 0.001$; $\eta^2 = 0.952$]. Approximately 95% of the SR variance can be explained by the different paces. Interaction between breathing and pace was significant [$F(2, 18) = 8.698$; $p = 0.002$; $\eta^2 = 0.491$].

DISCUSSION

This study was planned in a way to verify different breathing and pace effects on front crawl stroke linear kinematics parameters. Increases of SV (Table 1), related to the increased pacing, were obtained by the negative relation of increased SR and decreased SL, as previously described (5, 7).

The breathing effects were observed in higher SR values found in no-breathing trials when compared to the breathing trials (Figure 1), but breathing could not change SL values (Figure 2), which were similar under both, breathing and no-breathing condition. Previous study (9) has showed that front crawl swimmers can perform the breathing action without it interfering with their basic stroke parameters. This cited study (9) has analyzed kinematics of the trunk and upper extremity in six male swimmers under a 200 m freestyle race pace, differently of the present study, which has analyzed SR and SL under three different paces (warm up pace, 1500 m freestyle race pace, and 50 m freestyle race pace). Perhaps, under only one pace, these differences would not be visible.

In response to the increasing pace, the adopted strategy to increase SV was to increase SR, as SL decreased. Such acute adaptations have been described in literature (4, 7, 8). When swimming intensity increases from an aerobic to an anaerobic level, swimmer increases SR and decreases SL (8). It is not considered most economical strategy, but the most used (3).

It must be considered the high variance of SV, SR and SL which can be explained by the increased pace: respectively, 96%, 97% and 95%. It means that kinematics parameters are, in a strong manner, influenced by intensity of the swimming. So, when a coach evaluates the kinematics parameters of the swimmers, it must be done under different pace conditions, including training exercises and competition events. In this way, the evaluation would be more objective and complete.

CONCLUSION

Breathing, among sprinters swimmers, could increase, stroke rate and, consequently, stroking velocity. To increase stroking velocity, in an acute way, swimmers increased stroke rate and decreased stroke length. Assessment of the kinematic parameters should be performed under different paces and breathing condition.

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TIME-FREQUENCY PARAMETERS OF WRIST MUSCLES EMG AFTER AN EXHAUSTIVE FREESTYLE TEST

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The purpose of this study was to investigate the effects of an exhaustive test on the EMG frequencies of 2 wrist muscles. Seven male international swimmers (22.6 ± 2.7 years, height 191 ± 4 cm, weight 82,7 ± 5,3 kg, 1.92 ± 0.09m/s for the velocity on 100m) performed an exhaustive test of 4*50m freestyle. An EMG system was used to record the electrical activity of 2 wrist muscles: the M. flexor carpi ulnaris (FCU) and the M. extensor carpi ulnaris (ECU). The time-frequency treatment was done according to the Knaflitz'method. The instantaneous mean frequency (IMNF) was obtained for each stroke of each 50m. The mean IMNF was calculated for each 25m of each 50m. Results indicated for both muscles, a decrease of IMNF at the end of the intensive test indicating the attempt of fatigue and the high recruitments within the crawl stroke. Subjects' differences were observed which could support the individualization of the training process.

Key Words: freestyle, fatigue, EMG, frequency, forearm.

INTRODUCTION

The swimmers propulsion is determined by the ability to generate propulsive force while reducing the resistance to forward motion. Propulsive force is mainly generated by the arms, which provide more than 85 % of the total force of the crawl stroke (1, 7, 13). Richardson (11) suggested that the most forward propulsion was related to the ability to maintain a given hand angle during the swimming stroke which was directly affected by the ability of the forearm muscles to maintain this position. Different studies on elementary movements under-

lined the role of forearm coactivations in the wrist stabilisation (10). In a single-joint study with unstable loads, Milner (10) found that the extensor carpi ulnaris (ECU) and the flexor carpi ulnaris (FCU) cocontractions increased the mechanical stability of the hand by increasing the stiffness of the wrist joint. In fatigue conditions, different studies indicated a shift of the power density of the signal towards lower frequencies in isometric conditions (3).
In swimming, previous results underlined the high activation of the (ECU) and of the (FCU) (2). Few studies focused on the effect of fatigue on the EMG in swimming (12). Because of the complexity of the movements, the studies were based only on the amplitude signal process. Recently, new development allowed to assess muscle fatigue from spectral parameters of EMG during cyclic dynamic conditions (9). In regard to these previous results, the aim of this study was to evaluate the effects of an exhaustive exercise on time-frequency parameters of the ECU-FCU forearm muscles in freestyle swimming.

METHODS
Seven male international swimmers participated in this study (22.6 ± 2.7 years, height 191 ± 4 cm, weight 82,7 ± 5,3 kg, 1.92 ± 0.09m/s for the velocity on 100m). After a 1200m standardised warm up, each subject performed an exhaustive test of 4*50m freestyle with 10s rest between them. An EMG system (ME 3000 P8, Mega Electronics Ltd, Kuopio, Finland) was used to record the electrical activity of 2 right muscles: the M. flexor carpi ulnaris (FCU) and the M. extensor carpi ulnaris (ECU). Electrodes were waterproof fixed on the midpoint of the contracted muscle belly as suggested by Clarys and Cabri (1993). The gain of the amplifier was set at 1000 with a common mode rejection ratio of 92 dB and high and low passes filters respectively of 8 and 500 Hz. The EMG signals were stored on-line on an acquisition card (Flash memory 32 MB) with a sampling frequency of 1000 Hz. After validate the quasi-cyclostationarity of the EMG for successive crawl strokes, the time-frequency treatment has been using A Choi-Williams transform according to the Knaflitz'method (9). The instantaneous mean frequency (IMNF) was obtained for each stroke of each 50m. The mean IMNF was calculated for each 25m of each 50m.

RESULTS
Results indicated a significant decrease of the IMNF between the 1st 25m of the 1st 50m and the last 25m of the 4th 50m with of percentage of decrease (PR) of 11.41% for the ECU and 8.55% for the FCU (figure 1). The regular decrease of the ECU was statistically similar to the decrease of the FCU.

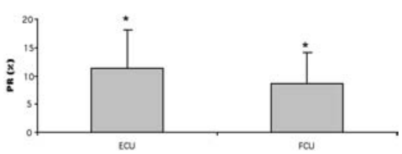

Figure 1. Percentage of decrease (PR) of IMNF between the 1st 25m of the 1st 50m and the last 25m of the last 50m.

Individual differences were observed in the decrease of IMNF from one 25m to another both for the ECU and FCU (figure 2).

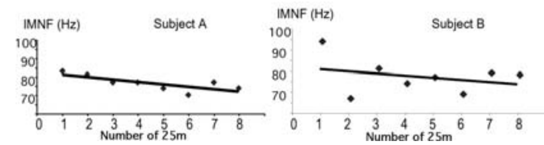

*Figure 2: ECU- IMNF decreases during the eight 25m of the 4*50m for 2 subjects.*

DISCUSSION
The decrease of IMNF at the end of the intensive test indicated the attempt of muscular fatigue of the wrist muscles as observed in elementary movements (3) or dynamic contractions (7). The lower frequencies at the end of the 4*50m reflected a decrease of muscle fibber conduction velocity (3) and/or a modification in the motor units recruitments (6) and/or an accumulation of chemical products (3).
The similar decreases for the ECU and the FCU indicated that both antagonist muscles are strong involved during the crawl stroke and reached similar statement of fatigue a the end of the 4*50m. The high recruitment of the antagonist ECU could be linked to the high water load supported by the swimmer's hand as De Luca (1987) showed that the higher the load that the subject supported was, the higher the "reciprocal activities" of the muscles were. In regard to previous results on elementary movements (5), ECU and FCU appeared as strong fatigable muscles in swimming as indicated by the magnitude of the frequencies decrease. Subjects' differences could reflect the individual variability in motor unit recruitments and /or the subject capacity to restore the muscle during the 10s rest between each 50m.

CONCLUSIONS
The decrease of EMG frequencies of both ECU and FCU muscles attempted the fatigue at the end of 4*50 m test. The magnitude of the decrease reflected the strong involvement of these 2 muscles in the crawl stroke. Individual results could be useful to adapt the training muscular exercises to each subject.

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EFFECT OF TECHNICAL MISTAKES ON ARM COORDINATION IN BACKSTROKE

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This study quantified the influence of two technical mistakes, the hand entry outside of the shoulder axis and head flexion on the thorax, on arm coordination in backstroke, with increases in velocity. Sixteen national level swimmers simulated these two mistakes, often observed in non-expert swimmers, individually and in combination at four race paces. They also swam with a traditional technique at the four paces. An adaptation of the Index of Coordination (IdC) (3) allowed the inter-arm coordination to be quantified in backstroke. In each swim condition, the negative values of IdC confirmed a catch-up coordination. This coordination was influenced by the mistakes adopted by the swimmers because, when the two mistakes were associated, the arm coordination was most disturbed.

Key Words: backstroke, non-expert swimmers, technical mistakes, coordination.

INTRODUCTION
The backstroke and front crawl are alternating strokes that allow a relative continuity of propulsive arm actions to overcome forward resistance as velocity increases (5). In backstroke, an increase in velocity is associated with an increase in stroke rate, and a decrease in stroke length (2, 4). In front crawl, Seifert, Chollet and Bardy (9) demonstrated a preferential arm coordination mode in relation to pace: for slow paces (from 3000-m to 200-m) swimmers adopted the catch-up coordination mode, during which they tended to glide with the arm extended forward, whereas they switched to a relative superposition coordination in sprint (from 100-m to maximal velocity). In backstroke, the alternating body roll, which may lead to a 90° abduction of the shoulder during the mid-pull (8), and limited shoulder flexibility (8) require an additional arm stroke phase and particular arm coordination. Lerda and Cardelli (6) showed that the clearing phase (after the push and before the recovery) does not allow continuity between the propulsive actions of the two arms. The swimmers, therefore, adopt catch-up as their preferential coordination mode whatever the skill level or velocity (6). Common technical mistakes observed in non-expert backstroke swimmers could disturb this coordination. The aim of the study was to quantify the influence of two mistakes (entry of the hand outside of the shoulder axis and head flexion on the thorax) and their combination on the arm coordination in backstroke with velocity increases.

METHODS
Sixteen national swimmers simulated two mistakes observed in non-expert swimmers and performed swim trials in four conditions: with the entry of the hand outside of the shoulder axis (OS), with head flexion on the thorax (FT), and with a combination of these two mistakes (2M); performance parameters in these three conditions were compared with those using their traditional (T) coordination. Moreover, they swam in all four conditions at four race paces (400, 200, 100 and 50-m). Two underwater video cameras (Sony compact FCB-EX10L) videotaped from frontal and side views (50Hz). They were connected to a double-entry audio-visual mixer, a video timer, a video recorder and a monitoring screen to mix and genlock the frontal and lateral views on the same screen, from which the mean stroke rate was calculated. A third camera, mixed with the side view for time synchronisation, videotaped all trials with a profile view from above the pool. This camera measured the time over a 12.5-m distance (from 10-m to 22.5-m) to obtain velocity. Stroke length was calculated from the mean velocity and stroke rate values. From the video device, three operators analysed the key points of each arm phase with a blind technique, i.e. without knowing the analyses of the other two operators. Thus, the arm stroke was divided into six phases (fig. 1): entry and catch (A), pull (B), push (C), hand lag time at the thigh (D), clearing (E) and recovery (F). The index of coordination used in crawl (1) was adapted for the backstroke so that arm coordination could be quantified.

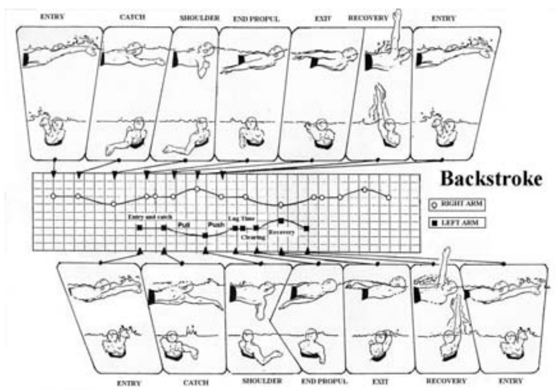

Figure 1. Modelling of arm stroke phases in backstroke between left and right arms.

Two-way ANOVAs (technical mistakes: 4 levels * race paces: 4 levels) analysed the effect of technical mistakes and race paces on the spatial-temporal parameters, the arm stroke phases and the inter-arm coordination with a level of significance set at 0.05.

RESULTS
With the increase in race pace, velocity and stroke rate significantly increased, while stroke length significantly decreased. Table 1 shows that velocity and stroke length were higher while stroke rate was lower for T than for the other conditions; the opposite was observed for 2M.

Table 1. Comparison of spatial-temporal parameters in the conditions with technical mistakes and the traditional coordination condition.

Conditions	Velocity ($m.s^{-1}$) ($m.s^{-1}$)	Stroke Rate ($stroke.min^{-1}$)	Stroke Length ($m.stroke^{-1}$)
T	1.28±0.16	36.2±6.5	2.15±0.2
FT	1.23±0.14	37.3±6.1	2.01±0.2 a
OS	1.15±0.18 a, b	39.9±7.3 a, b	1.76±0.3 a, b
2M	1.12±0.18 a, b	40.1±6.9 a, b	1.71±0.3 a, b

a: significant difference with T; b: significant difference with FT at $P<0.05$

With the increase in race paces, the propulsive phases (B and C) increased while the non-propulsive phases (A, D, E, and F) decreased. In the traditional coordination condition, the relative durations of the propulsive phases were significantly smaller (T: 35.6±4.4%, FT: 37.6±4.2%, OS: 39.4±3.5%, 2M: 40.9±3.9%) than in the conditions simulating technical mistakes. Table 2 indicates that only the entry and catch (A), push (C) and clearing (E) phases showed significant difference between reference condition.

Table 2. Comparison of the arm phases in the conditions with technical mistakes and the traditional coordination condition.

Conditions	A : Entry and catch phase (%)	C: Push phase (%)	E : Clearing phase (%)
T	16.1±5.2	16.2±3.5	15.6±2.5
FT	13.7±4.5 a	16.9±3.7	15.9±2.4
OS	8.5±1.2 a, b	18.9±4.1 a, b	17.8±2.9 a, b
2M	7.7±3.9 a, b	20.3±4.9 a, b	18.5±3.1 a, b

a: significant difference with T; b: significant difference with FT at $P<0.05$

Whatever the condition, the IdC tended to decrease with increases in race pace. The IdC was significantly more negative for traditional coordination (T) (-14.3±4.5%) than for OS (-10.6±3.6%) or 2M (-9.9±9.1%) ($P<0.05$), showing that the association of the two mistakes (FT + OS = 2M) led to less marked catch-up coordination.

DISCUSSION
In the four conditions, the increases in race pace were associated with an increase in stroke rate and a decrease in stroke length, showing that whatever the technical mistake adopted (and consequently whatever the skill level), the management of spatial-temporal parameters was similar (2, 4). In line with previous studies (2, 4), our study confirmed that higher velocity and higher expertise are related to greater stroke length. These spatial-temporal parameters changed according to the distribution of the arm stroke phases. Notably, the head flexion on the thorax (FT) and, more particularly, the entry of the hand outside of the shoulder axis (OS) led to a decrease in the relative duration of the entry and catch phase. These mistakes prevented the deep hand-sweep that prepares the propulsion and were regularly associated with a dorsal position without shoulder roll (8). Beginners are often not aware that having an entry of the hand outside of the shoulder axis is a mistake; they thus shorten the entry and catch phase to rest on the water (i.e. to maintain the upper body and the head on the surface) instead of plunging their hand deeper to find a resistive mass of water. Using the OS and 2M mistakes led to longer push and clearing phases and consequently to less marked catch-up coordination (less negative IdC), which did not indicate better propulsion, as commonly assumed. Indeed, a high IdC reveals good technique only if it is associated with high velocity and great stroke length. In the OS and 2M cases, the higher IdC and the longer push and clearing phases indicated a problem of hand-sweep rhythm. In particular, the premature entry of the hand in the water meant that the hand was in the water too long and had an upward path during the push phase, instead of a backward and downward path with acceleration. Even though the push phase was longer for the conditions with technical mistakes, a high average force may not be as effective as a high maximal force (3, 7). These authors (3, 7) showed that the hand undergoes a constant change in direction and alternating acceleration and deceleration during the underwater stroke phases, which does not enable it to apply high continuous force. Hence, although a relatively long propulsive phase is needed to apply high peak forces, a long push phase could be used by swimmers to compensate their mistakes and to balance the body.

CONCLUSION
The entry of the hand outside of the shoulder axis seems to be the non-expert behaviour that most influences inter-arm coordination, and even more so if this technical error is associated with a head flexion on the thorax. Coaches could use the index of coordination and the assessment of arm stroke phase durations to quantify the inter-arm relationships coordination. This information in association with the spatial-temporal parameters (velocity, stroke rate and stroke length) could then be used to correct non-expert swimmers.

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SIMULTANEOUS RECORDINGS OF VELOCITY AND VIDEO DURING SWIMMING

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A method is described for the recording a swimmer's velocity and synchronizing these records with the underwater video. Examples of these records during pushing off from the side of the pool, breaststroke, butterflystroke, backstroke, and crawlstroke are presented. These records demonstrate to swimmers and coach the biomechanics of swimming, and they are useful for immediate feedback.

Key Words: swimming, biomechanics, breaststroke, butterflystroke, backstroke, crawlstroke.

INTRODUCTION
There have been many pictures of swimmers from above or below the surface of the water (1, 4). Patterns of motion have been analyzed in detail, and many coaches form definite opinions about the best stroke techniques. As the arms and legs are moving about the center of mass of the body, it is difficult to judge the velocity, and incorrect conclusions about stroke mechanics are often made. Recordings of swimmers' velocities have also been reported (2). The current work involves underwater videos of swimmers synchronized with recordings of instantaneous velocity displayed on the computer screen. The videos and the recordings are stored, and the data are available for detailed analysis immediately or at a later time.

METHODS
Velocity is measured by attaching a fine (0.2 mm diameter) non-stretchable line to the back of a belt around the swimmer's waist. The line passes through a series of pulleys and over the wheel of a DC generator positioned at the side of the pool. The voltage output of the generator is converted to digital format at a sampling rate of 400/s. Underwater video cameras are spaced along the side and one at the end of the pool. The cameras along the side are spaced so that as the swimmer moves out of view from one camera the image appears in the next one. The videos are recorded sequentially, and the pictures are synchronized with the tracings of the velocity. The computer screen showing the velocity and the underwater picture can be viewed during the swim and is available for immediate review and analysis.

RESULTS AND DISCUSSION
Pushoffs
The simplest recording is obtained by asking the swimmer to push off from the side of the pool in a streamlined position and to remain motionless in a horizontal position for the rest of the glide. As shown in Figure 1, the velocity during this gliding motion decreases exponentially due to the swimmer's drag. The computer program calculates the characteristics of the velocity curve (Figure 2). From the point of view of competitive swimming, these curves reveal important considerations. First, it is noted that due to drag the swimmer's velocity immediately decreases upon loss of contact with the side of the pool. In addition the time spent gliding underwater after a start or turn is specific to the swimmer's mean swimming speed on the surface. (5). For example, if the swimmer's mean velocity on the surface is 1.8 m/s, swimming must be resumed by 0.8s after leaving the wall. It is possible to calculate that at this time the swimmer's waist would be 3.3 m from the side of the pool. The coach can know if the swimmer is making the optimal transition from the pushoff to swimming.

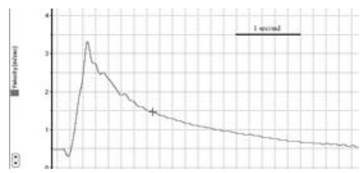

Figure 1. Tracing of velocity after pushoff.

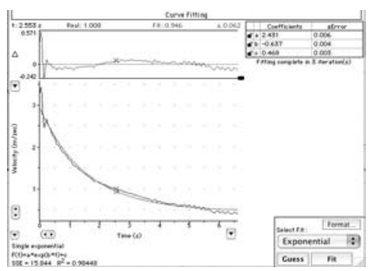

Figure 2. Analysis of velocity after pushoff.

In breaststroke races the swimmers are allowed one arm stroke and one leg stroke before coming to the surface and resuming swimming (Figure 3). It has been found that the mean velocity of this underwater swimming may be slower than swimming on the surface (5).

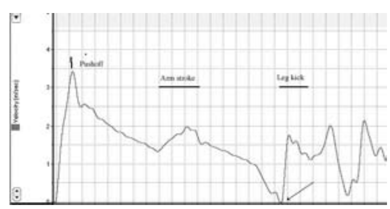

Figure 3. Recording of velocity after pushoff in breaststroke.

In figure 3 the swimmers average velocity from pushing off the wall to surfacing just before the first complete stroke cycle on the surface was 1.52 m/s, and he traveled 7.0 m. His average velocity during the remainder of the lap was 1.58 m/s. This difference indicated a need to complete the underwater phase in a shorter time so the average velocity would be greater or at least equal to his surface velocity. Figure 3 also shows that after the arm stroke the velocity decreased to zero as the swimmer brought the arms under the thorax and the legs were flexed in preparation of the kick (see arrow). Although this preparation for returning to the surface increases drag, zero velocity can be avoided by abbreviating the time underwater (5).

Breaststroke
This style of competitive swimming is the most definable of the four stroke patterns, and the one that is most amenable to analysis. It has the greatest oscillations of velocity. Figures 4 and 5 show stroke cycles of two breaststroke swimmers.

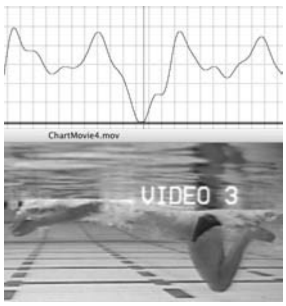

Fig 4. Breaststroke. Picture at minimal velocity.

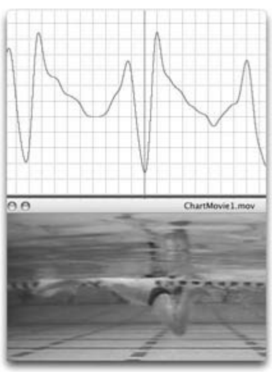

Fig 5. Breaststroke. Picture at minimal velocity.
Note: in all of the pictures of swimmers, the vertical dashed lines on the velocity recordings indicate the speed at the time of the video frame and are part of the computer program.

Although these recordings were made at slightly different swimming speeds, it is apparent that the swimmer in Figure 4 has a period of zero velocity when the legs are flexed in preparation for the propulsive kicking action. During the same part of the stroke cycle the velocity for the swimmer in figure 5 is significantly greater than zero. The cause of this difference can be explained by the differences in the angles of the thighs to the torso. The resistance to forward movement or drag is much greater for the subject in figure 4 than in figure 5. This increase of drag is related to the frontal surface caused by the position of the swimmer's thighs.
The pattern of breaststroke swimming can be characterized by defined phases.

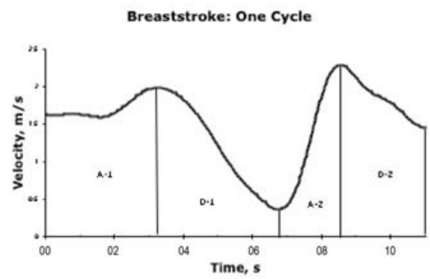

Figure 6. Phases of the breaststroke stroke cycle.

At the beginning of the stroke cycle the action of the arms produces an initial acceleration, A-1.This followed by a period of deceleration, D-1, as the legs are flexed in preparation for the kick. The acceleration due to the legs, A-2 is much greater than A-1. The glide after the kick is associated with the second period of deceleration, D-2.

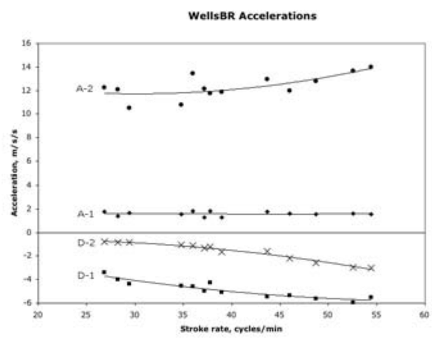

Figure 7. Accelerations during stroke cycle.

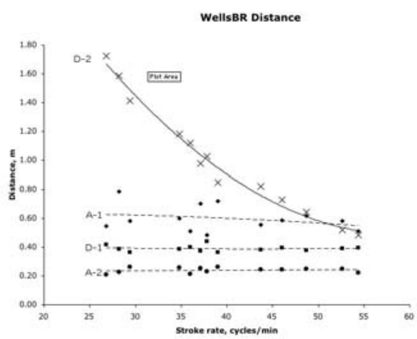

Figure 8. Distances of stroke phases.

Figures 7 & 8 show the results of the analysis of 13 one-length swims of a swimmer doing the breaststroke and going from slow to fast speeds. The accelerations of the kick phase (A-2) increased slightly, but the accelerations of the arm stroke (A-1) were independent of stroke rate and velocity. In the non-propulsive phases the decelerations were greater when the swimmer was going faster. These patterns were probably related to the increased body drag with increased velocity. As reported before (3), the distance traveled each stroke during the breaststroke is dependent on the time spent in the glide after the leg action (D-2) During all the other phases the distance traveled is independent of stroke rate. Another way of looking at breaststroke swimming is to say, "it's all about timing." These observation suggest that the breaststroke swimmer can practice the skills related to arm and leg action at slow stroke rates. Improvements should transfer to faster stroke rates. Practice at the faster speeds should focus on minimizing drag during the glide after the kick (D-2).

Butterflystroke

The butterflystroke is swum with greater variation of the pattern than the breaststroke. Figure 9 shows the velocity profile of three swimmers who were using the same stroke rate and were going at about the same speed.

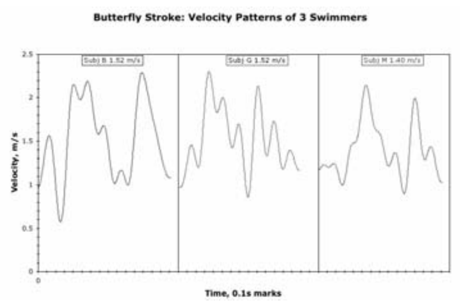

Figure 9. Butterflystroke velocity profile 3 different swimmers.

The first peak in each panel is the result of the arm and leg action. There is then a decrease of the velocity until the second leg action. Variations in the pattern can also be observed in the same swimmer.

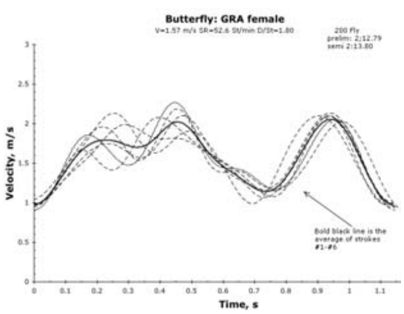

Figure 10. The velocity profiles of six sequential strokes are indicated by the dotted lines. The solid line is the average of the six stroke cycles.

In Figure 10 the variations occur in the timing of the arm and leg actions at the first part of the stroke. In some instances the arm flexion occurs before the leg flexion, and there is a decrease of the velocity between the two motions. At the other extreme the initial leg and arm actions are so closely related that the velocity shows just one maximal peak. The second peak of velocity is due to the legs acting alone, and is very reproducible.

Backstroke

Although fluctuations of the velocity during the stroke cycle may be apparent at slow stroke rates, they become very small at greater stroke rates swimming the backstroke.

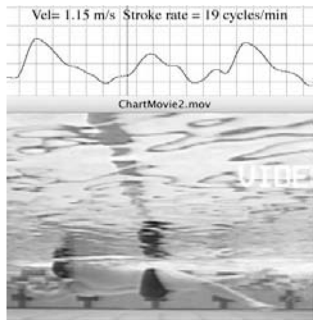

Figure 11. Backstroke at slow speed.

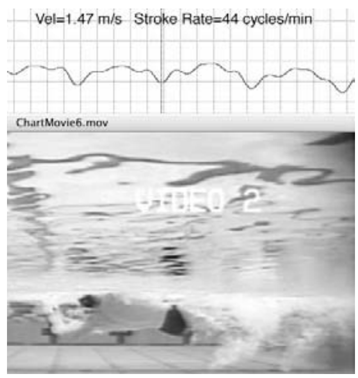

Figure 12. Backstroke at greater speed.

As shown in Figure 11 the velocity increases with each arm action and at this slow stroke rate there is a non-propulsive or glide phase. At greater stroke rates the glide phase almost disappears. The recovery of arm after its propulsive motion is fast, and on it's next entry is immediately used for propulsion without a gliding phase. The decelerations noted in Figure 12 are quite common for this stroke style. Although we initially attributed this to the increased flexion of the leg, other views suggested that it might be related to the swimmer's poor alignment at this phase in the stroke cycle.

Crawlstroke

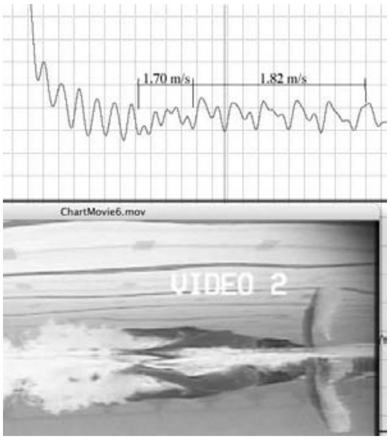

Figure 13. Female-swimming crawlstroke (freestyle).

After the swimmer entered the water from a diving start the velocity decreased rapidly and then showed fluctuations related to the repeated leg flexions and extensions known as dolphining (Figure 13). In this section the mean velocity of was 1.70 m/s. During swimming the crawlstroke the velocity was 1.82 m/s. It is apparent that this swimmer should limit dolphining to three cycles and then begin swimming. It is important for swimmers to learn when to begin and when to stop dolphining after a start or after a push-off from a turn. Such decisions can only be made from recorded data.

CONCLUSION

Swimming in all competitive stroke styles involves accelerations and decelerations. The simultaneous recording of the swimmer's velocity and the synchronized underwater video enables the viewer to see the effects of motion in different parts of the stroke. Additional calculations such as mean, maximal, and minimal velocities, time of a chosen segment, distance traveled are incorporated into the program and are useful in understanding the effects of different stroke patterns. Swimming involves major accelerations and decelerations. The patterns of movement and the resulting velocities are very different in the competitive stroke styles. In each there are variations among swimmers, and even during a single swim the patterns may change. Starts and turns can also be analyzed. These approaches are limited only by the imaginations of the swimmers and their coaches.

ACKNOWLEDGEMENT

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UNDERWATER UNDULATORY SWIMMING: STUDY OF FREQUENCY, AMPLITUDE AND PHASE CHARACTERISTICS OF THE 'BODY WAVE'

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The purpose of this study was to analyze wave motions of underwater undulatory swimming (UUS) and to compare these whip-like actions with previous studies developed in butterfly and breaststroke. UUS is characterized by vertical displacements of the body parts such that a wave progresses along the body with most of its power contained in a single sinusoidal harmonic (H1). Progression of the H1 wave from hip to ankle raises the possibility that energy is transmitted along the whole body in butterfly swimming and from the hips in USS. In UUS upper body segment movements were not part of the body wave and would be used to stabilize position. Increasing values of vertical velocities caudally from hip to knees to ankles appears to be related to maximising horizontal velocity of the CM in UUS. A future analysis of the wake structure generated by UUS and its relationship to wave characteristics seems a logical step for further understanding propulsive mechanisms in UUS.

Key Words: Fourier transform, harmonic, technique, hydrodynamics.

INTRODUCTION

When swimming underwater undulatory swimming (UUS) the swimmer's body parts are displaced horizontally and vertically through the kick cycle. These motions have been likened to oscillations or wave-like motions (2, 3, 5). When dolphins and butterfly swimmers were compared, based on body wave (BW) velocity and duration of the up beat, BW velocities were similar while the duration of the up beat was different (5). Harmonic or Fourier analysis[1] was applied by Sanders et al. (2, 3) to determine the frequency, amplitude and phase characteristics of the vertical undulations of the swimmer's body parts. They found differences in phase between body parts in butterfly swimming such that a body wave travelled caudally and suggesting that energy gained by raising the CM was transmitted caudally and contributed to a propulsive whip-like action, while in breaststroke the range of vertical motion of the hips was large relative to the vertical motion of the CM. It was proposed that these vertical motion differences reduced the need to do work to raise the CM and the transmission of a body wave enabled energy accrued by the upper body to be reused to raise

the caudal half of the body to a streamlined position in which drag is reduced.
The purpose of this study was to analyze wave motions of UUS and to compare these whip-like actions with previous studies developed in butterfly and breaststroke.

METHODS
Subjects
Twenty international and national ranked swimmers, ten male and ten female, were videotaped performing UUS for a 15m sprint after a water start. The distance was covered in the horizontal direction and at approximately one meter in depth to avoid wave resistance.

Instrumentation
One camera (S-VHS sampling at 50 Hz) with its optical axis perpendicular to the line of motion of the swimmer recorded each trial through an underwater window. To avoid the influence of impulse from pushing off the wall, the camera recorded the movement from 7.5 to 12 m from the wall. As this study was two-dimensional, a symmetrical 13 points model was digitized after each video-capture using Kinematical Analysis System developed by R. Schleihauf at San Francisco State University (www.kavideo.sfsu.edu). Coordinates of the CM were determined. The digitised coordinates of the body landmarks were exported to a set of MatLab routines (developed by R. Sanders). The program steps were: 1) Raw data was smoothed and interpolated to 100 samples per second. 2) Stick figures of the kick cycles were produced. 3) A kick cycle was selected based on the vertical displacement of the ankle 4) The cycle time was normalised to percentiles of the total cycle time. 5) Data and graphs of vertical displacement, vertical velocity and vertical acceleration versus % of kick cycle were obtained. 6) Fundamental harmonic (H1, H2, …Hn) velocity of body segment were calculated and graphically displayed. 7) A graph of wave amplitude of first five harmonics and their power contribution was displayed. 8) Phase analysis of the two first harmonics (H1 and H2) was performed. 9) Joint angles, angle velocity and angle acceleration evolution of hip, knee and ankle were determined for the kick cycle.

Variables
Distance of the body per kick (KL, m(cyc^{-1}), kick frequency (KF, Hz) and mean CM horizontal velocity (CMHV, m(s^{-1}) were the basic variables to describe the UUS technique (see table 1). Vertical position data were input to the Fourier analysis software to obtain the fundamental frequency and its harmonics. Amplitude of each frequency was calculated by $C_n=(A_n^2+B_n^2)^{0.5}$, were A_n and B_n are cosine and sine coefficients for the nth frequency (harmonic). The contribution of each harmonic to the power of the signal, that allows us to know its influence in the movement, was given by $2C_n^2$. Average velocity of the travel of the wave along the body was determined for the fundamental harmonic (n=1) for the vertex to shoulders, shoulders to hips, hips to knees and knees to ankles (m/s) by $u=d/t$ where u is the velocity of travel along the body, d is the displacement between adjacent landmarks and t the time taken to achieve the same phase as the previous landmark.

RESULTS AND DISCUSSION
Table 1 shows mean swimmers UUS kick characteristics. On average the group took approximately 0.46 s to complete a kick cycle. This was less than half of the that obtained in the studies of the butterfly stroke (2) and breaststroke (3).

Table 1. Means and SD for the displacement of the body per kick (KL), kick frequency (KF), kick index (KI) and CM velocity (v).

	KL (m·cyc^{-1})	KF (Hz)	CM v (ms^{-1})
Mean	0.76 (±0,14)	2.17 (±0,324)	1.63 (±0,17)

Figure 1 shows the vertical velocity (VV) of each body landmark and CMHV. Upper values of absolute VV were found in the downward kick compared with the upward kick in the knee and ankle. This produces a small increment in the CMHV at the end of the downward kick. Peak values of VV increase progressively from shoulder to hip to knee to ankle. CMHV showed a small range of variation during the cycle, this low variability demonstrates a likely contribution of different kind of propulsive mechanisms appropriately combined in a period of body oscillation. A wave transmitted in a cephalo-caudal direction along the body can contribute to conservation of mechanical energy. The vertical movement of the body parts was almost entirely comprised of one low-frequency waveform (Table 2) and it suggests a truly harmonic or wave-like pattern, as Ungerechts (6) and Sanders (2) suggested. This means that vertical movements of the body landmarks are phases of a simple sinusoid oscillation with very rhythmical motion. Upper body segment results were more variable. Our H1 results of the vertex and shoulder were similar than the obtained in butterfly (2) and breaststroke (3) however, hip, knee and ankle showed values about 100% of power contribution different than the previously obtained (2, 3) where the H1 and H2 harmonics contribution was very differently distributed in butterfly (about 50%) and breaststroke (about 70% for H1). The arm strokes performed during these strokes explained the differences found in UUS, where the arms are stretched and fixed forward in horizontal position.
The increasing amplitude of oscillation from hip to ankle suggested a 'whip-like' action. It can be hypothesized that there is a relation between this action and the production of a wake with rotating vortices that can be propulsive, as UUS visualized wakes suggested (1). Each time the tip of the feet change direction, it sheds a stop/start vortex. As the feet move to the other side, a low-pressure region develops in the posterior half of the legs, sucking a bolus of fluid laterally (as Tytell and Lauder (4) proposed in eel propulsion).

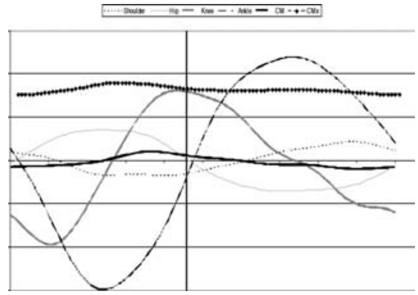

Figure 1. Average vertical velocity for each body landmark and CM horizontal velocity (m/s).

Table 2. Mean Percentage Power Contributions of H1 and H2 to waveform power.

Body Landmark	H1		H2	
	Mean	SD	Mean	SD
Vertex	91,28	9,02	6,29	8,50
Shoulder	94,34	5,63	3,15	3,41
Hip	96,89	3,15	2,43	2,91
Knee	96,77	1,84	2,77	1,82
Ankle	98,94	0,60	0,93	0,66

Table 3. Mean and SD for Fourier amplitude H1 wave and range of vertical motion (m).

	Amplitude	Range
Vertex	0,013 (±0,005)	0,102 (±0,04)
Shoulder	0,015 (±0,003)	0,066 (±0,02)
Hip	0,029 (±0,007)	0,068 (±0,016)
Knee	0,059 (±0,013)	0,136 (±0,031)
Ankle	0,099 (±0,02)	0,239 (±0,056)
CM	0,007 (±0,004)	0,041 (±0,021)

The range of vertical motion produced by the calculated waveforms was about four times that of the Fourier amplitudes presented. Mean Fourier amplitudes for H1 and range of vertical motion are presented in Table 3. Mean Fourier amplitudes of H1 and range, increased progressively from vertex to ankle showing the lowest vertical movement in CM. The obtained results were similar to those obtained in studies of butterfly (2) and breaststroke (3) in hip, knee, ankles and CM.

CONCLUSIONS

UUS is characterized by sequential vertical displacements of the body parts such that a fundamental sinusoidal wave harmonic (H1) dominates the waveform power and travels caudally from hip to ankle. This raises the possibility that energy is transmitted mainly from the hips in USS rather than along the whole body as in butterfly swimming. Upper body segment movements appear to be used only to stabilize the body and to maintain a horizontal position. Increasing values of vertical velocities of hip, knees and ankles appears to be associated with horizontal velocity of the CM in UUS. A future analysis of the wake structure generated by the underwater undulatory swimmer and its relationship to wave characteristics seems a logical step for further understanding propulsive mechanisms in UUS.

NOTES

[1] Any periodic signal can be broken down into its harmonic components. The sum of the proper amplitudes of these harmonics is called Fourier series (7).

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EMG-MODEL OF THE BACKSTROKE START TECHNIQUE

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This study researched in more depth a 6-phase model that describes the time pattern and the activity level of the muscles while executing the backstroke start. Five male backstroke sprinters of the German national swim team performed four backstroke starts over a distance of 7.5 m. EMG-data were recorded by a water protected 8-channel EMG from eight arm, shoulder, trunk and leg muscles. To compare the quality of muscular activity patterns, the IDANCO-system served as a quantitative method. The EMG recordings in the 5 swimmers indicated a medium repetition consistency and reproducibility of the identified patterns of muscle activity. In the initial hang phase, and the final glide phase the EMG recordings of the first dolphin kick demonstrated an identical and analogue movement behaviour. During the flight phase, and especially during the water entry the number of different muscle activation patterns grew significantly.

Key Words: swimming, backstroke start, EMG, reproducibility-system.

INTRODUCTION

Cossor and Mason (3) proved that the underwater speed during the glide phase of the start had a great impact on the position within the starter field, and in addition, influenced the total race time in the 100m backstroke swimming.
Furthermore, it was assumed that the out of the water phase plays a key factor in the sprint performance. For this reason, this study researched a 6-phase model that contains not only kinematic and dynamic parameters [Krueger et al., in this volume], but also describes the time pattern and the activity level of the muscles that generate and transmit the forces and stabilize the body while executing the different movements during the backstroke start.
EMG studies of the start movement in crawl swimming showed that in the out of the water and underwater phase the

grab start is characterized by lower interindividual differences in muscle activity when compared to the track start (4). The greater interindividual reproducibility of the muscle activity patterns in the grab start might be caused by the more standardized movement behavior of this technique. Since the backstroke start out of the water is characterized by small interindividual variations in the technical execution versus the start movements from the top of the block, it is hypothesized that in elite backstroke sprinters the EMG patterns of the most important propulsion and stabilization muscles are almost identical.

METHODS

Five male backstroke sprinters of the German national swim team performed four backstroke starts over a distance of 7.5 m. The comparably short start distance of 7.5 m had to be used due to the limited length of the cable of the EMG measuring device. The over all start time was recorded by high speed video analysis (Redlake Inc., 125 Hz). Kinematic parameters (block time, flight time, and overall start time, angles at take off and water entry, take off velocity) were calculated by motion analysis (SIMI-Motion, Ger). Dynamic data were measured as 3-dimensional ground reaction forces by a mobile water proof force plate (Kistler Inc., Ger) mounted to the pool wall. The EMG provides information about muscle activation and the specific temporal pattern of the coordinative interplay between the propulsive and stabilizing muscles. In the present study surface electromyography was used, which is a) more adaptable to global studies on athletes and b) was better accepted by the subjects (5). The skin was shaved, rubbed and cleaned, and the electrodes were fixed with adhesive tapes and plastic films (Tegaderm, 3M Inc.). EMG-data were recorded (sample frequency 1000Hz) by a water protected 8-channel EMG (Biovision Inc., Ger) from eight arm, shoulder, trunk and leg muscles located on the right side of the swimmers body (see Table 1). These muscles represent the most important kinetors for stabilizing the initial hang phase, the take off, flight and water entry movement, and also the undulating whole body movement when executing the dolphin kicks during the underwater phase. It is assumed that the investigated muscles produce most of the explosive power needed for an effective start of the swimmer.

Table 1. The eight muscles of the right side of the body chosen for the EMG in the backstroke start.

Upper body	Lower body
m. deltoideus	m. rectus femoris
m. biceps brachii	m. gluteus maximus
m. triceps brachii	m. semitendinosus
m. erector spinae	m. gastrocnemius medialis

Raw EMGs were corrected to obtain the full wave rectified signals. The data were band-pass filtered (butterworth 2nd-order, cut-off frequencies 10.0 Hz and 400.0 Hz) and averaged by Butterworth at 8.0 Hz, 2nd-order. The amplitude of the linear envelope was normalized with respect to the maximum muscle activity during the whole start movement up to the 7.5m limit. Each muscle of each subject was used as its own reference (5). The time durations of the four phases of the out of the water phase (reaction phase from signal to the first movement; pressure phase from first movement to hands off; jump phase from hands off to feet off; flight phase from feet off to hip entry), and of the first two phases of the underwater phase (entry phase from hip entry to the maximum depth of the feet, which is regarded as the starting point of the first dolphin kick, and glide phase I with the first dolphin kick that ends at the second maximum depth of the feet) were all normed separately in order to allow intra- individual and inter-individual comparisons of the patterns of the muscle activities during the different movements of the backstroke start.

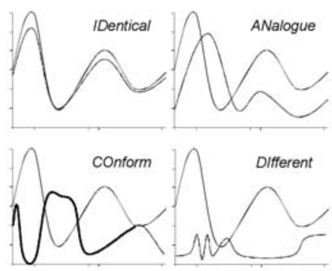

Figure 1. The IDANCO-system with four criteria for EMG pattern similarity (Bollens et al., 1988).

The IDANCO-system as used by Bollens et al. (1) served as a quantitative method to compare the quality of muscular activity patterns. The comparisons are based on the linear envelope of the raw EMG-signal. The term IDANCO stands for *IDentical*, *ANalogue*, *COnform*, and *different* muscle activity patterns (see fig. 1). Since the swim start is an acyclic movement, Conform patterns that are characterized by a reverse activation of agonists and antagonists could not be found. Because such phenomena primarily occur in cyclic movements, this category was dropped. The remaining three criteria (IDentical, ANalogue, DIfferent) led to a modified "IDANDI"-system indicating three different levels of muscular specificity. Furthermore, in contrast to Bollens et al. (1) the 3 point-score within each category that quantifies the degree of the differences in the time duration on the one hand and the amplitude of the muscle activation on the other hand, or in both modalities was not used. Differences in one of these or both modalities were all summarized in the category "analogue" patterns in the respective phase of the start movement.

RESULTS

Although 7.5 m is a very short distance to measure the swim start performance, the athletes exhibited remarkable differences in the overall start times (table 2).

Table 2. Kinematic parameters of the 5 athletes in the backstroke start.

	BW [kg]	F_{RMax2} [N]	Hands off [s]	Take off [s]	Hip entry[s]	Start time time 7,5 m	$v_{take\ off}$ [$m \cdot s^{-1}$]	PB 50B [s]
T.E.	71.0	742.3	0.48	0.82	1.10	3.69	3.75	26.89
T.R.	75.0	922.1	0.47	0.77	1.10	3.59	2.95	24.80
H.M.	73.0	1,055.6	0.53	0.76	1.17	2.72	2.92	26.16
M.C.	80.0	984.0	0.45	0.67	1.04	3.23	3.56	25.53
S.D.	90.0	1,243.9	0.49	0.78	1.08	2.77	3.50	25.14
Mean	77.80	989.56	0.486	0.761	1.097	3.200	3.34	25.70
SD	±7.60	±183.54	±0.029	±0.055	±0.047	±0.449	±0.38	±0.83

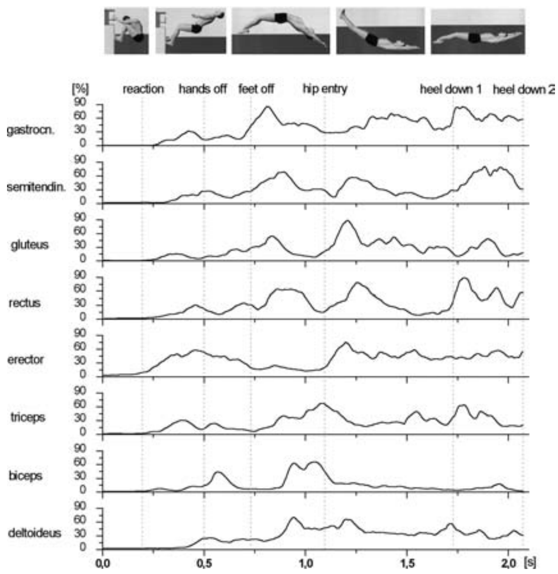

Figure 2. The normalized and averaged (3 trials) muscle activity pattern of the backstroke start movement of the athlete SD.

The EMG data of the 8 investigated muscles of one participant (100m backstroke finalist) of the Olympic Games in Athens 2004 (see Figure 2) form a representative model of the muscle activity pattern of the backstroke start. The start movement during the out of the water phase is initiated in the static reaction phase by the M. erector spinae (54.0±40.7%) that was active to move the upper body backward towards the jump off position. In the jump phase, after pushing the hands off the wall, the M. deltoideus (21.3±7.9%) helped to bring the shoulder backward. In addition, all four leg muscles showed very high activity during the explosive extension of the legs at the take off. In the flight phase Mm. biceps brachii (33.9±3.1%), triceps brachii (34.4±15.2%), and deltoideus (39.5±0.6%) contributed a lot to stabilize the body shortly before and during the water entry. After the hip entry M. gluteus maximus showed maximum activity (88.2%) to accelerate the body by sweeping the legs downward. In the underwater glide phase the cyclic propulsion movement of the dolphin kick was characterized by maximum muscle activities of the Mm. rectus femoris (89.2%) and gastrocnemius (84.7%) during the upward sweep, and by time lagged activities of the M. semitendinosus (79.9%) during the downward sweep (see fig. 2).
The EMG recordings in the 5 swimmers indicated a medium repetition consistency and reproducibility of the identified patterns of muscle activity (see Fig. 3). 13.0% of all patterns proved to be identical, and 57.2% were at least analogue. Thus, 70.2% showed a form of *intra-individual stability*, and only 29.8 % could not be held constant in the repeated trials of each athlete. Most of the identical patterns (85.2%) were found in the static hang phases I and II and in the following jump phase (11.1%). During the flight phase and especially during the water entry all investigated individuals exhibited a less specific activation. Since the swimmers performed different flight distances and showed a great variety in the way they adapted their movement behavior to the conditions of the water entry situation, the muscle activation was different or analogue from trial to trial. During the first dolphin kick 54.2% of the EMG recordings indicated analogue patterns which meant that in the glide phase the movement behavior of each individual was becoming more constant again.
The *inter-individual comparison* (dark circles in fig. 3) supported the growing variability of the muscle activation along the different phases of the backstroke start. Only in the initial hang phase did the swimmers exhibit more or less identical EMG patterns. During the flight phase and the water entry the number of different muscle activation patterns grew significantly. In the final glide phase the EMG recordings of the first dolphin kick demonstrated a more analogue movement behavior again.

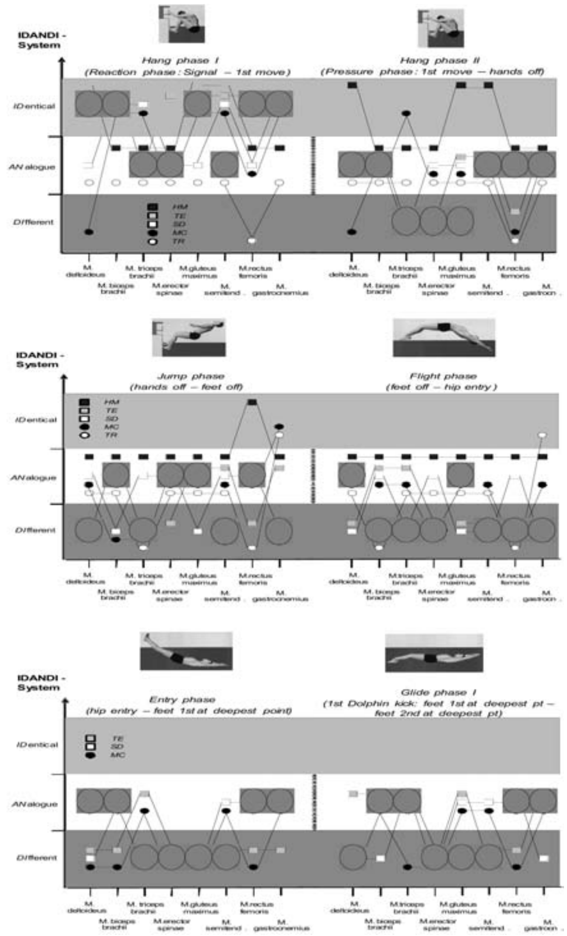

Figure 3. Comparison of the muscle activity patterns of five elite swimmers in the backstroke start (in the underwater phase two swimmers were excluded due to technical reasons).

DISCUSSION
In contrast to former EMG studies on the grab and track start technique (4), the EMG recordings of five male top swimmers

gave a very distinct indication of both a high repetition consistency and a high reproducibility of the identified patterns of muscle activity “during the initial hang phase and the final glide phase”. In the middle part of the start movement, i.e. during the flight phase and the water entry, the dynamic involvement of the propulsion and equilibrium muscles showed greater intra- and inter -individual variability. This may be caused by the necessity to adapt the specific movement behavior to the varying situational conditions of the transition from out of the water to underwater environment, like e.g. flight height and distance, angle and depth of water entry. Therefore, the electromyographic results are in line with former findings by Cabri et al (2) showing that the water entry movement required more activity from the stabilisation apparatus of the back and the arms, rather than from the propulsion muscles of the legs probably because of the higher resistance during water entry of the body. After the swimmer is fully immersed, the more standardized propulsive up and down sweeps of the dolphin kicks lead to more constant muscle activity patterns again.
In conclusion, the overall image of muscle contraction allowed the formation of a representative 6-phase model of the investigated muscles participation in the backstroke start.

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THREE-DIMENSIONAL ANALYSIS OF THE EGGBEATER KICK IN SYNCHRONIZED SWIMMING

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One of the fundamental techniques in synchronized swimming is the eggbeater kick. The purpose of this study was to examine the kind of kinematic parameters that are reflected in an excellent eggbeater motion and, in particular, to evaluate the rotational angle of the hip. Nine Japanese elite synchronized swimmers served as subjects. The kinematics of the lower limbs and the hip rotational angle of each subject were quantified using three-dimensional video analysis. The hip almost rotated internally during the eggbeater kick. It was considered that the internal and external rotation movements of the hip were reflected in the foot abduction and adduction movements. This was because the phase of the angle curve between the hip rotation and foot abduction was almost identical in the reverse direction.

Key Words: eggbeater kick, synchronized swimming, video analysis, hip rotational angle.

INTRODUCTION

The vertical eggbeater kick is the most fundamental and important technique in synchronized swimming, water polo, water rescues, and so on. A few researches have focused on the eggbeater kick. The foot speed was the most important factor contributing to the performance of the eggbeater kick, and the swimmers were required to learn sculling motions emphasizing horizontal rather than vertical motion (2, 3). In our previous study of the eggbeater kick (1), the rotational movement of the hip was considered to be important to control the strength and direction of the movement. The purpose of this study was to examine the type of kinematic parameters that are required to perform an excellent eggbeater motion and, in particular, to evaluate the rotational angle of the hip during the eggbeater kick. The rotational angle of the hip and other kinematic parameters were calculated by original programs using Mathematica (Wolfram Research, USA).

METHODS

Nine female synchronized swimmers (height: 1.60 ± 0.05 m, weight: 53.2 ± 4.16 kg) served as subjects for this study. All the subjects were Japan national A team members, four of whom were silver medalists in the 2004 Athens Olympic Games. All the subjects provided written informed consent. The eggbeater kick motion was recorded using three video cameras (60 fps), including two underwater cameras. One underwater camera was set on the bottom of the pool almost beneath the subject, and another underwater camera was also set on the bottom of the pool, but at the left side of the subject. The third camera was set in front of the subject through an underwater viewing window. All the subjects attached an additional landmark on their left thigh to facilitate the evaluation of the rotational angle of the hip (fig. 1). The semi-spherical landmark made of Styrofoam was attached to the middle of the left thigh with Velcro tape.

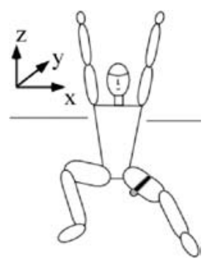

Figure 1. The coordinate system in this study and the additional landmark on the left thigh.

The subjects performed stationary eggbeater motion with maximum effort and extended both arms in the air; they maintained this elevated position for a duration of over 5 sec. The videotapes were manually digitized using Frame DIAS II (DKH Co., Japan). The Direct Linear Transformation (DLT) method was used to obtain the three-dimensional space coordinates of the lower limbs. The three-dimensional calibration frame was a rectangular parallelepiped (1.0 m*1.0 m*1.2 m), which had 160 control points. The errors in its reconstructed coordinates were 0.008 m (x-axis), 0.007 m (y-axis), and 0.006 m (z-axis). The coordinate system in this study is shown in Fig.1; the x, y-, and z-axes are the frontal, sagittal, and vertical axes, respectively. The three-dimensional data were smoothed using a low-pass digital filter with a cutoff frequency of 6 Hz.

RESULTS AND DISCUSSIONS
The left hip rotational angle

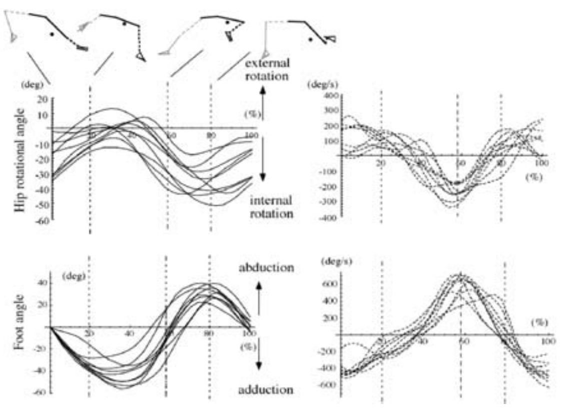

Figure 2. The time-angle curves (left) and the time-angular velocity curve (right) of the left hip (upper) and the left foot (lower) of all the subjects during one cycle of the eggbeater kick. A hip angle of zero implies that the toe is pointed anteriorly. The foot angle is the relative angle from its initial position.

Figure 2 shows the left hip rotational angle, the foot abduction and adduction angle, and each angular velocity that is influencing propulsive force in water, of all the subjects during one cycle of the eggbeater kick. The horizontal axes indicate the ratio when one cycle is assumed to be 100%. The rotational angle of zero implies that the toe is pointed anteriorly. The maximum internal rotation angle of the hip during the eggbeater kick ranged between –20° to –50°, which occurs just before the swimmer kicks outside after his foot was swept inside. In our previous study on the breaststroke kick of competitive swimmers (not published), the internal rotation of the hip was about –10°. In general, the range of internal rotation of the hip is considered to range from 0.0° to 45.0°; therefore, it was assumed that during the eggbeater kick, the internal rotation of the hip is very large. These rotational movements of the hip were connected to which the movements in the eggbeater kick? It was clarified as shown in Figure 2 that the phase between the hip rotational angle and the foot abduction angle was almost identical in the reverse direction. In addition, the peak values of the hip rotational angular velocity and the foot abduction angular velocity appeared almost at the same time. The eggbeater kick is a movement where the foot is abducted kicking water downward at the inside of foot; this is followed by adduction and inversion for generating a lift force due to the sculling effect. The foot movement is considered very important during the eggbeater kick for elevating the body. The results in this study indicated that the hip rotational movement is reflected in the foot abduction and adduction movement in the eggbeater kick.

Two movement types of the eggbeater kick

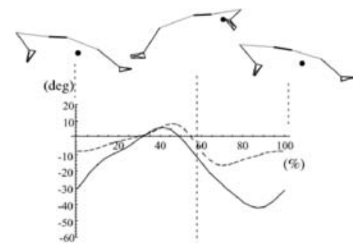

Figure 3. The left hip rotational angle of Sub. A (broken line) and Sub. B (solid line).

All the subjects were Japanese elite synchronized swimmers; however, different patterns of the hip rotational angle were noted in two subjects who were especially proficient performing the eggbeater kick. Fig. 3 shows the hip rotational angles of Sub. A and Sub. B, who had the highest and 2nd highest trochanter height in this experiment. Both Sub. A and Sub. B also got the higher scores of the eggbeater kick test in the Japanese National Team Trials. It must be clarified that the hip rotational angle of Sub. B was much larger than Sub. A in the latter phase of motion in which the knee joint was extended. Figure 4 shows the planes formed by the ankles through the eggbeater kick of Sub. A and Sub. B; ankle planes were calculated using the least square method on the supposition that an orbit drawn by the ankle is assumed to be on almost the same plane (1).

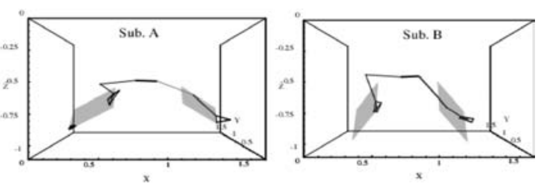

Figure 4. The planes formed by the ankles through the eggbeater kick of Sub. A and B.

There was a significant difference in the angles to the horizontal plane (water surface); the angles were 41.2° and 55.3°, respectively. However, as shown in fig. 5, the abduction angle of Sub. A was larger rather than that of Sub. B and there was negligible difference in the foot abduction angular velocity; therefore, it was considered that Sub. A performed the eggbeater kick using the hip rotation movement in addition to the high flexibility indexes of knee and foot joints. It would appear that Sub. A performed the eggbeater kick in a manner consistent with the results of Sanders's report (3), emphasizing horizontal motion, rather than vertical motion. In other words, Sub. A generated the upward propulsive force through the lift force generated the foot sculling motion. In contrast, Sub. B performed the eggbeater kick emphasizing the vertical motion, and generating the propulsive force mainly using the drag force. Almost half of the subjects in this study performed the eggbeater motion similar to Sub. B. This study did not clarify which motion was better for large propulsive force generations during eggbeater kick; however, it was suggested that there were two variants for the eggbeater kick—one emphasized the horizontal motion for the lift force and the other the vertical motion for the drag force.

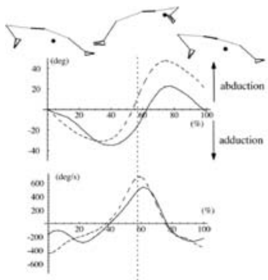

Figure 5. The left foot angle of abduction and adduction (upper) and the angular velocity (lower) of Sub. A (broken line) and Sub. B (solid line).

CONCLUSIONS

In this study, the magnitude of the rotational angle of the hip in the eggbeater kick was clarified performed by elite synchronized swimmers. The hip almost rotated internally during the eggbeater kick. In this study, the maximum internal angle ranged from 20.0° to 50.0°. It was considered that this internal rotation movement of the hip was reflected in the foot abduction and adduction movement that is expected to be very important for the generation of propulsive force to elevate the body. From the results of the analysis of the subjects who attains higher positions with regard the eggbeater kick, it was suggested that there are two variants of eggbeater kicks - one emphasizing the horizontal motion and the other emphasizing the vertical motion.

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INVERSE DYNAMIC MODELLING OF SWIMMERS IMPULSE DURING A GRAB START.

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Under race conditions, the start directly influences an athlete's performance. Taking into account the difficulties coming from the specific parameters relative to the start, comparing the swimmer's movement with the kinematic data stays the best approach to understand the motion. The model of the present work was developed through this approach allowing us to predict the swimmer's performance (trajectory, velocity) and the joint moment of each articulation during the impulse phase of the grab start. This model defines kinematical and dynamical data with the following mean dispersions: 9 % for horizontal and total speed at the instant of take off, 1 % for the swimmer's internal joint power. By means of this model, it becomes possible to analyze and understand the joint moment of each articulation and the segmental coordination for each swimmer performing a grab start.

Key Words: swimming, grab start, model, performance, joint moment, energy cost.

INTRODUCTION

Regardless of the discipline, whether 100 m Freestyle, 200 m 4 strokes (medley), or other, the study of the swimmers' performances involves the identification of three technical phases: start, turns and strokes phases. An analysis of the temporal distribution of the races showed that the start phase accounts for 15 % and 7.7 % of total time, respectively for 50 m and 100 m freestyle events (1). In short distance races (50m and 100m) the start represents a particularly important factor. For instance, at the Athens Olympic Games (2004), the time separating the eight finalists in the men's 50m freestyle finals was 0.44 s, which represents 2% of the winner's total race time (21.93 s). This difference in performance among the finalists may result from the time lost during the start phase.

Several studies carried out since the 1970's have shown that the start depends primarily on the quality of the swimmer's impulse on the starting platform and also on the water glide (7). However, the studies carried out to date are often contradictory when it comes to defining the most efficient movement required to optimize the athlete's performance impulse. This may lie partly in the fact that there are no objective tools currently available to provide a precise and quantitative evaluation of the movements in situ. Although recent studies have been undertaken, using both dynamic and kinematic approaches, they do not yield additional information concerning the relationship between the swimmers' movements and their actual performance (7). Few studies have addressed the modelling (dynamic and/or kinematic) of the parameters that determine the performance according to the swimmers' movements during start phases (4). Thus, the modelling method used for the study of movements in others sports (skiing, etc.) seems the most effective approach as far as understanding movements and predicting performance is concerned (5). A model based on inverse dynamic was developed in order to predict the impulse parameters during grab starts. The study presented here aimed the evaluation of the precision of this model by comparing the predicted speed and power values with experimental data collected in situ.

METHODS
Four national level swimmers were instructed to perform a grab start. Subjects' average height and mass were respectively 183.5 cm (± 3.41) and 75.77 kg (± 3.89). Swimmers were equipped with passive markers fixed on each articulation. For each start, a high speed camera (125 frames.s^{-1}) was placed at the edge of the swimming pool, at a perpendicular angle to the athlete's trajectory. The camera recorded the swimmers' profile movements. At the same time, ground reaction forces were recorded using a force platform fixed on the starting platform in order to simulate real competition starts (figure 1). The sampling frequency was 1000 Hz. Speed of the swimmer's centre of mass was obtained by integration of its acceleration. For each start, the kinematical (camera) and dynamical (platform) data were synchronised (0.008 s accuracy).

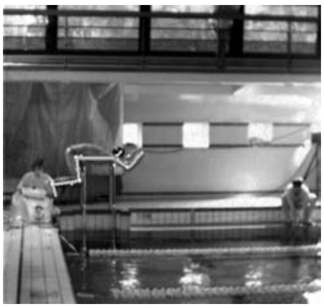

Figure 1. Image of recording a swimmer's impulse on the force platform by the high speed camera. In gray lines, segment's modelling using passive markers.

While the athletes were on the platform, a two-dimensional cinematography analysis was carried out during the impulse phase, in order to determine the angle between the subjects' segments (right side) and the horizontal axis. These data have been fitted using a polynomial method (6, 8). Morphological properties of the subjects are defined using their height, mass and the anthropometric tables of Dempster et al. (3). The sum of segment energies was obtained using the equations of sum of segment energies as defined in Winter (8).
During the impulse phase, subjects were represented using an open tree structure composed of eight straight segments connected with frictionless joints. Input data for the model consisted of the fitting angles calculated at each joint, and the subjects' morphological properties. For each joint, the dynamic torque, force and power were determined using the inverse dynamic equations (8, 5). Based on an analysis of the swimmers' forces and joint moments exerted during the impulse, the model predicts the total power of the subject during the impulse phase, as well as the speed, angle and position of the subjects' centre of mass at the instant of takeoff.

RESULTS
The model presented in this study was able to predict parameters that have also been collected from the force platform, with the following mean dispersions: underestimation of 9% (0.4 ± 0.1 m.s^{-1}) for horizontal and total speed, overestimation of 0.3 m.s^{-1} (± 0.15) for the vertical speed and overestimation of 4 degrees (± 3) for the angle between the vector tangent to the trajectory of subjects' centre of mass at takeoff and the horizontal axis (figure 2). The model was able to predict the swimmer's internal joint power observable using the video image and the time derivative of the sum of segment energies (8), with the mean dispersions of 1% (figure 3).

Subject	$V_{XGtakeoff}$		$V_{Zgtakeoff}$		$V_{Gtakeoff}$		$\alpha_{takeoff}$	
	a)	b)	a)	b)	a)	b)	a)	b)
1	3.56	4.09	0.38	-0.09	3.58	4.09	6.20	-1.35
2	3.92	4.25	-0.16	-0.35	3.92	4.26	-2.34	-4.82
3	3.75	4.14	-0.54	-0.66	3.79	4.20	-8.16	-9.16
4	4.10	4.44	-0.13	-0.44	4.10	4.47	-1.92	-5.73
mean	3.83	4.23	-0.11	-0.38	3.84	4.25	-1.55	-5.26
Sd	0.23	0.15	0.37	0.23	0.21	0.15	5.90	3.21

Figure 2. Swimmer's performance parameters: a) using the model; b) using force platform.
With: $V_{XGtakeoff}$: horizontal speed of the swimmer's centre of mass at take off (m.s^{-1}), $V_{ZGtakeoff}$: vertical speed of the swimmer's centre of mass at take off (m.s^{-1}), $V_{Gtakeoff}$: total speed of the swimmer's centre of mass at take off (m.s^{-1}), $\alpha_{takeoff}$: angle between the vector tangent to the trajectory of subject's centre of mass at takeoff and the horizontal axis (degree).

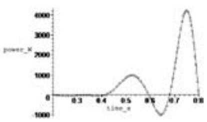

Figure 3. Swimmer's power: a) using the model (point); b) using the energies approach (line) of Winter (8).

DISCUSSION
This model makes it possible to consider joint moments resulting from the muscle activation during the movement (figure 4). These joint moments reflect the muscular activities of the subject (8). The main interest of this model lies in the possibility of analysing the individualised coordination of each segment of the swimmer.

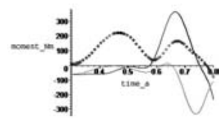

Figure 4. Joint moment of the hip (point), the knee (black line) and the ankle (gray line) during the impulse of a grab start.

The model still remains limited by the lack of the precision of the kinematics data and the lack of knowledge related to the morphological properties of the subject. The specificity of the measurement "in situ" imposes the use of passive skin fixed markers. The shifting of these markers during the subject's movement can differ from the anatomical centre of giration of each articulation and create a major source of error in the inverse dynamic estimations (2). This phenomenon is amplified by variations between the morphological properties of the segments resulting from the studies of Dempters et al. (3), and those specific to each swimmer. Using the same kinematical (video) and anthropometric data as input parameters, the estimations of the power developed by the swimmer resulting from the model and that resulting from the energy calculations (8) present a weak mean dispersion. This dispersion between the results of these two methods confirms the hypothesis that small errors in kinematic measurements will lead in mistakes in results obtained by the model.

CONCLUSION
The impulse model developed for a grab start is able to predict the swimmers' performance parameters using easy to install tools (only one camera). In the short term, this model should be able to provide more precise informations regarding the role played by joints in achieving the most effective grab start and to determine the swimmers' joint moments during the impulse phase. Future developments will increase the accuracy of the model and will contribute to the modelling and optimization of the most efficient movement strategies.

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SPEED VARIATION ANALYSIS BEFORE AND AFTER THE BEGINNING OF THE STROKE IN SWIMMING STARTS

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Currently, few biomechanics studies have been conducted to examine the transition from the underwater phase to the stroke phase in swimming starts. The objective of this study was to evaluate the speed before and after the beginning of the stroke in front crawl and its relationship to the time to 15 meters in order to determine the importance of the underwater phase and transition phase in the entire performance of the swimmer. The transition speed of four athletes was recorded with video cameras and signal synchronizer. According to the results, the majority of swimmers reduced speed after the beginning of the stroke. There was a negative correlation between the difference in speed before and after commencing the stroke and the time at 15 meters. Therefore, attention should be paid to the underwater phase of starts to improve performance in front crawl.

Key Words: stroke, performance, transition phase.

INTRODUCTION
In the beginning of the 1980s, the right point of the start of front crawl was intensely discussed (1). Hay (4) contributed the information about the position of the swimmer. His comments suggested that the swimmer had to be as horizontal as possible until the speed forward was less than the speed of the stroke. Only a few studies involving the swimming starts have been conducted to examine the transition from underwater to stroke in the swimming starts.
According to Hay (4), the swimmer's performance is measured by the time to cover a certain distance, being able to divide it in three partial times: the time between the start signal until the feet leaving the block is called 'start time'. 'Block time' refers to the period between the feet leaving the block until the first contact with the water. 'Time of glide' (underwater phase) is from the first contact with the water until the swimmer commences stroking.
Guimarães & Hay (3) found that the most important phase in swimming is the underwater phase. However, the transitions phases and turns are also related to performance. As well as the phases, the speed in each one of these suggests independent evaluations. Karpovich found that the speed of swimmer in front crawl comes 70% from arm and 30% of the legs (1). Counsilman (1) suggested that the upper limbs are the principal, and in some cases, the only propulsion source during the front crawl swimming.
To understand the time of a swimming competition it is necessary to evaluate the starting time, glide time, turn time and arrival time. The proportion of starts, turns and arrival times increases when the distance of the test decreases (7). Hay (5) verified that starts represents 11% of the total time of a 50 meters in front Crawl swimming, and suggested an intensification in studies of the techniques starts to reduce the time expense at this phase. Navarro (8) and Pereira et al. (9) recommended focusing on the start as one of the main factors for improving competition times.
The objective of this study was to evaluate the speed before and after the beginning of the stroke in national and state level swimmers, as well as relating them with the performance to 15 meters.

METHODS
Six starts of four male swimmers state and national level have been evaluated in accordance with the methods of Hubert (6). All participants were required to perform 6. The data were collected in the Doze de Agosto Club´s swimming pool and ana-

lyzed in the Aquatic Biomechanics Research Laboratory of CEFID/UDESC. The following variables were measured: speed before the beginning of the stroke (Sb), measured in the underwater phase, in the interval of 1 second before the first movement for beginning of the stroke; speed after the beginning of the stroke (Sa), measured in the interval of 1 second after the beginning of the stroke and time in 15 meters (T15m). The performance of the 15 meters corresponds to the time that the swimmer takes to cover this distance. Time to 15 meters was determined in accordance with the methods of La Fuente et al. (2). Four video cameras, one miniDV and three VHS type (30 Hz) were used to collect kinetic variables. For the underwater images, cameras had been connected to waterproof boxes and fixed each one to a tripod setting in deep of the swimming pool and an electronic trigger with a light bulb, composed of one led, a bell and two boxes of sound synchronized the video camera to the instant of the start signal. Data was analyzed using Intervideo 3 WinProducer and CorelDRAW 10 software. Statistical programs SPSS was used for Windows 11,0 and GraphPad InStat version 2.04 were used to obtain Spearman correlations to establish the relationship between the variation of speed and the time to 15 meters.

RESULTS AND DISCUSSION

The Sb and Sa and the time to 15 meters of each athlete in the six starts are presented in table 1. It was observed that only athlete 4 had a greater Sa than Sb. Consequently, his time to 15 meters was large.

Table 1. Sb(m/s) and Sa the beginning of the stroke and time to 15 meters.

	Athlete 1			Athlete 2			Athlete 3			Athlete 4		
Starts	Sb	Sa	T15m	Sb	Sa	T15m	Sb	Sa	T15m	Sb	Sa	T15m
1	1,78	1,61	7,199	1,58	1,54	6,799	1,78	1,71	6,766	1,30	1,52	7,133
2	1,66	1,57	7,233	1,65	1,66	6,866	1,94	1,57	6,633	1,36	1,67	7,199
3	1,66	1,56	7,266	1,52	1,61	6,866	2,01	1,55	6,699	1,91	1,76	7,000
4	1,89	1,52	7,099	1,67	1,54	6,832	1,99	1,55	6,666	1,44	1,75	7,233
5	1,60	1,52	7,399	1,80	1,56	6,899	2,14	1,62	6,533	1,94	1,74	7,199
6	1,91	1,52	7,199	1,69	1,62	6,832	2,08	1,58	6,566	1,32	1,64	7,233
Avg.	1,75	1,55	7,233	1,65	1,59	6,849	1,99	1,59	6,644	1,54	1,68	7,166
sd	0,13	0,04	0,099	0,10	0,05	0,035	0,12	0,06	0,086	0,30	0,09	0,089
cv	7,36	2,49	1,368	5,83	3,03	0,512	6,21	3,96	1,293	19,22	5,43	1,245

The speed before the beginning of the stroke varied from 1.3m/s to 2.14m/s, and the speed after the beginning of the stroke from 1.52m/s to 1.76m/s. Time to 15 meters varied from 6.53s to 7.4s. The standard deviation and the coefficient of variation were always smaller in the Sa than the Sb. There was negative correlation (-0.473) between the variation of the speed and the time to 15 meters when the speed decreased after the beginning of the stroke (Sa). The athletes 1, 2 and 3 had similar behavior in the underwater phases for the beginning of the stroke, whereas athlete 4 was different. This difference suggests that athlete 4 did not perform the underwater phase satisfactorily, since his Sa had been greater then Sb. The images of swimmer 4 had shown an incorrect position of the underwater phase considering the desirable positions described by Hay (4). For Guimarães and Hay (3) the best performances occur when the Sb is greater then Sa, what we could verify for swimmers 1, 2 and 3 (table 1).

CONCLUSION

It was verified that performance is better when Sb was greater than Sa, resulting with decrease time to 15 meters. That indicates that beyond the importance of the underwater phase, the transition phase must have special attention; therefore, to begin the stroke at the correct instant is an important factor for the performance in the starts.
Reevaluation of each swimmer individually is suggested, as well as the basis of trainings of underwater phase. The swimmer must be qualitatively evaluated through underwater images searching to verify the entrance angle in the water and the depth reached during the underwater phase. Therefore, it is necessary to continue studies and also increase the number of evaluated athletes.

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FUNDAMENTAL FLUID DYNAMIC RESEARCH ON CONFIGURATION OF THE HAND PALM IN SYNCHRONIZED SWIMMING

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In synchronized swimming, the hands usually describe a “figure 8” or an egg-shaped oval during sculling motion. Various types of sculling movements are employed depending upon the actions and purposes, although the function of all sculling motions is to produce lift force through reciprocating motion. Optimal hand configurations for sculling are not standardized among athletes and are instead determined empirically by coaches and athletes. In this research, the hydrodynamic characteristics of five hand configurations are investigated in a basic study in a steady-state flow field to determine the configuration that produces maximum resultant force.

Key Words: hand, synchronized swimming, maximal resultant force, steady-state.

INTRODUCTION

Synchronized swimming is a highly artistic sport in which points are awarded separately for technical merit and artistic expression, both of which demand high levels of skill and artistry. A stable lift force is desirable for artistry in competitions. The stronger this force is the better.

A continuous sculling motion with the hands and an eggbeater kicking motion with the legs produce the lift needed to create buoyancy. Sculling is a hand motion that describes a “figure 8” path or an egg-shaped oval path. Kartashov (1) classified sculling motions into many types according to their various operations and purposes, although fundamentally speaking these motions are virtually the same in that they all develop lift force using reciprocating motion. However, the configuration of the palm of the hands has not been standardized in principle among athletes. Instead, coaches and athletes determine the optimal configuration based on experience.

This study measures the aerodynamic characteristics of five different hand configurations to determine the configuration that provides maximum lift force for the best performance. In addition, the characteristics of hand configurations used by athletes are compared. Although sculling is a reciprocal and unsteady motion, especially when the hand changes orientation at the point where the direction of movement changes, the lift-drag force is investigated in this preliminary study under stable conditions.

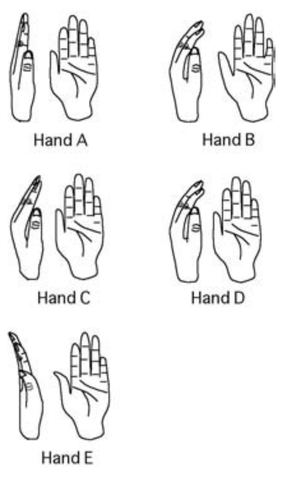


Figure 1. Configurations of hand model.

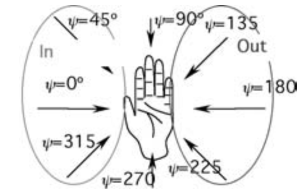


Figure 2. Sweepback angle y entering the palm, defined by Shleihauf (2).

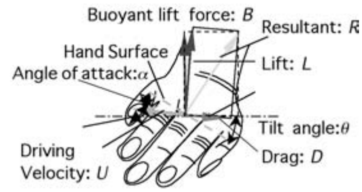
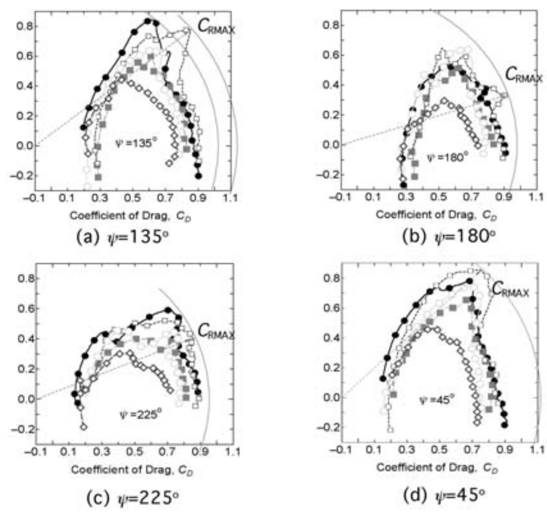


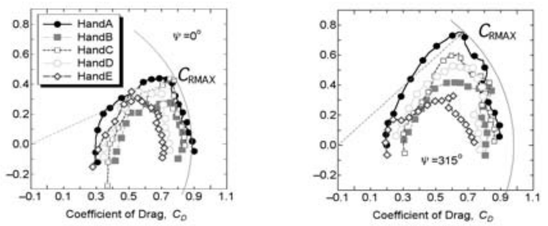
Figure 3. Forces and velocities acting on hand paddle.

METHODS

The aerodynamic characteristics of hand replicas are measured in a wind tunnel using a three-component load cell. Plaster models are made into the same size and shape taken from the hand of a female swimmer and molded into five different hand configurations as shown in Fig. 1 (A: A flat palm with no gaps between fingers, B: a cupped palm with gaps between fingers, C: a cupped palm with no gaps between straightened fingers, D: a cupped palm with no gaps between fingers, E: an inversely bent palm with no gaps between fingers).

The lift, drag and moment on each of the plaster models are measured with a three-component load cell at one-degree intervals from -5° to 95° for each angle of attack α. Each angle of attack α has seven types of sweepback angles ψ (0°, 45°, 90°, 135°, 180°, 225°, 315°) based on the Schleihauf (2) definitions shown in Fig. 2.





(e) ψ=0° (f) ψ=315°

Figure 4. Differences in polar curves during sculling between in out-sweep movement (ψ =135o, 180o, 225o) and in in-sweep movement (ψ = 45o, 0o, 225o) on different hand configurations.

Experiments are performed at a wind speed of 20 m/s, which corresponds to the Reynolds numbers (3.4x10^5). This speed is almost equivalent to actual swimming speed.

Figure 3 shows the flow aspects and fluid forces on the palm of the hand. The palm is tilted at an angle θ, and it moves in still water with a driving velocity *U* and at a driving angle *d*. The water hits the hand at an angle of attack α. If the hand were a wing, lift force *L* occurs at a right angle to the driving velocity *U,* and drag force *D* occurs at a right angle to lift force *L,* as shown in Fig. 3. The resultant force $R = \sqrt{L^2 + D^2}$ builds up on the back of the hand and its vertical component is buoyancy lift force *B*. Furthermore, the authors (2003) previously calculated the maximal buoyancy lift force based on these equations of motion, taking into consideration the relation between velocity and the fluid forces. The results showed that the highest buoyant lift was obtained at the highest resultant force of the lift-drag force; in other words, $\sqrt{C_L^2 + C_D^2}$ occurred at the point farthest from the origin in the polar curve or the lift-drag curve.

Sculling motion is a combination of in-sweep and out-sweep movements with the elbows bent at a right angles while swimming in a standing orientation. During the out-sweep movement, the forearm performs supination and during the in-sweep motion it performs pronation. When translated into changes in sweepback angles, these motions are equivalent to ψ =135°, 180°, 225° (out-sweep) and ψ = 45°, 0°, 315° (in-sweep), respectively.

RESULTS AND DISCUSSION

Figure 4 (a) to (f) are polar curves showing changes in the drag coefficient C_D and the lift coefficient C_L corresponding to changes in the angle of attack in which α = 0° to 90° based on differences in the hand configurations. Each figure represents a different sweepback angle ψ. Markers are placed every 5° for each attack angle α in these figures. It is assumed that the degree of buoyancy lift force developed by each hand can be expressed with respect to the distance from the origin of the polar curve. The circular arc C_{RMAX}, which is the maximum length from the point of origin along the polar curve, is indicated in each graph. The angle of attack α for C_{RMAX} is also shown in Table 1. Because the sculling movement utilizes mainly lift force, the farthest point from the origin when the angle of attack α <60° is determined to be the best hand configuration in each sweepback angle ψ.

Table 1. The maximum lift-drag force point in sculling motion.

Figure	ψ [deg]	C_{RMAX}	Hand Model with C_{RMAX}	Ratio against Hand A	α [deg]
Fig. 4 (a)	135	1.23	C	1.10	51
Fig. 4 (b)	180	1.07	C	1.11	55
Fig. 4 (c)	225	1.04	C	1.01	53
Fig. 4 (d)	45	1.21	C	1.08	47
Fig. 4 (e)	0	0.99	C, A	1.03	60
Fig. 4 (f)	315	1.08	A	1.00	47

Regarding the out-sweep ψ =135° in Fig. 4 (a), the polar curves for Hand C and Hand A have a big lump near at the point where the angle of attack α =50° and 45°. C_{RMAX}=1.23 is obtained with Hand C. Regarding the out-sweep ψ =180° in Fig. 4 (b), C_{RMAX} is 1.07 when Hand C and Hand D are α =55° and 45°, and in out-sweep ψ =225° in Fig. 4 (c), C_{RMAX} is 1.04 when Hand C and Hand A are α =50° and 60°, respectively. Similarly, regarding the in-sweep ψ =45° in Fig. 4 (d), significant lumps appears near the angle of attack α =50° and 45° on the polar curves of Hand C and Hand A. C_{RMAX} is 1.21 with Hand C. For the in-sweep ψ =0° in Fig. 4 (e), C_{RMAX}=0.99 is obtained when Hand C and Hand A are both α =60°, and for in-sweep ψ =315° in Fig. 4 (e), C_{RMAX}=1.08 when Hand A is α =50°. Hand C constantly produces the largest thrust during out-sweep. Since it is impossible to change the hand configuration during the in sweep/out sweep cycle, it is evident that Hand C consistently develops the largest buoyancy lift force.

Next, Hand B, which is a cupped palm with gaps between the fingers, is compared with Hand D, a cupped palm with no gaps between the fingers. It is interesting to note that competitive swimmers and water polo players often have gaps between their fingers whereas synchronized swimmers in general do not. Only in Fig. 4(e) is C_{RMAX} of Hand B with gaps about 3% greater than C_{RMAX} of Hand D without gaps. Thus, Hand D without gaps is relatively advantageous.

Hand configurations can be largely divided into three types: cupped, flat, and inversely bent as shown in Fig. 1. The results of hand E with an inversely bent shape shows the worst performance in every graph of Fig. 4. This is due to large detachment of water flow on the backside of the hand because the palm is bent inversely. Also, the inversely bent palm cannot grasp the water the water in the way the other hand configurations can. Thus, this configuration cannot develop a large resultant force. Comparing the two cupped hand shapes, Hand C with flat fingertips and Hand D with curved fingertips, in every sweepback angle ψ, Table 1 show that Hand C develops the largest resultant force C_{RMAX} compared to the other hand models. Hand A with a flat palm displays larger results than Hand C only when the sweepback angle is ψ=315°, but otherwise Hand C displays the largest C_{RMAX} values among all the configurations. Based on these results, it is found that Hand C, a cupped hand with no gaps between straightened fingers, provides the largest resultant force.

CONCLUSION

To find the best hand configuration for generating the largest lift-drag resultant force in synchronized swimming, five different models were constructed and their stable-state fluid characteristics investigated.

The following results concerning good buoyant lifting performance were obtained:
1. A cupped hand is better than a flat hand.
2. On a cupped hand, straight fingers are better than naturally bent fingers.
3. A configuration without gaps between the fingers is better than one with gaps.
4. Hand C, which is a cupped hand with straight fingers, develops the most buoyant lift force in sculling motion.

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BIOMECHANICS OF TOWING IN SKILLED AND LESS-SKILLED LIFESAVERS

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Successful and safe lifesaving operation depends on the effectiveness and skill of the lifesaver. The objective was to study lifesaving towing and to identify biomechanical differences in the performances. Eight lifesavers towed an unconsciously acting victim in a swimming pool. Skilled lifesavers towed the victim faster and with longer strokes than the less-skilled. Less-skilled lifesavers had a more upright body position leading to higher drag force. They also had difficulties in keeping the victim's head above the water surface. The victim also travelled considerably low in relation to the water surface with less-skilled lifesavers.

Key Words: lifesaving, technique analysis, towing grip.

INTRODUCTION

Lifesaving using body contact technique is physically demanding and even a dangerous manoeuvre both for the victim and the lifesaver. Therefore, as a general rule body contact should be avoided with a conscious victim (3). It is recommended to use some technical aid between the lifesaver and the victim (7). To avoid further hazards, it is very important that the lifesaver has adequate skills to be able to act effectively. An unconscious victim is more in life threatening danger than a conscious victim. So the speed and effectiveness is vital to both start the first aid and further actions for securing survival.
Lifesaving manoeuvre is anaerobic and exhaustive for the performer (8, 5, 4). The towing technique is optimal, when an effective survivor back stroke kick or a scissor kick will be used allowing streamlined body position in water. Ineffective kicking and hence poor towing performance aggravates drag forces in the same mechanism as during ordinary swimming (6). On the other hand, propelling and buoyant forces give additional help to a lifesaver with an optimal technique (2). In lifesaving towing drag forces increase especially due to the victim and his/her clothes (9). The aim of the present study was to compare two different towing grips during lifesaving manoeuvre between skilled (SLS) and less-skilled lifesavers (LSL).

METHODS

The subjects of the study were three female (20.0 ± 1 y) and five male (25.2 ± 8 y) lifesavers. They were voluntary university students or staff members, who had at least one qualification from level 1 - 4 of Royal Lifesaving Society Australia (RLSSA) or a valid international life guard certificate. Written informed consent was obtained from each subject. Ethical approval was obtained from the Human research Ethics Committee of the University of Ballarat, Australia.
The task was to tow a living victim acting unconscious (height 174 cm, body mass 62 kg, BMI 20 kg/m^2) for 50 m in a 25-m long swimming pool. Water temperature was 27° C. The participants used two different towing grips on the victim: cross-chest (CC) and head-neck (HN) in randomised order. They chose kicking style by themselves and used it similarly in both trials. The instruction for the performances was: "Swim as fast as you would in a real rescue situation. Do your best. Keep the victim's head above water all the times. Use your preferred towing kick. Use one hand to hold the victim. The other arm may be used to assist with towing." Instruction for an alive victim was: "Be as relaxed as you can. Act as an unconscious person. Do not move any parts of your body during the tow."
The division of the subjects into two groups, skilled and less-skilled, was based on the evaluation of their skills during the lifesaving tasks. The skills were evaluated by the researcher based on visual observation from video pictures, and subjects' 50 m towing time, and number of used strokes. The time for each 50 m towing lap was measured and the strokes were counted by an assistant. Selected strokes during the towing task were analyzed based on video recordings using Peak Motus movement analysis system. The performances were recorded by two Panasonic S-VHS cameras, which were placed on the pool side, one of them underwater. The cameras were synchronized with the timer on the accuracy of 0.02 s. The recordings were made at a frame rate of 50 Hz. Because of the limitations in camera locations only a two-dimensional movement analysis could be made. Markers on selected anatomical landmarks were placed by texture on both the participant and the victim (shoulder, elbow, wrist, hip, knee, ankle). From video recordings the locations of the markers were digitized frame by frame from the body side, which was closer to the pool bottom. The calibration frame was a 10 m long "seasnake" with nine floating balls. The calibration frame was 4 m long and 0.801 m high (Picture 1). The stroke analysis started and stopped at the beginning of kick on the maximal flexion of legs. Absolute coordinates were low pass filtered with Butterworth cut-off frequency 3 Hz. To characterize the differences in the towing technique, the angle of the shoulder-hip-line from horizontal ("Body angle"), the depth of the victim's ankle from the surface and the travel distance per stroke were calculated. Average values for one stroke were calculated for statistical comparison.

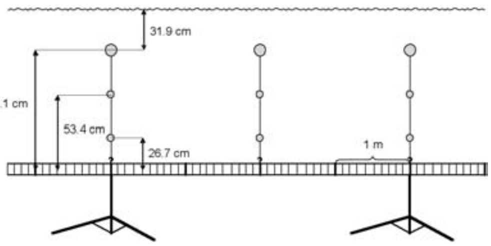

Figure 1. The calibration frame under water: 4 meter long "seasnake" and nine floating balls (design by Peter Clothier.)

RESULTS

Table 1 presents the main findings of the performances with two different towing grips. Mean towing time for 50-m with CC grip was 78 s for SLS and 147 s for LLS; and with HN grip 83 s and 126 s, respectively. The average number of strokes for 50-m using CC was 71 for SLS and 144 for LLS; and using HN 74 and 111, respectively. The average distance per analysed stroke using CC was 68 cm for SLS, and 30 cm for LSL, and using HN 63 cm, 44 cm, respectively. The average body angle from horizontal using CC was 24º for SLS, and 50º for the LSL, and using HN 32º, and 35º, respectively. The victim's mean ankle depth from the water surface during CC towing was 68 cm with the SLS, and 104 cm with the LSL, and during HN 80 cm, and 101 cm, respectively.

Skilled lifesavers towed the victim very close to their own bodies. They also acted closer to the water surface than their less-skilled colleagues (Fig. 2). They could keep the victim' s head well above the water during all efforts.

Contrarily, less-skilled lifesavers had their bodies deep in water and consequently, the lower part of the victim's body was noticed to sink down. Some lifesavers in the LSL group could not keep the victims' head constantly above the water surface during towing. The angle of the LSL's body was steeper than the SLS's. Some of LSL's body position resembled standing position.

Table 1. Towing time (s), stroke count, distance per stroke (cm), average body angle of the life saver (degrees from horizontal), average ankle depth of the victim (cm).

	Head and neck towing (HN)					Cross-chest (CC)				
Subjects	Time 50 m	Strokes 50 m	Travel distance / stroke	Max body angle°	Victim's ankle depth	Time 50 m	Strokes 50 m	Travel distance/ stroke	Max body angle°	Victim's ankle depth
Skilled lifesavers										
CC						71	59	88	25	47
BB	90	82	61	30	96	94	84	44	18	90
AA	68	63	74	23	84	70	69	72	30	67
RR	90	78	54	43	60					
Mean	**83**	**74**	**63**	**32**	**80**	**78**	**71**	**68**	**24**	**68**
SD	**12**	**10**	**10**	**10**	**18**	**13**	**12**	**22**	**6**	**22**
Less-skilled lifesavers										
VV	123	113	37	31	98	170	163	19	54	130
MM						138	144	35	36	78
SS	132	119	46	30	87					
PP	119	102	49	45	117	134	126	35	59	103
Mean	**126**	**111**	**44**	**35**	**101**	**147**	**144**	**30**	**50**	**104**
SD	**9**	**9**	**6**	**8**	**15**	**20**	**19**	**9**	**12**	**26**

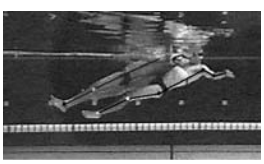

Figure 2. Typical examples of towing using cross-chest grip by a skilled lifesaver (first panel) and a less-skilled lifesaver (second panel).

DISCUSSION

The major finding of the study was that the skilled lifesavers as compared to their less-skilled counterparts could obtain higher speed by doing fewer and more effective strokes throughout the towing. Consequently they were able to keep the victim's body closer to the water surface. This helped to keep the victim streamlined and his face constantly out of water. According to Pia (7) it is impossible to keep the victim's body position horizontal during CC grip, because the rescuers' arm is crossing the victim's chest, which in turn causes the victim's head and body to sink lower in water. In this study the main reason why both the victim and the rescuer were drafting deep was due to the lack of skill to perform the manoeuvre. LSL typically had a low towing speed leading to more upright body position in relation to water surface and hence to difficulties in keeping the victim's face above the water. If each individual kick was ineffective, LSL needed to kick more frequently to travel forward, which increased physiological strain even to an exhaustive level (8).

The lack of towing skill means also that even though the limb movements produce a lot of kinetic energy it will not transform correctly to result in effective movement forward (1).

HN grip was noticed to be superior for the LSL to use.

Versatile lifesaving skills need to be frequently practised in water (5). The SLS subjects, who actually were competitive swimmers as well, had a reasonably good kicking technique. Other lifesaving qualifications seemed less important indicators in this case. We conclude that less-skilled or inexperienced lifesavers should not use CC towing grip as the principal technique especially when towing an unconscious victim. HN grip can be substituted by gripping on the victims's collar behind neck.

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gestions can be given to swimmers because the flow field is easily understood visually through analysis of mechanisms using PIV method.
Theoretical and experimental values were almost identical. It was suggested that a pair of vortices observed by the shift phase might be a vortex ring. In addition, from the comparison of both values, a swimmer with an efficient stroke can form a large vortex because swimmers propel themselves using the reaction force of the jet flow. Therefore, they might note the value of a large jet flow. It was also suggested that these values might serve as an index for propulsion force evaluation of swimmers in future. Moreover, by measuring the flow field around swimmers of different levels, strokes that produce greater propulsive force might be clarified. Suggestions for more efficient stroke skills can be given.

CONCLUSION
In conclusion, we confirmed that swimmers form vortices and use jet flow as a propulsion mechanism of sculling motion. Suggestions offered in this study are a first attempt at clarifying propulsion mechanisms; further study is intended. Future studies should examine the provision of feedback to facilitate coaching.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge the members of the Swim Laboratory and Matsuuchi Laboratory at University of Tsukuba. We also thank all participants in this study, which was supported by Grant-in-Aid for Scientific Research ((B) (2)16300202), ((B) (2)15300216)) from the Japan Society for the Promotion of Science, Japan.

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STROKE FREQUENCY STRATEGIES OF INTERNATIONAL AND NATIONAL SWIMMERS IN 100M RACES

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The purpose of this study was to examine stroke rate strategies of elite international and national junior level swimmers. Norwegian junior national (NOR) and European Short course championships (EUR) race analysis was performed by videography. Clean swimming velocity (v_{clean}) stroke rate (SR) and stroke length (SL) were analyzed for each lap. The frequency of use of five models for SR strategies during a race were identified for finalists (rank 4th – 6th/8th) and the top 3 performers for all 100m races. The most common strategy was model D for the top 3 performers (decreasing SR at the beginning, and increasing SR in the end of the race) and model B (decreasing SR throughout the race) for the finalists. It seems that the strategies most often used by the best performers in 100m short course races are decreasing during the first part of the race, and increasing at the end, and is a compensatory mechanism for a decrease in SL.

Key Words: Race analysis, swimming performance, stroke rate.

INTRODUCTION
It is documented that swimming race performance is, among other factors, affected by the strategies swimmers use to control the clean swimming velocity (v_{clean}), stroke length (SL) and stroke rate (SR) during the various phases of the race (e.g. 2). These authors found that for distances of 200m and longer the SL decrease with fatigue, and that faster swimmers compensate by increasing SR at the end of the race. In other studies it was found that for 200m races the decline in velocity at the end of the race was due to a decrease in SL (4), and that SL, and v_{clean} decrease throughout the race (9). Furthermore in the latter study mean SR increased for the last lap. For 100m races in long course it has also been reported that SL is a success factor for performance (6) and for breaststroke SR increased and SL decreased in the last part of the race (9). The SR strategies successful swimmers use during a short course 100m race is however rarely investigated, nor is there any information on differences in SR strategies between medal winners and other finalists. The purpose of this study was to examine successful SR strategies of elite international and national junior level swimmers, and furthermore to test the hypothesis that top 3 performers use a different race strategy than other finalists.

METHODS
Races from the finals at the Norwegian short course junior national championships (NOR, n=24) and from the finals at the European short course championships (3) (EUR, n=32) were studied. The races were all male 100m events. Mean (±SD) international point scores for the two groups were 626 (±59) and 911 (±31) respectively ($p<0.05$).
For all races, race analysis was performed by videography. Three or four cameras (50 Hz) were mounted perpendicular to the pool, making it possible to record all lanes at positions 0,

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ANALYSIS OF SCULLING PROPULSION MECHANISM USING TWO-COMPONENTS PARTICLE IMAGE VELOCIMETRY

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The flow field around a human body during swimming presents a very unsteady condition. This study analyzed the flow field around the hand using particle image velocimetry method. A male subject participated in this study, and the flow field around the hand during the sculling motion was visualized. The results indicate that a pair of vortices and the jet flow occurs around hand during sculling motion. The swimmer generated a great propulsive force as a reaction force of the jet flow. The theoretical value of the jet flow of a vortex ring and the experimental value were indicated as nearly equal. This measurement is expected to become an index for evaluating propulsive force in unsteady conditions.

Key Words: unsteady, PIV method, sculling, propulsion mechanism.

INTRODUCTION

Lately, many swimmers use an S-shaped pattern as a stroke pattern during swimming. This stroke pattern was advocated by Counsilman (1), who reported that it is used as a propulsive force that uses lift force effects. During the S-shaped pattern, there is sculling movement to increase the lift. Therefore, it is interesting to analyse the sculling propulsion mechanism, which is a basal motion of the S-shaped stroke pattern.
Numerous studies have estimated propulsive forces during human swimming. However, most have been based on quasi-steady analyses. The actual flow field around the swimming human body is in a perpetually unsteady condition. Unsteady effects must therefore be considered (8).
Recently, a method to analyse an unsteady flow field around a human body has been established in the field of engineering: Particle Image Velocimetry (PIV). Measurements taken near the bodies of fish and insects have been reported using PIV (2, 6). The flow field around moving fish and insect are in an unsteady condition. We therefore inferred that it is appropriate to use this method to analyse the flow field around a human swimmer. Some researchers have visualised the flow field around the human body by applying PIV to the swimmer's environment (4, 5, 7). Nevertheless, no studies have applied PIV to swimming humans.
This study was intended to analyse the propulsion mechanism of sculling motion in human swimming using two-components PIV (2C-PIV).

METHOD

A male subject participated in this study. His body height was 1.72 m; his body weight was 67 kg, with 141.1 cm^2 hand area. The subject had swum competitively before; he was sufficiently accustomed to sculling skills. The subject was informed of the experiments and their associated risks before giving his informed consent to the study.

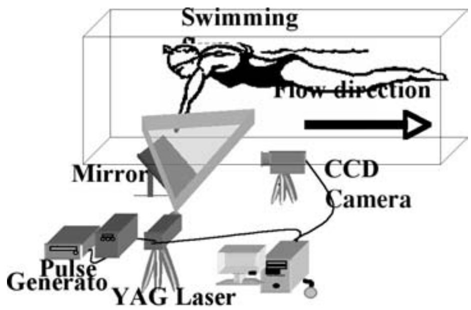

Fig. 1. The experimental situation.

This study used a swimming flume (4.6 x 2.0 x 1.5 m; Igarashi Industrial Inc., Japan). Figure 1 shows the device used for PIV measurement. Tracer particles (50 μm) were mixed in water. To illuminate the particles of the test section, the beam of an Nd-YAG laser (New Wave Research, USA) was spread to resemble a plane of light, thereby horizontally illuminating around the left hand from the side of the swimming flume. The subject was instructed to maintain a position against the flow (0.5 m/s) using a sculling motion in a prone position. Two hundreds time sequential images of the unsteady flow field around the left hand were captured using a CCD camera (15 Hz) from the lower side through a mirror. They were subsequently stored in a personal computer. The subject wore goggles during PIV measurements for protection from the laser light. Moreover, to reduce the influence of halation, the subject wore a black glove on the left hand. They did not influence the subject's skill.
Positional data and the particle velocity data were output from the image data obtained during the experiment. The velocity vector-vorticity distribution data were calculated from the output data using software (MATLAB; The MathWorks Inc., USA). In this study, the rotational direction of vortex was defined with counterclockwise as positive; clockwise was negative.
In addition, the force generated by the hand was evaluated. A pair of vortices was inferred to form because of the sculling motion in sections of the vortex ring. The circulation value when assuming that a pair of vortices observed in the flow field is a vortex ring was calculated using the following equation.

$$\Gamma = \int \omega ds \qquad \text{(Eq. 1)}$$

Therein, ω represents vorticity and *ds* indicates the unit area. Moreover, the induced velocity by the vortex ring was calculated using the formula and applying the law of Biot-Savart:

$$V_0 = \frac{\Gamma}{2R} \qquad \text{(Eq. 2)}$$

where V_0 represents the induced velocity, Γ was circulation of vortex ring, and R was radius of vortex ring. The forecast value of the jet flow by the theory (the theoretical value) was calculated using these formulae. Those calculated values were compared with experimental values of the jet flow of an actual flow field.

RESULTS

The time sequential velocity vector-vorticity map and image picture during sculling are shown in Fig. 2 and Fig. 3.

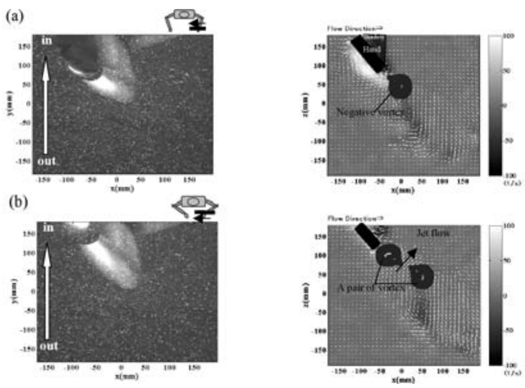

Fig. 2. Velocity vector-vorticity map at the shift phase from out-scull to in-scull. (Image picture: left, velocity vector-vorticity map: right)

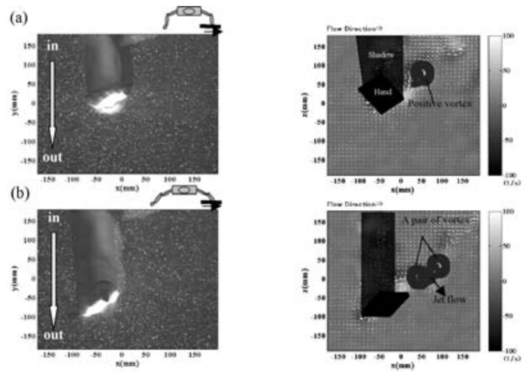

Fig. 3. Velocity vector-vorticity map at the shift phase from in-scull to out-scull. (Image picture: left, velocity vector-vorticity map: right)

Figure 2(a) depicts the middle of the shift phase from out-scull to in-scull. At that time, changing the hand direction formed a negative vortex opposite to the circulation around the hand; the flow of the back of the hand had separated. Subsequently, at the end of the shift phase, a pair of vortices was formed by a positive vortex that formed separate from the back of the hand and a negative vortex that had been formed previously (Fig. 2(b)). Additionally, velocity vectors (jet flow) were confirmed in the direction of the flow between a pair of vortices. Figure 3(a) is the middle of the shift phase from in-scull to out-scull. At this time, the flow had separated from the palm and the back of the hand; a positive vortex was observed to the palm side. Finally, at the end of the shift phase, the flow separated from the hand, and formed a pair of vortices. In addition, the jet flow was observed to the direction of the flow between a pair of vortices (Fig. 3(b)). Moreover, the jet flow to the direction of the flow was confirmed in the flow field other than between a pair of vortices.

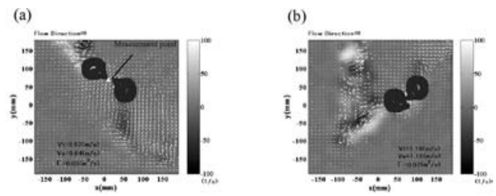

Fig. 4. The circulation value calculated from a pair of vortices formed in shift phase, the theoretical value and the experimental value of the jet flow. (a) Shift phase from out-scull to in-scull, (b) Shift phase from in-scull to out-scull.

The circulation value, the theoretical value and the experimental value of jet flow are shown Fig. 4. The circulation value of the shift phase from out-scull to in-scull was 0.05 m^2/s, the theoretical value was 0.63 m/s, and the experimental value was 0.64 m/s (Fig. 4(a)). In the opposite phase, the circulation value was 0.07 m^2/s, the theoretical value was 1.18 m/s, and the experimental value was 1.16 m/s (Fig. 4(b)).

DISCUSSION

Despite the plethora of opinions about propulsion mechanisms in fluids, those mechanisms have not been clarified. Such is also the case for swimmers' propulsive mechanisms. Positive and negative vortices were formed as characteristics of flow field phenomena of both shift phases in this study. After the change of direction of the hand motion, the vortex of opposite direction to that of circulation was formed around the hand. The flow separated from the hand as the angle of attack increased; then another vortex was formed. Moreover, the velocity vector to the direction of the flow between a pair of vortices was inferred to be a jet flow because the vortex of the reverse rotation is a vortex ring.

Sakakibara et al. (6) measured flow fields around propelling fish in water, thereby confirming the jet flow shown in the present study. Underwater creatures generate jet_flow using a wave motion. The resultant reaction force was inferred to be a propulsive force. A swimmer also uses the jet flow, generated by the sculling motion, as a propulsive force.

In this study, the flow separated from the hand was observed at the shift phase from out-scull to in-scull. This is thought to apply to the phenomenon called "delayed stall". Dickinson (2) reported on this phenomenon by observing the wing strokes of a fruit fly. This phenomenon increases the lift force using a "leading-edge vortex". In short, the flow separated from the hand in the end of the shift phase was the "leading-edge vortex" that caused a "delayed stall". Consequently, the swimmer increased the lift force through the sculling motion: the resultant lift force served as a propulsive force. Skill sug-

5, 10, 15, 20 and 25m of each lap (fig. 1). A manual switch was used to direct the signal from each camera to one recorder, after applying a timestamp, and after superimposing graphical lines representing the distances of 5, 10, 15, and 20m of the pool. Calibration of the lines was done by poolside markers. The video recording timestamp was synchronized with the official (Omega) time system by means of a flashing light at the starting signal visible on the video picture. This setup assures the possibility to analyze a number of parameters during each race for each swimmer. Time was measured when the head of the swimmer passed the 5, 10, 15 or 20 m mark, and time for 3 mid-pool strokes were measured for ach swimmer. In the present study stroke rate (SR), clean swimming velocity (v_{clean}) and stroke length (SL) was calculated. Clean swimming velocity (not affected by starts and turns) was calculated timing the swimmers head using distances 15-20m (lap 1) and 10-20m (lap 2-4) and divided by 5 or 10m respectively. Stroke length was calculated as: SL= $v_{clean} \cdot SR^{-1}$ (1). These methods of race analysis have also been described by Thompson, Haljand and MacLaren (9).

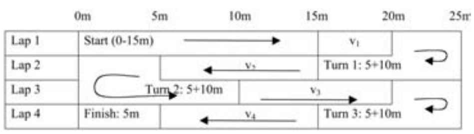

Fig. 1. Distances recorded to analyse temporal aspects of a 100 m race.

Before the study, six main models for SR strategies during a race were constructed, partly using models from (5). The models are displayed in fig. 2. These were model A - increasing SR throughout the race; model B- decreasing SR; model C - no change in SR; model D - a U-pattern, decreasing – then increasing; model E - a inverted U pattern - increasing then decreasing and model F - decreasing, increasing and decreasing. However, within these main characteristics several submodels existed (see fig.2). The frequency of use of these models for NOR and EUR were identified for finalists (rank 4th – 6th and 4th – 8th respectively) and the top 3 performers for all 100m races in all strokes. χ^2 statistics and two way ANOVA was used for comparisons.

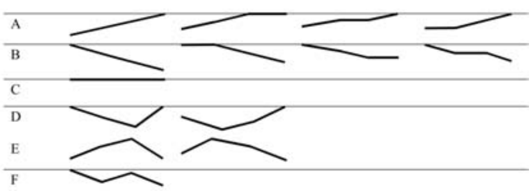

Fig. 2. The different models for stroke rate development in a 100m race. Each main model has several alternatives. Amplitude increase and decrease indicate stroke rate development during a race.

RESULTS

A summary of the results is displayed in table 1, showing which models are preferred for all the finalists and the top 3 performers of EUR and NOR. The most common strategy was model D for the top 3 performers (decreasing, and increasing SR in the end of the race) and model B for the finalists. Using a χ^2 test to check if the frequency distribution of models were significantly different than expected, revealed a significant different distribution ($p<0.001$). Performance, at two levels, championship type, and medalists or finalists, was found to significantly alter the expected frequency distribution of SR models ($p<0.01$). Attempting to explain the results from SR analysis, further analysis of v and SL was performed. The results of a two way ANOVA analysis of the development of v_{clean}, SL and SR from lap 3 to the last lap are shown in table 2. The effect of both performance factors was significant for stroke length differences ($p<0.01$). Furthermore medalists had a significantly lower SR difference compared to finalists ($p<0.05$) and EUR swimmers had additionally significantly higher difference of v_{clean} from lap 3 to lap 4 compared to NOR swimmers ($p<0.001$).

Table 1. Fraction of swimmers using each of the SR models for finalists and medalists, all numbers in %.

	Finalists			Medalists		
Model	EUR	NOR	Total	EUR	NOR	Total
B (\\)	35	45	39	25	50	38
C (--)	15	0	10	17	8	13
D (U)	30	45	35	50	42	46
E (∩)	10	0	6	0	0	0
F (\/\\)	10	9	10	8	0	4

Table 2: Mean (SD) of the difference in clean swimming velocity (v_{clean}), stroke length (SL) and -rate (SR) from lap 3 to lap 4 for EUR, NOR, medalists and finalists.

	EUR		NOR	
	Finalist (4-8th)	Medalist (1-3rd)	Finalist (4-8th)	Medalist (1-3rd)
$\Delta\ v_{clean\ 3\text{-}4}(m \cdot s^{-1})$	0.05 (0.05)	0.07 (0.04)	0.02 (0.06)	0.02 (0.05)
$\Delta\ SL_{3\text{-}4}(m \cdot cyc^{-1})$	0.05 (0.11)	0.11 (0.04)	0.05 (0.06)	0.05 (0.07)
$\Delta\ SR_{3\text{-}4}(cyc \cdot min^{-1})$	0.26 (2.87)	-0.93 (1.42)	-0.47 (1.37)	-0.68 (1.36)

DISCUSSION

The main results from this study is that the most common SR models for the medalists is model D (increasing SR at the end of the race), and model B for the finalists. The least successful models were model E and F, failing to keep up or decreasing the SR at the end of the race. This may be due to fatigue. By first sight, it seems as the ability to increase the SR at the end of the race is important to achieve a top performance. This is supported by the data in table 2, medalists have a lower difference of SR from lap 3 to lap 4 – this implies that SR is increasing more. Furthermore in a study of 100m races in Atlanta Olympic games it was found that the most common stroke rate model for the top 3 performers corresponds to model D (8 of 12 male medal winners) (5). However, the results from Atlanta were obtained in a 50m pool, which is different than for our data, obtained in a 25m pool. The two studies show that medalists are more likely to use model D, regardless of the pool length.

Additionally results from 159 males and 158 female 200m long course breaststroke races shows that mean SR develops according to our model D (9). Whether the appearance of model D is a chosen strategy or a result of changed technique due to fatigue is unknown in our study and not reported in other studies.

However, looking at SL decrease from lap 3 to lap 4 it is larger for medalists compared to finalists, and for EUR compared to NOR. Additionally medalists had a larger v_{clean} decrease on the last lap compared to finalists. Interpreting these results in the light of the SR development during the race is not straight forward. From studies on SL and SR with stepwise sub maximal testing Keskinen (7) have suggested that above anaerobic threshold, the SL and SR relationship changes in a way towards shorter SL and faster SR. When fatigue occurs, it have also been demonstrated that decrease of v_{clean} might be connected to the inability to increase SR and to a decrease in SL (8,10). More precisely we could possibly attribute the onset of fatigue at the end of the race as an explanation for changes in SR and SL revealed in the present study. This is also supported by the data from Craig et al. (2), who found that the faster swimmers compensated for the deteriorating SL by increasing SR more than did their slower competitors. In the study of Craig et al. (2) SL and velocity was measured as an average over the whole lap (i.e not measuring clean swimming velocity as in our study), and changes in underwater phases after the start and turn may have influenced these results.
Our results show that medalists increase SR more from lap 3 to lap 4 compared to the other finalists. Moreover, the medalists of EUR showed a larger decrease in v_{clean} from lap 3 to lap 4 compared to other finalists. It is thus tempting to conclude that top performers adopt a compensatory strategy of increasing SR at the last lap to avoid further decrease of v_{clean}. A higher v_{clean} on lap 3 for top 3 EUR performers is explaining their larger decrease in velocity from lap 3 to 4 compared to the finalists.
It may be speculated that the athletes which are least fatigued have the energy to increase SR and by this compensate for a decrease in SL and thus win the race. However, a closer analysis of these phenomena seems important, especially to the factors that may explain why medalists are able to increase SR at the end of the race by possible physiological mechanisms.

CONCLUSION
The strategies most often used by the best performers in 100m short course races are decreasing during the first part of the race, and increasing at the end. Moreover, swimmers should not try to increase SR in the end of the race per se, but use it as a compensatory mechanism for a decreasing SL, focusing on the last lap to minimize the decrease of SL.

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THE TEMPORAL DISTRIBUTION OF RACE ELEMENTS IN ELITE SWIMMERS

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The purpose of this study was to examine race element (start, turning and finishing) strategies of elite and national level swimmers in short course 100m races. For 56 finalists at the Norwegian junior national (NOR) and the European Short course championships (EUR) race analysis was performed by videography. Start- (0-15m), turn- (5m in and 10 m out) and finishing time (last 5m) were analyzed for each race, and these times were normalized to the total race time. The results show that EUR swimmers spend less time in starting, turning and finishing together ($p<0.001$), starting ($p<0.05$) and during the first turn ($p<0.02$) compared to NOR swimmers. The top 3 performers of both groups were found to have a stronger finish normalized to their end performance compared to the other finalists.

Key Words: Race analysis, swimming performance, starting, turning, finishing action.

INTRODUCTION
For many years it has been customary to perform race analysis of all finals during major swimming championships. A race analysis usually consists of timing of different parts of the race, like start (0-15m), turns (5+10m or 7.5+7.5m in and out of the turn), and finishing actions (last 5m). Furthermore measurements of stroke parameters like clean swimming velocity, stroke rate and stroke length is measured. Meta studies of race analysis have been published by various groups (e.g. 1-3, 5-8). An analysis of the 1992 Olympic swimming races revealed that starting time, turning times and finishing times were components of successful performances and correlated positively with performance (1). The strategies

of medallists and finalists were compared for the 200m freestyle event at the Sydney 2000 Olympics, and it was found that the velocity of the 2nd 50m and turn time for the 3rd turn were the most important parts of the race (2). In both studies, significant correlations were found between starting and turning parts and end time of the race. Furthermore Thompson, Haljand and MacLaren (8) found that main correlates of end time in breaststroke races was mid-pool (clean) swimming velocity, accompanied by moderate correlations for turning time and start time.
However, these studies have not considered starting, turning and finishing actions normalized for each individual swimmer's end time. By looking at the start, turning and finishing actions normalized, it is possible to determine if individual swimmers may choose different strategies of their temporal distribution of race elements within their end race time. Whether the temporal distribution of the race elements is different for elite performers compared to other competitive swimmers is not well, if ever documented. The purpose of this study was thus to examine the race strategies of elite swimmers compared to national junior level competitive swimmers in terms of their temporal distribution of start, turning and finishing elements within their end race time of 100m races, and in addition to investigate whether medalists have a different distribution of race elements compared to other finalists (rank 4th-8th).

METHODS
Races from the finals at the Norwegian short course junior national championships (NOR, n=24) and from the finals at the European Short course championships (5) (EUR, n=32) were studied. The races were all male 100m events. Mean (±SD) international point scores for the two groups were 626 (±59) and 911 (±31) respectively ($p<0.05$).
For all races, race analysis was performed by videography. Three or four cameras (50 Hz) were mounted perpendicular to the pool, making it possible to record all lanes at positions 0, 5, 10, 15, 20 and 25m of each lap (fig. 1 and fig. 2). A manual switch was used to direct the signal from each camera to one recorder, after applying a timestamp, and after superimposing graphical lines representing the distances of 5, 10, 15, and 20m of the pool. Calibration of the lines was done by poolside markers. This setup assures the possibility to analyze the time when the head of the swimmer passed the 5, 10, 15 or 20 m mark, and from these data the time spent starting - t_{ST} (0-15m), turning t_{TRN} (5m in and 10m out of the turn) and finishing t_F (last 5m of the race) and their corresponding velocities were calculated. The video recording timestamp was synchronized with the official (Omega) time system by means of a flashing light at the starting signal visible on the video picture. These methods of race analysis have also been described by Thompson, Haljand and Lindley (7).
The starting, turning (the sum of 3 turning times) and finishing times were each normalized by dividing by the end race time. Furthermore the normalized sum of times spent for starting, turning and finishing is called non-swimming score, it was calculated according to this equation: $(t_{TRN1} + t_{TRN2} + t_{TRN3} + t_{ST} + t_F) / t_{TOT}$. Thus a high non-swimming score means that more time is spent in these phases of the race, reflecting a worse performance in these phases. To compare two levels of performance (medalists 1st – 3rd place vs finalists 4th – 8th place and EUR vs NOR) a two way ANOVA was applied.

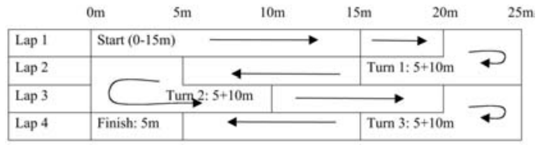

Fig. 1. Distances recorded to analyse temporal aspects of a 100 m race.

Fig. 2. Camera placement at different positions perpendicular to the pool, from the NOR championship.

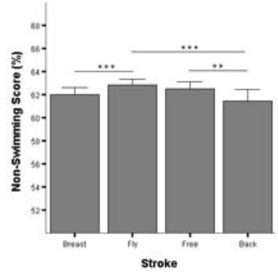

Fig. 3. Mean (error bars are SD) non-swimming score for the 4 strokes.
*** p< 0.01, *** p<0.001.*

RESULTS
A summary of the results is displayed in table 1. All participants in the EUR championship used a significantly lower portion of their end race time to starts, turns and finishes combined (non-swimming score) compared to the Norwegian junior swimmers ($p<0.001$). Furthermore the starting score was found to be lower ($p<0.05$), the first turn score was found to be lower ($p<0.02$) and the difference between turn 3 and turn 1 scores was found to be higher ($p<0.01$) for the EUR races compared to NOR races. The effect of performance level within the two groups of swimmers was found to be significant only for finish score ($p<0.01$), where the medalists were found to have a lower finish score – meaning that they performed a better finish compared to their own race end time. The correlations coefficient between international points score and non-swimming score was $r=-0.47$ ($p<0.01$) for all the races included in the study, however within the groups no significant cor-

relations was found. The differences in non-swimming score between the four strokes are shown in fig. 3.

Table 1. Mean (SD) race analysis scores for medallists and finalists of short course European and Norwegian junior Championships. See text for statistics.

	EUR		NOR	
	Medallist (1-3rd)	Finalist (4-8th)	Medallist (1-3rd)	Finalist (4-8th)
Non-swimming score (%)	61.81 (0.76)	61.89 (0.70)	62.70 (0.73)	62.64 (0.95)
Start Score (%)	12.19 (0.44)	12.27 (0.55)	12.69 (0.69)	12.48 (0.72)
Total Turn Score (%)	44.41 (0.99)	44.31 (1.03)	44.77 (1.13)	44.70 (0.99)
Finish Score (%)	5.21 (0.22)	5.31 (0.21)	5.24 (0.24)	5.46 (0.19)
Diff. Turn 3- Turn 1 (%)	1.05 (0.33)	1.19 (0.38)	0.71 (0.44)	0.98 (0.39)

DISCUSSION

The results of this study show that the better performers (EUR) use a smaller portion of their end race time for turning, starting and finishing actions compared to the juniors (NOR). This implies that the relative importance of these phases is greater for international level swimmers and might be a success criterion. Several studies have previously shown that better performers have faster starts and turns compared to less successful performers (e.g. 8), however this was absolute and not normalized values. We do not know of any other studies that may confirm the normalized results. For the starting score separately and turn 1 score separately, the EUR races showed significantly lower means. This implies that elite international swimmers spend less time starting and during the first turn as a percentage of their end race time. On the other hand the drop in turn time was significantly larger for the elite international swimmers. Relative to their performance it may seem that the international level swimmers have a faster first part of their race. Previous studies have also suggested that both at international and national level, 200m breaststroke races are swam with a positive split – i.e. a faster first part of the race (8).
Looking at the performance groups within the EUR or NOR championships, i.e. whether the medalists have a different distribution of their race elements than the other finalists another aspect is emerging. The effect of within group performance was significant only for the finish action score. It means that medalists, both in EUR and NOR championships have a stronger finish than the rest of the final. This may not come as a surprise, however, it should be added that the strong finish is in relation to each swimmers own end time. Whether this is due to a better physiological capacity to deliver energy at the end of the race, the ability to maintain adequate race-end swimming technique, a better finish stretch technique or better psychological abilities is not known. Very little research of the last part of swimming races is present, and this research area deserves further attention.
Analyzing the four different strokes, backstroke swimmers seem to have the smallest portion of their race time devoted to starts, turn and finishes. Non-swimming score was significantly lower for backstroke compared to freestyle and butterfly, and significantly lower for breaststroke compared to butterfly. These results may describe the characteristics of backstroke and breaststroke races – normalized to end race time, the sum of start- turning- and finishing time are lower for these two strokes.
Several studies have pointed out that the range of strokes from fastest to slowest is front crawl, butterfly, backstroke and breaststroke (e.g. 4). Our race analysis also shows that for freestyle and butterfly the clean swimming velocities are higher than for back and breaststroke. This may alter the optimal temporal distribution of the different race elements. In this regard one may claim that breast and backstroke races rely more on good starts, turns and finishes, than do freestyle and butterfly races. The under water kicking phase of backstroke and butterfly is very similar (however supine vs. prone positions) and with the butterfly being the fastest mid-pool stroke of the two this may explain why butterfly have a higher non-swimming score compared to backstroke.
Further investigation and analyses are required in this topic. Finally it should be kept in mind that the presented results are only valid for males, and that similar analyses should be done for females.

CONCLUSION

International level swimmers have, relative to end race time, better starts, turns and finishes compared to national caliber junior swimmers in 100m races. One factor that distinguishes medalists from finalists is their stronger finish – relative to their performance. Of the different strokes, backstroke is characterized with the least amount of time spent in starting, turning and finishing phases of the race, relative to end time.

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GOALKEEPER'S EGGBEATER KICK IN WATERPOLO: KINEMATICS, DYNAMICS AND MUSCULAR COORDINATION

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By using a Doppler-Ultrasound-Velocimeter System yielding the vertical speed of a goalkeeper's head during different actions in waterpolo the kinetics of the total body could be determined approximately. Synchronous measurements of the electrical activity of Mmi. glutaeus maximus, vastus medialis and adductor longus were taken to study the muscular coordination during the execution of the eggbeater kick. This leg kick could produce climbing heights up to 0,7 m; the vertical speed varying from +/- 0,8 m/s to 2 m/s. The muscle activation pattern showed a clearly defined order of appearance in time, announcing a high potential of muscular fatigue.

Key Words: waterpolo, eggbeater kick, kinetics, electromyography.

INTRODUCTION

Unlike his colleagues of a waterpolo team the goalkeeper has to maintain an upright position the whole time and must be prepared to raise his body very quickly out of the water, reaching out for the ball thrown in the corner of his goal and catching it. The reaction forces necessary to meet these requirements must be generated by the interaction of the goalkeeper's body parts and the surrounding water since no rigid platform exists for a push-off of the body. Not only to avoid sinking down in the water but even more performing ascending movements out of the water the goalkeeper exerts a special leg kicking motion –the eggbeater kick- as well described by Sanders (1) in a very detailed way. The objectives of this study aree to give some examples of kinematics of a goalkeeper's typical movements, estimates of the forces necessary for "jumping out of the water" combined with the presentation of some activation patterns of leg muscles during eggbeater kick.

Physical Background

The balance of vertical forces acting on the CG of a body in the water is determined by weight, hydrostatic lift and reaction forces caused by the body movements: the weight force is expressed by the product of the body's mass and the terrestrial acceleration (g), the hydrostatic lift is given by the weight of the water displaced by the body (as a function of the immersed body volume), and the reaction forces generated by the flow surrounding the body parts in motion, thus generating propulsive or resistive force effects. So, the sum of external and inertial forces can be written as:

$$L_{stat} - W - F_r - M \cdot \frac{dv_{vert}}{dt} = 0 \qquad \text{(Eq. 1)}$$

L_{stat} = hydrostatic lift, W = weight, F_r = reaction force, M = body mass, v_{vert} = vertical speed (the "+" sign denotes upward direction of forces and speed).

A special situation is described by setting $F_r = 0$: In this case, the body moves vertically to a stable static position depending on the force difference $L_{stat} - W$. The ascending movements of the body in the water due to propulsive arm/leg actions are to be characterized not only by an amount of higher forces with growing climbing height but by the fact that a loss of the static lift occurs when the upper part of the body has left the water, demanding a still higher level of propulsive forces.

METHODS

The kinetics of the goalkeeper's movements (the subject: a skilled male test person, mass: 89 kg) was obtained by using a Doppler-Ultrasound-Velocimeter System measuring continuously the speed of vertical ("up and down") movements of the test person's head (see fig.1). From this signal, the time curves of the vertical distance covered by the jumps were obtained by integration whereas a numerical differentiation yielded the acceleration curves representing an approximation for the acceleration of the goalkeeper's centre of gravity.

By multiplying with the body mass estimate values of the vertical forces generated by the eggbeater-kick could be obtained. The leg kicking motion was examined by observation of an underwater video system operating synchronously with the speed measurements. Muscular coordination was registered synchronously also via underwater electromyograms from M. glutaeus maximus, M. vastus medialis and M. adductor longus of the subject's right hand side. These muscles were considered to play an important role in the execution of the eggbeater kick, giving a first insight into the structure of muscular action. The EMG-signals were high-pass filtered (25 Hz) to avoid movement artefacts and, if necessary, had to undergo a 50 Hz notch filtering process for hum suppression.

Figure 1. Measuring procedure using the Doppler-Ultrasound-Velocimeter System.

RESULTS

In this chapter, the results of three different movement types of a goalkeeper are presented: single "jump" out of the water, multiple, successive lifting and sinking movements, and the maintaining of a certain height above water level for some seconds.

The single jump (cf. fig.2) is characterized by a lifting speed maximum of about 1,4 m/s being reached within about 0,5 seconds. A maximal acceleration value of 8,6 m/s^2 appears in a very early phase of the jump, possibly caused by a synchronous activity of Mm. glutaeus maximus and adductor longus, followed by a strong activity of M. vastus medialis, leading to the maximal speed in upward direction. During the whole lifting movement, at positive speed values, an activation of the M. adductor longus is present. Rapid deceleration of the body and sinking of the body are combined and explained by the sudden stop of the activity of M. vastus medialis while the M. glutaeus maximus is active to stop the sinking movement, supported by a strong activation of M. vastus medialis.

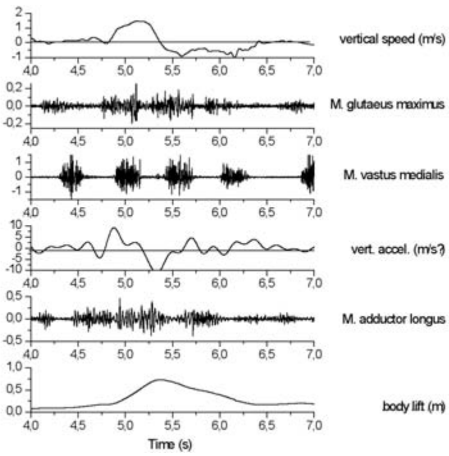

Figure 2. Kinetics and muscular activity in the eggbeater kick: single jump.

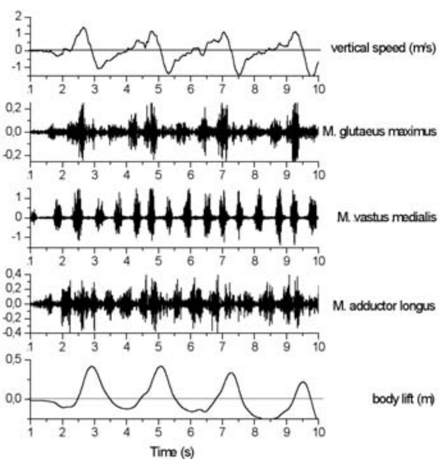

Figure 3. Kinetics and muscular activity in the eggbeater kick: multiple jumps.

In contrast to the single jump pattern, the movement with the generation of quickly repeated lift (see fig.3) leads to a higher frequency of activation of M. vastus medialis working partially alternatively and partially synchronously with M. adductor longus. The activation of the M. glutaeus maximus leads either to an increase of speed directed in an upward direction of the body or to a decrease of sinking speed of the body. It can be seen clearly that a reduction of negative segments of the speed curve means a higher degree of muscular activity in the frequency domain. This effect is intensified for the movement when the goalkeeper is forced to maintain an elevated position in the water for some time (cf. fig.4).

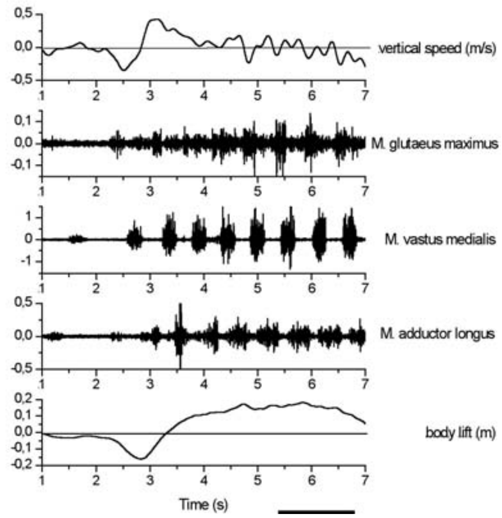

Figure 4. Kinetics and muscular activity in the eggbeater kick: maintaining an elevated position.

This example shows the background of muscular activity necessary to generate a constant propulsive force using the eggbeater kick, i.e. executing oscillatory movements. Of course, the EMG measurements presented here include only a minor part or all muscles of the leg, but it seems to be reasonable to attribute similar activity patterns to the remaining muscles of the lower extremity. Estimates of the vertical reaction forces generated by the eggbeater kick can be derived from *fig.1*: here the maximal acceleration of the total body has the order of magnitude of about 8-9 m/s^2, announcing that a maximal force of up to 700 N must have been generated by the leg kicking movements. With the assumption of lifting 50 % of body mass out of the water for a while a force estimate of 50 % of body weight force is necessary since hydrostatic lift acts only on the immersed part of the body.

CONCLUSION / CONSEQUENCES

Further research of the eggbeater kick can be done by several means: studies using more EMG channels should lead to a deeper insight into muscular coordination of a complex movement. This research can be combined with 3D-analyses yielding the kinetics of the kicking movement (1). Furthermore, the investigation of the relationships between movement parameters and water flow effects due to the generation of propulsive forces could be useful to a better understanding of hydrodynamics of this special kick.

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KINEMATICS AND DYNAMICS OF THE BACKSTROKE START TECHNIQUE

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The investigation is the lack of complex biomechanical analysis of this starting technique based on kinematic, and dynamic data. Nine male backstroke sprinters performed four backstroke starts over a distance of 7.5 m. During the start the over all start time, and split into reaction time, wall time, flight time, and glide time was recorded. Dynamic data were measured as 3-dimensional ground reaction forces. The correlation of the resultant take off force and the final over all start time (7.5 m) turns out to be significant (r=-.83, p<.01; [n=9]). Correlations were found between the times of hands off and take off (r=.71, p<.05; [n=9]) and hands off and hip entry (r=.93, p<.01; [n=9]). The influence of the kinematic and dynamic parameters of the overwater phase (wall and flight activity) of the backstroke start technique is clearly shown by the analysis.

Key Words: backstroke start technique, kinematic, dynamic, reaction force.

INTRODUCTION

The backstroke swim start has been estimated to contribute up to 30% of the total race performance in the 50 m backstroke sprint (3). Despite its importance there is a lack of complex biomechanical analysis of this starting technique based on kinematic, dynamic and electromyographic data (for more information see 4).

METHODS

Nine male backstroke sprinters, all members of the German national team in swimming, performed four backstroke starts over a distance of 7.5 m. The over all start time was recorded by high speed video analysis (125 Hz), and split into reaction time (signal until hands off), wall time (signal until take off), flight time (take off until hip entry), and glide time (hip entry until head passing 7.5 m). The start section of the swimming pool was calibrated and a 2-dimensional video movement analysis was carried out to determine the kinematic parameter of the four starts (see figure 1). Kinematic parameters were calculated by videographic motion analysis (SIMI-Motion, Ger). Dynamic data were measured as 3-dimensional ground reaction forces at a sampling frequency of 1.000 Hz by a mobile water proof force plate (KISTLER, Ger) mounted to the pool wall. All differences in the kinematical and dynamical data between the starts were tested by Pearson correlation test and by paired T-test (SPSS; Version 12.0).

Figure 1. Picture of the backstroke start movement (up) and under water view (down).

RESULTS

In a first step, kinematic parameters of the whole body movement during the different phases of the backstroke start of all nine swimmers were measured. In the elite swimmers the correlation of the resultant take off force and the final over all start time (7.5 m) turns out to be significant (r=-.83, p<.01; [n=9]). Likewise a significant correlation could be found between the take off force and the official start times (head passing 7.5 m) of 8 out of the 9 investigated athletes in the German national championships 2005 (r=-.74; p<.05; [n=8]). Correlations were found between the times of hands off and take off (r=.71, p<.05; [n=9]) and hands off and hip entry (r=.93, p<.01; [n=9]). Other start parameters (wall and flight time, take off velocity and underwater speed) did not show significant correlations with the over all start time at 7.5 m. Table 1 shows the kinematical and dynamical data of the nine athletes during the backstroke start.

Dynamical analysis of the force distribution on the start block (pool wall) leads to a characteristic curve of the individual and time normalized horizontal (F_Z) and resultant (F_R) force that is similar in eight athletes to the backstroke start (fig. 2).

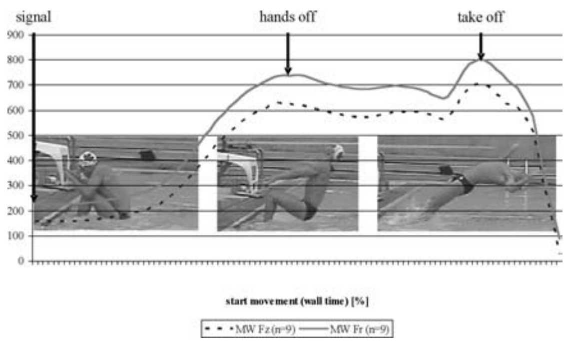

Figure 2. Example of the force reaction of the time normalized force curve of the start movement (n=9).

One athlete shows a different force–time–curve with a higher impulse in the first part and a decreasing second impulse in comparison to take off.

Table 1. Kinematical and dynamical data.

athletes	body weight [kg]	F_{RMax2} [N]	hands off [s]	take off [s]	hip entry [s]	start time 7.5m [s]	$v_{take\ off}$ [$m\cdot s^{-1}$]	best time 50m [s]
T.H.	82.00	1,043.390	0.440	0.772	1.068	3.340	4.72	24.02
R.K.	88.00	1,066.750	0.413	0.747	0.949	3.013	4.18	26.08
T.E.	71.00	742.326	0.482	0.821	1.099	3.688	3.75	26.89
J.G.	70.00	710.362	0.428	0.665	1.027	3.693	2.73	28.40
T.R.	75.00	922.092	0.474	0.770	1.098	3.590	2.95	24.80
R.P.	78.00	1,018.050	0.590	0.874	1.194	3.522	2.74	28.10
H.M.	73.00	1,055.554	0.532	0.760	1.168	2.724	2.92	26.16
M.C.	80.00	983.946	0.453	0.673	1.037	3.233	3.56	25.53
S.D.	90.00	1,243.886	0.491	0.783	1.084	2.767	3.50	25.14
Mean	78.55	976.26	0.478	0.763	1.080	3.285	3.45	26.12
SD	±7.14	±166.12	±0.055	±0.065	±0.074	±0.378	±0.69	±1.47

A higher impulse (F_Z/F_R) in the jump off phase between hands off and take off (**F_Z**: t(8)=-2.448, p<0.05 (*); **F_R**: t(8)=-2.147, p=0.064 (+)) leads to a higher acceleration at the end of the start movement, and a higher velocity (r=0.840, p<0.05 (*), n=6)) in the backstroke start. With these higher take off velocity and take off force (F_R) are associated also faster starting times with the 7.5 m split time (r=-0.825, p<0.01 (**), n=9).

DISCUSSION
This investigation is in extension with the electromyography analysis (4) one of the first complex analyses of the starting technique in the backstroke swimming.
The influence of the kinematic and dynamic parameters of the overwater phase (wall and flight activity) of the backstroke start technique is clearly shown by the analysis. High correlations occure between the absolute (resultant) force at the time of take off from the wall and the over all start time at 7.5 m (3).

CONCLUSION
A higher impulse on the block (pool wall) leads to a higher acceleration and take off velocity (v take off) in the backstroke start. That can be referred to the meaning of a technically good start movement. A high impulse to take off is crucial for fast starting times (head 7.5 m) with the backstroke start and other starting forms (especially track or grab start) (1, 2, 3, 4, 5, 7).

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FLOW VISUALIZATION OF UNSTEADY FLOW FIELD AROUND A MONOFIN USING PIV

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Swimmers swimming with monofins are much faster than without although the human power is the same. To predict how fast they can swim we have to know the complex flow field which is extremely unsteady. The study of the flow field was executed in a flume using a kind of swim manipulator equipped with a monofin. We set the fin in a flume and drove it by a motor. Flow fields around a monofin in a pitching motion was measured by means of a recently-developed technique called the Particle Image Velocimetry (PIV). Time variations of velocity and vorticity fields were calculated from the image captured by PIV system. Unsteady flow characteristics such as a vortex formation and the movement of vortices were investigated in detail. Information on unsteady flow and vortex motion serves the understanding the mechanism of propulsion in aquatic motion.

Key Words: monofin swimming, vortex-induced propulsion, PIV, unsteady flow.

INTRODUCTION
Swimmers wearing a monofin can swim very fast. The world record of the apnea, which is the one of the categories of fin swimming, is one and half times faster than swimming crawl-stroke using arms and legs. The swimming speed cannot be explained by our knowledge of fluid mechanics using rigid body approach. This is why the much higher speed of dolphins is still a mystery. This mystery is called Gray's paradox and has not been solved yet, entirely. There has not been much work made on monofins except for the direct measurement of propulsive force (1). Research on the flow characteristics still is in need of more attention. The high speed is related to the high momentum generation of water. To know the generation of momentum, the characteristics of unsteady flow field have to be investigated. Vortex formation and movement are known to play an essential role on the generation of propulsive force in the animal locomotion such as insect flight and fish swimming (see, for example, 2).
So far the means to determine the unsteady flow field are very limited, but recently a powerful technique for the measurement of the flow field called the PIV (Particle Image Velocimetry) has been developed. It was found that the method is powerful for analyzing the unsteady flow field around a swimmer (3). This PIV system was adapted to the measurement of the flow field occurred by the pitching motion of a monofin.

METHODS
A monofin model of a half-scale (see Fig.1) was attached to the device that can carry out a pitching motion. The fin was handmade of carbon-fiber sheets by laminating them four times at thickest. The use of the driving device of a fin instead of wearing it on swimmers is better from a practical view of the controllability and reproducibility of the experiment. The device has the ability of varying the pitching angle of the fin between –20 deg and +20 deg whose mean angle is 15 deg upward from horizontal. We used the flume whose test section is 4.6 m in length, 2 m in width, and 1.2 m in depth. Unsteady velocity fields were measured in several horizontal and vertical planes illuminated by the YAG laser of the PIV system. A CCD camera takes the images of tracer particles at two subsequent times. From the distance a particle moved for the time interval, the velocity is determined and vorticity is then calculated. Our PIV system can get 15 planes per second and 100 planes at once.

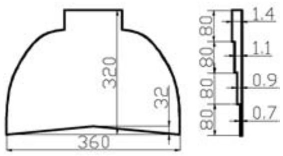


Figure 1. Model fin shape (half-size model).

In Fig.2 it is demonstrated how the effects in the horizontal plane is measured. Similar configuration was used for the measurement in the vertical plane. In this case, a laser sheet was irradiated from the bottom of the flume through the bottom window.

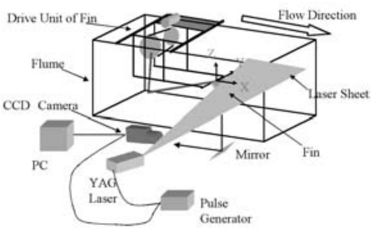


Figure 2. Experimental configuration (horizontal).

RESULTS AND DISCUSSION
Time-sequential variations of the velocity fields were obtained. First we show the unsteady field in the horizontal plane. Figure 3 shows the velocity and vorticity field in upward motion at flume speed u=0.5 m/s. To make the image of vortices more convenient to understand the mean velocity has already been subtracted from the velocity vectors. The gray scale denotes the magnitude of vorticity measured in 1/s. Bright and dark zones correspond to vortex rotating anticlockwise and clockwise, respectively. A black shadow zone extended from the top of the fin to downstream and a white one from the bottom of the fin are clearly discerned. These are the cross-sectional view of longitudinal vortices whose axes are parallel to the flume. The upper longitudinal vortex ends at a vortex rotating anticlockwise existing near (290, -100). The axis of the vortex seems to be vertical to the measuring plane. Similarly, the lower one has a vortex rotating clockwise at the right end the longitudinal vortex.
Next, we consider the flow fields in the vertical plane located at the center of the monofin. Fig. 4 shows the velocity and vorticity fields at three subsequent instants during downward motion of the fin at flume speed u=0.5 m/s. In the figure, the origin of the coordinates is not the same as that in Fig. 3 and the white region is the shadow of the fin where we cannot detect any tracer particles.
Fig. 4(a) shows the instant just after downward motion of the fin started. A thick black line denotes the fin. Near and above the edge of the fin there is a strong vortex rotating anticlockwise. This is separated at the beginning of the downward motion of the fin due to transversal action of the fin. A short time later (Fig. 4(b)), the vortex rolls up and leaves the trailing edge of the fin. The line connecting the trailing edge with the vortex brightens like a white ribbon. This layer means a gap of tangential velocity component above and below the sheet. It is elongated at the next step shown in Fig.4(c).

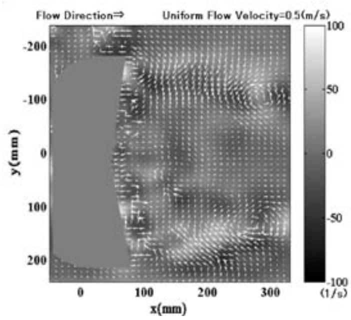
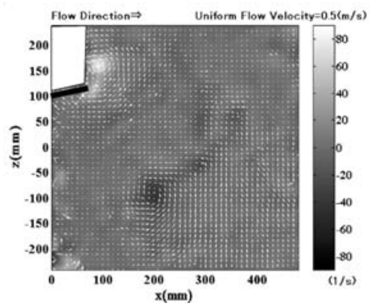
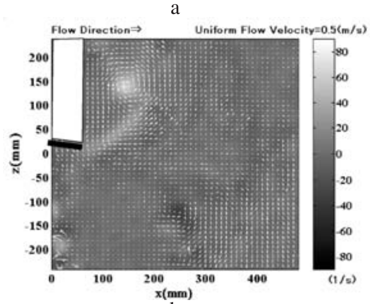


Fig. 3. Velocity and vorticity fields in upward motion of the fin (viewed from below, x-y plane). The mean velocity was subtracted in the velocity vectors.



a



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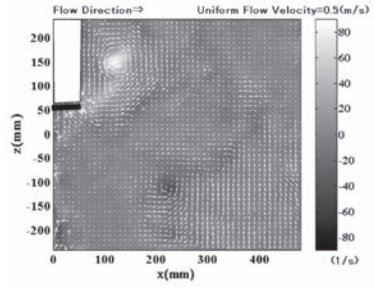

c

Fig. 4. Sequential variation velocity and vorticity fields in downward motion (viewed from side, x-z plane). The sampling period is 67 ms or 15 Hz. The mean velocity was subtracted in the velocity vectors.

Another distinguished characteristic of the flow field in the wake is the existence of a vortex rotating clockwise (dark shadowed area in the lower part of Fig. 4) whose axis is vertical to the plane. This vortex was released when upward motion of the fin started and carried downstream with the mean flow. A pair of counter-rotating vortices (represented by the white and dark areas in Fig. 4) produces additional flow directed towards the downstream of the flume. The pairs generated continuously construct a vortex street like a Karman vortex street. The vortices induce an additional velocity in the flume direction. From the knowledge on the velocity fields and vortex structure obtained in the vertical and horizontal planes, we can image the three-dimensional vortex structure generated by a monofin. It sees to be similar to the structure appearing in the wake of a still cylinder of finite length (4) except for the direction of rotation.

CONCLUSIONS

By this experimental study the flow field around a fin was visualized and vortices were detected shed from the fin after transversal actions. There are two types of vortices; one is similar to the Karman vortex and the other a pair of counter-rotating longitudinal vortices. The Karman-type vortices change their signs or the orientation of vortex alternatively and produce momentum in the downward direction. Such momentum generation by the vortex shedding is related to the propulsive force. The mechanism of force generation by a fin is therefore very similar to that done by natural lives like birds and fish moving by generating vortices. Studying on a monofin is also an easier and quicker way to clarify the detailed mechanism of generation of propulsive force in comparison with the direct way to animal locomotion.

ACKNOWLEDGEMENTS

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KINEMATICS PARAMETERS OF CRAWL STROKE SPRINTING THROUGH A TRAINING SEASON

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Swimming velocity (SV) is the product of stroke length (SL) by stroke rate (SR). The purpose of this study was to verify training influence on front crawl SR, SL, SV and stroke index (SI) in sprinting trials. Nine competitive swimmers (7 males and 2 females; age = 14.78 ± 1.48 years) participated. The protocol consisted on the evaluation of SR, SL, SV and SI in a 25 m maximal effort test, every ten weeks, before (M1), during (M2), and after (M3) five months of training. Measurements were obtained from manual counting of cycles and time from 10 to 25 m of the trials. Anthropometric data were collected. Intensity and distance during the training season were controlled. Kinematics data showed stability along the training season. There were improvements ($p < 0.05$) on anthropometric data throughout the training season. In this age group, anthropometric characteristics seem to be more important than kinematics adaptations due to training for sprinting.

Key Words: stroke rate, stroke length, swimming velocity, training effects.

INTRODUCTION

Swimming is a modality highly dependent from the athlete's technical level (2). So it's necessary that the coaches and assistants, in competitive swimming, can use easily applicable assessment methods, to verify the training effects above kinematics characteristics related to the specific stroke technique.
Swimming mechanical efficiency evaluation can be made through the kinematics parameters stroke rate (SR), stroke length (SL), swimming velocity (SV) and stroke index (SI) (4,5). It is suggested that swimming performance is the interaction result among physiological systems and biomechanical stroke characteristics (8); this can be understood by increasing propulsive forces and decreasing drag forces. These factors combined lead the swimmer to a better performance: to finish a competitive event in a shorter time (1).
SV can be obtained by the product of SL and SR (4,5) or by the quotient of distance and time (12). In this way, SV is modified by the combinations between SR and SL (7). An optimal relation there should be between the stroke's number and the time to perform them, to get, chronically, increased SV values (2). This adjust is due to the negative relation between SR and SL, when there is an increase in SL, time to perform propulsive phase is either increased, so SR tends to decrease, for the same distance (3,5). SI is the product of SL and SV. Has an incremental behavior due to age, and can be a practical

index for instructors and coaches to assess technique of beginner swimmers (5).
Disposal energy for the swimmer muscle contraction is from, basically, two sources: aerobic and anaerobic, although a small ATP-CP reserve is either utilized (9). To enhance swimming performance, adequate energy supply must be obtained by the training program (10). So kinematics parameters can be altered due to better technique and or better energy supply. The purposes of this study were to verify swimming training, with high percentage of aerobic training, influence on front crawl SR, SL, SV and SI in sprinting trials, among age group swimmers.

METHODS
Nine swimmers (7 males and 2 females; mean age = 14.78 ± 1.48 years) participated in this study. The protocol consisted on the evaluation of SR, SL, SV and SI in a 25 m maximal effort test, every ten weeks, before (M1), during (M2), and after (M3) five months of training. Measurements were obtained from manual counting of cycles and time from 10 to 25 m of the trials. Anthropometric data (height, mass and upper limb span) were measured. Intensity and distance swan during the training season were controlled. Training exercises were classified in technique, aerobic (6), anaerobic (9) and velocity (11). There were four to six training sessions each week. Table 1 shows the absolute and normalized distances (% of all distance swan in the specific period) performed through the 20 weeks training season, in each period (M2 and M3; M1 is related to the pre-season period), for each training exercise.

Table 1. Distance swan (km and %) for training areas in each period of the season.

Training area	M2	M3
Technique, km (%)	23.1 (7.77)	28.7 (9.34)
Aerobic, km (%)	266.9 (89.80)	260.9 (84.97)
Anaerobic, km (%)	2.5 (0.85)	8.4 (2.75)
Velocity, km (%)	4.7 (1.58)	9.0 (2.94)

To verify differences among the variables in each moments to the data were applied ANOVA repeated measures and, when necessary, Bonferroni post-hoc tests. To verify stability, Intra-Class Correlation Coefficients (ICC) were used, adopting a 0.05 significant level. Statistical Package SPSS 12.0 was used.

RESULTS
Mean and standard deviation (s.d.) of anthropometrics and kinematics results for the three evaluation moments are in Table 2.

Table 2. Mean ± s.d. of height, upper limb span, total body mass, SR, SL, SV and SI; M1 = before training season; M2 = during training season; M3 = after training season. Letters indicate significant differences.

Variables	*n*	M1	M2	M3
Height (cm)	9	168.8 ± 0.13 [a]	169.3 ± 0.13	170.0 ± 0.12 [a]
Upper limb span (cm)	9	172.1 ± 0.13 [a,b]	173.3 ± 0.13 [a,c]	174.3 ± 0.13 [b,c]
Total body mass (Kg)	9	56.2 ± 14.2 [a]	57.2 ± 13.3	58.5 ± 13.3 [a]
SR (Hz)	9	0.85 ± 0.08	0.91 ± 0.09	0.89 ± 0.08
SL (m)	9	1.79 ± 0.17	1.72 ± 0.18	1.78 ± 0.11
SV ($m \cdot s^{-1}$)	9	1.52 ± 0.135 [a, b]	1.57 ± 0.14 [a]	1.59 ± 0.15 [b]
SI ($m^2 \cdot s^{-1}$)	9	2.73 ± 0.45	2.73 ± 0.46	2.83 ± 0.36

There were improvements ($p < 0.05$) just on anthropometric data hroughout the training season. No differences were found in SR, SL and SI data among the moments. But SV has increased significantly from M1 to M2 and from M1 to M3. Figures 1 and 2 show, respectively, individual SR and SL values' comportment along the training season.

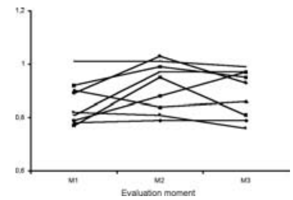

Figure 1. Individual stroke rate values for the three moments.

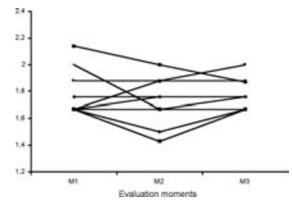

Figure 2. Individual stroke length values for the three moments.

Stroke length and stroke rate showed stability along the training season: SR: (ICC= 0.808; Ic 95%]0.40; 0.953[; $p = 0.002$); SL: (ICC = 0.815; Ic 95%]0.421; 0.955[; $p = 0.002$); Figures 3 and 4 show, respectively, individual SV and SI values' comportment along the training season.

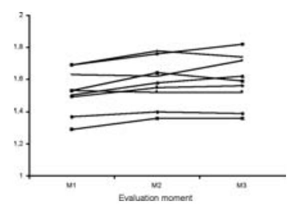

Figure 3. Individual swimming velocity values for the three moments.

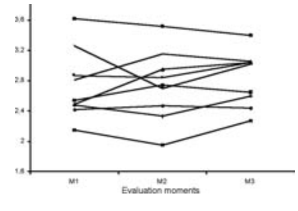

Figure 4. Individual stroke index values for the three moments.

Swimming velocity and stroke index showed stability along the training season: SV: (ICC = 0.977; Ic 95%]0.927; 0.994[; $p < 0.001$); and SI: (0.939; Ic 95%]0.809; 0.989[; $p < 0.001$).

DISCUSSION

Aerobic exercise performed by the swimmers (between 84 and 89%) could be an explanation about the similar values found for the SR, SL and SI during the training season for the 25 m maximal effort. Perhaps, in longer distances, this behavior would be different. High stability values found for the kinematics show that most of the subjects kept in the same track, in response to the applied training.

There are two ways to increase swimming velocity: (a) acutely, when the swimmer normally increases SR and (b) chronically, when, due to training, swimmer increases SL (12). It can be observed, in this study, that verified increases in SV was due to no-significant increases in SR, so, training, per se, was not able to increase SL. When an athlete maintains a high SR to keep high SV, dispends high energy values, which is related to fall in performance (1), when the energetic systems are not prepared to a high intensity work. During training, this could lead to a negative adaptation in the stroke technique, with a poor relation between SR and SL.

Technique exercises, during training, should reach two objectives: (a) to keep the stroke in a better technique level and (b) enhance swimming economy. So, after a training season a reduction in SR values, concomitant to an increase in SL values, is expected (2, 12). It could be verified high stability in all kinematics parameters analyzed. So, the adopted training program just kept the ranking of the swimmers, with just few of changes in the tracks for the variables.

CONCLUSION

In this age group, swimming training, with high percentage of aerobic training, could not increase swimming velocity in front crawl stroke for sprinting trials by increases in stroke length. Stability found for kinematics variables for the subjects indicates that ranking was kept during the training season.

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UNSTEADY FLOW MEASUREMENT OF DOLPHIN KICKING WAKE IN SAGITTAL PLANE USING 2C-PIV

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This study presents a method to visualise and to analyse the wake of a swimmer's dolphin kick in a sagittal plane viewed from the side of a swimming flume using two-component PIV (2C-PIV). One trained male swimmer was instructed to maintain a swimming position with dolphin kicking. Results showed a pair of vortices and jet flow between them. The value of the jet flow velocity showed good agreement with the value of the induced velocity that was predicted by assuming that the pair of vortices represented sections of a vortex ring. It was plausible that the dolphin kicking motion performed in this study generated a propulsive force by generating the vortex ring. The vortex pair confirmed in the present study is likely of a part of this larger structure.

Key Words: PIV, dolphin kick, unsteady flow, vortex ring, jet-propulsion.

INTRODUCTION

In competitive swimming using four modern styles, the dolphin kicking motion, or butterfly kick, is used after the start and turn. The dolphin kicking motion, which resembles the propelling locomotion of the dolphins, produces a high propulsive force by the momentum induced due to the up and down motion of the feet. In addition, the underwater undulation swimming phase after the start and turn presented an advantage of less drag (2). Therefore, effective dolphin kicking is very important to improve swimming performance in competitive swimming (1, 2, 4). Ungerechts et al. (7) emphasises the reverse action of the kick, using a whip-like action as much as possible to propel the swimmer more effectively. Furthermore, Arellano et al. (2) visualised the flow with bubbles in dolphin kicking wake and reported that the efficient undulatory underwater swimmer created a large vortex at the end of the downward kick and a small vortex at the end of the upward kick to obtain a strong propulsive force.

Many studies have been undertaken to estimate the propulsive force of human swimming. Most were estimations of front crawl swimming, which were based on quasi-steady analyses (3). As Ungerechts et al. (8), and Toussaint et al. (6) reported, it was suggested that it was very important to consider the unsteady flow condition to argue propulsion in swimming. Therefore, it seems to be necessary to consider the unsteady flow around a human body in a real swimming situation to reveal the propulsion mechanism. Lately, a new analysis method, particle image velocimetry (PIV), has been established and improved in engineering society. It

allows us to visualise the unsteady flow field instantaneously and to estimate the fluid force. PIV has generally been used to analyse the flow field around an aerofoil in a wind tunnel or that around flying or swimming creatures (5). However, experiments using PIV to analyse the overall human swimming motion are still lacking.
As mentioned above, most past studies that have examined the propulsion mechanism of human swimming have investigated swimmers' hands or arms only, based on quasi-steady analysis. In addition, studies of the propulsion mechanism of kicking motion have used qualitative estimation based on unsteady flow theory, but no quantitative estimations have been reported. The aim of the present study was to visualise qualitatively and to analyse quantitatively the dolphin kicking wake of a swimmer in a sagittal plane viewed from the side using two-component PIV (2C-PIV).

METHODS
The Human Subjects Committee of the University of Tsukuba approved the present experimental design. One trained male swimmer participated in this study and was asked to give informed consent. The experiment was executed in a swimming flume (4.6 x 2.0 x 1.5 m; Igarashi Industrial Inc., Japan). The swimmer was instructed to remain in the same place relative to the oncoming flow with dolphin kicking. Trials were executed with the flume flow speed of 1.0 m/s (five trials). A schematic view of the experimental setup is shown in Fig. 1. Nylon tracer particles (50 μm) were admixed to the flume. A Nd-YAG laser (New Wave Research, Inc., USA) was placed below the flume and illuminated, intermittently and vertically, the flow area in a sagittal plane just behind the swimmer's feet (the wake). From the side window of the flume, 200 time-sequential pictures were captured (15 f/s) using a CCD camera (Kodak Megaplus ES1.0; Kodak Co., USA). The images were stored in a personal computer (Dell Dimension 4200; Dell Computer Corp., USA). The timing of the laser exposure and of the camera shutter were synchronised using a pulse generator (Quantum Composers Inc., USA). A lattice was set at the measurement plane and was filmed in advance to calibrate the image co-ordination system. The particles' displacement (Δx, Δy) was detected using cross-correlation analysis from the sequential two images. Displacement after a short interval Δt (= 1 ms) determined the particle velocity as

$$u = \frac{\Delta x}{\Delta t},\ v = \frac{\Delta y}{\Delta t},$$

where (u, v) respectively represent the velocity components of x-axis and y-axis. The particle velocity vectors and vorticity (ω) were plotted as a velocity-vorticity map using MATLAB software (MATLAB version 6.5.1, Release 13; The MathWorks, Inc., USA). Vorticity (ω) indicates the magnitude of vortices and direction of rotation (see 5).

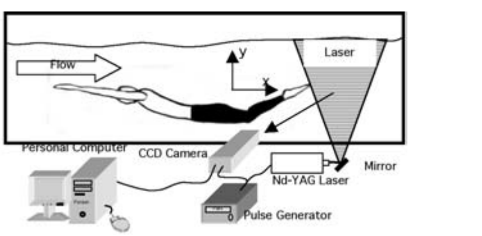

Figure 1. A schematic view of a 2C-PIV setup with the swimming flume viewed from the side window and the coordination system. The flow direction was from left to right. Nd-YAG laser illuminated the wake of a swimmer vertically in a measurement sagittal plane. Timing of the laser exposure and the CCD camera shutter were synchronized by a pulse generator (15 f/s).

RESULTS AND DISCUSSION
The results confirm the existence of a pair of vortices and jet flow in the wake of dolphin kicking motion. Examples of the particle image and velocity-vorticity map of downward dolphin kicking wake are shown respectively in Fig. 2(A) and Fig. 2(B). The left panel (A) shows the toe direction at $t = 0$; the white rectangle frame corresponds to the Fig. 2(B). Figure (B) shows the velocity field 134 ms after downward kicking relative to Fig. 2(A); the curved arrows indicate the direction of the vortices' rotation. The long white arrow in Fig. 2(B) indicates the jet flow. The grey scale is used as an index of magnitude of vortices rotation (ω). The flume-flow direction was from left to right. The mean x-component of velocity has already been subtracted in the velocity vectors plot (B) to clarify the map. Jet flows which are directed to the flume flow direction (positively along the x-axis) are contributing to thrust.

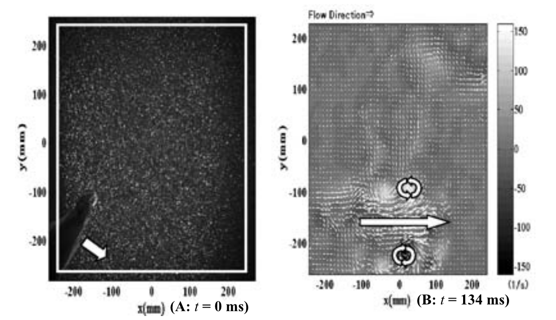

Figure 2. An exemplary image of downward dolphin kicking motion (tiptoe image, A: t = 0*) and the velocity-vorticity map (B:* t = 134 *ms). The white rectangle in the left panel corresponds to the right panel. The grey scale indicated in the right column denotes the magnitude of vortices.*

Colwin (4) explained butterfly leg (dolphin kick) propulsion by visualising the natural bubble in the wake of the swimmer. He called a mechanism of efficient leg propulsion the fling-ring mechanism. As the feet move downwards forcefully, a bound vortex formed around each foot. These vortices combine to form one large vortex ring that is shed in the vertical plane. Along this concept, we assumed that the vortex pair was the sectional part of a vortex ring; we also compared the value of the jet flow velocity (V_J) to that of the induced velocity of the vortex ring (V_O) when the pair of vortices was observed in the velocity field.
Comparison of the values of jet flow velocity and the induced velocity were confirmed for the pair of vortices in the flow field. The values of jet flow velocity agree well with the values of induced velocity of the vortex ring, as predicted by the assumption that the pair of vortices represents sectional parts of the vortex ring (table 1). It was plausible that the subject in this study generated a vortex ring with the dolphin kicking motion for propulsion in pool swimming or for remaining stationary in the flume swimming.

*Table 1. Examples of the values of jet flow velocity (V***J***) and the induced velocity of the vortex ring (V***0***) when the pair of vortices was confirmed in the velocity field. The distance between the vortices (***D***) is also listed. Not all data are shown.*

Trial No. (Plane No.)	Flume speed (m/s)	***D*** (m)	V_J (m/s)	V_0 (m/s)
Trial 2 (25)	1.0	0.12	1.3	1.3
Trial 5 (20)	1.0	0.12	2.0	1.8

After the upward kicking motion, some pairs of small vortices and the jet flow were also confirmed (Fig. 3). However, the appearances of the pairs of vortices and the jet flow directed to the *x*-axis were observed mainly after downward kicking. Most of the jet flow observed after the upward kicking directed slightly upward along the *y*-axis.

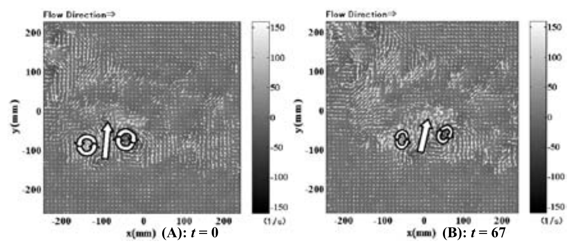

Figure 3. Examples of time sequential velocity fields after the upward dolphin kicking motion in a given moment. The jet flows in between the pairs of vortices directed slightly upward along the y-axis.

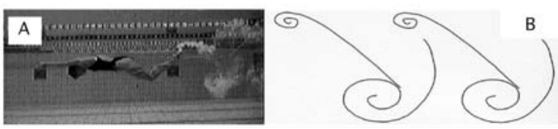

Figure 4. An exemplary image of the vortices generated during underwater undulatory swimming with the injecting bubble visualisation technique (A) and a sketch of the generated vortices of the wake (B) (alteration from Arellano, 1999).

The subject apparently propelled by downward kicking and kept the consequent position by upward kicking.
According to the reports of Arellano (1), the undulatory underwater swimmer generated the large vortex after the downward kick and the small vortex after the upward kick (Fig. 4). However, their visualisation technique and the point of view to the flow fields were completely different from ours. Their method was to see qualitatively the larger flow field and the larger vortex structure behind the dolphin kicking motion. On the other hand, our method is to visualise the instantaneous flow fields and to analyse quantitatively the smaller flow fields. From the difference of the visualisation method between Arellano's and ours, the vortex pair confirmed in the present study might be likely of a part of the larger vortex structure reported by Arellano (1). As mentioned above, our visualisation technique is limited to a smaller flow field. Therefore, further research to clarify the mechanism of efficient dolphin kicking propulsion is necessary.

CONCLUSIONS
We applied the 2C-PIV to the unsteady flow field of the dolphin kicking motion. We can visualise the flow field of the dolphin kicking wake. The subject created the vortex ring for propulsion. Although there might be larger vortex structures in the dolphin kicking wake for propulsion, our measurements were executed only in a sagittal and vertical plane. In addition, our measurements were restricted to two-dimensional flow analysis. Therefore, further research is necessary for understanding the generation mechanisms of propulsive force.

ACKNOWLEDGMENTS
The authors would like to thank Dr. Bodo Ungerechts of University of Bielefeld, Germany, for the valuable information and suggestions used for this study. This work was supported by a Grant-in-Aid for Scientific Research ((B) (2)16300202)) and a partly ((B) (2)15300216)) of the Japan Society for the Promotion of Science, Japan.

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"SWUM" AND "SWUMSUIT" – A MODELING TECHNIQUE OF A SELF-PROPELLED SWIMMER

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The author proposes a simulation model "SWUM" (SWimming hUman Model) and a simulation software "Swumsuit" (SWimming hUman Model with Synthetic User Interface Tools) as its implementation. This modeling technique is developed to analyze various problems in the mechanics of a self-propelled swimmer. The overview of SWUM and Swumsuit are firstly described. Next, the validity of the model is examined by comparing the simulation results of swimming speed with the actual values for the four strokes. A sufficient agreement between the actual and simulation was obtained, indicating the validity of SWUM.

Key Words: simulation, self-propelled swimmer, modeling, fluid force, free software.

INTRODUCTION

Many studies have been carried out to date with respect to the mechanics of swimming. However, there is no analysis tool which can take into account of all fluid forces unsteadily acting on each part of the swimmer's body and which can analyze mechanics of dynamic swimming motion. Therefore, the objective of this study is to provide a simulation model, which can compute all the fluid force and inertial force acting on all parts of the swimmer's body, and can be an analysis tool used widely by swimming researchers all over the world for various problems of mechanics in swimming.

For this objective, the authors have already developed such a simulation program and proposed its idea as a conceptual simulation model "SWUM" (SWimming hUman Model) (1). In this previous study, it has been clarified that the simulation model has sufficient capability to discuss quantitatively the mechanics of swimming, since the swimming speed of the simulation agrees well with the actual one in a simulation example of standard six beat crawl stroke. The developed simulation program, however, was written in Fortran of thousands lines and there were no interface part. Therefore, as the next step, the interface part of the simulation program was developed and integrated with Fortran main program as a simulation software (2). This software, named "Swumsuit" (SWimming hUman Model with Synthetic Use Interface Tools) is a free software, and available at the web site (3). In this paper, the overview of this modeling technique by the authors is firstly described. Next, the validity of the model is examined by comparing the simulation results of swimming speed with the actual value for the four strokes.

METHODS

Overview of Simulation Model "SWUM"

In SWUM, the relative motion of the swimmer's body is given as joint motions, and the absolute motion for the whole swimmer's body in six degrees-of-freedom is solved, based on the six equations of motion for a rigid body, whose formulation is similar to that in Robotics (1). Figure 1(a) shows the analytical model of a self-propelled swimmer in SWUM. The swimmer's body is modeled as a series of rigid segments. The segments are represented as truncated elliptic cones, whose actual number is 21 in the analysis. The geometry and density of all the body segments are determined based on the actual data. Figure 1(b) shows the example of the modeled body for averaged Japanese 20-29 years old male.

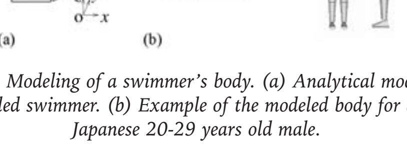

Figure 1. Modeling of a swimmer's body. (a) Analytical model of a self-propelled swimmer. (b) Example of the modeled body for averaged Japanese 20-29 years old male.

As the external force acting on the swimmer's body, unsteady fluid force including the buoyancy and the gravity force are taken into account. The unsteady fluid force is assumed to be obtained from local motion of each body part without solving the flow field. Figure 2(a) shows the schematic figures of the fluid force modeling. The drag force tangential to the longitudinal axis of the cone $\boldsymbol{F_t}$ which basically corresponds to the so-called 'passive drag', the drag force normal to the axis $\boldsymbol{F_n}$ which basically corresponds to the drag and lift force generated by limb motion, and the inertial force due to the 'added mass' effect of the fluid $\boldsymbol{F_a}$ are respectively computed with respect to each thin elliptic plate divided from the truncated elliptic cone. The force $\boldsymbol{F_t}$ and $\boldsymbol{F_n}$ are assumed to be proportional to the local velocity at the thin plate's center in the tangential and normal directions, respectively. The force $\boldsymbol{F_a}$ is assumed to be proportional to the local acceleration in the normal directions. These fluid force components are computed using their coefficients. The authors identified the coefficients by an experiment, in which the relationship between the motion and the fluid force acting on an oscillating artificial limb model in water was measured (1).

For the buoyancy, on the other hand, the side surface of the thin plate is again divided into tiny quadrangles in the circumference direction, as shown in Figure 2(b). The static pressure force $\boldsymbol{F_b}$ is computed for each quadrangle, and its summation becomes the buoyancy acting on the thin plate. Note that the force $\boldsymbol{F_b}$ is only computed for the quadrangles below the water surface, as shown in Figure 2(c).

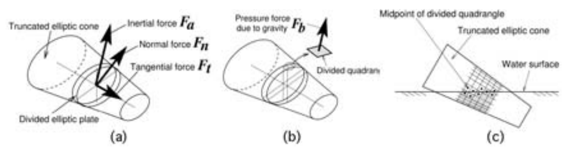

Figure 2. Modeling of fluid force. (a) Fluid force components acting on a thin elliptic plate's center. (b) The static pressure, which is the source of the buoyancy, is computed with respect to the tiny quadrangles. (c) The static pressure acts only on the quadrangles below the water surface.

Summing up all the fluid force components and resultant moment acting on the thin plate with respect to the cone's longitudinal direction, total force acting on each cone is obtained. By summing up again the force acting on all the cones, total force acting on the swimmer's body is obtained. These formulations are solved by time integration using the Runge-Kutta method. As the outputs of the computation, the swimming speed, rolling, pitching and yawing motions, fluid force acting on each part of the body, joint torques and so on are obtained.

Simulation Software "Swumsuit"

The simulation software Swumsuit consists of main program as the analysis engine part and GUI (graphical user interface) part. Figure 3 shows the structure of Swumsuit. The analysis engine part which implements SWUM reads three input files, that is, data files of body geometry, joint motion, and analysis settings. The parameters in these three files can be changed through three GUI editor parts. With respect to the output, a motion data file is produced to display animation of swimming motion. And many other data files are output, such as, swimming speed, time history of absolute position, consumed power, thrust, roll moment, joint torques at all joints, and so on. These data files are displayed by the graph display part.

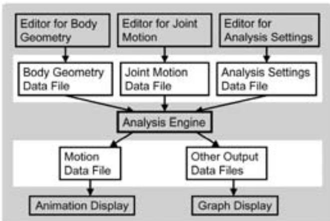

Figure 3. Structure of Swumsuit, which has analysis engine, three editors for input files, animation and graph display parts. Each part has graphical user interface.

RESULTS AND DISCUSSION

Figure 4 shows the screenshots of the Swumsuit. Figure 4(a) is the start window, from which all the function can be invoked. Figure 4(b) is the editing body geometry window. Figure 4(c) is the editing joint motion window, on which the user can edit the joint motion, viewing the graph of the joint angles and the animation of relative motion. Figure 4(d) shows the outputs displayed as graphs and animation. In the animation, the direction and magnitude of the fluid force acting on the each part of the body is displayed by dark (red) sticks as shown in Figure 4(d). The animation can be exported to a MPEG movie file. From movies of model swimming by an athlete swimmer, joint motions for the four strokes, that is, crawl, breast, back, and butterfly strokes, were created. In the simulation, after several cycles of unsteady motion, swimming motions at the 'clean speed' were obtained for all strokes. Figure 5 shows the results. Figure 5(a)~(d) are the screenshots of animation, which are available at the web site (3). Figure 5(e) shows the comparison of normalized stroke length during the steady swimming between simulation and actual value for the four modern strokes. The sufficient agreement between the actual and simulation indicates the validity of SWUM, although the simulation value of the breaststroke is somewhat smaller. The reason of the discrepancy of the breaststroke is thought to be the modeling error of the fluid force during leg kick.

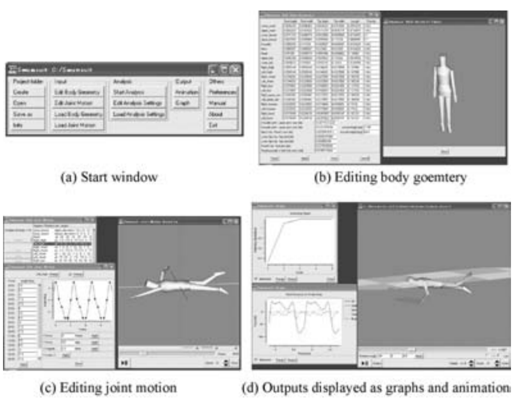

Figure 4. Screenshots of the developed software "Swumsuit".

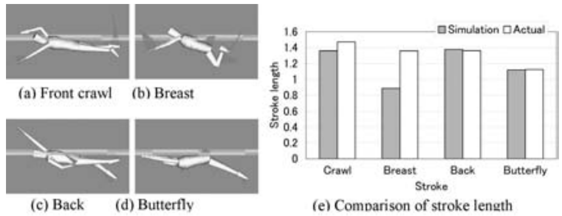

Figure 5. Simulation results of four modern strokes. (a)~(d) animations. (e) Comparison of nondimensional stroke length.

Further detailed investigation for the fluid force acting on the limb will be necessary. Figure 6(a) shows the simulation results of velocity fluctuation of the front crawl during one cycle. Note that the velocity becomes negative value according to the direction of the coordinate. Figure 6(b) is the thrust produced by the left hand. The negative value means positive thrust by definition. It can be seen that the thrust becomes maximal at 8.7s~8.8s, and that its main component is the normal drag. Other full data for the four strokes are available at the website (3). By these output directly outputted by Swumsuit, the phenomenon and mechanics in swimming could be understood.

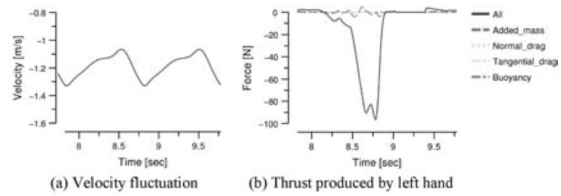

Figure 6. Velocity fluctuation and thrust produced by left hand during one cycle.

CONCLUSION

The author's modeling technique of a self-propelled swimmer, SWUM and Swumsuit, is introduced. This modeling technique can be a powerful analysis tool and can be applied to various fields of training and coaching, for example, understanding the mechanics of swimming, analysis of race and daily training together with a motion capture system, and discover the better swimming form to improve stroking individually.

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PATTERN MATCHING APPLICATION FOR THE SWIMMING STROKE RECOGNITION

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In the field of sports biomechanics, we have been quantifying the similarity between subjects using their kinematics. Many studies applied the normalisation in this procedure. On the other hand, in the field of speech recognition, in order to distinguish a phoneme by different speakers or voices, the dynamic time warping (DTW) method have been applied. In this study, it was quantified the similarity of the swimmers' stroke motion, which depends on their skill level and swimming speed using dynamic time warping.

Key Words: swimming, stroke, dynamic time warping, pattern recognition.

INTRODUCTION

The author has been analysing swimming stroke skill using inertia sensors, such as accelerometer and gyroscope, which were attached on the swimmer's wrist (1, 2). For the improvement of stroke skill in swimming, coaches, swimmers and researchers are eagerly desiring to compare and evaluate different arbitrary strokes. It means that different swimmers' strokes or identical individual swimmer's strokes on different situations. For example, comparing kinematics between top swimmer's and novice's strokes. In case of stroke drill practice, coaches want to know whether or not a swimmer can change his stroke technique as they instructed. However, in order to compare and discriminate two different strokes, durations and kinematics, such as coordinates of stroke paths, velocities and accelerations, depend on subjects and also each lap and each stroke. Granted that it can be obtained three dimensional underwater stroke images, and stroke path can be calculated with orientation of the swimmer's hand, it will be very difficult to determine where is the similar or different phase between their strokes and quantify how much each one differ from the other. In the field of biomechanics, we have been standardizing our single cycle of motion, such as walking, running and swimming, into 100% normalized time duration and then compared each other. But nobody argued the validity of this time normalization. On the other hand, in the field of speech recognition, they have a traditional method, named dynamic time warping (DTW) to recognize different utterances, whose duration vary and depend on the speaker or their voice. In this study, for the purpose of stroke pattern recognition, the author applied DTW using the inertia sensor data which was obtained from the body attached sensor in swimming.

METHODS

Subjects were five well-trained college swimmers. Tri-axial accelerometer and tri-axial gyroscope data logger, Prototype II, was attached on subject's left wrist. Figure 1 shows Prototype II data logger and its local coordinate system for the experiment. Sensor data were recorded at 128Hz sampling rate. In addition to the sensory measurement, three dimensional underwater videography was conducted to acquire swimmer's stroke pattern. All subjects swam 50m trials at slow, middle and fast speeds, in both the crawl stroke and breaststroke. Time series of acceleration and angular velocity in single stroke cycle was extracted from the acquired total data. As for the crawl stroke data, single stroke duration was determined by the impact acceleration at the entry instant. On the other hand, for the breaststroke extraction, the steep transition of the y-axis acceleration at the start of the recovery phase was used. In this study, the author will examine this extracted single stroke time series of both the acceleration and the angular velocity. Dynamic time warping is one of the popular speech recognition algorithm based on the dynamic programming (3, 4). It allows us to recognize utterances by different speakers or different speaking durations. For the stroke pattern recognition, the author applied the classic fixed end point DTW method to examine swimmer's stroke kinematics. In order to measure the distance between two arbitrary time series value, the Manhattan distance function was used.

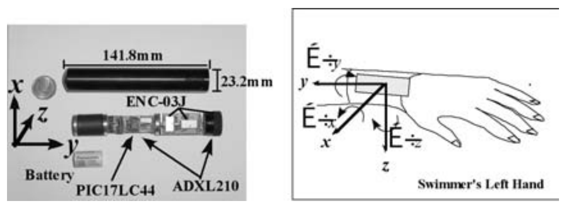

Figure 1. Tri-axial acceleration and tri-axial gyroscope data logger and its local coordinate system on the subject left wrist.

RESULTS AND DISCUSSION

Although, Prototype II data logger was capable to measure six channel data, which corresponding to the tri-axial acceleration and angular velocity of the swimmer's forearm motion, it might be complicated to apply all combined data into DTW algorithm. Thus, the author conducted DTW pattern matching using each selected time series between two different swimming trials. The longitudinal axial acceleration (A_y) and its rotational angular velocity (ω_y), were distinctive of stroke styles (2). Figure 2 shows a result of the pattern matching within subject (sub. B) using y-axial acceleration (A_y) on his different speed crawl stroke trials. The left figure shows two time series of A_y in his middle and fast speed trials, and corresponding value between both time series. The right figure shows the searching path of the DTW process in comparison with both time series.

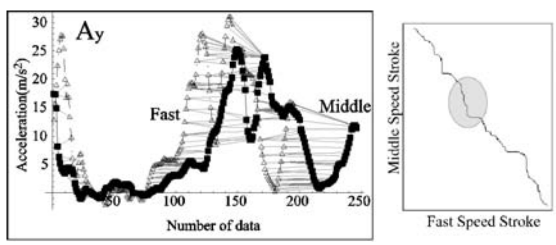

Figure 2. DTW stroke pattern matching within subject using swimmer's wrist y-axis acceleration (sub. B).

Figure 3 also shows a result of comparison using ωy within same subject, sub.B.

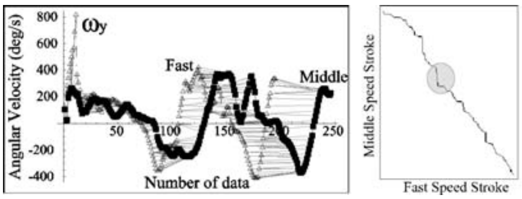

Figure 3. DTW stroke pattern matching within subject using swimmer's wrist y-axis angular velocity (sub. B).

Figure 4 shows a result between subjects by using ω_y. This comparison was examined between sub. B and sub. H on their fast speed crawl stroke trials. For those examples, the cumulative distances between those time series were 261.03 m/s²(fig. 2), 8140.62 deg/s (fig. 3) and 16882.3 deg/s (fig. 4), respectively. When both two time series have same magnitude and differ in only their duration, or differ in their magnitude with same duration, the searching path would be a diagonal line. If a horizontal or vertical line existed in the searching path, there would indicate that there is a different phase between two target time series. Since, the acceleration A_y corresponds to the longitudinal acceleration with the swimmer's forearm, the centrifugal acceleration by his rotational motion around both the shoulder and elbow joint is dominant in this axis (3). It can be seen an almost diagonal line on the result of the stroke pattern matching on A_y in Figure 2, except middle of his stroke. However, there is a vertical and then horizontal line in the middle of his stroke. And also, as for his angular velocity $\omega_{y,}$ which corresponding supination and pronation of the forearm, there is a vertical and horizontal line at the same time. It means that the stroke motion of the swimmer with respect to the y-axis can be quite similar irrespective of the swimming speed, except in the middle phase of stroke. In Figure 4, it can be seen one of the results of pattern matching between subjects. Between sub.B and sub.H, there are several different stroke phases in their y-axial angular velocity, which was equivalent to the forearm supination/pronation motion in their stroke. Thus, we can find out both similar and different stroke phases between two other strokes' inertia data using the dynamic time warping. For example, it becomes possible that we will be able to examine the similarity of the swimmers or whose stroke technique is closest to the swimmer. To be more precise, there is a possibility to distinguish swimmer's attempt to improve his stroke technique in skill training, and predict his fatigue or change of physical condition using sensor data. Since underwater videography is difficult to observe for us, DTW stroke pattern matching on the inertia sensor data will be a strong tool for the stroke monitoring, both in the competitive swimming research and coaching.

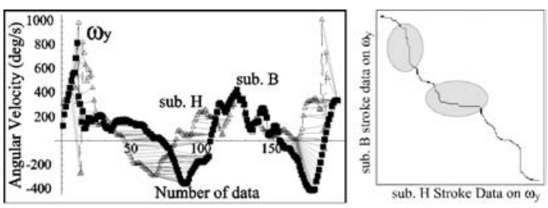

Figure 4. DTW stroke pattern matching between subjects using swimmer's wrist y-axis angular velocity (sub. B and sub.H).

Table 1 shows cumulative distances between subjects stroke comparison using y-axis acceleration, A_y. Because A_y is strongly influenced by the upper arm rotational movement, results tell us that the arm rotational acceleration pattern is similar between sub.A and subH, and also between sub.B and sub.K.

Table 1. Cumulative distances by DTW pattern matching for Ay during the crawl stroke.

	sub. A	sub. B	sub. H	sub. K	sub. T
sub. A					
sub. B	692.6				
sub. H	361.2	506.3			
sub. K	489.4	360.8	500.0		(m/s²)
sub. T	1002.3	1016.7	917.7	818.5	

CONCLUSION

The author propose the dynamic time warping method to the swimming stroke pattern recognition using swimmer's stroke inertia sensor data, such as tri-axial acceleration and angular velocity. Since, the cumulative distance of DTW process is equivalent to the difference between strokes, using DTW method, we can examine between subjects differences or within subject changes of their stroke skill or specified stroke phase.

ACKNOWLEDGEMENTS

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THE INFLUENCE OF REPEATED SPRINTING ON THE KINEMATICS OF BUTTERFLY SWIMMING

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The purpose of this study was to determine the effect of repeated sprint performance and fatigue on the kinematics of butterfly swimming. Six experienced national youth male butterfly swimmers undertook a maximal effort repeated sprint test set, during which swimmers were filmed with two underwater and two above water cameras (oblique plane) at 50Hz. The whole body was digitised during a full stroke cycle for each view, with the three-dimensional coordinates being obtained using a DLT algorithm. The results of this study indicate that as swimming speed decreased (i) stroke rate decreased while stroke length remained relatively constant, (ii) hand movement patterns remained similar while changes in elbow angle suggested that the effectiveness of joint flexors and extensors may have been reduced, (iii) the Upsweep, Recovery and Catch appear to the critical stroke phases when swimmers become fatigued.

Key Words: repeated sprinting, kinematics, butterfly swimming.

INTRODUCTION

The breakdown of optimal swimming technique has been suggested to be as a result of muscular fatigue during sprint swimming (4), with only a few studies investigating intra-cyclic stroke kinematic variations under exhaustive conditions. Front crawl swimmers spend more time in the propulsive phase of the stroke whilst fatigued (1), displaying a reduced ability to generate propulsive forces due to a decrease in hand velocity (2), an altered hand trajectory (3), and a reduced lever arm length (6). Throughout a 200 metre butterfly swim, decreases in swimming speed have been shown to correlate strongly with changes in three-dimensional hand velocity components (5), specifically during the final phases of the arm stroke. However, front crawl kinematics differ to those of the butterfly stroke and previous research (5) was limited to evaluating swimming speed and hand velocity during a single endurance swim. The purpose of this study was to establish the effect of repeated sprint performance and fatigue on spatial, temporal and kinematic parameters of butterfly swimmers.

METHODS

Six experienced national youth male butterfly swimmers (16.8 ±1.5 years; 1.75 ±0.07 metres, 72.7 ±4.6 kg; 100m P.B. time 58.7 + 2.5) participated in this study.
After a standardised warm-up, each subject performed a maximal effort repeated sprint test: 8 x 50 metres (long-course) at intervals of 1 min 30 sec from a dive start. Time for each repeat was recorded by an experienced timekeeper using a chronograph stopwatch (Model 898). Blood lactate concentrations were measured pre- and post-test from the earlobe using a Lactate Pro™ automated analyser.
On the first and seventh 50 metre repeats, a full stroke cycle was filmed within a previously calibrated volume (5m x 2.25m x 1m; above & underwater) using 36 control points, between 20 to 25 metres. Swimmers were filmed at 50 Hz with two above water (Sony TRV900E DV) and two underwater (M37CHR-IR linked to a Sony GV-D1000E DV recorder) cameras. The four camera views were synchronised using hand entry.
Symmetry between the left and right sides of the body was assumed and accordingly eight body landmarks defined a seven-segment model of the right arm, trunk and right leg. The estimated locations of these landmarks were manually digitised using SiliconCoach Digitiser software for each camera view. The above and underwater image coordinates were then reconstructed to three-dimensional space coordinates using a direct linear transformation algorithm, combined and then smoothed at a cut off frequency of 8Hz using a fourth order Butterworth filter (in MatLab).
The complete motion of the stroke was subdivided into six arm phases: Catch, Outsweep, Downsweep, Insweep, Upsweep, Recovery. The following parameters were used to describe the stroke kinematics: *Stroke length*: distance per stroke cycle; *Stroke rate:* number of stroke cycles per second; *Phase time*: time spent in each stroke phase; *Pull depth*: vertical displacement of the hand from entry to deepest point; *Pull width*: medial displacement of the hand from widest to narrowest point; *Pull length*: horizontal displacement of the hand from most forward to backward point; *Hand velocity*: mean of the finger and wrist velocities relative to the water; *Elbow angle*: angle between the forearm and upper arm viewed in the frontal plane; *Trunk angle*: angle between the trunk and the horizontal viewed in the sagittal plane.
Mean and standard deviations were calculated for all parameters. Significant differences (*p value = 0.05*) between conditions were determined using paired (dependent) *t-tests*.

RESULTS

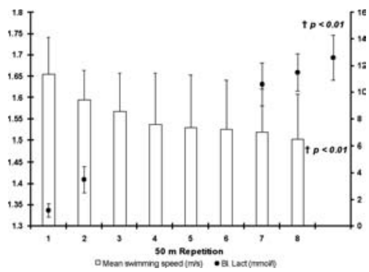

Figure 1. Mean swimming performance decreased by 9 ±5% ($p<0.01$) over the 8 x 50 metres, mean blood lactate concentration rose to 12.6 ±1.7 mmol.l-1 ($p<0.01$) post- test.

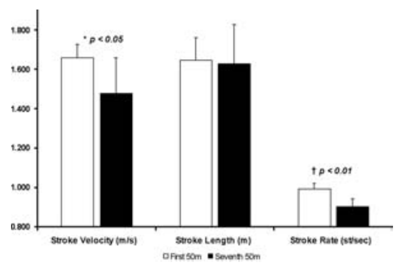

Figure 2. Mean stroke speed decreased by 8 ±6% ($p<0.05$) between repeats one and seven, with swimmers exhibiting slower stroke rates ($p<0.01$) but similar stroke lengths.

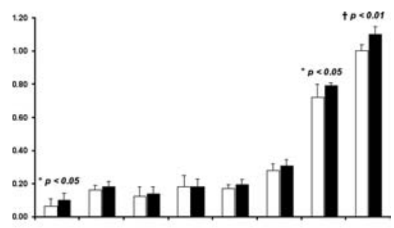

Figure 3. Total stroke time increased by 10 ±6% ($p<0.01$), as a result of a longer duration in all stroke phases (Recovery and Catch $p<0.05$).

Table 1. Differences in selected three-dimensional directional components of peak hand velocity (m·s-1) during five phases of the stroke.

	Outsweep (lateral m·s-1)	Downsweep (downward m·s-1)	Insweep (medial m·s-1)	(backward m·s-1)	Upsweep (lateral m·s-1)	(upward m·s-1)	Recovery (upward m·s-1)
First 50 m (M ± S.D.)	1.87 (± 0.42)	2.40 (± 0.50)	3.09 (± 0.51)	3.12 (± 0.47)	4.05 (± 1.05)	5.13 (± 1.48)	3.44 (± 0.66)
Seventh 50 m (M ± S.D.)	1.55 (± 0.43)	2.37 (± 0.54)	2.75 (± 0.46)	2.74 (± 0.42)	3.11 (± 1.03)	4.26(± 1.08)	3.02 (± 0.86)
P value (*p=0.05*)	0.07	0.84	0.25	0.18	0.09	0.13	0.12

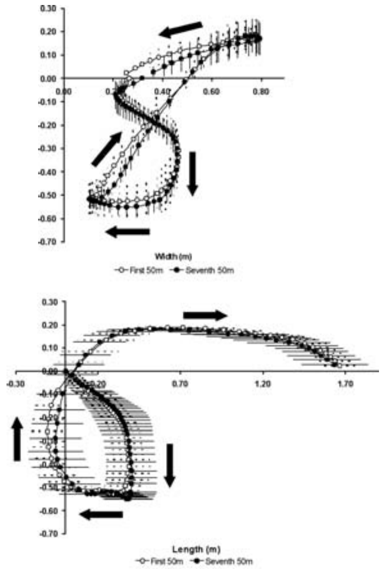

Figure 4a (frontal view) & 4b (sagittal view). Swimmers exhibited slightly deeper (4 ±7%), narrower (7 ±12%) and shorter (3 ±8%) propulsive hand path trajectories.

Table 2. Differences in elbow angle (deg o) during five arm phases of the stroke.

Outsweep	Downsweep (max °)	Insweep (mean °)	Upsweep (min °)	(max °)	Recovery (max °)
First 50 m (M ± S.D.)	163 (± 16)	116 (± 23)	91 (± 18)	134 (± 21)	178 (± 1)
Seventh 50 m (M ± S.D.)	166 (± 9)	113 (± 18)	94 (± 12)	144 (± 14)	175 (± 2)
P value (*p=0.05*)	0.56	0.55	0.70	0.51	0.04

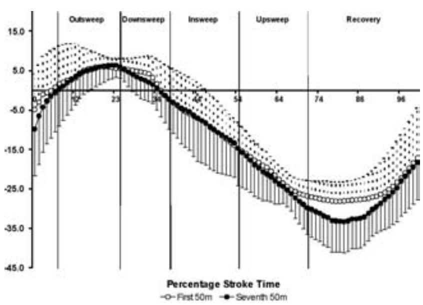

Figure 5: Maximum trunk undulation increased by 13 ±15% during the Recovery phase.

DISCUSSION

Decrease in mean swimming performance and rises in blood lactate concentration (fig. 1) were comparable to previous findings reported in the literature (1, 3), suggesting that swimmers were experiencing muscular fatigue by the seventh 50 metre repeat.

As swimming speed decreased, stroke rate decreased, while stroke length remained relatively constant (fig. 2), contrasting with front crawl swimming, where stroke length rather than stroke rate is influenced by repeated sprinting (1). The reduction in stroke rate was due to swimmers spending more time in all phases of the stroke (fig. 3), in particular the non-propulsive Catch and Recovery phases. This would imply that the decrease in swimming speed may have been influenced by increased duration between the propulsive phases.

Peak hand velocities during all propulsive phases decreased (table 1): Outsweep: lateral by 17 ±18%; Insweep: medial by 11 ±19%; with the greatest changes observed during the Upsweep: backward, upward and lateral by 12 ±17%, 17 ±18% and 23 ±26% respectively. Similar changes have been previously shown during the course of a 200 metre butterfly swim (5), and suggest that the swimmers' ability to generate propulsive forces was compromised, especially during the final propulsive Upsweep phase of the arm stroke.

Swimmers exhibited similar hand movement patterns between the first and seventh repeats (fig. 4 a & b), with 4 ±10% less elbow flexion during the Insweep and 7 ±18% less elbow extension during the Upsweep (table 2). Such changes may indicate that while the hand path trajectory remained relatively consistent, the effectiveness of the elbow flexors and extensors may have been reduced by the seventh 50 metre repeat.

Trunk angle remained relatively unchanged throughout the stroke phases, with the exception of the Recovery phase (fig. 5). This increased vertical inclination would imply that the swimmers were experiencing a greater amount of form drag as a result of reduced streamlining. Such an increase in resistive forces during this stroke phase, following the reduced ability to generative propulsive forces during the preceding phase, would combine to limit the swimmers' forward progression through the water.

No differences in arm and leg phase coordination were observed, and although peak vertical foot velocities during all leg phases decreased, these were not found to be significant.

CONCLUSION

The results of this study indicate that as an effect of repeated sprinting and fatigue: (i) swimming speed and stroke rate decreased while stroke length remained relatively constant; (ii) all stroke phases were longer in duration, in particular the Catch and Recovery; (iii) greatest decreases in hand velocity were observed during the Upsweep; (iv) hand movement patterns remained similar while changes in elbow angle suggested that the effectiveness of joint flexors and extensors may have been reduced; (v) the largest increase in trunk angle occurred during the Recovery.

The Upsweep, Recovery and Catch appear to the critical stroke phases (greatest changes were observed) as swimmers become fatigued. Encouraging swimmers to accelerate the hands outwards during the Upsweep while maintaining a more horizontal trunk and a lower and faster hand recovery, may help to resist changes in stroke mechanics brought about by the onset of fatigue.

ACKNOWLEDGEMENTS
Thanks is expressed to the swimmers of City of Sheffield and Nova Centurion squads for their participation in this study, Matt Pain for his assistance during data collection and British Swimming's Sport Science Research Group for their logistical support.

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INTRA-CYCLIC SPEED FLUCTUATIONS OF UNI-LATERAL ARM AMPUTEE FRONT CRAWL SWIMMERS

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Front crawl swimmers with an arm amputation at elbow level are deprived of an important propelling surface. The purpose of this study was to determine the extent to which uni-lateral arm amputee front crawl swimmers are able to generate swimming speed with their sound and with their affected limbs. Eight trained swimmers (2 male, 6 female) performed front crawl trials (without a leg-kick) at middle distance pace, while attached to a velocity meter (100 Hz). Trials were simultaneously videotaped underwater. Mean intra-cyclic speed fluctuation was 35 ± 5% of the mean swimming speed. Peak swimming speed achieved during the push phase of the sound limb (1.30 ± 0.17 $m.s^{-1}$) was significantly higher than that found during the push phase of the affected limb (1.14 ± 0.11 $m.s^{-1}$). This indicates that the swimmers were able to use their affected limb to increase their swimming speed, but not as effectively as with their sound limb.

Key Words: arm amputees, front crawl, speed fluctuation.

INTRODUCTION
Front crawl is the fastest of the four competitive swimming strokes and the arm action is generally thought to supply more than 85% of the total propulsion (4). Previous studies that have attempted to quantify the propulsive forces generated by the front crawl arm action have assumed that either the hand alone, or the combination of the hand plus forearm, is the major 'propelling surface' responsible for propulsion. No study has considered whether the upper arm segment contributes to propulsion in the front crawl. This is perhaps not surprising given that, whilst the arm is in its propulsive phase, the most proximal end, the shoulder, moves forwards relative to the water and encounters drag forces that resist its forward motion (2).
Competitive swimmers with an amputation at elbow level are clearly at a disadvantage when compared to able-bodied swimmers, as they are deprived of an important propelling surface. Although the majority of these swimmers do perform an arm pull with their affected limb when swimming front crawl, the effectiveness of this pull, compared to that of the sound limb, has not been established.
Although it has been stated (3) that the most efficient type of propulsion is where speed fluctuations are zero, all four competitive strokes are characterised by significant speed fluctuations within each stroke cycle. In able-bodied front crawl swimming, intra-cyclic speed fluctuation may be as much as ± 20% due to the intermittent application of force within a stroke cycle (1). It would seem reasonable to speculate that the intra-cyclic speed fluctuation of uni-lateral arm amputee front crawl swimmers might be even higher than in able-bodied swimmers, due to a reduced force application during the pull of the affected limb. The purpose of this study was to determine the extent to which competitive uni-lateral arm amputee front crawl swimmers are able to generate swimming speed with their sound and with their affected limbs.

METHODS
Participants
Two male and six female, highly trained competitive swimmers (age 17.6 ± 3 years; stature: 1.69 ± 0.09 m; body mass 60.6 ± 13.3 kg) consented to participate in this study. All participants were single arm amputees, at the level of the elbow, and competed in the International Paralympic Committee S9 classification for front crawl. Best 100 m front crawl times ranged from 64.0-65.9 s for the males and from 69.1-99.3 s for the females.

Underwater filming procedure
Participants performed a series of 25 m front crawl trials at their middle distance pace with a small buoy placed between the legs in order to isolate the arm action. To control for the effects of the breathing action on the swimming stroke, participants were requested not to take a breath through a 10 m test section of the pool. Trials were filmed below water from the side view with a digital camcorder (Panasonic NVDS33) sampling at 50 Hz with a shutter speed of 1/250 s. The camcorder was enclosed in a waterproof steel housing that was suspended from a trolley on the pool deck. This set-up enabled the participants to be recorded over the full length of the pool.

Swimming Velocity Meter
The intra-cyclic speed fluctuations of each participant were measured using a custom-built velocity meter, which was secured at the end of the pool. Participants were linked to the velocity meter by a lightweight, inelastic line that attached to a belt around their waists. As the participants swam, the line was pulled from the velocity meter, turning a low inertia wheel

linked to a rotary optical encoder. The encoder produced 500 pulses per revolution and was connected to a frequency-to-voltage converter. The output from the converter was sampled at 100 Hz and then recorded on a laptop PC via a 12-bit A-D converter. To synchronise the output from the velocity meter with the underwater video recordings, a light-emitting diode (LED) was manually triggered in view of the camera during each swimming trial. The trigger simultaneously superimposed a short duration pulse on the velocity meter output.

Data Processing & Analysis
Velocity meter data were smoothed using quintic splines. Three consecutive, non-breathing stroke cycles, for each participant, were then selected for analysis. A stroke cycle was defined from the entry of the hand of the unaffected arm to the next entry of that hand. Digital video footage was transferred to a laptop computer and analysed using SIMI Motion 6.0 software. The time of occurrence of key moments in the stroke cycle (e.g. hand entry) were recorded relative to the time of the LED flash. Thus, it was possible to determine the time of occurrence of these key moments on the velocity meter curves. The gleno-humeral joint centre and the most distal point of the affected limb were digitised (50 Hz) to obtain the angular position of the limb, as a function of time. The angle-time data were smoothed with a 6th order polynomial.

Definition of Variables

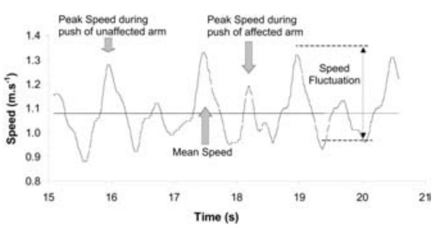

Figure 1. Intra-cyclic speed-time curve for three consecutive stroke cycles of an arm amputee front crawl swimmer.

The following variables were obtained from the velocity meter data or video recordings (mean of three stroke cycles):
— *Mean speed* / $m.s^{-1}$ – mean forward speed of the participant over three stroke cycles.
— *Stroke length* (SL) / m – distance travelled down the pool with one stroke cycle.
— *Stroke rate* (SR) / Hz – number of stroke cycles performed in one second.
— *Peak speed* / $m.s^{-1}$ - maximum forward speed of the participant recorded during the underwater push phase, for the affected and unaffected sides (Figure 1).
— *Speed fluctuation* / % – difference between the maximum and minimum speeds within a stroke cycle, expressed as a percentage of the mean speed (Figure 1).
— *Arm extension velocity* / $rad.s^{-1}$ – mean angular velocity of the upper arm about a horizontal axis through the shoulder, calculated over the middle third of the pull.

Statistical analysis
Between measures analysis of variance tests were conducted to establish the differences between the affected and unaffected limbs with regard to the dependant variables. Pearson's Product correlation tests were used to investigate the strength of relationships between selected variables. The level for statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION
The mean speed of the swimming trials was 1.09 ± 0.13 $m.s^{-1}$. This speed is somewhat lower than that typically reported in studies of trained, able-bodied front crawl swimmers, because the trials were sub-maximal and were performed without a leg kick, in order to isolate the action of the arms. The mean stroke length and stroke rate of the amputees was 1.45 ± 0.13 m and 0.75 ± 0.10 Hz, respectively. This stroke length is substantially lower and the stroke rate higher than those used by trained, able-bodied swimmers at 1.1 $m.s^{-1}$ (1). This difference can primarily be attributed to the physical impairment of the swimmers but may also be linked to the absence of a leg kick and the relatively small stature of the swimmers (1.69 ± 0.09 m).
The mean intra-cyclic speed fluctuation for each swimmer is presented in Figure 2. Swimmer F1 had the greatest speed fluctuation (41%) while swimmer F3 had the least speed fluctuation (30%). On average, the group had a speed fluctuation of $35 \pm 5\%$ which is slightly less than the 40% previously reported for trained front crawl swimmers of 'varying skill levels' (1). This result was unexpected, as it was anticipated that the speed fluctuations would be higher in amputee swimmers due to a less consistent application of force through the stroke cycle. Two possible reasons for this finding are: 1) the absence of a leg kick. If the swimmers had been permitted to kick, it is likely that this would have changed the maxima or minima on the speed curve (Figure 1) and, consequently, the speed fluctuation, 2) the timing of the two arm strokes. The amputee swimmers demonstrated a variety of different timings. Some or all of these timings could be more conducive to achieving a consistent application of force, and therefore a low speed fluctuation, than the timing used by able-bodied swimmers. Further work is needed to verify these speculations.

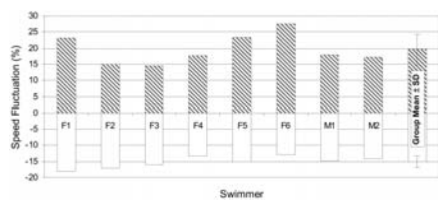

Figure 2. Speed fluctuation, as a percentage of mean swimming speed, for six female (F) and two male (M) arm amputee front crawl swimmers.

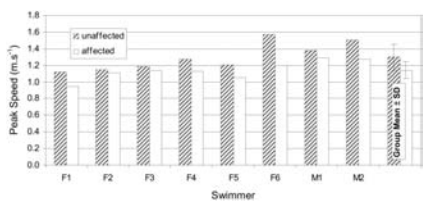

Figure 3. Peak intra-cyclic speed for six female (F) and two male (M) arm amputee front crawl swimmers, during the push phase of the affected and unaffected arms.

The velocity meter curves provide some tentative evidence that the swimmers were able to generate propulsion with their affected limb, as there was a marked increase in intra-cyclic speed during the push phase of this limb. This occurred when the sound arm was either still recovering, entering or in the non-propulsive glide phase. Not surprisingly, the swimmers were more effective at increasing their swimming speed with their sound limb than they were with their affected limb (Figure 3). The peak swimming speed achieved during the push phase of the sound limb (1.30 ± 0.17 m.s^{-1}) was significantly higher than it was during the push phase of the affected limb (1.14 ± 0.11 m.s^{-1}).
Inter-swimmer correlations revealed a significant relationship (r=0.72, p<0.05) between mean swimming speed and stroke rate. Interestingly, the swimmers who exhibited the highest stroke rates were not necessarily those who pulled their affected limb through the water the quickest, as the correlation between the extension velocity of the affected limb and stroke rate was non-significant (r=-0.36). Extension velocities of the affected limb ranged from 8.8 to 12.9 rad.s^{-1}. There was no relationship between the extension velocity and the peak swimming speed that was produced during the push phase of this limb. This indicates that factors other than limb speed, such as the timing and trajectory of the pull, may be more important in determining the effectiveness of the pull.

CONCLUSION
Swimmers with a uni-lateral arm amputation have demonstrated that, in the absence of a forearm and hand, it is possible to use the upper arm to increase swimming speed within the front crawl stroke cycle, but not as effectively as with the complete arm.

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THE EFFECT OF THE BREATHING ACTION ON VELOCITY IN FRONT CRAWL SPRINTING

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Ten competitive, national level adult swimmers (age 25 ± 3 years (mean ± SD) swam three 25m freestyle sprints with different breathing patterns in randomised order to examine how breathing actions influence velocity during a 25m front crawl sprint. Velocity measurements were carried out using a computerized swimming speedometer and data from mid-pool free swimming (10-20m) was extracted. There was no significant difference in mean (±SD) velocity (v) between sprinting with one breath (v=1.74±0.14 m_s^{-1}) compared to no breath (v=1.73±0.14 m_s^{-1}). There was a significant ($p<0.05$) reduction in velocity when breathing every stroke cycle (v=1.70±0.14 m_s^{-1}), compared to both no breath and one breath trials. Swimmers should breathe as little as possible during 50m freestyle races and breathe no more than every 3rd stroke cycle during a 100m freestyle race.

Key Words: biomechanics, breathing, swimming performance, freestyle, sprint.

INTRODUCTION
To achieve a high swimming velocity, one main goal for swimming technique is to create optimal propulsion and minimal resistance (4). For a front crawl swimmer, minimal resistance winds down to keeping an optimal streamline; the head and body in a straight line and the body as horizontal as possible. Optimal propulsion means keeping effective propulsive forces, high propelling efficiency and high power output throughout the swimming distance. The breathing action in front crawl swimming is in most cases a movement that inflicts the swimmers streamline or propulsion because the head has to move out of normal swimming position to make inspiration of air possible. How long the inspiration lasts will also inflict the swimmers streamline and propulsion (1). Both Cardelli, Lerda & Chollet (1) and Lerda & Cardelli (2) have found in previous studies that there is a connection between how good a swimmer is to coordinate the breathing action in front crawl swimming and their technical level. More expert swimmers tend to use shorter time on the inspiration of air compared to less expert swimmers (1). Furthermore more expert swimmers were found to have an improved ability to coordinate armstrokes and inspiration of air so that body balance and continued propulsion is more efficient also during the breathing action (2). Even so swimmers are often instructed to breathe as little as possible during 50 m sprint swimming, and during a 100 m race swimmers tend to reduce their breathing compared to longer distances.
The purpose of this study was to examine how breathing actions influence velocity during a 25m front crawl sprint by using two different breathing patterns compared to no breathing.

METHODS
Subjects
Ten competitive, Norwegian national level, adult swimmers volunteered to participate in this study (8 males and 2 females, mean±SD; age 25±3 years, personal best 50m freestyle 25.15±1.98 sec, season best 50m freestyle 25.62±2.19 sec). All subjects signed an informed consent after having the protocol explained to them both verbally and in writing.

Test protocol
Before start of the trial the subjects conducted a standardized warm up of about 1500m including four short sprints. The trial consisted of three 25m freestyle sprints with different breathing patterns conducted in a randomised order: a) 25m sprint with no breathing b) 25m with one breath after 15m of swimming c) 25m with one breath every stroke cycle. All breathing was to the subjects' preferred side. Each 25m sprint started every 4 minutes, giving the subjects about 3 min and 45 sec recovery between each sprint. During this recovery they had to swim one 25m to get back to start, the rest of the recovery was passive.

Measurements
Velocity measurements were carried out using a computerized swimming speedometer, connected to the swimmer via a thin non elastic line. The speedometer, attached to the pool side, consisted of the speedometer and a digitizing unit. The speedometer had a reel for the line which was set to give a small, but constant resistance on the line to ensure a trouble free outlet of the line. The line went from the reel via a small wheel to the hip of the swimmer. The small wheel (9 cm inn diameter) was connected to the axis of an incremental encoder (Leine & Linde nr IS630, Strängnes, Sweden) which gave 250 square pulses (0-5V TTL logic) for every rotation of the wheel. The swimmers pulled the line and the incremental encoder produced impulses for every turn of the small wheel. These pulses was digitized in a computer card (DAQ 6024E, National instruments, USA), and the signal was treated with Digital acquisition software LabVIEW 7 Express (National Instruments, USA).
Every impulse from the speedometer gave position data which the program smoothened by a floating mean of 10 measurements. The velocity was then calculated in the program by a mean of two positions. Fig. 1. shows an example of the velocity output vs time. Sampled frequency was 100 Hz. The coefficient of variation for the equipment used was calculated to <2 %.
A camera (Panasonic GS3, Japan) was used to film the swimmers above water while they swam each trial. This film was later used to find out the number of strokes performed in the 10m distance of the one breath trial, and how many breaths the swimmers had on the same distance on the breath every stroke cycle trial.
Data from mid-pool free swimming (10-20m) was extracted and used in all analyses.

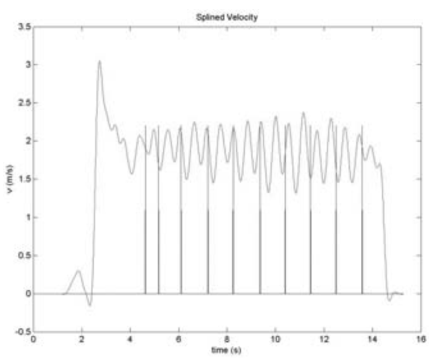

Fig. 1. Example of velocity vs time curve from the speedometer data. Vertical lines represent right arm entry.

Statistics
All data are presented as mean ± standard deviation. A paired t-test was used to determine difference between the trials where $p<0.05$ was considered significant.

RESULTS
There was no significant difference in mean velocity (v) between 10m of mid pool sprinting when the swimmers took one breath compared to no breath. To breathe once every 10 meters equalled about one breath every 3rd stroke cycle for the swimmers in this study. There was a significant ($p<0.05$) reduction in velocity when breathing every stroke cycle, compared to both no breath and one breath trials, see table 1. The swimmers in this study breathed 5-7 times over 10m of mid pool sprinting when breathing every stroke cycle.

Table 1: Mean velocity (±SD) from the three trials.

	No breath	One breath	Breath every stroke cycle
	$v_{10\text{-}20}$ ($m{\cdot}s^{-1}$)	$v_{10\text{-}20}$ ($m{\cdot}s^{-1}$)	$v_{10\text{-}20}$ ($m{\cdot}s^{-1}$)
Mean (±SD)	1.74 (±0.14)	1.73 (±0.14)	1.70 * (±0.14)

** significant different from both no and one breath trials (p<0.05)*

DISCUSSION
The results indicate that swimmers at this performance level may breathe once every 3rd stroke cycle without loosing velocity due to breathing actions in front crawl sprint. If swimmers breathe every stroke cycle they may loose up to about 0.1 sec pr 10m of mid pool swimming.
Unpublished observations of 50m freestyle for males at the Norwegian Long course National championship 2004 showed that all the top 8 swimmers breathed 1, 2 or 3 times with at least 3 stroke cycles in between each breath in the final. Even though there was no significant difference between the one and no breath trial in this study, a difference of only 0.01 $m{\cdot}s^{-1}$ as found here represents a loss of 0.03 sec over 10 m swimming. Even at this performance level a loss of 0.03 sec because of one extra breath could mean 2nd place instead of 1st place. There were individual differences; the highest difference between no- and one breath trial was 0.04 $m{\cdot}s^{-1}$ or 0.15 sec. This indicates that all swimmers can gain by learning better breathing technique and breath control, but coaches should know that some individuals have even more to gain.
Furthermore, observations of the 100m freestyle race for both females and males in the same National Championship revealed that 100m freestyle swimmers seemed to vary what breathing pattern they choose, but most common was to breathe every 2nd, 3rd or 4th stroke cycle for the first part of the race, and than increase to every stroke cycle or every 2nd stroke cycle the last part of the race. Only a few swimmers choose to breathe as little as every 3rd or 4th stroke cycle throughout the race, amongst these was the winner of both male and female 100m freestyle. The main reason for swimmers to increase their breathing pattern the last part of a 100m race is caused by an urge to breathe more due to a lower partial CO_2 pressure in the blood caused by the high intensity of the swimming. Peyrebrune et al. (3) found no reduced performance based on physiological markers when swimmers breathed as little as every 4th stroke cycle, during 55 sec of tethered swimming. This indicates that the swimmers can choose to breathe as little as every 3rd to 4th stroke cycle without loss in performance due to either physiological factors or biomechanical factors (breathing action).

CONCLUSION
Coaches should stress breath control both in training and competitions and also teach effective breathing technique to avoid velocity reductions due to breathing actions. In a 50 m freestyle sprint the swimmers should breathe as little as possible, but during 100 m race swimmers must breathe more and can breath as often as every 3rd stroke cycle without to much

loss of velocity compared to breathing more often. To give accurate advice about which breathing patterns to use in 100m races, both individual differences in technique and physiological and metabolic variables must be taken into consideration. A further investigation in this matter seems necessary, combining biomechanical and physiological methods.

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BIOMECHANICAL ANALYSIS OF THE TURN IN FRONT CRAWL SWIMMING

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The main purpose of this study was to investigate the contribution of the dynamic and kinematic variables to the performance in freestyle. The turns of 38 swimmers were analyzing using an underwater force platform and two video cameras that supplied. Angle of knee flexion (AK), maximum normalized force peak (FPn) and contact time (CT) were measured as variables. Through investigation of the contribution of the variables AK, PMn and CT to the variable TT it was possible identify that PMn explains the greatest percentage of variance in turn performance (17,70%). The relation between AK and PMn indicated that larger values of AK (smaller flexions) tend to provide larger values of PMn (r = 0,38). Start from the results analysis, it can be suggested that angles of knee flexion between 110 and 120 degrees tend to provide larger force peaks, smaller contact times and smaller turn times, reaching the best performance of the crawl stroke turn execution.

Key Words: swimming, turn, biomechanics, flip turn, dynamometry, kinemetry.

INTRODUCTION

The final times of swimming tests can be influenced from the turns in up to 20% (6). The process of the biomechanical study of the turns developed by the Research in Aquatic Biomechanics Laboratory of the University of the State of Santa Catarina (UDESC) is described by Roesler (8) and is part of the studies (1), (5) e (7). The present research complements previous studies and researched parameters on improving performance of the turns, investigating the relationships between the variables: Maximum Peak of normalized force (PMn) and Time of Contact (TC) with the performance in the turn in it I swim Crawl (TV), through the time of turn in 15m.

METHODS

38 swimmers, integrant of the team of swimming of the Club “12 de Agosto” of the city of Florianópolis/SC, federated by Aquatic Federacy of Santa Catarina (FASC), participated in the research, chosen intentionally once they have domain over the technique of execution of the flip turn in front crawl swim. They have an average age of 18,2 years, average body mass of 63,8Kg, and average stature of 1,70m.

For the acquisition of the dynamic data, an underwater strain gauge platform (9) with sensitivity of 2N and natural frequency of 60Hz was used. The force plate was associated to a special support to be fixed to the inside of the turning wall of the swimming pool, in the vertical plan, and on the opposite side to the departure blocks, in lane 4. Once the platform cover is 0,2m thick, the black traces in the swimming pool bottom were modified to adapt to the new configuration, respecting the same official distance for the accomplishment of the turns.

For the kinematic data acquisition, a video camera Mini-DV Mega Pixel 3CCD (60Hz) inserted into a water proof box (camera 1), and a VHS camera with acquisition frequency of 60Hz (camera 2) were used. Camera 1 was located inside the swimming pool, allowing a underwater sight from the bottom to the top of the force platform. It was used for the assessment of the angle of knee flexion (AK). To determine the variable AK, a set of anthropometric landmark points were used (great trochanter, lateral epicondilus and lateral maleolus), made with coloured adhesive ribbon for the ulterior recognition in the video analysis. For the assessment of the turning time (TV) in 15m, camera 2 was located outside the water, 17,5m of the departure platforms, allowing a lateral sight of the swimming pool. The measurement of the turning time was initiated at the moment where the image of the swimmer's head reached the mark of 7,5m in direction to the turning wall, and finished when the swimmer's head reached again the mark of 7,5 m, but after the turn.

Data collection of was carried out during a training session. The swimmers warmed-up in accordance with the coach, trying successive impulses with the feet in the platform, in order to adapt themselves to the experimental conditions. Each swimmer started swimming from inside the swimming pool, under the departure blocks, reaching maximum speed at 12m from he starting wall, carrying through the turn and keeping the maximal speed until the 12m. This exercise was repeated 8 times with a resting interval of 12 minutes between each repetition.

The data obtained through the force platform has been separated and filed for swimmer, calibrated and filtered through a Butterworth filter from (30 Hz), and the normalization was conducted dividing the measured force archive by the weight of the swimmers, both carried through in system SAD 32 (10) supplying the PMn, which are the greater value registered of the force and the TC, that is the time during which the swimmer keeps contact with the platform. The swimmers weight was measured directly with a digital scale, Plenna, model MEA-08128 (0,1kg). For the assessment of AK, the images of camera 1 were used, selecting, through the edition images program *Adobe Premiere 6,5*, the picture where the swimmer carries through the maximum knee flexion when touching the force platform. The flexion angle was obtained using the program *Corel Photo-Paint* version 10.

For the statistical treatment it was used multiple linear regression, Pearson´s correlation coefficient for the group, and Spearman for the sub-groups, *One-Way Variance Analysis (ANOVA)* and descriptive statistics with level of significance of 95%. The *Post-Hoc* test of Scheffé was used.

RESULTS AND DISCUSSION
The swimmers carried through a total of 304 turns. However, in some variables, this number is reduced because the turn was considered failed for the attainment of that particular variable. These data are displayed in Table 1.

Table 1. Average, standard deviation and coefficient of variation of the studied variables.

VARIABLES	n	$\overline{X}$	S	CV%
Turn Time – TV: (s)	301	9,06	1,10	12,1
Maximum Peak of normalized force – PMn: (N/N)	293	1,38	0,38	27,5
Angle of Knee Flexion – AJ: (graus)	304	78,34	24,4	31,4
Time of Contact – TC: (s)	291	0,41	0,11	26,8

The smaller value of TV was of 7,08s and the higher was 11,24s, which are in accordance with previous reports (4), the best time of turn in 15m for the tests of 100m and 200m in Freestyle swim, in long course swimming pools (50m), is of 6,86s and 7,54s, respectively. Records of better turning times for short course swimming pools (25m) were not found in literature.
The biggest value of PMn was of 2,78N/N, the smaller value was of 0,61N/N. The biggest value for AK was 161 degrees and the smaller 29 degrees. For the discussion of the data was adopted as higher angles the values equal or above 100 degrees and as lesser angles the values equal or below 99 degrees. The smaller value of TC was of 0,18s and the higher one was of 0,8s.
When investigating the contribution of the PMn variable, TC and AK for the TV, it was observed that the PMn contributed with 17,7% for the turn time, and that the AK contributed with 4,8%. The smaller contribution came from variable TC, with only 1%. Therefore, the PMn variable presents the highest contribution value for the performance of the flip turn in front crawl stroke.
In the correlation between the variables studied, it was observed positive correlation between AK and PMn, indicating that a greater flexion angle of the knee tends to allow higher application of force in the wall during the turn and, consequently, faster turns. These results approach to the theory (12) when saying that the maximum torque of extension is gotten with 110 to 120 degrees of knees flexion. They are also in agreement with Takahashi et al. (11), authors that suggested that angles of knee flexion during the turn must be of about 120 degrees. Nevertheless they are opposing Counsilman (2), that suggests angles of flexion between 50 and 60 degrees.
Between TC and PMn, a negative correlation was observed, indicating that smaller contact times with the wall allow higher peaks for force application. The same negative relationship was obtained between AK and TC, indicating that higher angle of knee flexion seems to be associated to a low contact time.
To better interpret the data, a rank of the turn times was organized in groups: Group A (band of the 7 seconds), Group B (band of the 8 seconds), Group C (band of the 9 seconds) and Group D (band of the 10 seconds or more).
The results gotten with the variance analysis indicated that the groups distinguished significantly between themselves. It was evidenced, also, a reduction of the PMn values as the TV increases, allowing to state that the increase of the applied force is favourable to a reduction of the turn time, improving the performance of the swimmer. This reduction is significant when times of groups A and B are compared. For variable AK the values get smaller when the turn times increase, confirming previous results: greater angles of knee flexion tend to favour higher force peaks and better performance in the turn. This difference was significant only for the groups A and B. For the TC, increased values were noticed with increased turning times, presenting significant differences for groups A and C. Investigating the correlation between the variable in the groups, Group A presented higher correlations between AK and TC ($r = -0,429$, $p = 0,018$) and between AK and PMn ($r = 0,38$, $p = 0,038$), strengthening the results obtained for the variable without the separation in groups for turn times. In Group B, the correlation between AK and TC was $r = -0,297$ ($p = 0,007$), AK and PMn, $r = 0,216$ ($p = 0,049$) and between PMn and TC with $r = -0,406$ ($p = 0,000$). In this group the higher angle of knee flexion tend to be associated to highest peaks of force and smaller contact times, so to better performance in turns. In Group C significant correlations were found for variables AK and PMn ($r = 0,439$, $p = 0,000$), and AK and TC ($r = -0,232$, $p = 0,024$). For Group D, all the correlations had been positive for low times of turn suggesting that these swimmers have an inferior turn technique comparing to the swimmers of the groups of lower times. Although, in Group B it has a correlation between the TC with the other variable (PMn and AK), and the Group A did not have a significant correlation, the general average of the contact time for this group was lesser, thus explaining, in part, the lowest time of these swimmers.

CONCLUSION
It was possible to identify PMn as the variable that mostly contributes to the performance of the turn during front crawl swimming. We can also suggest that flexion angles of the knee between 110 and 120 degrees tend to allow higher peak forces, lower contact times, and lower turning times, providing higher performances during the turning action in front crawl swimming. These results may promote the development of training programs with planning focused in correcting and improving the turning technique.

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BIOMECHANICAL ANALYSIS OF THE UNDERWATER PHASE IN SWIMMING STARTS

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This study analyzed, through kinemetry, the underwater phase of the swimming start. The sample was composed by 4 swimmers of national and state levels. Three VHS video cameras (30Hz) and signal synchronizer equipment were used. Analyzed variables: maximum depth achieved, time, distance and average velocity of the underwater phase and total start time in 15 meters. The maximum depth achieved after the entrance in the water had influenced significantly the underwater phase. The average velocity during this phase seems to be the variable which most affects the total start time in 15 meters. Maximum depth achieved and average velocity are important factors to be observed by athletes and coaches, who should look forward to perform best values of those variables in order to improve the execution of swimming starts.

Key Words: biomechanics, swimming, start, underwater phase.

INTRODUCTION

The swimming start can represent between 0.8% and 26.1% of the overall race time depending on the event distance (1) and, on average, the improvement of the start technique can reduce the event's total time in at least 0,1s (3).

Several studies analyzed the start variables observed during the block and flight phases, previously the water entrance: time (reaction time, impulse time and block time), impulse (vertical, horizontal and resultant), angles (take-off angle and angle of entrance in the water), distance of flight, etc. (3, 4, 5, 6).

Despite of analyzing only the block and flight phases, these authors cite the importance of the underwater phase in the swimming start. Even so, studies which do reference to this phase are scarce (1, 6, 7, 8, 9) and show, in the majority of the times, distance and time values observed during the underwater phase. According to Cossor and Mason (1), beyond values of time and distance travelled under the water, the maximum depth achieved after the water entrance is an important factor to be observed, therefore can influence significantly the underwater phase during the swimming start.

The authors of the area recognize the importance and representation of the underwater phase regarding the performance of swimming start. The considerations presented by most of these authors, suggesting the need of analyzing the underwater phase subsequent to the entrance in the water, stimulated the main objective of this study: analyze, through kinemetry, the underwater phase of the swimming start.

METHODS

The sample was composed by 4 swimmers of national and state levels (Florianópolis, SC, Brazil), and chosen deliberately, by being specialists in strokes whose starts are performed from the starting block (freestyle, breaststroke and butterfly). The main characteristics of the subjects were: 20.0 ($\pm$3.7) years of age, 74.3 ($\pm$7.04) kg of mass, and 182.0 ($\pm$0.03) cm of height. For data collection three VHS cameras (30Hz) were used. Two of them were coupled to watertight boxes and were both positioned inside the water, distant 5 meters and 10 meters of the starting wall, enabling the acquisition of the variables: *maximum depth achieved* (maximum depth reached by the swimmer after the water entrance, observed in the moment that the swimmer's head reaches the deepest point under the water surface); *underwater phase distance* (distance from the point of the head entrance in the water to the point of the first arm stroke begins); *underwater phase time* (time elapsed from the moment of the head entrance in the water to the beginning of the first arm stroke); *average velocity of the underwater phase* (average velocity reached by the swimmer since the entrance in the water to the beginning of the first arm stroke). The third camera was positioned outside of the water to provide a lateral view of the swimming pool in order to obtain the variable *total start time in 15 meters* (time elapsed since the start signal to the moment that the swimmer's head reached the mark of 15 meters).

To synchronize the start signal to the kinemetry a starter device was used. This equipment is instrumented to simultaneously produce the starting sound and export a LED signal to the video system, allowing data synchronization.

Data collection was carried out in the swimming pool of the Doze de Agosto Club (Florianópolis, SC, Brazil). Each swimmer performed 6 starts with a 5 minutes rest period. Immediately after the start, the athletes had to perform the Crawl stroke at maximum speed up to opposite wall, totalling up 25 meters. The starting procedures conformed to the swimming rules of an official competition.

The *InterVideo WinProducer 3* software was used to digitize data. According to the analyzed variable one selected the charts originating figures. The image files were exported and analyzed by Microsoft® MsPaint and Corel Photo Paint® 10 softwares.

Data were treated using common descriptive statistics and Pearson's Correlation (α = 0.05).

RESULTS AND DISCUSSION

The main results of the study are presented in Table 1.

Table 1. Values of average ($\overline{X}$), standard deviation (s) and relative standard deviation (RSD) of variables maximum depth achieved (DP), underwater phase distance (UPD), underwater phase time (UPT), average velocity of the underwater phase (UPV) and total start time in 15 meters (T15m).

	$\overline{X}$	s	RSD (%)
DP (m)	1,10	0,18	16,98
UPD (m)	5,75	0,87	15,11
UPT (s)	2,18	0,53	24,39
UPV (m/s)	2,70	0,36	13,42
T15m (s)	6,97	0,25	3,65

It can be noticed that the total start time in 15 meters presents the smaller variation (3,65%) when compared to the other variables, indicating that, even performing similar starting times, the swimmers presented heterogeneous values for the variables observed during the underwater phase. It suggests that this phase is intimate connected to the individual characteristics of each subject, like the streamline position and the underwater stroke technique used, being still influenced by several factors and actions that happen since the instant of entrance in the water to the beginning of the first kicking and the first stroke movements.

In order to verify the relationship of the variables observed during the underwater phase with total start time in 15 meters Pearson's correlation was used ($p<0.05$). Table 2 presents the values of "*Pearson's r*" for the correlation between the total start time in 15 meters (T15m) and the variables maximum depth achieved (DP), underwater phase distance (UPD), underwater phase time (UPT) and average velocity of the underwater phase (UPV).

Table 2. Values of "Pearson's r" *for the correlation between T15m and DP, UPD, UPT and UPV.*

CORRELATED VARIABLES	n	r
T15m x DP	24	0,515*
T15m x UPD	24	0,109
T15m x UPT	24	0,376
T15m x UPV	24	- 0,645**

* p<0,05 ** p<0,01

n = number of analyzed starts

It can be observed that the total start time in 15 meters was significantly correlated with the maximum depth achieved ($r=0.515$) and with the average velocity of the underwater phase ($r=-0,645$).

The significant coefficient of correlation observed between T15m and DP indicates that higher values of maximum depth correspond to higher values of T15m. Counsilman et al. (2), even without carrying out the correlation between these variables, verified that, on average, the slowest starts were performed when the swimmers presented higher values of depth achieved.

Average velocity of the underwater phase was negatively correlated at a significant level ($p<0.01$) to the total start time in 15 meters, which indicates that higher values of average velocity during the underwater phase correspond to slower starts.

Despite of UPV is a derived variable from UPD and UPT, these did not present significant values for the correlation with T15m ($r=0,109$ and $r=0,376$ respectively). This fact suggests that, more important than the distance travelled or the time elapsed under the water, is the great combination between those variables, requiring from the swimmer the ability of minimizing the water resistance and maximizing the propulsion during the underwater phase, performing a longer distance in a shorter time. In order to confirm the importance of the underwater phase to the start performance in 15 meters, Cossor and Mason (1) combined the variables flight distance and flight time; underwater distance and underwater time; and time and distance of the first arm stroke. They verified that the combination of underwater distance and underwater time was the one which more affected the total time in 15m, suggesting that there is a strong relation between the velocity during the underwater phase and the start performance.

Rabalais (4) affirms that one of the factors that affect the underwater phase during the swimming start is the depth reached by the swimmer after the water entrance, which may influence the distance travelled and the time elapsed under the water. In order to confirm the information found in the literature one carried out the correlation between the maximum depth achieved (DP) and the variables underwater phase distance (UPD), underwater phase time (UPT), average velocity of the underwater phase (UPV) and total start time in 15 meters (T15m).

Table 3 presents the values of "Pearson's r" for the correlation between DP and the variables UPD, UPT, UPV and T15m.

Table 3. Values of "Pearson's r" for the correlation Between DP and UPD, UPT, UPV and T15m.

CORRELATED VARIABLES	n	r
DP x UPD	24	0,778**
DP x UPT	24	0,910*
DP x UPV	24	- 0,838**
DP x T15m	24	0,515*

* p<0,05 ** p<0,01

n = number of analyzed starts

Concerning the influence of the DP values in the underwater phase, it was observed a significant correlation between the maximum depth achieved and the variables underwater phase distance, underwater phase time and average velocity of the underwater phase ($r=0,778$, $r=0,910$ and $r=-0,838$ respectively). The correlation coefficients indicate that higher values of DP correspond to higher values of UPD and UPT, at the same time, to smaller values of UPV.

Cossor and Mason (1) suggest that the depth achieved is related to the total time in 15m. One carried out the correlation between DP and T15m and observed a significant coefficient ($r=0,515$), which indicates that higher values of depth achieved correspond to bigger values of total time in 15m, therefore, slower starts.

CONCLUSION

The characteristics of the underwater phase are inherent to each subject and depend on several factors that happen since the start signal until the beginning of the first stroke move-

ment, requiring from the swimmer the ability of combining actions in order to minimize the resistance forces and maximize the start performance in all of its phases.
The depth achieved after the water entrance and the velocity performed under the water are both important factors to be observed by athletes and coaches, which should look forward to reach best values of those variables in order to improve the execution of swimming starts. It suggests that the swimming start analyses should contemplate, beyond the block and the flight phases, the underwater segment, that is an essential phase to be considered for the determination of performance parameters of the start in swimming.

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RACE PACE CONTROL BY MEANS OF A NEW CHRONOMETER SYSTEM

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This paper describes a new chronometer system that provides feedback in real time and without interfering with the swimmer's execution. The system consists on a leds screen (water resistant) installed on the bottom of the pool, so that swimmers can see it every time they perform a turn. This system can be connected to a PC or PDA, which permits register lap times for further analysis. Feedback provided by the chronometer to control swimming speed was compared with the condition "traditional feedback" provided by the coach and with the condition "no feedback". Results show little dispersion on lap time with this new kind of feedback at aerobic swimming speed. At an anaerobic threshold swimming speed, dispersion was similar between "traditional feedback" and chronometer feedback, and a little more dispersion in "no feedback" condition.

Key Words: chronometer system, race pace control, feedback, biomechanics.

INTRODUCTION

Compared with other terrestrial sports, coach-swimmer communication during training is a very difficult task. However, numerous studies indicate the importance to provide real time feedback for technique improvement (1). The lack of feedback can harm the swimmer learning. In this direction, in the past few years there has been an increasing interest in systems that permit guide swimmers speed and/or systems which permit coach-swimmer communication.
Most of these systems are based on some kind of optical devices that guide the swimmer along the swimming pool (2). These are useful systems, but they only guide swimmers speed with no other kind of feedback. Other systems allow effective coach-swimmer communication using a snorkel with FM and a transmitter base station (3), but the system interferes with swimmer execution.
The aim of the present communications is double: first, to present a new chronometer system that provide real time feedback without interfering with swimmer's execution and, second, to evaluate three different ways to provide feedback to swimmers in order to control swimming speed (and, in a future second phase of the project, "key words" from the coach to provide feedback concerning technical aspects).

METHODS

Six male (age = 16´48 ± 1´10; height = 1´756 ± 0´084 m; mass = 71´29 ± 3´51 kg) well-trained swimmers of national level volunteered for the study. All subjects provided written consent before participating in the study.

1) The chronometer system

We have developed a chronometer system, called SwimTimer (figure 1), based on a leds screen (figure 2) installed on the bottom of the pool, so that swimmers can see it every time they perform a turn. The leds screen receives information from a contact platform placed on the wall of the swimming pool, so that, when swimmers contact it, the chronometer switches on. Lap, total time and lap number can be seen by swimmers and registered by a PC or PDA (figure 3). The system allows to control six swimmers (same order) on the same line. We are working, too, in the possibility that coach could write a little text (key words) to provide technical feedback to swimmers.

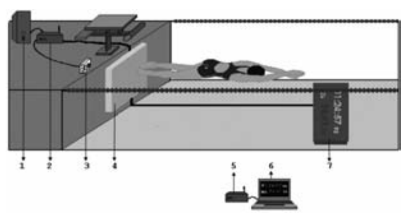

Figure 1. Chronometer system Scheme: 1) battery, 2) and 5) telemetric system, 3) start-stop control, 4) contact platform, 6) PC or PDA, 7) leds screen and subaquatic box.

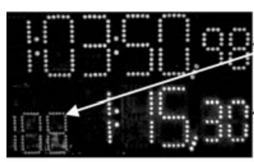

Figure 2: Leds screen putted on the bottom of the pool on the top [green] total time, rigth bottom [red] lap time and left bottom [green] number of laps.

Figure 3. Software on a PC.

2) Feedback tests
Each swimmer swam 200 m under three feedback conditions (independent variable): (1) without feedback, (2) with chronometer system and (3) traditional (coach) feedback. These three conditions were evaluated under two different speeds: aerobic speed and anaerobic threshold speed. These swim speeds were individualy determined by the coach. Lap time for every 50 m was recorded.
Statgraphics v.4.0 was used to perform a descriptive analysis and an ANOVA for repeated measures, for factor "kind of feedback" with the levels above indicated. The level of significance was set at p < 0´05. This analysis was performed for both swim speeds.

RESULTS
Table 1 shows the results for the dispersion (variance and range) descriptive statistics for the aerobic speed condition. As it can see, at the aerobic speed there are less dispersion on lap times with feedback provided by the chronometer system, while dispersion with traditional feedback and without feedback are more or less the same.

Table 1. Dispersion data for lap times at the aerobic speed condition.

Aerobic swim speed	Without feedback	Traditional feedback	Chronometer system
Variance	2´3382 s	2´1154 s	0´9756 s
Range	4´92 s	5´0 s	3´23 s

At the anaerobic threshold speed, dispersion data on lap times were very similar between feedback provided by chronometer system and by coach, while condition without feedback presented a little more dispersion.

Table 2. Dispersion data for lap times at the anaerobic threshold speed condition.

Anaerobic threshold swim speed	Without feedback	Traditional feedback	Chronometer system
Variance	1´7554 s	1´1433 s	1´1317 s
Range	4´76 s	3´86 s	3´28 s

ANOVA analysis show no significant difference among mean values (p > 0´05 for both speed conditions), as it can see in figures 4 and 5.

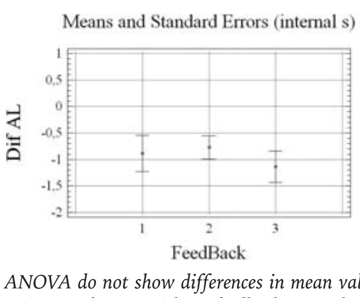

Figure 4. ANOVA do not show differences in mean values for the aerobic swim speed. 1 = without feedback, 2 = chronometer feedback, 3 = traditional (coach) feedback.

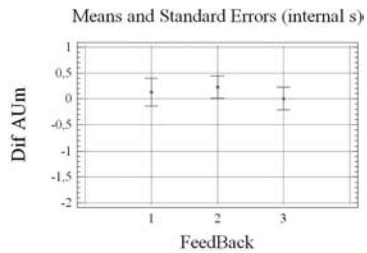

Figure 5. ANOVA do not show differences in mean values for the anaerobic threshold swim speed. 1 = without feedback, 2 = chronometer feedback, 3 = traditional (coach) feedback.

DISCUSSION
Results show little dispersion on lap time with this new kind of feedback at aerobic swim speed. At an anaerobic threshold swim speed, dispersion was similar between "traditional feedback" and chronometer feedback, and a little more dispersion in "no feedback" condition. The reasons why these differences on results between aerobic and anaerobic threshold speeds are not clear, so that, more studies with a greater sample are necessary. However, results show similar data dispersion in aerobic and anaerobic speeds when using the new system which indicates its validity and interest.

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THE INFLUENCE OF TUCK INDEX, DEPTH OF FOOT-PLANT, AND WALL CONTACT TIME ON THE VELOCITY OF PUSH-OFF IN THE FREESTYLE FLIP TURN

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Effective turns play a critical role in the outcome of swimming competition. The purpose of the study was to investigate the effect of three variables on the velocity of the push-off during the freestyle flip turn. The variables are: (a) the distance of the hips from the wall at foot contact (Tuck Index); (b) the depth of the foot plant on the wall during push-off; and (c) wall-contact time (WCT). Twenty three collegiate swimmers participated in the study. Following underwater video-taping, 2D analyses in the saggital plane were made using Motion Analysis software. Statistical analysis of the data found a significant, negative correlation between push-off velocity and Tuck Index. No significant correlations existed between push-off velocity and foot-plant or between "active" WCT and push-off velocities.

Key Words: freestyle flip-turn, push-off velocity, 2D analysis.

INTRODUCTION

Effective turns play a critical role in the outcome of swimming competition. In short-course events, turns comprise up to one-third of the total race time (7, 15, 16). While mid-pool swimming velocity is the primary determinant of race performance at the elite level (11) it does not necessarily indicate a similar proficiency in turning technique (12). In the 2000 Olympic Games in Sydney, Australia, the performances of finalists and semi-finalists in the 200 meter events were studied for the start phase, swimming velocity, stroke frequency, stroke lengths, and turns. One of the study's conclusions was that the velocity of the final turn was a differentiating factor between medalists and non-medalists (5). Consequently, at elite competitive levels, although mid-pool swimming velocity is the primary determinant of race performance, the turns have the potential to determine a winner among swimmers with the same mid-pool swimming velocities.

Kinematic examination of swimming turns have included such parameters as the velocity of the swimmer when approaching the wall; the orientation of body during wall contact; time spent on the wall; orientation of the body during push-off; timing of the initiation of the kick and arm stroke; and the total time taken to complete the turn (1-3, 9, 10, 15, 17). How about "The push-off phase of the turn can be broken down into several components for analysis. These components include Tuck Index, Foot Plant Position, and Wall Contact Time (WCT).

Tuck Index measures how close a swimmer's hips are to the wall at the start of push-off, relative to leg length (1, 2). It is defined as the distance of the greater trochanter of the femur from the wall at foot contact, divided by the actual trochanteric height. A higher number indicates straighter legs at wall contact. Previous analyses of freestyle and backstroke turns have indicated that higher tuck indices (straighter legs at wall contact) are correlated with faster turns (1, 2). One study found that peak forces were generated when the knee was flexed at 120 degrees (14). However, it is clear that a turn performed with the legs in an excessively straight position at wall contact (very high Tuck Index) would not allow the leg muscles the opportunity to generate optimal muscular force (8, 13).

A second component of the push-off phase is the depth of foot plant below the surface of the water. No research published to date has examined the effect of the foot plant position on the ensuing push-off. The foot plant position has the potential to alter the trajectory of the body at push-off. Positioning the feet too high on the wall may result in a push-off with a deep trajectory. In contrast, positioning the feet too far below the surface may result in the swimmer surfacing too quickly.

Total wall contact time (WCT) is the third component of the push-off phase and may be divided into two segments, a "preparatory" segment and an "active" segment. The "preparatory" segment occurs prior to forward motion, beginning when feet make contact with the wall, and ending at the moment before the hips make their first forward displacement. The "active" segment of WCT begins at the first forward displacement of the hips and ends when the feet leave the wall. In freestyle and backstroke turns it has been reported that shorter overall WCT resulted in faster turns, higher peak forces, and faster peak velocities upon push-off (1, 2, 4). However, in examining the two segments of WTC, a longer "active" segment of WCT is reported to be associated with faster velocities upon push-off. One study examining "active phase" of the push-off of elite swimmers reported values ranging from 33% - 94% of the total WCT (9). Consequently, exploring the ideal percentage of total WCT spent in the "active" phase of pushing off may help optimize turning technique.

The purpose of this study was to examine the effect of three variables on the velocity of the push-off during the freestyle flip-turn. These variables are: (a) the distance from the wall a swimmer's hips should be at foot contact (Tuck Index); (b) the depth of the foot plant on the wall during push-off; and (c) the wall-contact time.

METHODS

Twelve male and eleven female members of a United States University -Division I swimming team participated in the study. Subject ages ranged from 19 to 25 years. Each subject was required to perform a series of trials, each trial consisting of a 50-yard freestyle swim over a 25 yard (22.5 m) course which included one turn. Subjects were instructed to perform the flip turn at race pace, swimming at maximum speed for 5 meters before and after the turn. Each turn was videotaped from underwater using a single digital camera. The camera was placed at a depth of half a meter below the surface, and located 2 meters from the end of the pool and 7 meters laterally to the turning surface. A four-point calibration rod was used as a scaling factor for the kinematic analysis. Two-dimensional analyses of saggittal planar movements were conducted using motion analysis software (Vicon/Peak, Denver, Colorado).

The dependent variable selected was the push-off velocity, the average velocity taken to cover the first 60 centimeters upon leaving the wall, as measured by displacement of the hips. Independent variables selected for analysis included tuck index, foot plant index and %WCT Active. Tuck index is defined as the distance of the greater trochanter of the femur from the wall at foot contact, divided by the actual trochanteric height (measured from the ground to the greater trochanter). Foot-plant index is the distance from the ankle to the surface of the water, divided by trochanteric height. %WCT Active is the percentage of the total wall contact time spent actively pushing off the wall. A Pearson correlation matrix was established to investigate the strength of the bivariate association between each independent variable (tuck index, foot-plant index and %WCT Active) and the dependent variable (push-off velocity). Simultaneous regression analysis was conducted using the push-off velocity as a dependent variable to determine the overall predictive characteristics of the variables.

RESULTS AND DISCUSSION

Push-off velocity

The mean push-off velocity for all turns analyzed, males and females combined, was 2.47 ± .40 ms^{-1}, with a minimum value of 1.3 ms^{-1} and the maximum value of 3.29 ms^{-1}. The mean push-off velocity for males in the present study was 2.69 ±.34 ms^{-1}. As a means of comparison, the mean push-off velocities of 30 experienced male swimmers with a mean age of 19.8, were reported as 2.75 ±.25 ms^{-1} (9). Another study which measured push-off velocity on trained young swimmers aged 10 to 14 years old reported average values of 1.14 ms^{-1} (6).

Tuck Index

Tuck Index can be used to indicate how close a swimmer is to the wall after the foot plant. A higher Tuck Index indicates straighter legs. In the present study, the mean Tuck Index of all turns was 0.57 ± 0.14, indicating that the hips were at a distance from the wall that was approximately 57% of the trochanteric height. Tuck Index was the only significant predictor of push-off velocity in the present study. Tuck Index was negatively correlated with push-off velocity, indicating that the more tucked position (lower Tuck Index) predicted higher push-off velocity. This result appears to contrast with previous studies, which indicated that a higher Tuck Index results in a faster turn (1, 2, 4). However, these studies calculated round-trip time by measuring the time taken to travel in and out of the turn from a prescribed distance from the wall, either 2.5 or 5 meters. In these cases, the time for the round trip can be shorter because the center of mass of the measured body segment is further from the wall upon foot contact. It is important to note that both methods of evaluating flip-turn performance have their weaknesses. When using round-trip time, it is not possible to discern the actual velocity of the push-off. When using push-off velocity, the overall time it takes to perform the turn is not taken into account. As a result, the optimal Tuck Index value of 0.46 is specifically for optimizing push-off velocity, and may not result in an optimal round-trip time. While no research to date has explored the curvilinear relationship between Tuck Index and push-off velocity, the relationship is a logical one. Performing a flip-turn with the hips either extremely close to the wall, or in an excessively straight position, would not allow the leg muscles the opportunity to generate optimal muscular force. This concept was illustrated in a study that examined optimal take-off range in vertical jumping by requiring track athletes to perform squat jumps and countermovement jumps using a force platform (8). Squat jumps performed with legs close to full extension produced approximately 25% less vertical ground reaction force than those with the more optimal starting position. While these numbers do not take into account possible variations in leg length, they provide general support for the concept that the relationship between Tuck Index and push-off velocity may be a curvilinear one. It should be noted, however, that trained swimmers perform their flip-turns with very little countermovement, so it may be more appropriate to examine squat jump rather than countermovement jumps when making comparisons between jumping and flip-turns.

Foot-plant index

Foot plant index was developed as a way to measure the distance of the feet from the surface of the water while taking into account the length of the swimmer's leg. A higher number for foot plant index indicates a deeper foot plant. The mean foot plant index in the present study was 0.45 ± 0.10, indicating that the mean foot plant was approximately 45% of the swimmers' leg length below the water. No other research has been conducted to date examining the depth of foot plant and possible implications for flip-turn performance. Thirty-three of the 109 turns in the present study resulted in glides that were performed above the 0.40 meter depth. While no significant relationship was found between foot plant index and push-off velocity, further examination of the present data could examine the link between foot plant index and push-off depth.

Wall Contact Time

The mean WCT of turns rated "normal" was 0.28 seconds. This value was the lowest when compared to other studies which reported times ranging from 0.29 to 0.32 seconds in experienced adult swimmers who have been studied (9, 10). The mean percentage of the wall contact spent in the "active" push-off phase was 74.3%. The minimum percentage was 35%, and the maximum was 95%. One previous study found that the active push-off segment of elite swimmers ranged from 33% to 94% of the total WCT, with a mean of 67.5% ± 15.2% (9). The positive correlation in that study indicated that longer active segments resulted in faster final push-off velocities. However, in the present study, no significant relationship was found between % WCT active and push-off velocity.

CONCLUSIONS

The following conclusions may be of practical value for the coach:

— Since the values of the push-off velocities in this study reasonably matched with other studies of elite swimmers, ie. those competing at the national and international levels, we can deduce that once a certain level of performance is achieved, swimmers tend to drive off the wall at a fairly predictable velocity. The fact that younger swimmers tested show velocities that are almost half that of the elite groups, implies a on-going need to address this aspect of the turns.

— When examining how close the wall should be approached, as measured by the Tuck Index, the study found that, up to a point, the closer the hips are to the wall at foot-plant, which imply a higher degree of knee flexion, the higher the velocities of push-off. Therefore, it is better to be closer than further from the wall when starting the push-off.

— The depth of the foot-plant for elite swimmers performing the freestyle flip turn appears consistent. However, the range of values that are seen with less experienced swimmers, clearly affecting the trajectory of the body, is a strong reminder of the need to refine turning skills.

— Although this study did not find a clear association between how long the feet should remain on the wall once the knees start to extend, ie. the "active phase of wall contact time", it may be counterproductive to shorten this period of the turn. Consequently, it is better for the swimmer to maintain a firm footing on the wall during the push-off rather that attempting to "bounce" the feet off the wall during the turn.

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INFLUENCE OF TIMING DELAY ON MONOFIN INTRACYCLE SWIMMING VELOCITY

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The aim of the study was to analyze the temporal delay of the body segments and monofin movements while generating propulsion. Swimmers were filmed under water while covering 50m distance without breathing. Input data as time series of kinematics parameters of the points marked on the swimmers bodies and on the monofin were recorded on the basis of randomly filmed single cycles for each swimmer. The data showed inversely proportional relationship between the sum of vertical velocities of the reference points (ΣVVER) and the horizontal velocity of the swimmers' center of mass, indicating the significance of the ΣVVER in generating propulsion. Our study further indicated that the analysis of temporal delays of the time structure in the body segments and monofin tailored for swimmers according to the leg movements and equipment used will allow elimination of the hip and the lower thigh mistakes.

Key Words: monofin, kinematics, technique quality, dynamic statistics.

INTRODUCTION

The mechanics of propulsion classifies monofin swimming as analogous to tuna fish swimming (1). This type of locomotion consists in generating propulsion mainly by caudal fin with the use of unstationary flow (6). The propulsion effect is determined by the shape and trajectory of the fin action, which is the consequence of its shape and flexibility, as well as the leg movements. These factors are described by dynamic and kinematic parameters (1, 2, 3, 4). As it is known, due to the non-parallel water flow along the surface of the monofin, difference in pressure is generated due to the differences in speed of flow caused by the change in angular parameters (angle of attack and angular velocity) of these surfaces' movements. Angular parameters, through their relations with lift (and indirectly with drag), are correlated with the resulting force propelling the swimmer (3). The shape and trajectory of movement also affect the value of additional components of the propulsion force resulting from the vortex around the fin's surface (6) and from the use of additional mass of water a swimmer uses to push oneself in direction opposite to swimming (1). These components are present as the momentum generated by the segments of the biomechanical chain (in a certain time sequence, during the swimming cycle) In this context, the quality of swimming technique may be defined by maximizing of the momentum transferred in water or their most effective transfer through consecutive legs and fin segments. In all cases there is a rule of balance of momentum, which in the aspect of constant speed in the swimming cycle, is the basis for developing criteria for the quality of technique. High stability of the swimming speed is represented by the parameters' features determining it (2). Therefore, delay of these parameters with respect to swimming velocity is also the measure of the monofin swimming technique, which can be quantified with the use of dynamic statistics tools (cross correlation and retardation). This study aims at analyzing the retardation of the body segments and monofin movements while generating propulsion to resolve the problem of efficiency and effectiveness of fin swimming. Such analysis is possible because the legs and monofin movements occur in one dimension. This describes explicitly the transfer of momentum mechanism during undulatory movements. Moreover, a fin surface, due to its size, is treated as the main source of propulsion.

METHODS

16 men – participants in Monofin Swimming World Championships - were filmed under water while covering 50 m distance without breathing. A digital camcorder was placed in the middle of the pool. The equipment parameters, filming procedure and computer movement analysis (SIMI) were compliant with the ISO 9002 standards. Input data as time series of kinematics parameters of the points marked on the swimmers bodies and on the monofin were recorded on the basis of randomly filmed single cycles for each swimmer (frequency - 50 Hz) (fig. 1). Reference points were the following: middle finger, wrist, elbow, shoulder, hip, knee, ankle, as well as tail, middle and edge of the fin. Each of the parameters was recorded during the test, after which the average was calculated. On the basis of the analyses of the sums of vertical velocities of the reference points reduction of data was carried out, which limited the calculation to the analysis of legs and fin movements. The basis for this was the classification of the monofin swimmer's movements to the category of tuna movements, (1) (Highest fluctuation in the vertical velocity referred to the legs and fin movements respectively, and the vertical actions of the upper body were insignificant). Preliminary analysis showed also (fig. 2) inversely proportional relationship between the sum of vertical velocities of the reference points (ΣVVER) and the horizontal velocity of the swimmers' center of mass

(VHOR). This shows the significance of the (ΣVVER) in generating propulsion. The role of it is due to the correlation: the lower the ΣVVER fluctuation, the higher the VHOR stability. The speed stability in the cycle is the effect of the balance between the momentums generated as a result of the monofin propulsion movements (2). It seems logical then that the temporal delays in the momentum transfers in the swimmers leg – monofin chain water will have an adverse effect on the swimmer's speed. Therefore, the main part of analysis was based on the calculation of the cross correlation coefficient and retardation with the average function of recorded parameters (movements in leg joints and in reference points in tail (T), in the middle (M) and on the edge (E) of the monofin) with respect to VHOR (Fig. 2). On the basis of CC ≥ 0,7 values, 16 parameters were assigned, which were assumed to be significant for the swimming speed. These parameters are the following: trajectories - vertical of the hip movement (HIP), knee (KNEE), ankle (ANKLE) and the fin's tail (TAIL); angles of knee flexion (H-K-Aα), in the monofin's tail against foot and the middle of the fin (front part (A-T-Mα)), in the fin's tail against foot and edge (entire surface (A-T-Eα); angular velocities of flexion in hip joints (S-H-Kω) and ankle joints (K-A-Tω) as well as the entire fin's surface against foot (A-T-Eω); angles of attack (against tail) of the front part of the fin (T-M-Hα), and its end part (M-E-Hα), as well as the entire fin's surface (T-E-Hα); angular velocities of attack (against tail) of the fin's front part (T-M-Hω), its end part (M-E-Hω) and its surface (T-E-Hω). The results were empirically verified based on the analysis of directly input data (Fig. 1, 2).

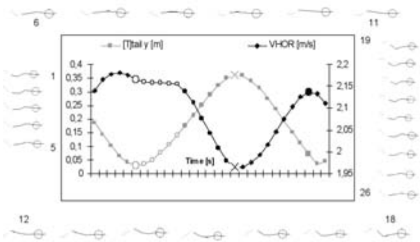

Fig.1. Description of average breakdown of monofin's tail (T) trajectory against horizontal velocity of the center of mass (VHOR), illustrating the way in which a movement cycle is differentiated from the total cycle and consecutive legs and monofin sequences.(● – start of cycle; ❍ – most stable part of cycle (seq.6-11); ✖ – time of movement shift monofin's tail up to down, ■ - end of cycle).

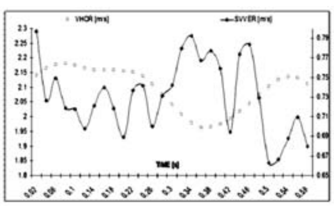

Fig. 2. Correlation between the sum of vertical velocities on points on the swimmers body and monofin (ΣVVER) against horizontal velocity of the center of mass (VHOR).

RESULTS

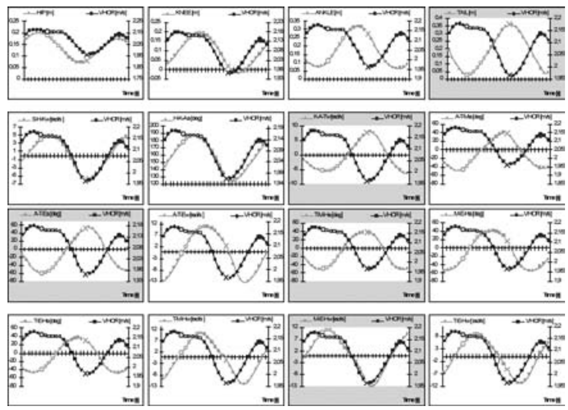

Fig. 3. Graphs illustrate average breakdown of the parameters in the biomechanical chain leg-monofin against horizontal swimming speed. Function graphs with '0' retardation - marked grey.

DISCUSSION

The parameters of legs and monofin movements correspond to the parameters, which had been specified on the basis of the neural network development (4). We have identified parameters describing angles of attack and angular velocities of legs and monofin parts. In this way, we have developed the basis for validation of the diagnostic value of the method based on statistics tools.

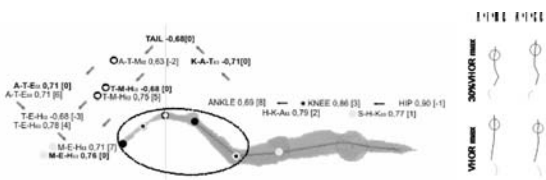

Fig.4. Interpretation of balanced and stable mechanism of momentum transfer based on the correlation between parameters of legs and monofin movements against tail as the transfer point (marked with similar points). Segments marked in the ellipse and sequences A-T-Mα and A-T-Mα are analogous to "tuna like" propulsion mechanism (1).

The analysis of the cycle's parts where horizontal velocity is most stable shows many regularities (Fig. 2, 4). The analysis of trajectory HIP against VHOR shows how the hip movement contributes to maintaining constant intra-cycle velocity. Slightly higher speed of HIP in relation to VHOR (R=-0,02s) is caused by an early start of the hip downward movement. S-H-Kω has a strict correlation with VHOR, (R=0.02s). Intervention in the structure of hip movement (assuming the rigidity of the corpus) suggests the extension of time in which the speed of lowering hips is highest. In the case of the trajectory KNEE and A-K-Tα (R= 0.06s and 0.04s) it is feasible to maintain constant VHOR thanks to an earlier commencement of the knee upward movement and their earlier extension. ANKLE trajectory with respect to VHOR shows retardation (0.16s) which is suggested by the earlier ankle upward action and its limited scope of movement. Time structure of K-A-Tω precedes VHOR changes and causes the fall of the retardation to zero. Limiting the angular velocity of hip and feet upward movement contributes to maintaining constant, high swimming velocity. High correlation and the lack of temporal delay between VHOR and TAIL, as well as A-T-Eα trajectory suggests the limitation in feet and fin upward movement which sag at an angle showing parallel distribution of its segments. Similarly, increase in A-T-Eω contributes to maintaining constant VHOR. In the context of the retardation (0.12s), limiting VHOR decrease means flexing the tail while aiming at maximizing the speed. In the case of A-T-Mα stability, VHOR is helped by the positioning of feet and the front part of the fin in one line. Slight overtaking of VHOR by the action of the tail flexion (-0.04s) is due to the latter's early flexion. High correlation and the lack of retardation was recorded between VHOR and T-M-Hα. Maintaining constant velocity in the cycle is helped by lifting the front part of the fin to the position parallel to the swimming direction. In the case of T-E-Hα, slight overtaking of VHOR by the attack angle of the whole surface (-0,06s) suggests a longer period of its edge downward movement. M-E-Hα in relation to VHOR (0.14s) suggests that the constant swimming velocity is secured by quick start of the further part of the fin's movement which leads to its positioning parallel to the swimming direction first and next quick positioning of its end part so as the angle of attack is as high as possible (M-E-Hω). Relationships between VHOR and T-M-Hω, and T-E-Hω are similar. In both cases the retardation in angular velocities changes (0.1s and 0.08s) leads to the situation where the maximum angular velocity falls on the last part of the stable VHOR cycle.

From the description and fig. 3, 4 one may conclude that the monofin's tail, as the point of transfer of the momentum generated by legs on its surface, is the key element in the action of the biomechanical chain analyzed. The monofin's tail divides it into two parts: one – controlled by the swimmer- chain of leg segments and a chain composed of monofin components, which depends on the legs structure and the fin's characteristics. In this context the interpretation of the stable, balanced transfer of forces mechanism in the whole cycle is based on the correlation dependencies between legs and monofin movement parameters which shows high cross correlation and zero or minimum retardation (fig.4.). Knee movements determine the trajectory of the monofin's middle part. The lower the amplitude and the longer the time of the knee movement, the bigger the amplitude of the monofin's middle part. This correlation applies to the phase of the legs upward movement, where the slowing down of the movements in direction of the swimming is justified from the hydrodynamics point of view. Angular velocity of the flexion in the hip determines the parameters of the monofin's rear part's angle of attack. Longer time of maintaining maximum (S-H-Kω) with extended knee joints results in faster positioning of the monofin's end part at the maximum angle of attack in the described position (M-E-Hω). Earlier flexion of the monofin's rear part results in its positioning along the swimming direction (M-E-Hα). It may be assumed that the correlations shown support the transfer of the momentum occurring between the leg and the fin. More so as the influence of the angles of attack on swimming velocity has been documented, with particular attention to the role of the monofin's rear part positioning in relation to the direction of flow (3, 4). The angle of flexion of the fin's tail determines the angles of attack of the monofin's front part and its whole surface. Positioning of legs and the monofin's front part in one line, (A-T-Mα) in a cycle contributes to the shift of its front part to the position parallel to the swimming direction (T-M-Hα) and extending in time the movement of its edges (T-E Hα). This correlation refers to the transfer of momentum in the structure of leg flexion and the sag of the monofin's parts. That is because the shift in the mutual positioning of the fin segments with the adequate breakdown of velocities of flow leads to a vortex which, at a stable vortex circulation, generates additional propulsion (6) in the form of added mass of water pushed backward (1). Speaking more broadly, the structure of the further segments of legs affects the movement of the monofin's further elements. In the same manner, front elements of the leg chain affect the monofin's front segments. The lower the retardation (more stability) of the angular velocity around the furthermost point of legs (HIP), the smaller the retardation of the angular velocities of attack with respect to the fin parts which are furthest from the tail (M-E-Hω and T-E-Hω) According to this method, based on the balance of momentum generated by both parts of the chain, one may interpret the mechanism of the legs and fin movement. Such evidence results from analogy between analyzed monofin and legs movement and the structure of the fish movements (1, 5). The angles of the tail flexion, together with the angles of attack, illustrate the features of the material the monofin is built from. The lower the A-T-Mα angle, the smaller the monofin's tail and front part flexion (harder tail). The lower the A-T-Eα angle, the bigger the fin's tail and middle flexion (softer fin). The shape and the hardness suggest that in the monofin's structure there are premises to maintaining the balance of momentum transferred in water, and vice versa, in both phases of the propulsion. This is supported by the analysis of angles of attack, which (with the exception of T-E-Hα are characterized by R=0 in relation to VHOR may signify that the source of errors which disturb the balance of momentum should be looked for in the fin upward phase time structure. This is supported by delays in the angular velocities of attack (with the exception of T-E-Hω) in relation to VHOR.

Additionally, the monofin's upbeat phase is accompanied by delays M-EHORα and T-E-HORα in relation to VHOR, which may be interpreted that more rigid fin would eliminate time shift. The balance of momentum generated by legs is more difficult due to the different nature of the upbeat as compared to downbeat. What seems to be the most important is that due to the hip downward and the thigh upward movement in the limbs chain degrees of freedom are created (which do not occur in the downbeat), which changes the breakdown of momentum in both phases. Adverse balance of momentum in the upbeat is due to the shortening of the arm of the force generated by the movable segments. Additionally, increase in the number of degrees of freedom does not positively affect the stability of the system, which transmits momentum-propelling (2, 4). Thigh downward action is justified from the propulsion generation perspective, as it is performed against the swimming direction. However, the upward action is not justified, which generates additional resistance. The consequence of the movements along the swimming direction applies most of all to improper shape and its trajectory and, as a consequence, to avoiding the water resistance (3, 4). The loss of propulsion results from the lack of the sources that could generate such propulsion (direction and components of the propulsion force – lift and drag) (3, 5), which is the prerequisite for the generation of the vortex circulation which propels the swimmer (6) and the direction in which the added mass of water is pushed (1). It may be assumed that upbeat (in limited scope) is necessary to prepare the push with the thighs in the downbeat. However, a purposeful thigh movement seems to be pointless.

CONCLUSION

Analyses of temporal delays of the body segments and monofin movements tailored for swimmers according to the leg movements and also equipment used will allow elimination (or limiting) of the hip downward movement to the torso level. In effect, it will be possible to search for the optimum scope of the thigh upward movement. Insufficient swimmer's force potential to properly carry out leg movements constitutes the basis for interference in the monofin's properties to use it in the tail's downward movement. One should be focused on optimization of the monofin's hardness in points responsible for its shape and trajectory in conditions of water resistance. This means that optimization should ensure best hydrodynamic conditions (angles of attack and momentum balance).

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INTRACYCLIC VELOCITY SIGNAL AS A TOOL TO EVALUATE PROPULSIVE PHASE DURATION

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This paper examines how intracyclic velocity signals may be helpful in determining propulsive phase duration in front crawl swimming, serving, thus, as a basis for Index of Coordination (IdC) calculation. Nine swimmers performed two experimental tasks: (i) swimming with one arm at maximal speed and (ii) swimming at eight individual swim paces. Video analysis was mixed with the intracyclic velocity signal. The duration of the propulsive phase was then determined visually and using the inversion of acceleration as determined from the velocity signal. The results indicated a gap between the beginning and end of the propulsive phase as determined visually and the same propulsive phase measured from the velocity signal. Thus, the visual method gave lower IdC values. However, the adoption of one or the other method has no significant impact on the assessment of the magnitude of coordination change within swim paces. It was concluded that IdC could be calculated with or without the help of the intracyclic velocity signal.

Key words: front crawl, swimming, biomechanic, coordination, methodology.

INTRODUCTION

Chollet et al. (1) proposed a methodology to investigate changes in coordination with pace in freestyle swimming. This concept, called the Index of Coordination (IdC), is based on the determination of five key-points that delimit four stroke phases. However, these key-points are determined visually, which could introduce bias. The use of direct kinematic measurement might thus be an alternative in determining the propulsive phase duration. Indeed, in breaststroke, Seifert et al. (2) proposed the use of the intracyclic velocity signal to determine the beginning of the propulsive phase. In this case, the swimming phase was considered propulsive when the acceleration signal became positive. In front crawl, the methodology of Chollet et al. (1) assumes that arm propulsion continues up to the hand's exit from the water. However, experimental data from Schleihauf (4) showed that propulsive forces are not applied until the end of the underwater phase, and that an additional non-propulsive phase named "exit" occurs. It thus seems that the methodology of Chollet et al. (1) may overestimate the duration of the propulsive phases, although the impact of this potential methodological bias has not yet been investigated. Once again, data from intracyclic speed variations may provide a useful tool for increasing the precision of visually determined values. Indeed, when the application of propulsive force stops, the swimmer faces resistances that imply speed reduction, or negative acceleration. The aim of this study was thus to determine how data from intracyclic velocity might help in determining the duration of the propulsive phases. We then sought to quantify any differences in IdC values obtained by the two methods, i.e., one with, and one without the intracyclic velocity signal.

The tested hypotheses were:

— the propulsive phases determined by the method of Chollet et al. (1) and the phases of positive and negative acceleration do not correspond;
— the gap between the beginning of the pull (method: Chollet et al., 1) and the beginning of the positive acceleration is due to a persistent higher intensity of active drag;
— The gap between the hand's exit from the water and the end of the acceleration phase does not depend on swim speed.

METHODS

Nine swimmers of national and international levels (7 men, 2 women; 20.3±2.1 years) performed two experimental tasks. Firstly, they swam 25 m at maximal speed with only one arm. Secondly, they performed eight swim trials over 25 m at the speeds corresponding to those adopted for different competitive distances. We thus differentiated between swimming speed (in m.s^{-1}) and swim pace, which corresponded to the mean speed adopted for specific race distances (from 3000-m to maximal speed on 25 m).

Arm stroke phases
The arm stroke was divided into four distinct phases, similar to those presented in the front crawl study of Chollet et al. (1): *entry and catch* of the hand in the water (entry of the hand into the water and the beginning of its backward movement), *pull phase* (time between the beginning of the backward movement of the hand and its entry into the plane vertical to the shoulder), *push phase* (time between the positioning of the hand below the shoulder to its exit from the water), and *recovery phase* (time between the exit of the hand from the water and its following entry into the water).
The duration of each phase was measured for each stroke with a precision of 0.02 s and was expressed as a percentage of the duration of a complete arm stroke. The IdC was calculated as the mean time gap between the end of the push phase for one arm and the beginning of the pull phase for the other arm, and expressed as a percentage of total swim stroke duration.

Video-velocity system
Video analysis was synchronized with a swim speedometer (Fahnemann 12 045, Bockenem, Germany). The swimmers wore waist belts connected to an unstretchable cable driving an electromagnetic angular velocity tachometer in order to analyze the evolution of intracyclic velocity variations, at a sampling rate set at 100 Hz. The resistance applied to the swimmers' forward displacement was 10N. The lateral view of the video and the video timer were associated with the instantaneous velocity curve read on the computer. For each subject, three to four complete strokes were filmed and analyzed. The time between the measured positive and negative acceleration of the hip was quantified with the swim speedometer (fig. 1) and compared with the duration of the propulsive phase obtained with the visual method. Then, the gap between the beginning of the pull phase and the beginning of positive acceleration, as well as between the hand's exit and the beginning of negative acceleration, was quantified. Three swimming cycles were analyzed per trial.

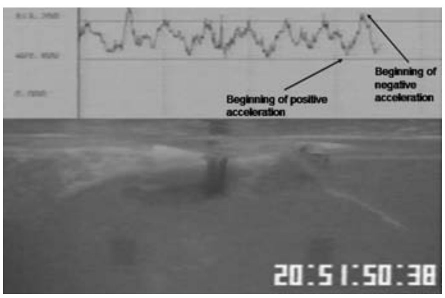

Figure 1. Moment of the change in acceleration with intracyclic velocity signal.

Statistical analysis
For all variables, a normal distribution (Ryan Joiner test) and the homogeneity of variance (Bartlett test) were verified and allowed parametric statistics (Minitab 14, Minitab Inc., 2003). Two-way ANOVAs (pace, 8 levels; random factor: subject, 9 levels) were used to determine the pace effect on swimming speed, IdC, and the temporal gaps between visual and intracyclic velocity determination of propulsive phase. Then, the mean values of IdC obtained on the basis of three methods [(i) speedometer: intracyclic velocity signal only, (ii) Chollet: visual determination only, and (iii) visual-speedometer: beginning of pull determined visually and end pull phase with beginning of negative acceleration] were compared with one-way ANOVAs. Last, one-way ANOVAs compared the standard deviations of IdC obtained with the three methods. For all tests, the level of significance was set at $P < 0.05$.

RESULTS
Table 1 shows the gap between the beginning of the pull phase determined visually and the beginning of the positive acceleration with a speedometer in the one-arm swimming condition.

Table 1. Temporal gap in the propulsive phase as determined visually and with the acceleration signal.

Gap between beginning of pull and re-acceleration (%)	Gap between beginning of deceleration and hand exit (%)
11.7 ± 6.6	11.2 ± 8.7

Table 2 presents the coordination parameters with swim pace, and the gaps regarding the beginning and end of propulsive phases using the method of Chollet et al. (2000) and the method based on intracyclic speed determination.

Table 2. Changes in speed, IdC and gaps regarding the beginning and end of the propulsive phase determined visually vs. speedometer, with swim pace.

Swin paces	spedd (m.s-1)	IdC (%)	Gap between pull beginning acceleration (%)	Gap between deceleration beginning-hand exit (%)
25	1.72±0.11	-2.8±4.1	16.4	5
50	1.69±0.11	-3.2±4.3	16.3	5
100	1.6±0.16	-7.3±6.8	14	7.5
200	1.56±0.16	-8.2±6.9	10.2	6.1
400	1.56±0.09	-8±4.5	8.6	6.1
800	1.46±0.12	-10.9±5.3	7.5	6.6
1500	1.43±0.12	-11.5±5.9	5.5	7.6
3000	1.35±0.11	-11.8±6.3	7.2	6.2
	*	*	*	*NS*

**: significant difference with $p<0.05$ NS: no significant difference*

Table 3 shows the mean values of IdC from the eight swim paces calculated on the basis of three different methods.

Table 3. Mean IdC values calculated on the basis of three methods.

Name of the method	Video (Chollet)	Visual+ speedometer	Speedometer
IdC (%)	-9.5±5.9	-15.2±6.7	-21.5±5.3
Difference	a, b	b, c	a, c

a: significant difference with visual+speedo method; b: significant difference with speedometer method; c: significant difference with chollet method $p<0.05$

The standard deviations of IdC with swim pace (SD IdC) are listed in table 4. This compares the SD IdC of the three methods of calculating IdC.

Table 4. Comparison of standard deviations of IdC calculated with three methods.

Methods	SD IdC
Chollet	4,1±1,6
Visual-speedometer	5,3±1,7
Speedometer	4,2±1,6
	NS

NS: non significant difference

DISCUSSION

In the first part of the experiment, the swimmers were asked to swim with only one arm, thus with only one source of propulsion. The results showed a temporal gap between the beginning of the pull phase (visual determination) and the beginning of the positive acceleration measured with the swim speedometer, as well as between the hand's exit from the water and the beginning of deceleration. In the latter case, the gap can be easily explained by the end of the hand's application of propulsive force, in accordance with the experimental data from Schleihauf (4). Our data indicate that the method of Chollet et al. (1) may overestimate propulsive phase duration, once it assumes that propulsion ends at the hand's exit from the water.

Two hypotheses can explain the gap between the beginning of the pull phase determined visually and the re-acceleration signal:

— either the catch phase duration is visually underestimated

— or the propulsive force generated during the catch phase is of lower intensity than the drag force that the swimmer suffers during the same phase.

In this last case, the beginning of the pull phase might have corresponded to the beginning of propulsive force application, even though its magnitude was not high enough to create positive acceleration.

To determine which of these hypotheses was correct, we tested whether the temporal gaps in visual vs. speedometer propulsive phase determination changed with swimming speed. Eight swim paces were performed by the swimmers, according to the methodology proposed by Chollet et al. (1). The changes in IdC across these swim paces was in accordance with previous studies (1, 3). Moreover, our results indicated that the gap between the beginning of the pull phase (determined with the method of Chollet et al., 1) and the positive acceleration increased significantly with swimming speed. It thus seems that the swimmers drag, once it grows with swimming velocity, required the propulsive forces to be high enough to produce positive acceleration.

The same methods were applied to quantify the gap between the hand's exit and the beginning of negative acceleration. Table 2 shows that this gap did not significantly change with swim pace, having, thus limited methodological impact.

We also evaluated the impact of adopting different methods to calculate IdC. Table 3 shows the results of a comparison of the method of Chollet et al. (1), the method using only the intracyclic velocity signal, and an intermediate method that used visual determination of the pull beginning and the speedometer signal to assess the end of the propulsion. The results showed that the method had a significant effect on the IdC value. The more intracyclic velocity data were used, the lower the IdC was. In agreement to our hypothesis, the methodology from Chollet et al. (1) seems to overestimate the IdC by 5.7 to 12%. In this case, the superposition model proposed by Chollet et al. (1) may be questioned. However, the analysis of the standard deviations of IdC for the different swim paces indicated that the magnitude of the measured adaptations did not statistically differ between the three methods. In this case, it seems that these three methods of determining IdC can be used to estimate the magnitude of a swimmer's adaptation to changes in swim pace.

CONCLUSION

The combination of visual determination for the beginning of the pull phase and intracyclic speed signals for the end of the push phase appears to offer an interesting opportunity to better assess propulsive phase duration, thus resulting in a more precise value of IdC.

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THE BREASTSTROKE START IN EXPERT SWIMMERS: A KINEMATICAL AND COORDINATIVE STUDY

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This study used a video camera to compare the kinematics and coordination of the grab start in one international and eight national breaststroke swimmers at the 100-m pace. The kinematical analysis assessed the durations of leave block, flight, entry and glide, pull-out phases, and the swim up to 15 m. The coordination analysis assessed the time spent with the arm close to the thigh after a complete arm pull-push and the time gap between the end of the arm recovery and the beginning of the leg propulsion. The international swimmer had a shorter 15-m start time than the national swimmers, which was explained by a shorter swim phase, more time in the underwater phase and more time with the arm close to the thigh after the pull-push of the arms. The whole population showed a superposition of two contradictory phases: leg propulsion began whereas the arms were not extended forward because their recovery was not finished.

Key Words: motor control, biomechanics, swimming starts.

INTRODUCTION

Recent studies have quantified the start time in relation to the actual swim and turning times, during competition, to assess their relative contribution to overall race performance (1, 3). The 15-m start times have been found to range from 0.8% to 26.1% of the overall race time, depending on the event (3). Most of the kinematical analyses of the start phases have focused on the reaction time on the starting blocks, and the flight and entry phases, comparing the grab with the track start (6). Although differences were noted in start techniques, Sanders and Byatt-Smith (5) emphasised that, in all cases great consideration should be accorded to the underwater phase. Indeed, Arellano et al. (1) showed that 95% of the variance in start times was explained by the glide. Cossor and Mason (3) noted a negative correlation (r=-0.734) between the underwater velocity and the 15-m start time in the 100-m breaststroke, which suggested that great velocity during the underwater phase of the start is critical to achieving high swim velocity. Although the FINA rules require that the swimmer's head break the surface of the water before the 15-m mark for the front crawl, backstroke and butterfly, the only constraint to the breaststroke is that the head must break the surface before the hands turn inward at the widest part of the second stroke. Unlike the actual swim, during which the hands cannot be brought back beyond the hip line, the FINA rules allow a complete arm and leg stroke with a push of the arms back to the thighs during the first stroke after the start and each turn. Therefore, the arm to leg coordination of the underwater start phase is different from that of the swim segment because it includes: (1) a more propulsive phase of the arms (push from the shoulder to the thigh) and (2) some glide time within the complete stroke of the arms and legs. Several recent studies have emphasised the need for high arm to leg coordination in breaststroke to minimise the propulsive discontinuities, either by reducing the glide time, or by overlapping two contradictory phases (i.e. the propulsion of one pair of motor limbs during the underwater recovery of the other pair of motor limbs) (2,4). Similarly, during the underwater phase of the breaststroke start, the arm to leg coordination is an important variable that coaches and swimmers should not neglect. The aim of this study was to analyse the kinematics and coordination of a start in breaststroke, comparing eight national swimmers with the bronze medallist of the Athens 2004 Olympic Games in the 100-m breaststroke. We hypothesised a longer underwater phase in the Olympic swimmer due to a better start technique, notably higher arm to leg coordination.

METHODS

Eight national swimmers (age: 21.3±1.7 years, mass: 75.7±2.8 kg, height: 185.3±2.9 cm, 100-m time: 66.9±1.7 s) were compared with the bronze medallist of the Athens 2004 Olympic Games (age: 21, mass: 85 kg, height: 193 cm, 100-m time: 60.01 s) during a simulation of the 100-m breaststroke event over 25 m and after a grab start. Two aerial lateral cameras (50Hz) placed at the 5-m and 15-m marks and a trolley on which an aerial lateral video camera was superposed to an underwater lateral video camera (50Hz) were video timed, synchronised and genlocked. The kinematical analysis included five phases: (1) the leave block phase, (2) the flight phase, (3) the entry and glide phase, (4) the pull-out phase (the sum of the entry and glide phase, and the pull-out phase was termed the underwater phase), and (5) the swim phase until the head reached the 15-m mark. The arm to leg coordination of the start was assessed at two key points of the pull-out phase: (1) the time gap between the arm's arrival to the thigh after the complete arm pull-push and the beginning of the arm recovery, and (2) the time gap between the end of the arm recovery and the beginning of the leg propulsion. The duration of each time gap was measured for each stroke with a precision of 0.02 s by three operators who analysed the key points of arm and leg phases using a blind technique. The absolute duration of each phase was expressed in seconds, while the relative duration was expressed in percentage of the 15-m start time. Kinematical and coordinative parameters between the international swimmer with the eight national swimmers were compared by *t*-test to the norm (the international swimmer) at $p<0.05$.

RESULTS

The international swimmer had a faster 15-m start time than the national swimmers, due to the shorter durations of the swim phase, the greater durations in the underwater phase (notably, the higher durations of glide and pull-out phases) and the greater time durations spent with the arms close to the thighs after the pull-push of the arms (Tables 1 and 2).

Table 1. Kinematical differences between international and national male swimmers.

Skill level	Leave block	Flight	Glide	Pull--out	Under-water	Swim	15-m start time
	(s)	(s)	(s)	(s)	(s)	(s)	(s)
International	0.74	0.35	2.16	2.78	4.94	1.43	7.46
National	0.75 ±0.07	0.36 ±0.07	1.55 ±0.37 *	2.63 ±0.43	4.18 ±0.57 *	3.12 ±0.77 *	8.41 ±0.52 *
	(%)	(%)	(%)	(%)	(%)	(%)	(%)
International	9.9	4.7	28.9	37.3	66.2	19.2	100
National	8.9 ±1.1	4.3 ±0.9	18.4 ±4.4 *	31.4 ±5.6	49.9 ±7.3 *	36.9 ±7.7 *	100 100

Table 2. Coordination differences between international and national male swimmers.
**: significant difference between the international swimmers at p<0.05; absolute values are in seconds (s) and relative values are in percentage of the 15-m start time (%).*

Skill level	Arms to things	Arm recovery / Leg propulsion
	(s)	(s)
International	1.08	-0.14
National	0.39±0.19 *	-0.13±0.05
	(%)	(%)
International	14.5	-1.9
National	4.6±2.1 *	-1.5±0.6

DISCUSSION

In agreement with the proportions observed by Cossor and Mason (3), the relative duration of the underwater phase of the start represented most of the international swimmer's 15-m start time, and was related to the greater relative durations of the glide and the pull-out phases. This swimmer also spent more time in the glide with the arms close to the thighs after the pull-push phase of the arms. According to Sanders and Byatt-Smith (5), these results indicate the capacity of elite swimmers to maximise propulsion and minimise drag, notably by adopting a streamlined position during the glide phase, and by monitoring the glide times. Indeed, in breaststroke, the swimmer must distribute the glide time from the entry to the beginning of the arm pull, and from the end of the arm push to the beginning of the arm recovery. In other words, the swimmer must decide when to start the arm pull and how much time should be spent in the glide with the arms close to the thighs. Normally, the glide ends and swimming begins when the mean swimming velocity has been reached. Therefore, Sanders and Byatt-Smith (5) has advised focusing on the underwater part of the start in front crawl, particularly to determine the appropriate moment to initiate the kick in turns and starts. Kicking too late leads to a loss in velocity and kicking too early wastes energy and increases drag. By digitizing the joints of the body, Sanders and Byatt-Smith (2001) proposed a method to calculate the velocity of the centre of mass, which indicates when the instantaneous velocity of the swimmer attains the mean swimming velocity, and thus when swimming should begin. This feedback can be quickly provided to the swimmer by calculating the velocity of a marker fixed, for example, on the hip (5). Based on the hip instantaneous velocity in the 100-m breaststroke of the bronze medallist of the Athens 2004 Olympic Games, Figure 1 shows the key start events for each arm and leg and the velocity differences in relation to the mean velocity (1.52 $m.s^{-1}$). The relatively long time that the Olympic swimmer spent with the arms close to the thighs may not be as effective as previously suggested because, when the video was synchronised to the speedometer (Fahnemann 12 045, Bockenem, Germany, see 2, 4), this swimmer seemed to have waited too long before beginning the arm recovery. Figure 1 show a velocity difference in comparison with the mean velocity, which decreased from -3.9% when the arms were close to the thighs to -21.7% when the arms began their recovery. The combination of too much time spent with the arms to the thighs and the high drag due to arm and leg underwater recoveries led to a velocity decrease of -93.4% as regards the mean velocity when the legs initiated their propulsion.

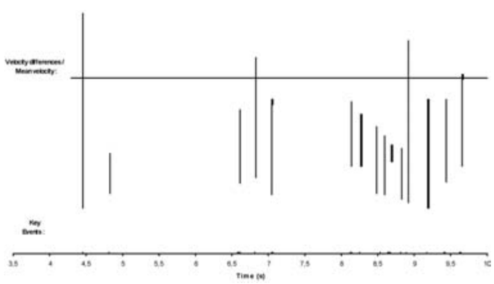

Figure 1. Velocity differences in relation to the mean velocity for the key start events of each arm and leg.

Thus, it appears to be very important to adopt a streamlined position when leg propulsion begins. However, our results showed that both the Olympic and the national swimmers had negative superposition coordination because they overlapped two contradictory phases: the end of arm recovery and the beginning of leg propulsion. Although this coordination mode can be effective in sprint events to help some elite swimmers to maintain high mean velocity (2), it was detrimental to performance in non-expert swimmers (4). Figure 1 confirmed the ineffectiveness of this arm to leg coordination for the start, because it increased a drag that was already high from the underwater recovery of arms and legs. Indeed, the velocity differences decreased from -93.4% to 100% as regards the mean velocity due to a late recovery and the extension of arms. The fact that swimmers can bring their hands back beyond the hip to the thigh during the underwater phase may explain a lack in their habit, which should be corrected to enable effective arm to leg coordination.

CONCLUSION

One of the practical applications of these findings has been the recommendation to monitor the durations of the start phases, particularly the underwater phase, especially for the Montreal 2005 World Championship, for which the FINA rules allowed a single downward dolphin kick followed by a breaststroke kick while the swimmer was wholly submerged. Thus, the glide times (1) before the downward dolphin, (2) between this leg propulsion and the beginning of the arm pull, and (3) with the arms close to the thighs, should be monitored so that too long or too short glide times in relation to the mean swim velocity can be corrected. Similarly, the arm to leg coordination during the first stroke should be monitored so that contradictory superposition that increases drag can be replaced by a more effective coordination mode.

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COMPARISON OF SUBJECTIVE AND OBJECTIVE METHODS OF DETERMINATION OF STROKE PHASES TO ANALYSE ARM COORDINATION IN FRONT-CRAWL

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The aim of this study is to evaluate the reliability of the subjective method of determination of the arm stroke phases in front crawl 1) by studying the influence of the expertise level of the operator, and 2) by comparing the phases results determined subjectively by an operator with data obtained from a digitizing process. These two methods were used to calculate an index of coordination (IdC) based on phases durations. The IdC values assessed by the novice operators were higher than those of the expert operators, due to a higher of the pull phase and to a smaller catch phase. Smaller standard deviations of IdC were observed for experts compared to novices indicating a greater reproducibility in the phases determination. No significant differences of stroke phases and IdC were observed between the results obtained from the expert operators and the digitising process.

Key Words: motor control, phases, kinematic, subjective method.

INTRODUCTION

The decomposition of the front crawl arm stroke was largely studied and determined arm phases (1, 2, 3, 4, 5, 6). Based on 3D hand kinematic analysis, the handsweeps (entry, downsweep, insweep, outsweep, upsweep) were determined by seven characteristic points of the fingertip trajectory: entry into water, maximal forward coordinate, maximal backward coordinate and exit from the water on x-antero-posterior axis, maximal outward coordinate, maximal inward coordinate on y-transversal axis, maximal depth on z-vertical axis (2, 3, 6). The arm stroke phases have also been determined from trunk-arm angles with five phases (4, 5): catch phase was from hand entry until a arm-trunk angle of 45° , pull phase occurred from 45 to 90°, push phase occurred from 90 to 135°, upsweep was from 135° to the hand exit, and the aerial recovery. Based on this last method, Chollet, Chalies and Chatard (1) proposed to decomposed a complete arm stroke in four phases (entry and catch, pull, push, recovery), which were subjectively defined in the sagittal plane from hand positions appreciated by an operator. Then, inter-arm coordination in front crawl was most of time quantified by an index of coordination (IdC), based on the time lag between the end of the push phase of the first arm and the beginning of the pull phase of the second arm (1). This subjective method is related to the expertise of the operator to recognize the key points of the stroke. This study evaluated the reliability of the subjective method 1) by studying the influence of the expertise level of the operator on the phases determination, and 2) by comparing the phases results determined subjectively by an operator with data obtained from a digitizing process.

METHODS

Comparison between expert and novice operator using subjective method

Two elite swimmers simulated two freestyle race paces (the 1500-m and the 50-m) on 25-m and were filmed by two synchronised frontal and sagittal underwater video cameras (50Hz). Six expert operators who have more than 30 hours of experience and nine pair of novice operators (i.e. eighteen operators) subjectively video-determined the hand positions of the arm stroke for three strokes of the central portion of swims. According to Chollet, Chalies and Chatard (1), the hand positions enabled to define four arm phases: 1) Entry and catch of the hand in the water: this phase corresponded to the time between the hand entry into the water and the beginning of its backward movement. 2) Pull: this phase corresponded to the time separating the beginning of the hand's backward movement and its position in a vertical plane of the shoulder and constituted the first part of propulsion. 3) Push: this phase corresponded to the time from the hand in the vertical plane of the shoulder to the hand exit of the water i.e. the second part of propulsion. 4) Recovery: this phase corresponded to hand exit to the following hand entry. The duration of the propulsive phase was the sum of the pull and push phases, and the duration of the non-propulsive phase is the sum of the entry and recovery phases. The index of coordination (IdC) is defined as the time gap between the beginning of propulsion of the first right arm stroke and the end of propulsion of the first left arm stroke, and between the beginning of propulsion of the second left arm stroke and the end of propulsion of the first right arm stroke (1). For each trial, the average IdC was calculated on three complete strokes and expressed as a percentage of the mean duration of the stroke. When a lag time occurred between the propulsive phases of the two arms, the coordination was called "catch-up" (IdC < 0). When the propulsive phase of one arm started when the other arm ended its propulsive phase, the coordination was called "opposition" (IdC = 0). When the propulsive phases of the two arms overlapped, the coordination was called "superposition" (IdC > 0).

Two sample *t*-tests were used to compare expert to novice operator phases for each swimmer and each race pace. The difference of variance between the two skill levels groups of operators for each trial was determined from *F*-tests the level of significance was set at 0.05.

Comparison between subjective and objective method

Nine elite swimmers (mean weight: 79±6.5 kg, mean height: 187±0.7 cm, mean age: 22.5±2.3 years, mean time on 100-m front crawl: 50.63±2.12 s) swam a 50-m at their maximal velocity. They were filmed by two synchronised frontal and sagittal underwater video cameras (25Hz). The subjective analysis of the hand positions was conducted as previously described, but only on one stroke and by one expert operator. For the objective method, the hand was digitised frame by frame for one arm stroke, using Schleihauf's software (Kinematic Analysis, 2004). The coordinates corresponding to the hand positions (hand entry, maximal forward coordinate of the hand, hand in the vertical plane of the shoulder, hand exit) were extracted from the smoothed 3D hand trajectory. One-way ANOVA compared the phases and the IdC obtained from the expert operator and the digitising process (P<0.05).

RESULTS

The IdC values assessed by the novice operators were higher than those of the expert operators, due to a higher pull phase duration and to a smaller catch phase duration (table 1). Smaller standard deviations of IdC were observed for expert operators compared to novice operators (table 1).

Table 1. Mean and variance differences between expert and novice operator subjective analyses.

	Expert operators				Novice operators			
	Swimmer 1		Swimmer 2		Swimmer 1		Swimmer 2	
	1500-m	50-m	1500-m	50-m	1500-m	50-m	1500-m	50-m
IdC (%)	-13±3	-3.1±2.6	-9.7±3	-9.6±3.3	-1.2±6.1 a b	4.3±3.3 a	- 2±5 a b	0.4±4.6 a b
Entry (%)	32.8±3	29.5±3.8	34.9±3.6	32.8±3.2	26.3±5.7 a b	20.3±3.6 a	25.6±5.6 a b	22.9±4.6 a
Pull (%)	15.8±2.8	22±4.2	19.6±8	17.7±3.2	28.5±6.9 a b	31.3±6.1 a	27.4±4.2 a b	28.7±6.9 a b
Push (%)	21.5±1	23.2±1.4	18.6±8.2	20.4±1.3	21±6.3 b	24.5±5.1 b	19.8±5.1 b	21.8±6 b
Recovery (%)	24±1.1	25.4±1.5	26.9±2.7	29.1±1.2	24.2±2.1 b	23.9±5 b	27.2±3.3 b	26.7±4.7 b
Propulsion (%)	37.3±3.1	45.2±4.3	38.2±3.3	38±3.7	49.5±6.7 a b	55.8±5 a	47.2±6 a b	50.5±5.7 a b

*a: significant difference of mean with expert operators (*t*-test at P<0.05); b: significant difference of variance with the group of expert operators (F-test at P<0.05).*

No significant differences of stroke phases and of IdC were observed between the results obtained from the expert operators and the digitising process (Table 2).

Table 2. Differences between subjective and objective methods.

	IdC (%)	Entry (%)	Pull (%)	Push (%)	Recovery (%)	Propulsion (%)
Objective method	-0.2±4	23.8±3.4	27.6±3.8	23.5±2.3	25.1±2.5	51.1±3.6
Subjective method	-0.6±3.8	26.2±3.4	27±4.4	23.1±2.1	23.7±3.5	50.1±3.9

DISCUSSION

The higher pull phase duration and the large standard deviations of IdC for the novice operators could be related to their confusion to determine the beginning of this phase, because for them, the phase started when the hand went downward instead of downward and backward. After discussion with the two groups of operators, the novice operators said that they focused on the maximal forward extension of the arm before going downward rather than focusing on the maximal forward coordinate of the hand before going downward and backward. Therefore, the higher pull phase duration corresponded to an overestimation of this phase that also lead to overestimate the propulsive phases and hence the IdC. These results showed the non-reliability of the subjective method for operators without experience and underlined the necessary training process to use this method. Conversely, the reliability of the visual determination of the hand positions from the expert appeared to be sufficient to evaluate the stroke phases in regard to the similar results obtained from the digitising process. Consequently, the phases determination did not automatically required the digitising method and thus allowed to minimise the time process.

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ASSISTED VELOCITY SWIMMING TRAINING IN TWO AND SIX BEATS AGE GROUP FRONT CRAWL SWIMMERS

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The aim of this study was to verify the effects of an assisted velocity training (AVT) on stroke rate (SR) and time to perform 25 m in front crawl stroke with 2 and 6 beats kicks in age group front crawl swimmers. Ten swimmers (13 to 15 years old) allocated in group 2 beats (TB; n = 5) and group 6 beats (SB; n = 5) performed, before and after 6 weeks of training, a 25 m maximal effort in front crawl. First 5 stroke cycles, after 10 m, were recorded manually, to obtain SR and time to perform the 25 m. AVT was applied twice a week. It consisted of 8 trials of 20 m (1 min rest). A 7 m length and 203 mm thickness rubber band was fixed to the pool edge and to a belt around the swimmer's waist. Subjects were towed by the coach into the 20 m to perform back in high assisted velocity. Results showed increased values just on SR for TB after the AVT. This increase in SR values has not affected the time to perform the 25 m.

Key Words: assisted swimming, stroke rate, stroke length.

INTRODUCTION

Swimming performance is closely related to the stroke kinematic parameters (4). Swimming velocity (SV) is the product of stroke length (SL) and stroke rate (SR) (6). In front crawl stroke, swimmers adopt determined number of kick beats for each stroke cycle. Two beats for each stroke cycle is a characteristic of long distance swimmers as six beats for each stroke cycle is a characteristic of short distance swimmers, and economy is a main factor for this stroke characteristic (1). Two beats swimmers usually show more difficulties to increase their swimming velocities. Under such situation, assisted velocity training could help them to increase SR, and, consequently, SV. Assisted velocity training (AVT) is a method commonly used by coaches and swimmers to increase SV, by increasing SR without decreasing SL (5). In this training method, swimmer performs the stroke towed to a rubber band, which increases his velocity. It is recognized that assisted swimming, as resisted swimming, can alter stroke's characteristics (2). So, the aim of this study was to verify and to compare the effects of an AVT program on SR and time to perform 25 m in front crawl stroke in two and six beats age group front crawl swimmers. The hypothesis formulated in this study was that AVT effects would be more present in swimmers who perform front crawl stroke with two beats, than in swimmers who perform with six beats.

METHODS

Ten age group swimmers (four female and six male; age = 13.9 ± 0.8 years old; height = 1.66 ± 0.8 m, body mass = 52.7 ± 7.4 kg; upper limb span = 1.70 ± 5.4 m), allocated in group two beats (TB; n = 5) and group six beats (SB; n = 5), participated in this study. Front crawl kick characteristics were defined by the coach. All swimmers have been participating in competitive official events for, at least, three years. Subjects performed a 25 m maximal effort in front crawl stroke before and after a six weeks training program, each time after a 1000 m swimming warm up. First five stroke cycles, after 10 m, to obtain SR, and time to perform the 25 m, were recorded with a manual chronometer. Performance (T25) was considered the time to perform the 25 m front crawl in maximal effort.
AVT program was applied twice a week (six weeks) and consisted of eight trials of 20 m (1 min rest interval). It was used a 7 m length and 203 mm thickness rubber band fixed by its extremities to the swimming pool edge and to a belt around the swimmer's waist. Subjects were towed by the coach and

assistants until they reached the mark of 20 m and then swam back in maximal velocity assisted by the rubber band.
Statistical analyses were made assuming a 0.05 significant level: Wilcoxon and Mann-Whitney Tests. Statistical Package SPSS 12.0 was used.

RESULTS
Mean and standard deviations (s.d.) of SR results for both groups, before and after AVT program, are summarized in Figure 1.

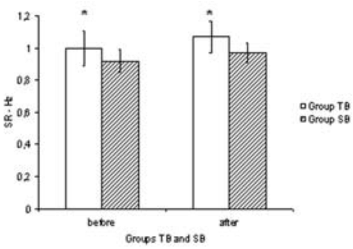

*Figure 1. Mean ± sd of stroke rate (SR - Hz) for both groups (TB – two beats; SB – six beats), before and after assisted velocity training; * indicates difference between groups for* p *< 0.05; n = 5 each group.*

For TB group mean SR values were 1.00 ± 0.11 Hz and 1.07 ± 0.10 Hz, respectively before and after AVT. For SB group mean SR values were 0.92 ± 0.07 Hz and 0.97 ± 0.06 Hz, respectively before and after AVT. The only difference found in SR was for TB group, when compared before and after AVT. No differences were found when compared the groups. Figure 2 summarizes mean T25 results for both groups, before and after AVT program.

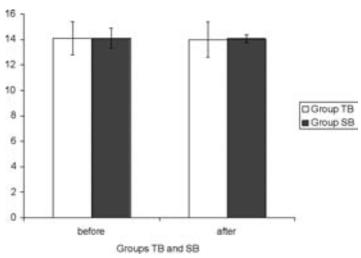

Figure 2. Mean ± sd of time to perform 25 m (s) for both groups(TB – two beats; SB – six beats), before and after assisted velocity training; n = 5 each group.

For TB group mean T25 values were 14.1 ± 1.3 s and 14.0 ± 1.0 s, respectively before and after AVT. For SB group mean T5 values were 14.1 ± 0.8 s and 14.07 ± 0.6 s, respectively before and after AVT. No differences were found in T25 when compared the values for groups or moments.

DISCUSSION
This study was planned to verify if effects of an assisted velocity training program, in swimming, would be different among swimmers who perform front crawl stroke with two and six beats kick. Both groups started and finished this study with similar SR and T25, but TB group has increased its SR values during a 25 m maximal effort. But this increased SR was not sufficient to increase performance in 25 m, which has not change after the six weeks program. Since swimming velocity is the product of stroke rate and stroke length, it is supposed that stroke length has decreased concomitantly to the increase in stroke rate in this group.
When compared to free swimming, assisted swimming has shown some distinct biomechanics aspects (6): during assisted swimming, SR and SL tend to be higher, while maximal hand depth is lower (6). It seems that there is transference of higher SR values to the free swimming after an AVT program, but it does not happen with the SL. In this study, even with higher SR values after AVT, TB group has not reached a better performance in a 25 m maximal effort. It could be explained, perhaps, by a less deep position of the hand, as a negative adaptation of the technique by the AVT. So, when swimmers are not able to position the hand in adequate depth, possibly they decrease their ascencional lift, one of the propulsion sources in swimming (1). This could, substantially, decrease stroke length (4).
The formulated hypothesis for this study has been partially confirmed: AVT program effects were more presented in swimmers which perform front crawl stroke with two beats kick. This effect was just in stroke rate and could not increase swimming velocity. Maybe a longer training program, with a special attention to stroke length, would be more effective.

CONCLUSION
An assisted velocity training program, during six weeks, for age groups swimmers, increased stroke rate in swimmers who performed front crawl stroke with a two beat kick. But performance, in 25 m maximal effort, was not increased. This training method can be detrimental to technique.

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THE IMPACT OF VELOCITY ON PULL AND RECOVERY TIMES AND AVERAGE PULL FORCE IN FREESTYLE SWIMMING

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Twelve non competitive swimmers participated in this study. The purpose of the study was to evaluate the impact of two different velocities on arm pull and recovery times, as well as to evaluate the average force applied. Force sensors, were positioned between the swimmers' fingers and were connected through cables to a computer. Participants swam two 25-meter length trials, a slow swim trial (SS) and a fast swim trial (FS), with a rest of 2 minutes in between swims. As velocity increased, stoke rate increased, stroke length decreased, and reductions in swimming (20%), arm pull (15.4 %) and arm recovery (45.7%) times (seconds) were recorded. A significant increase (62.3%) in average pull force (N) was recorded in the fast swim trial. As far as arm contribution to swimming speed is concerned it appears that pull and recovery times as well as forces exerted by the arms directly affect velocity.

Key Words: swimming, freestyle, pull/recovery times, pulling force.

INTRODUCTION
To date, the time space variables of armstroke in freestyle that have been extensively studied as determinants of speed, are stroke rate and stroke length. Relatively little attention has been drawn on the impact of pull and recovery times and forces exerted by the hands underwater on performance. In limited studies arm recovery times have been reported, with data demonstrating that the non-propulsive phase seems to be a key factor for better performance (6, 7). Stroke rate and stroke length are very often the only variables mentioned in connection to speed when other arm variables may contribute equally or even greater on speed and acceleration. The relationship of stroke length to stroke rate has not provided definite guidelines since it greatly depends on the distance and the intensity of the effort swam and creates certain difficulties for training applications. Researchers suggest that an optimum combination, without however reaching maximum or minimum values, of both stroke rate and stroke length would appear to produce the fastest swims (2, 5). It also appears that the longer the distance, the lower the velocity the longer the length of the pull and the lower the stroke rate (3). The impact of other arm pull characteristics such as speed of pull and/or recovery on speed, as well as forces exerted during fast and slow swim trials have drawn little attention perhaps due to the difficulty of data collection. However, due to the advancement of aquatic equipment coaches, trainers and investigators nowadays can obtain information for their swimmers that in the past could have only been performed in well equipped laboratories. It is necessary to focus on parameters that affect performance, such as the ones in our study in order to provide coaches with measurable indices that can help them evaluate swimmers' progress.
The purpose of this study was to investigate the contribution of pull and recovery times and average force on swimming velocity.

METHODS

Table 1: Anthropometric characteristics of swimmers (mean ± SD).

	Male (N=3)	Female (N=9)
Age (years)	21.66±0.57	21.77±0.58
Height (cm)	186.00±1.41	170.33±5.29
Body mass (kg)	83.66±2.49	62.55±5.71
BMI ($Kg.m^{-2}$)	24.17±0.87	21.60±2.07

Twelve, non-competitive swimmers participated in this study. Subjects' characteristics are presented in Table 1. All subjects were University students and trained 4 times per week in a scheduled swimming course and swam an average of 2850±245 meters per session. Arm pull characteristics and forces were measured by a hydrodynamic measuring device incorporated in a portable laptop (Aquanex by swimming technology research, Inc., Florida, Tallahassee, USA).
Prior to entering the water, cables with RSU Type A sensors (Aquanex, Florida, Tallahassee, USA) were secured with elastic bands from the back of the swimmers' waist to their fingers and were connected to an interface and a laptop computer (Picture 1). The force sensors were placed between the swimmer's third and fourth finger from the back of the hand on both hands. The cables were secured with a strap worn around the wrist and the upper arm and also looped under a belt that was worn around their waist. The cables led from the swimmer's waist to the side of the pool, to the interface, perpendicular to the direction of the swim to keep the cables free of the kicking action. The laptop was powered by a battery in order to eliminate any risks of electrical shock or injury to the participants. The swimmers entered the water without a dive and performed two consecutive 25 meter trials with a 2 minute rest in between the trials at two different velocities. The slow swim was relaxed and easy (warm-up pace) (SS) and the fast swim (FS) was at their fastest perceived velocity.

Figure 1. Preparation of the swimmer by securing force sensors prior to water entry.

RESULTS
The increase in velocity of the fast trial produced the expected results in certain variables. As a result of increasing velocity, swimming times decreased (20%), stoke rate (strokes per second) increased and stroke length(yards per stroke) decreased as expected (table 2).

Table 2. Stroke rate, stroke lenght and stroke count at two velocities.

VARIABLE	SLOW SWIM	FAST SWIM	P
Swimming Velocity yds /sec	0.48±0.05	0.60±0.07	P<0.0001
Stroke Rate (strokes/sec)	1.04±0.09	1.48±0.12	P<0.0001
Stroke Length (yds/stroke)	0.47±0.05	0.40±0.04	P<0.05
Stroke Count (strokes)	20.54±3.12	23.61±3.12	P<0.05

The average pull time and the recovery times of the FS were shorter than the SS (table 3). However, the decrease in pull time of the FS was of a magnitude of 15.4% when compared to the SS while the decrease of the recovery time interestingly was of a magnitude of 45.7% when compared to the SS freestyle. The average force (N), and the swimming velocity (yds/sec) were greater in the FS. Also a significant increase (62.3%) in average pull force (Newton) was recorded in the fast swim trial (Table 3).

Table 3. Arm Pull and Recovery times and Average force at two speeds.

VARIABLE	SLOW SWIM	FAST SWIM	P
Trial Time (sec)	21.10±2.50	16.90±2.20	$P<0.0005$
Average Pull Time (sec)	0.91±0.17	0.77±0.12	$P<0.05$
Free Recovery Time (sec)	1.03±0.28	0.56±0.12	$P<0.0001$
Average Pull Force (N)	18.05±8.10	28.96±13.30	$p<0.01$

DISCUSSION

Great emphasis has been placed on the effects of stroke rate and stroke length on velocity and generally stroke rate increases while stroke length decreases with increasing velocity (1). However, no attention has been drawn to the contribution of speed of pulling and recovery on velocity. The important finding of this study was that in the freestyle swim, the increment of speed of the recovery phase was much greater (45.7%) than the increment of speed of the pulling phase (15.4%) during the fast swim in freestyle. It appears as was also evidenced in other studies focusing on breastroke, that the non-propulsive phase is a key factor for better performance (2). Takagi et al, have suggested that swimmers must avoid rapid deceleration during the non-propulsive phase by adopting a low resistance posture and stroking technique (7). Boons et al also have also noticed a limited deceleration during the first arm recovery phase of the undulating breastroke style as opposed to the flat style, perhaps basically due to reduced drag which in turn affects velocity. (6) There aren't any other studies reporting the effect of speed of arm recovery, i.e. the non-propulsive phase, in relation to other determinant of speed in freestyle. Speed is a result of the product of applied power in relation to time according to Newton's Law of acceleration, thus even if the relationship of stroke length to stroke rate indirectly reflects changes in velocity, the power applied under water may be a major determinant of speed and its fluctuations attained by swimmers (4). In this study speed was affected by the, increase in stroke rate which was accompanied by a decrease in stroke length. This was in agreement to the existing literature one of the determinants of the increase of velocity (3). However, the great increase in power evidenced during the pulling phase cannot be regarded secondary but of equal or even greater importance to its effect on speed. The average increase of power during the pulling phase was accompanied by a decrease in the average pull time during the 25 meters of fast crawl swimming. Thus, on the basis of our results a faster, shorter and more powerful pulling phase with a considerably even faster arm recovery time appear to be the major determinants of the increase in velocity. The impact of stroke rate to stroke length upon velocity needs to be reevaluated taking into consideration changes in the average force of pulling and the time(sec) of pulling and recovery of each armstroke. As it appears from the data the increase in swimming velocity in freestyle may be generated by a greater pulling force and an acceleration in the arm recovery time (table 3). Further studies need to elucidate whether the increase of stroke rate and the decrease in stroke length, are primary or secondary to force changes and fluctuations in arm pull and recovery times.

CONCLUSION

Since speed and high level performance are considered the goals of most swimmers training at a higher level, it is also very important for the coach and the swimmer to realize the determinants of performance. A great performance is equally affected by physiological and medical parameters as well as technical and biomechanical ones. Very often, after swimmers appear to have mastered an efficient stroke, coaches do not systematically re-evaluate the efficiency of their stroke but focus mainly on physiological adaptations. However, fatigue is multidimensional and can be manifested in the face of either poor training practices or poor technique and failure of the coach to realize the swimmer's weaknesses. The emergence of advanced technical tools, however, could offer the coach and the athlete greater insight on stroking and kicking assessment and evaluation. Also, underwater video analysis depicting the various pull phases parallel to the measurement of force and stroke characteristics could provide ample information for the study of efficient performance (fig. 2). Propulsion can be greatly affected by the way forces are exerted under and over the water by both the upper and lower limbs and further research is necessary to establish measurable guidelines for every stroke. This study, was an attempt to use easily accessible and applicable to the coach and swimmer devices and study the pulling determinants of speed in freestyle. Further research, will combine the impact of leg action to overall speed as well as the measurement of overall efficiency of swim through respiratory gas analysis in relation to arm force and stoke characteristics. Also the determinants of speed for every stroke (i.e. butterfly, backstroke, breastroke, and freestyle) as far as forces exerted and stroke characteristics need to be separately evaluated.

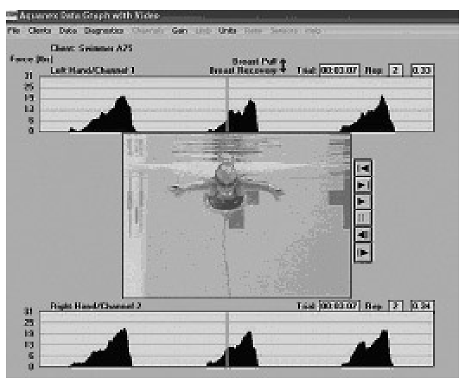

Figure 2. Sample data of force curves in combination to video stroke analysis.

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THROWING WITH DIFFERENT KINETIC CHAINS

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Overarm throw is determined by a so called proximal-to-distal principle (9). Our concept of studying kinetic chain was to gradually add the active muscles in the throwing kinetic chain, and measure the throwing velocity. Doing so, the contribution of the newly added muscles to the final velocity of the ball can be estimated. As kinetic chain was prolonged from P1 to P3 position, the throwing velocities increased with both normal and heavy ball. However, in water throw (P4) normal ball velocity was additionally increased while in heavy ball decreased, very likely due to insufficient leg/pelvis stabilization in water during heavy ball throw. On individual basis, players playing in different positions (driver, center-forward, goalkeeper) had different velocity increase due to changed kinetic chain.

Keywords: overarm throw, water polo, kinetic chain, throwing velocity.

INTRODUCTION
Ability of throwing a ball with high velocity is an important factor of performance for water polo players. An individual's maximal throwing velocity depends on optimal throwing mechanics and body segments characteristics. Overarm throw is determined by a so called proximal-to-distal principle (9). This principle has been observed in various sport throwing movements – baseball pitch, handball, javelin throw, tennis serve and water polo throw. Proximal-to-distal principle describes progressive contribution of the body segments to the momentum of the throwing object, beginning from the base of support and progressing through to the hand/ball. Because of the constant mass of the ball or other throwing objects, the change in momentum corresponds to the change in throwing velocity. Using computer simulation (1) it has been reported that there is an optimal delay between the activation of the more proximal muscle corresponding to the more distal one. If the delay is shorter than optimal, the throw is completed sooner, and less time is available for contraction of the proximal muscle which then does less work. If the delay is longer than optimal, less time is available for the contraction of the distal muscle, which, therefore, does less work (2).
Beside proper muscle activation, other factors can influence throwing velocity. Elastic energy stored by muscles contracting eccentrically, and myotatic reflex, also contributes to powerful concentric contraction, therefore generating higher acceleration (stretch-shortening cycle). Skilled throwers are able to move the arm through greater range of movement, and into more extreme positions, compared to less skilled throwers (8), which results in applying force, and accelerating the ball, over a higher distance, and enhancing greater ball velocities.
Until now, proximal-to-distal principle has been mostly studied using kinematical analyses and electromyography. Our concept of studying kinetic chain was to gradually add the active muscles in the throwing kinetic chain, and measure the throwing velocity. Doing so, the contribution of the new added muscles to the final velocity of the ball can be estimated.

METHODS
Seven Slovenian national team water polo players (26,9 ± 5,1 years, 192,1 ± 5,5 cm, 97,6 ± 6,7kg), all skilled throwers, participated in the study. After explained the nature and the purpose of the study, they all signed a written form of consent. Subjects were asked to throw the ball with dominant arm with maximum velocity three times in four different body positions: (ascertains were irrelevant?)
P1: subject seat on a chair, so that the trunk (chest) was fixed on the back of a chair. This position allowed the subject to throw the ball only with the arm;
P2: subject seat on a chair, so that pelvis was fixed on a chair. This position allowed the subject to rotate the upper trunk while throwing the ball;
P3: subject stand with the opposite leg stepped forward. This position allowed the subject to fix legs at the base of support (floor) and rotate the pelvis while throwing the ball;
P4: subject threw the ball from the basic floating water polo position in the water.
Throws were executed with two balls of different weight – normal (N) water polo ball (0.43 kg) and 3 kg medicine (H) ball. The ball was thrown in the direction of a 5 m distant radar (Speed Check Personal Sport Radar, Tribar Industries, Quebec, Canada), which measured the velocity of the ball. Radar was positioned behind the net of a water polo goal, which protected it from the impact. The radar was positioned in front of subject's right shoulder, approximately at the height of the release of a ball, to enable its most direct (optimal) path to the radar. The throws were executed without faints, like penalty throws in water polo. The highest velocity of three throws was used for further analysis. Basic descriptive statistics and ANOVA were conducted.

RESULTS AND DISSCUSION

Average values of ball velocities, and comparison between normal and heavy ball velocities are presented in Figure 1. In all positions throwing velocities with normal ball were greater than with heavy ball. The highest average normal ball velocities were detected in a P4N position, 77.3±4.3 km/h (21.47 m/s). The velocities in a P3N positions were slightly lower (but not statistically significant). The highest velocity measured was 84 km/h (23.3 m/s) in a P4N position, which corresponded to other references where values from 15 – 20.2 m/s (3, 4, 5) and maximum 25.8 m/s (10) were reported. The highest velocity of a heavy ball was measured in a standing P3H position – 40.0 ± 3.3 km/h. On the contrary to normal ball throws, the heavy ball velocities measured in a P4H position were significantly lower than in a P3H.

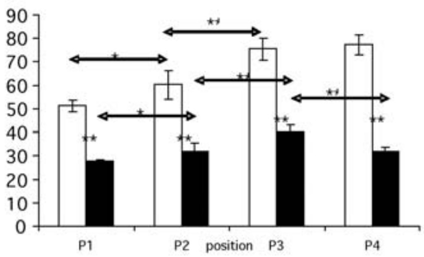

*Figure 1. Comparison between normal (white) and heavy (dark) average ball velocities. *p<0.05, **p<0.01.*

Increasable throwing velocity from P1 to P3 supports proximal-to-distal principle in throwing both balls. More muscles are activated in throwing kinetic chain, more energy is transferred from joint to joint and higher final velocity of the ball is achieved. There are no statistically significant differences between P3N and P4N. Because subjects were not familiar with any throwing positions except P4N (in the water), the lack of experience/training on the obtained velocities in P1, P2 and P3 positions can be rejected. Expressing the ball velocities as percentage of a P3 (P3 position was 100 %), throwing the ball with arm only (P1) resulted in a 68% and 70% of the referent maximum velocity of the ball, for normal and for the 3 kg ball, respectively (fig. 2). By activating the trunk muscles (P2), the average ball velocity increase was 11 % (P2N) and 9 % (P2H), respectively. In standing position (P3N and P3H) the velocity was further increased by 20 %.

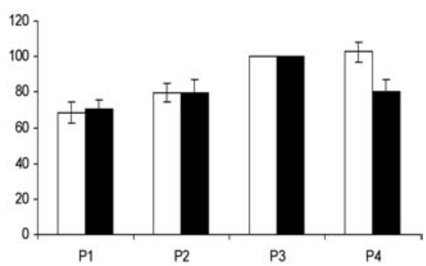

Figure 2. Comparison between normal (white) and heavy (dark) average ball velocities, expressed as percentage of a P3.

However, in water throw (P4) normal ball velocity was additionally increased for 3%, on average (no statistical significance), while heavy ball throwing velocity decreased significantly for 20%. Very likely, this happened due to insufficient leg/pelvis stabilization in water during heavy ball throw, where greater forces are produced. While throwing normal ball, players were capable of fixing the pelvis and therefore the normal function of upper trunk and arm were enabled. Theoretically, increased pelvis and upper torso velocities would allow more momentum to be transferred from the trunk to the throwing arm, and ultimately to the ball, leading to the increased throwing velocities (6, 7). Using legs properly in the water, players enable stable position similar to the base of support on dry land. This stabilization seemed to fail when throwing heavy ball. The highest correlation between P2H and P4H (r = 0.92) showed on smaller pelvis/leg action involvement in heavy ball water throws. This data underlines the importance of proper leg work when throwing in the water.

The N/H throw velocity relationship $[(v_{norm}/v_{heavy})*100]$ did not change in first three positions and therefore showed no dependence on the length of the kinetic chain (fig. 3). Every position actually represents different throwing technique, because new (more) muscles were added to the kinetic chain. This showed that throwing technique might be independent on the ball weight when throws were performed on dry land. However, this might not be true for throws in the water.

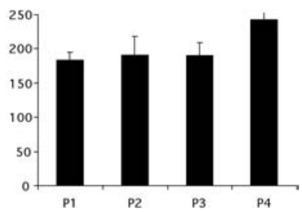

Figure 3. Velocity coefficient between normal and heavy ball.

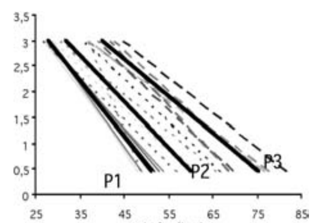

Figure 4. Force-velocity relationship for each subject. Bold lines represent mean relationship for each position.

Connecting the velocities of H and N ball, we can present the force-velocity relationship. Steeper line is assumed to be more on the left side of the force-velocity curve representing greater relative load. Since in every position stronger muscles were added, the same balls became relatively lighter. We believe that non-systematic differences were due to individual characteristics and specific adaptation, which was a consequence of long term specific training. Figures 5 in 6 show ball velocities increase for all subjects for N and H ball respectively. Subjects are arranged on the basis of the maximal P3N throw. Similar patterns (except subject C) of ball velocity increase from P1-P3 can be observed for both normal and heavy ball. The player who threw the ball with the highest velocity was able to increase ball velocities from P1 to P4 most proportionately with both the normal and heavy balls. On an individual basis, it could also be observed that players playing in different positions (driver, center-forward, goalkeeper) had different velocity increases profiles due to changed kinetic chain. With longer kinetic chain, center-forward and goalkeeper were not able to perform throws with such velocities as players playing in field position. This could be explained with conditional and technical specificities of goal-keepers and center-forwards. Goalkeepers normally do not perform throwing with maximal velocities (shots), and center-forwards perform throws from positions near the goal using, most of the time, rather different techniques than overarm throw.

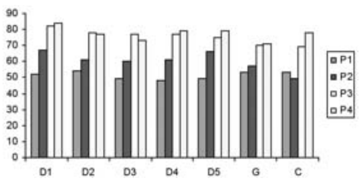

Figure 5. Normal ball velocities for all subjects. D1..D5-drivers, G-goalkeeper, C-center-forward.

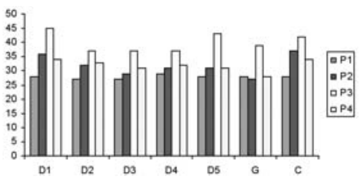

Figure 6. Heavy ball velocities for all subjects. D1..D5-drivers, G-goalkeeper, C-center-forward.

CONCLUSIONS
It is concluded that method of adding muscles to the active throwing kinetic chain provide important information for water polo players in order to characterize their throwing performance.

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ESTIMATION OF THRUSTS GENERATED BY EACH BODY PART DURING UNDERWATER DOLPHIN KICK USING "SWUM"

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It is important to understand the dynamics of the entire human body during swimming, but measurement of the fluid force of a self-propelled human body is extremely difficult. A simulative model of human swimming "SWUM" (SWimming hUman Model) incorporates dynamics of the entire human body. This study is intended to use the simulation model to calculate the thrust generated by each body part during underwater dolphin kick. First, an outline is described for the simulation model. Second, the methods of measuring input data for the simulation model are described. Third, methods to recreate dynamics on the simulation are described. Consequently, the dynamics of the underwater dolphin kick were recreated through the simulation. Results showed that the feet mainly generate thrust during the underwater dolphin kick. Furthermore, both increased thrust and drag are important for faster swimming because greater thrust generates greater drag.

Key Words: Fluid dynamics, dolphin kick, simulation model, thrust.

INTRODUCTION
It is important to understand the dynamics of the entire human body during swimming for proper evaluation of swimming motion because swimming motion is a movement of the entire body in water. Nevertheless, a quantitative method of unsteady fluid forces affecting each body part during swimming has not been established yet because humans change their posture during propulsion through the water. For that reason, a simulation model of human swimming, SWimming hUman Model (SWUM), was developed to incorporate the dynamics of the entire human body during swimming (1). This study calculates the thrust generated by each body part during swimming

using the simulation model. In this study, the underwater dolphin kick was taken as an object of this study because swimming motion is symmetric and simple.

METHODS

Outline of SWUM

In SWUM, the entire body is represented as a series of elliptic cylinders whose radius can vary along the axial direction. Three unsteady fluid forces (added mass, F_a; resistive force for normal direction, F_n; resistive force for tangential direction, F_t), buoyancy and gravity all act on the elliptic cylinders. They are computed from the shapes and densities of the elliptic cylinders and the joint motions as relative body motions for one cycle. These computed forces provide six degree-of-freedom absolute motion of the entire body as one rigid body from equations of motion for the human body. The simulation yields the swimming velocity and angular motions of roll, pitch, yaw, etc.

Input data

The input data for the simulation are the shapes and the densities of the elliptical cylinders and joint motions as relative body motion for one cycle. This study measured these input data in one well-trained male swimmer (Masters world-record holder). The human body was represented as 21 elliptical cylinders. Lengths of the major and minor axes and the height of each elliptic cylinder were measured in the subject's body shape. The weight of each elliptic cylinder was computed using a mass ratio (2) and the subject's body weight. Then the density of each elliptic cylinder was computed from the weight and the volume of each elliptic cylinder.
Joint motions as relative body motions for one cycle were measured in an underwater dolphin kick with two different velocities (slow and fast), as determined by the subject's intention. Swimming motions were recorded on video recorders (WV-PR9; Sony Corp.) at each trial using two synchronised cameras (TK-C1381; Victor Inc.) that had been positioned to take underwater images. Co-ordinates on the right side of the body were calculated using three-dimensional DLT method. The co-ordinates on the left side of the body were computed from right-side data, assuming that underwater dolphin kick motion was symmetric. Only joint motions of the sagittal plane were incorporated into the simulation in this experiment because the underwater dolphin kick motion mainly comprised the rotation in the sagittal plane.

Identification of fluid coefficients

To recreate the dynamics of the underwater dolphin kick motion on the simulation, three fluid coefficients, used to calculate the three unsteady fluid forces (F_a, F_n, F_t), were identified as slow and the fast trials. The combination of the three fluid coefficients was determined to fill differences in the swimming velocity changes for one cycle between simulated values using measured input and measured values by motion analyses. After identification of the fluid coefficients, the fluid forces acting on the human body were simulated. The thrust generated by each body part was analysed.

RESULTS

Figure 1 shows the subject's body represented by 21 elliptic cylinders applied the measured subject' body shapes. Figure 2 shows stick pictures of underwater dolphin kick motions analyzed from motion analyses and animations of the elliptic cylinders applied those motions and the subject's body shapes. By adapting the measured input data to the 21 elliptic cylinders, the subject's body geometry and the underwater dolphin kick motions were recreated in the simulation.
At both slow and the fast trials, the simulated velocity changes for one cycle almost corresponded to the measured ones (Fig. 3). The swimming velocity increased at the extension phase of the knee joints and decreased at the preparation phase of the next downward kick motion at both trials. As Fig. 4 shows, the thrust generated by the entire body nearly corresponded to the value generated by the lower limbs. During the slow trial, the thrust generated by the lower limbs was generated almost entirely by the feet. Moreover, the trunk with the head, also contributed to the thrust. Along with slow trials, the thrust generated by the entire body closely corresponded to the value generated by the lower limbs, and the thrust generated by the lower limbs was almost entirely generated by the feet during the fast trial (Fig. 5). However, the trunk with the head did not contribute to the thrust. During both trials, the thrust reached a maximum value at the extension phase of the knee joints. The maximum thrust of the fast trial (665 N) was almost twice that of the value of the slow trial (371 N). The minimum thrust of the fast trial (-247 N) was smaller than the value of the slow trial (-163 N). This results shows the maximum drag of the fast trial was greater than the value of the slow trial because negative thrust means drag.

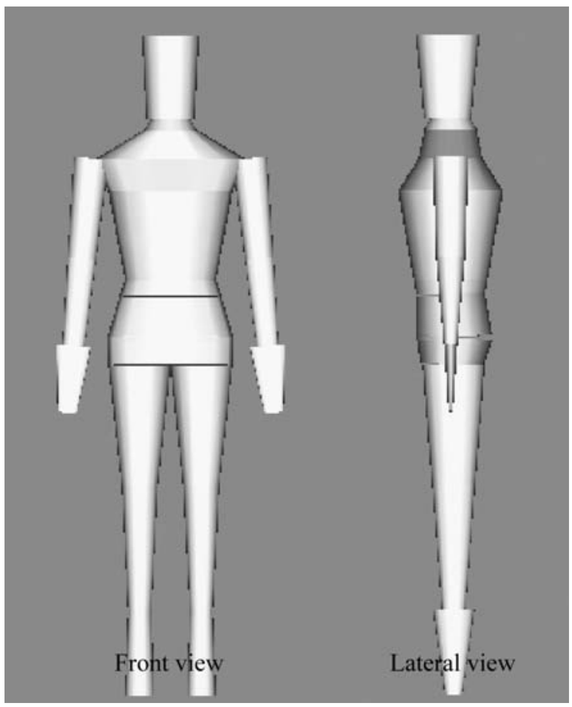

Fig. 1. Subject's body represented by 21 elliptic cylinders. The entire body is divided as follows: head, neck, shoulder, upper breast, lower breast, upper waist, lower waist, upper hip, lower hip, right upper arm, left upper arm, right forearm, left forearm, right hand, left hand, right thigh, left thigh, right shank, left shank, right foot, and left foot.

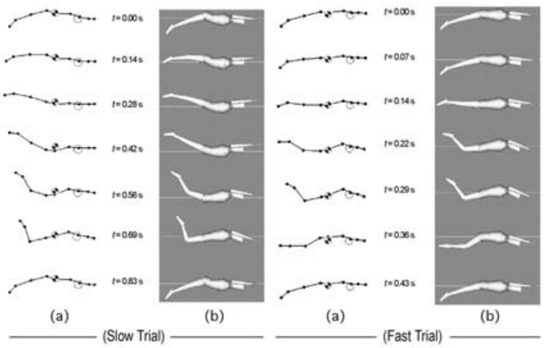

Fig. 2. Stick figures (a) of underwater dolphin kick motions (slow and fast trials) drawn from motion analyses and animations (b) of elliptic cylinders that applied those motions. The required time of the underwater dolphin kick motion for one cycle is 0.83 s during the slow trial and 0.43 s during the fast trial.

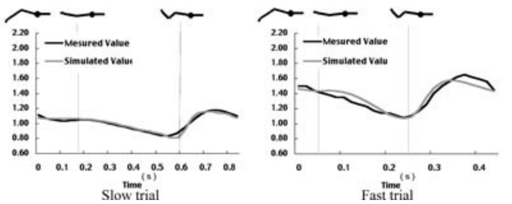

Fig. 3. Velocity changes for one cycle (slow and fast trials). During the slow trial, the mean measured swimming velocity was 1.01 m/s; the mean swimming velocity simulated using the identified coefficients was 1.02 m/s. During the fast trial, the mean measured swimming velocity was 1.36 m/s; the mean swimming velocity simulated using the identified coefficients was 1.37 m/s. The stick figures above the graphs show the phase of the underwater dolphin kick motion.

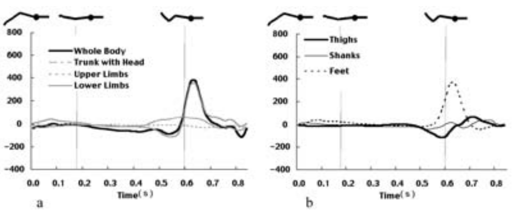

Fig. 4. Contribution of each body part to thrust for one cycle during the slow trial. The left graph (a) shows the respective contributions of the entire body, the trunk with the head, the upper limbs, and the lower limbs to the thrust. The right graph (b) shows the respective contributions of the thighs, the shanks and feet to the thrust.

DISCUSSION AND CONCLUSIONS

The subject's body geometry and the underwater dolphin kick motions were recreated through the simulation by adapting the measured input data to the 21 elliptic cylinders. The simulated velocity changes for one cycle almost corresponded to the measured one at both slow and the fast trials. Results showed that the dynamics of the underwater dolphin kick were recreated on the simulation through identification of the fluid coefficients. That simulation verified that feet mainly generated the thrust of the underwater dolphin kick. In addition, by increasing the swimming velocity, both the maximum thrust and drag were increased. As expected, both increased thrust and drag were important to swim faster because generating greater thrust was attended by generating greater drag.

Further research should examine how joint torque is generated and how it contributes to thrust during the underwater dolphin kick. Moreover, analytical methods that can determine the best dolphin kick motion suitable for each swimmer's figure can be established using this simulation model. Results can be used to instruct swimmers and their coaches, facilitating faster swimming.

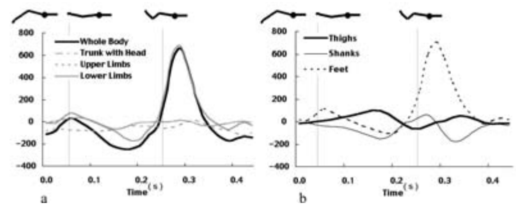

Fig. 5. Contribution of each body part to thrust for one cycle during the fast trial. The left graph (a) shows the respective contributions of the entire body, the trunk with the head, the upper limbs, and the lower limbs to the thrust. The right graph (b) shows the respective contributions of the thighs, shanks and feet to the thrust.

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WHAT ARE THE DIFFERENCES BETWEEN GRAB AND TRACK START?

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This study was intended to explain the difference in kinematic characteristics between a grab start and a track start in competitive swimming. The starting movement was modeled using a pendulum model. The take-off velocity (V_t) was resolved to a rotational component (Vr_t) and an extensional component (Ve_t). The Vr_t of the track start was higher than that of the grab start, although Ve_t of the grab start was higher than that of the track start. A swimmer with a track start would be able to generate the high Vr_t through the large moment of vertical force acting on the rear foot about the center of gravity. In contrast, swimmers using the grab start would be able to generate high Ve_t because the foot placement is in the same position on the front edge of the starting block. The take-off velocity of the grab start is higher than that of track start because of the great contribution of Ve_t to take-off velocity. In addition, the rotational displacement of the track start around the front edge of the starting block was small. Therefore, the track-start block time was shorter than that using the grab start.

Key Words: swimming start, grab start, track start, pendulum model.

INTRODUCTION

The grab start and track start are major starting techniques of competitive swimming. Numerous studies have compared both starts (1, 2, 4, 5, 6). Differences in their kinematic characteristics are that the take-off velocity of the grab start was faster than that of the track start, whereas the block time of the track start was shorter than that of the grab start (3-5). Most studies have concluded that no difference exists between these starts in terms of the start performance time (1, 2, 5, 6).

The number of swimmers using the track start has increased recently. It is important for swimmers to know the kinematic characteristics of both starts to allow rational selection of either the grab start or track start. Nevertheless, the differences in kinematic characteristics between both starts have not been explained adequately.

The apparent difference between both starts is the placement of feet on the starting block at the set position. With the track start, the swimmer's foot placement is open and back and front; one foot is on the edge of starting block and the other foot is behind its foot. With the grab start, both feet are in a similar position on the front edge of the starting block. Such feet placements are inferred to be attributable to the respective kinematic characteristics of both starts. This study is intended to explain the differences between both starts according to foot placement on the starting block.

METHODS

In the experiments of this study, 12 elite college competitive swimmers (age=20.4 ± 1.0 yrs, height=178.4 ± 5.7 cm, weight=70.2 ± 6.5 kg) participated. They were separated into two groups according to their type of starting technique (grab: $n = 6$ or track: $n = 6$). After a warming-up period, each subject performed a maximal effort trial of each starting technique. Starting movements of subjects were recorded from a sagittal view using a high-speed camera at 125 fps. Video images were taken, and then stored in a personal computer. Kinematic variables were calculated using 2D-DLT method with motion analysis software (Frame Dias 2 version 3; DKH, Japan).

Modeling

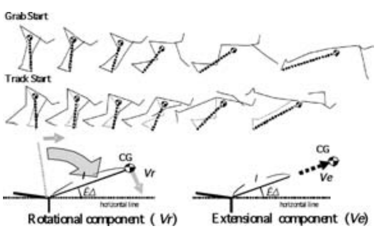

Figure 1. The pendulum model diagram. The starting movement was modeled as a movement including the rotation of segment l around the front edge of the starting block (rotational component: Vr*) and expansion-contraction of segment l (extensional component:* Ve*). The body angle (θ) represents the angle between the segment l and horizontal line.*

In this study, starting movements were modeled using a pendulum model. In this model, swimmers were depicted by segment *l*, which is the center of gravity (CG) connected with the front edge of starting block. The starting movement comprised rotational movement around the front edge of the starting block, and expansion-contraction of segment *l*. Figure 1 shows a diagram of this model. The velocity vector of CG was resolved to the rotational component (*Vr*) and the extensional component (*Ve*).

Definitions of kinematic variables

The block time was measured from the starting signal until take-off, which was defined as the time of swimmer's foot leaving the starting block. The body angle (θ) was defined as the angle between segment *l* and the horizontal line. The respective body angles at the set position and take-off were θ_s and θ_t. The take-off velocity (V_t) was the magnitude of resultant velocity vector of CG (V) at take-off. The rotational component (*Vr*) and the extensional component (*Ve*) were calculated from the following equations (i). In addition, *Vr* and *Ve* at the take-off were expressed respectively as Vr_t and Ve_t.

$Vr = -l\theta$

$Ve = l$ (Eq. i)

The take-off angle (Φ) was defined as the angle between the take-off velocity vector and the horizontal line. The flight distance was the horizontal distance from the wall on the water surface to the entry point of CG.

Data smoothing and statistical analysis

Coordinate data were smoothed using a second-order Butterworth digital filter; with cutoff frequencies determined for each subject based on the horizontal velocity of CG after take-off until water entry became constant (6–8 Hz). Statistical analyses of the grab and track starts were performed using a non-paired *t*-test ($P<0.05$ was inferred as significant).

RESULTS

Mean values and standard deviations of each kinematic variable are shown in Table 1. Block time was significantly shorter for the track start. No significant difference existed between the groups in take-off velocity (V_t) ($P=0.11$). Vr_t was significantly faster in the track start and Ve_t was significantly faster in the grab start. θ_t was significantly larger in the track start. Figure 2 showed changes of the mean velocity of CG (*V*), *Vr* and *Ve* until the take-off in grab and track start. The x-axis is the normalized time to assume the mean block time of the grab start as 100%. Regarding the patterns of velocity change until take-off, after increment of *Vr*, *Ve* increased.

Table 1 Comparisons of kinematic variables between grab and track start.

		Grab start (n=6)		Track start (n=6)		
		Mean	±SD	Mean	±SD	
Block time	sec	0.78	0.03	0.71	0.05	*
V_t (Take-off velocity)	m/s	4.38	0.13	4.26	0.11	
Vr_t (Rotational component at the take-off)	m/s	1.99	0.11	2.56	0.05	**
Ve_t (Extensional component at the take-off)	m/s	3.91	0.12	3.42	0.12	**
Flight distance	m	3.25	0.20	3.15	0.10	
θ (Take-off angle)	deg	-1.6	4.1	-3.4	1.6	
θ (Body angle at the set position)	deg	95.1	2.5	99.0	5.6	
θ (Body angle at the take-off)	deg	24.7	3.7	33.4	1.4	**

*: Significant difference between grab start and track start. ($P<0.05$)

**: Significant difference between grab start and track start. ($P<0.01$)

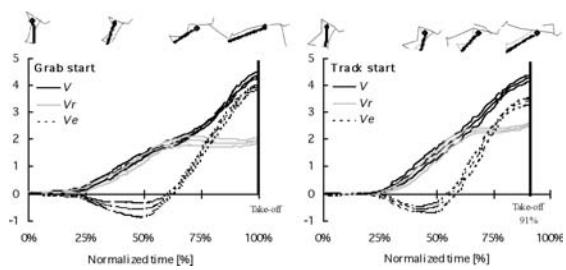

Figure 2. Changes of velocity of CG (V), Vr and Ve for the grab (left) and track start (right). Each velocity was plotted as a mean (thick) ± SD (thin). The normalized time was the percentage, assuming the block time of the grab start was 100%. The mean block time of the track start corresponded to 91% of the normalized time of the grab start.

DISCUSSION

Using the pendulum model, the swim-starts can be explained as a movement composed of rotation (*Vr*) and expansion-contraction (*Ve*) of the segment *l*. Rotation of segment *l* was caused by the moment of forces that the body received from the starting block (fig. 3). When the body angle (θ) was less than 90 degrees, vertical forces would generate the moment about the center of gravity, which tends to sink the head, whereas horizontal forces would generate the moment that tends to elevate the head.

Results of this study show that the track start was superior to the grab start in Vr_t (grab: 1.99 ± 0.11 m/s, track: 2.56 ± 0.05 m/s). It was therefore deduced that the moment in the track start was larger than that of the grab start. The apparent difference between both starts was the foot placement on the starting block. In the track start, swimmers generate greater moment of vertical force acting on the rear foot ($Fy_{rear\text{-}foot}$) because the moment arm of $Fy_{rear\text{-}foot}$ about the center of gravity is greater (fig. 4b). In contrast, it would be difficult to generate a moment of vertical forces acting on the feet (Fy_{feet}) in a grab start because of the shorter moment arm of Fy_{feet} about the center of gravity (fig. 4a).

In relation to Ve_t, the grab start was superior to the track start in Ve_t (grab: 3.91 ± 0.12 m/s, track: 3.42 ± 0.12 m/s). The expansion-contraction of segment *l* depends on pushing off the starting block using the legs. It would be difficult for the track start to push off the starting block strongly using the lower limbs in comparison to the grab start because of the foot placement. The rear foot in the track start was not on the front edge of the starting block, so the horizontal force acting on the rear foot depends almost entirely on the frictional force to the surface of the starting block. Consequently, the track start was inferior to the grab start in Ve_t. Ultimately, the take-off velocity of the grab start was higher than that of the track start because Ve_t contributed a greater deal to take-off velocity. Although there was no significant difference between both starts in take-off velocity, this suggestion would be supported by literatures reporting on take-off velocity of both starts (3, 5).

The block time would be associated with the body angle at take-off (θ_t), which indicates the angular displacement of θ until take-off. As a result, the θ_t of the track start was larger than that of the grab start, but no significant difference existed between both starts in the body angle at the set position (θ_s). This lack of difference indicated that the angular displacement of θ from the set position to take-off was smaller than that of the track start. Therefore, a shorter block time of the track start resulted from the small angular displacement of θ and the higher *Vr*. In the pendulum model, θ_t, Vr_t and Ve_t were factors to determine the take-off angle (Φ). This relationship is expressed by following formula (ii).

$$\Phi = \theta_t - \arctan\left(\frac{Vr_t}{Ve_t}\right) \qquad \text{(Eq. ii)}$$

The arctangent of track start was larger than that of the grab start because of the higher Vr_t and the lower Ve_t. Therefore, the θ_t of the track start was larger than that of the grab start. Even if a swimmer using a track start would take off at the same take-off angle (Φ) as that of the grab start, the angular displacement of θ until take-off would become small (fig. 5). Consequently, the block time of the track start might be shorter than that of the grab start.

The difference between the techniques is attributable to foot placement, especially the rear foot on the starting block. The rear foot in the track start was inferred to contribute to generation of high *Vr* and lower angular displacement of θ than that of the grab start.

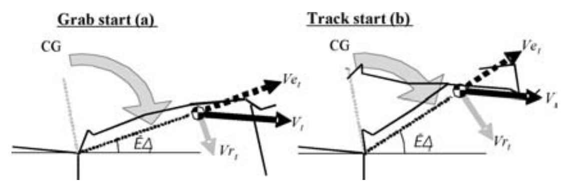

Fig. 5 Stick-pictures of grab (a) and track start (b) at the take-off. The body angle at the take-off (θt) in track start was large because of a great contribution of the rotational component (Vrt) to the take-off .velocity (Vt), if the take-off angle were equivalent.

CONCLUSION

In the track start, the great contribution of rotational component (*Vr*) by the rear foot leads to a lesser angular displacement of the body angle (θ) until take-off, thereby shortening the block time of the track start. In the grab start, the great contribution to the extensional component from pushing off of both legs engenders the high take-off velocity. It might be necessary in future studies to analyze the starting movement using kinetic data, and to verify the implications of this study.

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INTRACYCLE SPEED AND COORDINATION VS FATIGUE IN SWIMMING

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Intracycle speed variations have been widely studied. However, few studies have focused on the fatigue effect on such intracycle speed in freestylers. The aim of this study was to analyse such effects. Hence, a synchronized speedmeter connected with a video camera was used and 17 swimmers were recorded with and without fatigue conditions. A complete cycle, four phases average speed and arms coordination were analysed in both conditions. There is a correlation of the average speed with phases 1 and 3 speed in both genders with and without fatigue. Also phase 2 speed in male and phase 4 in female swimmers are related to the average speed with fatigue. Coordination is related to the phase 4 in female swimmers with fatigue. Summarizing, the whole analysis of the partial speed and the coordination index gives us relevant information about intracycle kinematic responses of freestyle swimmers.

Key Words: intracycle speed, fatigue, coordination index and freestyle.

INTRODUCTION
The analyses of the speed variations carried out within a swim cycle provides information about the way in which the different phases of the cycle contribute to the swimmer's movement (2). The unequal application of the propulsion forces and the resistance forces to the advance is the cause of the changes of acceleration and, as a consequence, of the fluctuation of the speed during a complete swim cycle (4). Interaction between both generates fluctuations of the intracycle speed (5). A coordination index is used to evaluate freestyle coordination. This index is focused on the position of the upper limbs (3). For the study of the intracycle speed, 4 phases can be established in freestyle swimmers (6). Before and after appearing the muscular fatigue to a maximum intensity, the average speed of the complete cycle diminishes, the times of propulsion of the propulsive phases increase and differs neither in the percentage variations of the maximum and minimal speed, nor in the coefficient of variation of the speed (1). The aim of this study is to establish a model of changes of intracycle speed in freestylers in efforts of maximum intensity with and without fatigue and its relation with swimming coordination.

METHODS
Sample: 17 national level swimmers (10 males and 7 females) aged between 14 and 16. Equipment: In order to record the intracycle speed, a JLML MV-30m speedmeter was worn by the swimmers through a belt and wire. The sample frequency was 1000Hz. Such record was synchronized to an underwater video camera. The image registered to a frequency of 50 Hz. The synchronization of both signs is marked by a common base of times generated by the measuring computer. The video camera was located at 15 meters off the start line, and in a perpendicular way at a distance of 5 meters to the swimmer's movement. Intracycle velocities record protocol: swimmers performed two series at maximum speed. The first over a distance of 25m was considered "without fatigue" condition (A), while the second one over a 100m distance was as "with fatigue" condition (B). There was a break of about 10 seconds between the first 75m and the last 25m so as the swimmer could have the belt attached. There was a 10 min rest between first and second conditions. A complete cycle of the swimmer was selected as he was passing in front of the camera, about 15 meters from the start in both series ("with fatigue" and "without fatigue"). Data report: Each cycle was divided in four phases from the video pictures (table 1). The cycle was divided on the basis of the propulsive actions performed, so the insweep of an arm does not coincide with the propulsive action of the other arm. However, the upsweep and the downsweep do coincide in some instants with the opposite arm propulsive actions. Therefore, phase 1 coincides with the right arm insweep and phase 3 with the left arm insweep. Phases 2 and 4 start with the upsweep of one of the arms and finish with the downsweep of the opposite arm. The index of coordination (IC) was used for the evaluation of the coordination. This index is a percentage value on the total time of a complete cycle and there is zero when the end (purpose) of the propulsion of an arm with the beginning of another one coincides. IC is negative in case of a delay (dead time). It is positive if there exists overlapping of the actions of both arms (3). The dependent variables were: cycle length (CL), cycle frequency (CF), cycle index (CI), speed of cycle (V) and index of coordination (IC) as well as the average speed, and the speed of each one of the phases (Sph1, Sph2, Sph3 and Sph4). The statistical analysis was with the statistical package SPSS 11.5 and consisted of a descriptive analysis (comparison of related samples and independent samples) and of a correlational analysis (Pearson correlation coefficients) for the variables above mentioned.

Table 1. Phases selected for the analysis intracycle.

	phase 1 (insweep right arm)	phase 2	phase 3 (insweep left arm)	phase 4
Start phase	Final of the downsweep right arm	Start of the upsweep right arm	Final of the downsweep left arm	Start of the upsweep left arm
Final phase	Start of the upsweep right arm	Final of the downsweep left arm	Start of the upsweep left arm	Final of the downsweep right arm

RESULTS
The table 2 shows the differences between the dependent variables CF (cycles/minute), CL (meters/cycle), CI (CL*V), V (meters/Second) and IC (%). According to the type of series, both male and female swimmers obtain significant differences in CF, V and CI. According to gender, in A series the significant differences are obtained in the CL, V and CI. In the B series only significant differences are obtained in V and in CI between genders.

Table 2. Differences between the dependent variables CF, CL, CI , V and IC.

	Male					Female				
	Set	N	Mean	sd	p	N	Mean	sd	p
CF	A	10	56.87	4.29	0.000	7	54.75	6.78	0.002
CF	B	10	48.89	4.85		7	45.37	7.29	
CL	A	10	1.78*	0.12		7	1.60*	0.26	
CL	B	10	1.76	0.12		7	1.60	0.23	
S	A	10	1.68**	0.07	0.000	7	1.43**	0.09	0.001
S	B	10	1.42**	0.09		7	1.19**	0.13	
CI	A	10	3.02**	0.33	0.000	7	2.32**	0.36	0.001
CI	B	10	2.54**	0.23		7	1.85**	0.28	
IC	A	10	4.84	2.48		7	6.34	2.41	
IC	B	10	5.47	4.05		7	8.44	3.85	

Differences male-female * p<0.05 ** p<0.01

The intracycle analysis shows the differences between the average speeds in each of the phases (table 3 and graph 1). Thus, when the different speeds are compared between genders, only the Sph4 in the B series does not show significant differences. There are only significant differences between the Sph1 and the Sph2 in the B series from the analysis of the evolution of the speeds of the different phases in swimmers. In female swimmers, there are significant differences in both Sph1 and Sph2, as with Sph2 and Sph3 and between Sph3 and Sph4 in the A series. The differences found in the average speeds by phases in the A series with regard to the series B are significant in both genders.

Table 3. Statistics of the average speeds in each phase.

							Same gender and set			Same gender and set B			
							Sph2	Sph3	Sph4	Sph1	Sph2	Sph3	Sph4
	Set	Gender	N	Mean	sd	p	p	p	p	p	p	p	p
		M	1	1.68	0.09					0.000			
Sph1	A	F	7	1.42	0.10	0.000	0.004			0.001			
		M	1	1.71	0.10						0.001		
Sph2	A	F	7	1.55	0.03	0.000		0.004			0.002		
		M	1	1.65	0.09							0.000	
Sph3	A	F	7	1.41	0.10	0.000			0.032			0.001	
		M	1	1.74	0.12								0.001
Sph4	A	F	7	1.52	0.09	0.001							0.004
		M	1	1.40	0.11		0.026						
Sph1	B	F	7	1.17	0.15	0.002							
		M	1	1.49	0.13								
Sph2	B	F	7	1.26	0.13	0.003							
Sph3	B	M	1	1.43	0.10	0.000							
		F	7	1.18	0.11								
		M	1	1.39	0.23								
Sph4	B	F	7	1.25	0.20								

The correlational analysis shows that, in A and B, S has a high and positive correlation (r>0,8; p<0,01) with Sph1 and Sph3 in both sexes. In B, Sph2 for the male swimmers (r=0,8; p<0,01) and Sph4 for the female swimmers (r=0,9; p<0,01) obtain a positive correlation. In B, IC shows a high and positive correlation (r=0,9; p<0,01) in female swimmers with Sph4.

Table 4. Relationship average S and IC with S, Sph1, Sph2, Sph3 and Sph4 in female and male.

S	N	S phase 1	S phase 2	S phase 3	S phase 4	IC	S	S phase 1	S phase 2	S phase 3	S phase 4
Male $_A$	10	.84**	.55	.89**	.18	Male $_A$	0.14	0.41	-0.05	-0.13	0.02
Male $_B$	10	.84**	.77**	.96**	.24	Male $_B$	-0.02	-0.13	0.19	0.03	-0.23
Female $_A$	7	.96**	.67	.97**	.52	Female $_A$	-0.09	-0.01	0.27	-0.19	0.50
Female $_B$	7	.98**	.60	.99**	.92**	Female $_B$	0.79*	0.69	0.49	0.70	0.88**

* p< 0.05 ** p<0.01

DISCUSSION

The CL and the IC in fatigue do not differ with the values obtained without fatigue. CF, V and CI reduce their values in a significative way. This information contrasts with the reduction of CL and IC in other studies that analyze these variables at the beginning and at the end of a maximum effort (1). The difference between the results obtained with the present study can be caused due to the variability in which the swimmers response to the speed loss. The correlational analyses of these variables with the intracycle speed might facilitate information on how the best swimmers modify the CL and IC.

As for the speeds obtained in the different studied phases, the female swimmers obtain lower speeds that the male swimmers in all the phases and series, except in the phase 4 and in conditions of fatigue. Without fatigue, the speeds of the phases 2 and 4 are higher than the speeds of the phases 1 and 3. This is significant as for of the female swimmers is concerned. With fatigue, the differences between the speeds are not significant. According to these results, the changes of speed for phases that take are produced by female swimmers in the A series can only be emphasized as a repetitive pattern.

Also the losses of speed obtained in the different studied phases do respond to repetitive pattern in both genders. Concerning the changes of speed in the described phases in this study, it would be necessary to do new studies with more swimmers to determine, if so, the patterns of change of the best swimmers.

The results allow determining that the best swimmers obtain the highest speeds in the phases 1 and 3 in both series. This distinguishes the importance of these phases in the performance of both male and female swimmers. Contrary to this, only the best male swimmers have higher speeds in the phase 2 in situation of fatigue, as well as the best female swimmers obtain the higher speeds in the phase 4 in situation of fatigue. These relations in the phases 2 and 4 may occur because the best swimmers have a better balance between the propulsive forces and the resistance forces. As well as the fatigue in the worst swimmers might impede the coordination body/arms/legs in a few phases where the body rolling is maximum (4 and 5).

In this study, the IC does not change when the swimmers are fatigued. This fact contrasts with IC's decrease in other studies (1). Hereby, IC's increase obtained before diminishing speeds (3) cannot take place when the speed loss is due to a situation of fatigue as it is described in the present study. For this the IC cannot contribute with relevant information about the changes of coordination in situations of fatigue.

The correlational study of the IC with the average intracycle speeds and with the average speeds in the different phases shows that no relation exists between the best male swimmers and the type of coordination. On the other hand, in the female swimmers, the established relation indicates that the swimming improvements in situation of fatigue have a higher IC. Hereby, it is possible to indicate that the best female swimmers, with fatigue, reach major speeds due to a higher IC. Moreover, a high relation between the speed in the phase 4 and IC's values is obtained, which can emphasize the importance of supporting IC's high values in order to reduce the speed losses registered of Sf4 in conditions of fatigue. The speed of the phase 4 in conditions of fatigue does not obtain significant differences between male and female swimmers. This descriptive result might be justified by the increase of the IC in the female swimmers in conditions of fatigue and its high correlation with the speed in the phase 4.

CONCLUSION
1-When swimming without fatigue, Sph1 and Sph3 seem to be good indicators of the performance.
2-When swimming with fatigue, Sph1, Sph2 and Sph3 for the male swimmers and Sph1, Sph3 and Sph4 for the female swimmers ones are good indicators of the performance.
3-In the female swimmers, a high IC when swimming with fatigue is related to a better performance in S and Sph4. In conclusion, the whole analysis of the IC and of the Sph1, Sph2, Sph3 and Sph4, can contribute to relevant information about the most suitable type of coordination when swimming in different conditions of fatigue.

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THE RELATIONSHIP OF ANTHROPOMORPHOLOGICAL CHARACTERISTICS OF CRAWL SPRINT SWIMMERS OF BOTH GENDERS WITH CRITICAL SPEED AT 50 AND 100 M

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The aim of this work is to establish a relationship between the various anthropomorphological ($A_{nth}M_{orph}$) characteristics of crawl sprint swimmers of both genders in relation to critical speed at 50 and 100 meters (sprint distances). The research has been carried out over a sample of 13 male and 12 female swimmers in sprint crawl style. The given value of the critical speed at 50 and 100 meters was obtained by applying the mathematical modelling of Distance – Time ratio, calculated from the 15, 25, 50 and 100m distances covered in crawl style. The $A_{nth}M_{orph}$ characteristics of swimmers are evaluated over a set of eight variables: BMI, LBM, and percentage of fat, leg-length and arm-length index, the shape of the chest, the trunk and the body. With regards to men, a higher level of critical speed had those with a more pronounced rectangular shape of trunk (the same proportion of the width of shoulders and hips in relation the the body height) and a higher level of lean body mass – LBM. With regards to women, a higher level of critical speed had swimmers with a shorter arm length in relation to body height and a higher LBM.

Key Words: crawl sprint swimmers, critical speed, anthropomorphological characteristics.

INTRODUCTION
The elite results in swimming depend on a number of factors including the efficiency of the swimming technique, various functional and metabolic characteristics of swimmers and the level of training accomplishment. They also depend on a number of features of the swimmer's body (2, 8, 9). In general, besides an efficient swimming technique, that is the way swimmers move in the water, the body shape and/or the body size of a swimmer may help him to obtain a better position for a more efficient swim from the hydrodynamics standpoint. In this way, the body shape or the body size, i.e. the anthropomorphological characteristics, may contribute significantly to achieving better results. It is known that during the movement of the body in the water, the phenomenon of resistance appears. It has two basic characteristics, that is the active and passive drag forces. In general, the passive drag forces constitute themselves the hydrodynamic of the swimmer's body and could be more related to the gliding phase of swimming (2, 7, 9). On the other hand, active drag forces would be more closely related to the changes of the body position during swimming and they have three basic causes, namely: "pressure or form drag, frictional drag and wave drag" (6, 8, 10). It has been found that mean active drag force (Fd) is related to swimming velocity and demonstrates an approximately quadratic dependency on velocity. Besides, it is different for female and male swimmers (10). It is concluded that differences in the body structure, that is the body shape and size, may have a different impact on the results achieved. In other words, it can play a negative role or provide an advantage in achieving a higher level of performance.
The aim of this study is to initially establish a relation between the critical speed in swimming, as a simple indirect parameter to use in following the general efficiency in swimming (6, 8, 11) and a score of various, but not difficult for measuring and observation, antropomorphological characteristics defining the swimmer's body shape. The obtained results could also prove useful in perfecting the swimmers selection methods, and in certain aspects of the hydrodinamics of swimming.

METHODS
The research has been carried out over a sample of 25 swimmers (13 male and 12 female) in a sprint crawl style. The basic descriptive characteristics of the sample were: Male – Age=15.3±1.4 years, BH=1.754±0.079 m, BW=63.58±5.84 kg; Female - Age=14.8±1.2 years, BH = 1.612±0.064 m, BW = 49.48±7.19 kg. All of them were members of swimming clubs in Athens. The given value of the critical swimming speed (CSS) at 50 (V_{crit}50) and 100 meters (V_{crit}100) was obtained by applying the mathematical modelling of Distance – Time ratio, calculated from the 15, 25, 50 and 100m swim in crawl style (measured from the start up in one training session) (11).
The $A_{nth}M_{orph}$ characteristics of swimmers were evaluated over a set of eight variables (1):
— Morphological variables –
- body mass index-BMI (kg/m^2), lean body mass-LBM (kg), and percentage of body fat (%),
— Anthropometrical variables -

- leg-length index, calculated as a ratio between sitting height and body height,
- arm-length index, calculated as a ratio between front arm span and body height,

— Body shape variables –

- index of the chest shape, calculated as a ratio between chest depth and shoulder width (biacromial),
- index of the trunk shape, calculated as a ratio between hips width (bitrochanteric) and shoulder width (biacromial),
- index of the body shape, calculated as a ratio between hips width (bitrochanteric) and body height.

All anthropometrics and body shape variables are presented in the arbitrary units.

The results have been analyzed by applying descriptive and multiple regression analysis where the variables of the CSS represented the criteria and, the $A_{nth}M_{orph}$ characteristics represented the predictor system (5).

RESULTS

In Tables 1 and 2, the results of the descriptive statistical analysis of the sample variables are presented. In accordance with the values of the coefficient of variation (cV%) it is recognised that the all results are reliable because their variation ranges below the limit of 30% (5). For the male swimmers, the cV% is in the range at 2.65% as regards the variable of the arm-length index and 25.61% for the variable of the body fat, whereas for the female swimmers the values are from 2.55% to 25.61%, respectively.

The results of multiple regression analysis show that for male swimmers, the given $V_{crit}50$ is explained at the level of 56.85% ($AdjR^2$ = 0.5685), and statistically in a significant way (F = 4.95, p = 0.026). It was defined as a model structure by the following set of predictors: index of the body shape (t = 3.09, p = 0.015), index of the trunk shape (t = - 1.43, p = 0.188), LBM (t = 3.73, p = 0.006) and BMI (t = - 2.37, p = 0.045).

The $V_{crit}100$ is explained at the level of 57.79% ($AdjR^2$ = 0.5679), and it was defined in a significant way statistically (F=5.10, p=0.024) by the model structure of the following set of predictors: index of the body shape (t=1.32, p=0.224), index of the trunk shape (t= - 1.52, p=0.168), LBM (t=2.18, p=0.061) and the percentage of the body fat (t= -3.26, p= 0.012).

Table 1. The variable descriptive analysis of male swimmers.

	MALE swimmers (N = 13)									
	$V_{crit}50$ (m/s)	$V_{crit}100$ (m/s)	BMI (kg/m²)	LBM (kg)	% of Body fat	leg-length index	arm-length index	Index of the chest shape	Index of the trunk shape	Index of the body shape
MEAN	1.656	1.572	20.70	59.05	7.13	0.5196	1.0429	0.5150	0.8102	0.1858
SD	0.106	0.084	1.73	5.62	1.83	0.0138	0.0349	0.0349	0.0288	0.0054
cV%	6.38	5.36	8.38	9.51	25.61	2.65	2.77	6.78	3.56	2.90
Min	1.477	1.462	17.29	52.28	4.02	0.5028	1.0056	0.4512	0.7750	0.1782
Max	1.786	1.715	23.95	72.18	10.19	0.5479	1.0847	0.5732	0.8750	0.1955

Table 2. The variable descriptive analysis of female swimmers.

	FEMALE swimmers (N = 12)									
	$V_{crit}50$ (m/s)	$V_{crit}100$ (m/s)	BMI (kg/m²)	LBM (kg)	% of Body fat	leg-length index	arm-length index	Index of the chest shape	Index of the trunk shape	Index of the body shape
MEAN	1.516	1.445	18.97	41.37	15.23	0.5310	1.0402	0.5104	0.8119	0.1825
SD	0.076	0.074	2.17	4.70	3.71	0.0140	0.0245	0.0624	0.0809	0.0136
cV%	4.98	5.15	11.42	11.35	24.38	2.64	2.35	12.23	9.96	7.44
Min	1.387	1.319	14.74	31.84	8.35	0.5158	1.0127	0.4167	0.6857	0.1548
Max	1.623	1.529	21.57	47.24	22.59	0.5578	1.1056	0.6349	0.9841	0.1975

For female swimmers, the $V_{crit}50$ is explained at the level of 57.09% ($AdjR^2$ =0.5709), and it was defined in a statistically significant way (F=8.31, p=0.009) by the model structure of the following set of predictors: arm-length index (t= -3.21, p=0.011) and LBM (t =3.40, p=0.008).

The $V_{crit}100$ is explained at the level of 47.29% ($AdjR^2$ = 0.4729), and it was defined in a statistically significant way (F = 5.93, p = 0.023) by the same set of predictors, that is arm-length index (t = -3.03, p = 0.014) and LBM (t = 2.52, p = 0.033).

DISCUSSION

The results show that statistically there is a significant relationship between the crucial swimming speed in the sprint distances of 50m and 100m in sprint crawl style for both male and female swimmers and that there exist different anthropomorphological characteristics which affect a specific critical speed. In addition, the results demonstrate that there are significant differences between male and female swimmers with respect to the CSS.

As regards both critical speeds (at $V_{crit}50$ and $V_{crit}100$) for male swimmers, it was confirmed that a positive correlation between them and the body shape index and the LBM. This implies that swimmers who with a more pronounced rectangular shape of trunk (the same proportion of the width of shoulders and hips in relation the the body height) and a higher percentage of muscle mass, have a higher $V_{crit}50$ and the $V_{crit}100$. On the other hand, the negative relationship between the $V_{crit}50$ and $V_{crit}100$ and the index of the trunk (chest) shape, the BMI and % of the body fat was also confirmed. This mean that swimmers who have broader shoulders in relation to their chest depth (that is, who have a flattered shape of chest) and small BMI as well as a small percentage (%) of body fat (that is, who have a lesser body surface area) have a higher $V_{crit}50$ and $V_{crit}100$ in sprint crawl swimming.

As regards $V_{crit}50$ and $V_{crit}100$ for female swimmers the positive relationship concerning the value of the LBM was confirmed. That means that female swimmers who have a higher percentage of muscle mass have a higher $V_{crit}50$ and $V_{crit}100$. On the other hand, the negative relationship between the $V_{crit}50$ and $V_{crit}100$ and the arm–length index was also confirmed. This implies that female swimmers having short arms in relation to their body height, that is they are short-armed 0swimmers, and have a higher critical speed at 50m and 100m. In the past it was proved that female swimmers pulled deeper and narrower than male swimmers and had a lower propulsive force (4). It is well known that higher swimming velocities are mainly achieved by an increase of stroke frequency (10), especially at sprint distances (3).

It is possible, regarding the sample, that short-armed female swimmers were capable of achieving, in sprint distances, a higher swimming speed because they were managing to obtain a higher stroke frequency during the swimming.

CONCLUSION

The results have shown the existence of important differences between genders regarding the relationships between indices of $V_{crit}50$ and $V_{crit}100$ and $A_{nth}M_{orph}$ characteristics. As regards male swimmers from this sample, swimmers who attained faster critical speeds were those who had a more rectangular shape of trunk, a more flattened shape of the chest, higher LBM, lesser BMI and a lower % of the body fat. With regards to female swimmers from this sample, a higher level of critical speed at $V_{crit}50$ and $V_{crit}100$ was achieved by swimmers with shorter arms in relation to the body height, and by those who had and a higher level of lean body mass – LBM.

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CONSEQUENCES OF UNSTEADY FLOW EFFECTS FOR FUNCTIONAL ATTRIBUTION OF SWIMMING STROKES

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The purpose is to direct attention to the relation of unsteady approach and functional attribution of strokes. Swimming strokes can be executed with different modes per action, which require an answer what for is the function of a mode? The functional attribution of modes is closely related to the idea about flow conditions and its effects. Here flow is characterised by a mixture of steady and unsteady effects. In front-driven locomotion the momentum-transfer is related to effects from bound vortex (rotating water), shed vortex and the interaction between bound and shed vortex, called jet-flow which does not exist in stationary flow. Based on this, the functional attribution of actions are re-checked placing emphasis on common goals of motion mutual to all four swimming strokes, showing that appropriate flow-forms are created and organised by similar actions of the hand/arm.

Key Words: PIV-method, unsteady flow, vortex-induced momentum, action modes, jet-flow.

INTRODUCTION

Swimming strokes are means to propel the body into a desired direction. They are individual corporal motions according to men made rules, based on mental programs and powered by the organism with limited energy reservoirs. Counsilman (3) pointed out that swimmers have no alternative but to obey laws of nature. Appropriate laws will be found in the field of natural science including flow physics. Biomechanics of swimming is a field to bridge the gap between practise and science. It is the duty to give notice whenever the scientific view on motions in water changed and to provide some hints for the practise. The proceedings of the BMS-Series demonstrate the changes in understanding locomotion in water. Among others it became obvious that the unsteady nature of the flow demands more attention (to avoid misunderstandings concerning terminology: unsteady means non-stationary and steady flow means stationary flow). In an unsteady flow its effects are depending both on velocity and acceleration of the flow whereas in steady flow velocity is the only relevant parameter (again to avoid misunderstandings concerning terminology: unsteady flow is not equivalent to the notion "turbulence" and does not mean swimming in a flume). The question may arise to which extent the unsteady-flow-approach has consequences for the understanding of modes of motion, e.g. closed or spread fingers during of underwater action of arm-motion? The following approach is oriented on a theory called Functional Motion Analysis (4), emphasising that each action is closely connected to a function (this distinguishes the Functional Motion Analysis among others from motion analysis which prefers relation of action and success of the athlete). A major part of Functional Motion Analysis is called functional attribution which is the step to combine mode of action or sequences with a function. In swimming, the functional attribution of modes of actions is closely related to conception of flow conditions. A conception of flow can be "You need still water to gain more thrust" or "Apply different hand orientation to constant flow condition". Cyclic activity in water, however, creates flow which is characterised by a mixture of steady and unsteady effects. The purpose of this paper is to direct attention how the unsteady approach do affect the functional attribution of cyclic swimming strokes.

METHODS

In this chapter some aspects are presented concerning unsteady flow conditions and functional attribution, respectively. In water, corporal actions create flow conditions combined with generation of momentum (again to avoid misunderstandings concerning terminology the term momentum sometimes could mean swing or inertia when used in conjunction with the release of the hands from water like "allowing the momentum of upsweep to carry the hand upward"). Due to reciprocal interaction of body motion and motion of water momentum is created and transferred simultaneously which is called momentum-induced propulsion. Generating momentum coincides with momentum transfer (according to "actio = reactio). A problem is to produce more momentum to thrust the body ahead than momentum which slows the body down.
In unsteady flow conditions momentum generation/-transfer differs from steady flow conditions (1, 5, 6, 7, 10). Unsteady flow aspects can be studied in swimming of vertebrates somewhat easier due to the harmonic nature of body motions. Ungerechts (8) demonstrated that the spatio-temporal pres-

sure gradients (per cycle) varies locally, characterised by changing from negative to positive and vice versa which results in local flow acceleration (Fig. 1) which –in steady flow- would have disastrous effects.
In addition it was shown that the flow in the wake was set into rotation as vortex which are known as a very good means "for carrying as much momentum as possible in relation to their energy" (4). In this context we have to learn to understand the meaning that Fish create vortices, which are like teeny whirlpools, and the vortices create changes in water pressure that move the fish forward (9).

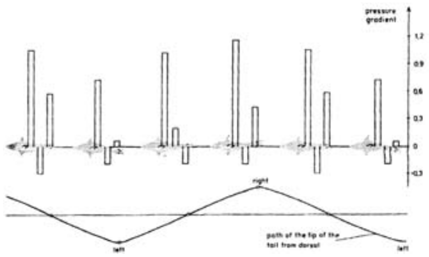

*Fig. 1. Intra-cyclic pressure gradient distribution (per cycle) of a shark model (Re = 9 * 105, Reduced Frequency Σ = 0,5).*

Unsteady flow effects found with vertebrate swimming can be in great part also applied or found to the human swimming according to Blickhan (1) as follows:— Reduction of total drag due to body undulation realised in human swimming during the underwater period after start and turns.
— Added mass supports thrust in periods of body deceleration realised in human swimming in breaststroke due to the intracyclic variation of velocity.
— Bound vortex start earlier realised in human swimming when turning action of hands are executed.
By using flow-visualisation techniques like PIV-Method in human swimming the existence of unsteady flow fields became obvious (7). Moreover it was demonstrated that propulsion is produced more effectively by vortex-induced momentum transfer. In front-driven locomotion (by arms/hands) the momentum transfer at the hand is related to effects from bound vortex (rotating water), shed vortex and the interaction between bound and shed vortex, called jet-flow; with pressure changing in time. In rear-driven locomotion (by legs and feet) vortex rings are created with the potential to create also jet-propulsion. Jet-flow related propulsion does not exist in stationary flow. The additional thrust due to jet-flow depends largely one the orientation of that jet-flow, the more the direction of the jet-flow is oriented opposite to swimming direction the more the body is pushed ahead.

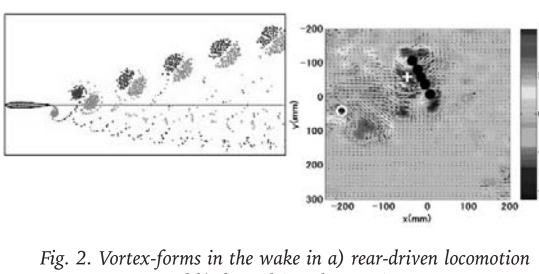

Fig. 2. Vortex-forms in the wake in a) rear-driven locomotion and b) front-driven locomotion.

In the context of competitive swimming, a consequent application of flow physics is nearly the only way to judge the solutions by transferring complex laws to functional attributions.
Attributions which are applicable in human swimming should consider the change of view due to unsteady flow approach which provides some remarkable changes as a) sources of drag and thrust are not separable in self propulsion, b) the Wagner Effect deals with the circulation which rises in steady flow slowly whereas in unsteady flow the starting vortex at the beginning of a stroke rises rapidly, c) total drag becomes a relative issue since the mass of water "How many mass a body carries per meter?" may be much closer related to the feeling of being exhausted due to swimming locomotion than to the generally quoted drag forces and d) effects due to rotation of water masses are relevant.
Functional Motion Analysis offer a frame to examine nearly every locomotion by starting to answer the following questions: a) "Under which condition the motion takes place?", b) "What is moved?", c) "Who moves what?" and c) "In which surrounding the motion takes place?" Answering these questions for motions in aquatic space a unique situation arises. The answer to "What is moved?" is ambiguous because it could either be "water mass" or "body mass". The answer to "Who moves what?" could either be "Swimmer moves water" or "Water moves swimmer". One major aspect of Functional Motion Analysis, however, is the requirement to give explicit information to what end a mode of action (or sequence) is executed, simply to answer the question "what for". This steps is called functional attribution. The attributions can be derived from different sources, however, biomechanics offer best grounds.

Consequences
In an extensive study Ungerechts and colleagues (9) listed: 1st the actions, 2nd the modes of actions and 3rd the functional attribution of each (action) mode for all strokes.

Table 1 Example of three steps of Functional Motion Analysis applied to the beginning of the underwater sequence in butterfly arm-motion.

Action	Modes of action	Functional attribution
Arms/hands sweeping	• Stretched arms are rotated	…prepare a long path to
outwards below waterline	inwards (outward rotated	"induce unsteady flow"
and backwards rotation	elbow) to	…direct the flow on th
starts	• Hands are sculled outwards	e back of the hand(s)
	and upwards; simultaneously to	creating steady flow effects

In essence, hand/fingers disturb water, inducing a flow after a certain time lag for fetching and catching water mass creating micro-vortices. During sweeping sequences, *steady* flow effects the momentum transfer whilst during the transition of the hands *unsteady* flow effects a marked increase of momentum. Finally, as a result it turned to be out that some mutual actions exist in all four strokes. Each of these actions as such are functionally alike (irrespective to the stroke considered) in two respects: anatomical-morphological and flow-related. For the arm/hand motion (upper limb) these mutual actions were as follows: a) starting the cycle with stretched arm and outward rotated elbow position, b) fingers slightly spread, c) rotation either around the long axis in crawl- and backstroke or rotation around the short axis in breast- and butterfly-stroke, d) supination of the hand (before bending elbow) in breast- and butterfly-stroke,

e) pronation of the hand (before extending elbow) in crawl- and butterfly-stroke, f) sweeping action (outward, upward, inward sweep), g) slicing action before leaving water.
In any of the four swimming strokes appropriate flow-forms are created and organised by similar actions of the hand/arm:
— Goal: creating flow around the hand(s) and arms at the beginning of the arm cycle by: fully stretched arm, fingers slightly spread, thumb abducted, shrugging shoulder(s).
— Goal: creating long path to induce unsteady flow supported by body rotation: sculling hands with nearly stretched arm, fingers slightly spread (outward and upward scull in breast and butterfly-stroke, downward sweep in crawl- and back-stoke).
— Goal: creating jet-flow by: transition motion of the hand, either supination in breast- and butterfly-stroke, followed by inward scull of hands and/or pronation in butterfly, back- and crawlstroke followed by slicing hand (extending arm during upward scull).
Irrespective of the stroke it is valid that the rotation around body axes are modulating relative velocity (at the hands) and thus influencing momentum generation. While interacting with water mass hand/arms transfer momentum to the centre of body mass (propelling the body) as follows: a low pressure in the back of the hand refrains the hand from being moved *back*wards - the body is moved *for*ward instead while self-propulsion in water means that the "propelling limbs" allow for motion on each side of the limb resulting in momentum-production and in reaction to that the proximal end is moved as well and the swimmer's body is pushed ahead.

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MOTION ANALYSIS OF FRONT CRAWL SWIMMER'S HANDS AND THE VISUALIZATION OF FLOW FIELDS USING PIV

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Flow fields around a swimmer are extremely unsteady. Top swimmers are expected to swim by using effectively unsteady flow force. A motion analysis can evaluate the unsteady motion quantitatively. In addition, PIV (Particle Image Velocimetry) can visualize the unsteady flow field. With this method, the vortex motion around a hand can be evaluated quantitatively. Our study is to clarify the relationship between the vortex behavior and the motion of a hand in crawl swimming by using the motion analysis combined with PIV. The analysis is made for two subjects; one is a male with no competitive career (subject 1) and the other a female Olympic swimmer (subject 2). It was found that the hand motion in swimming was closely related to the vortex generation.

Key Words: PIV, motion analysis, front crawl, propulsion, unsteady flow, circulation.

INTRODUCTION

Schleihauf (1) evaluated a force exerted on a hand in swimming using a quasi-steady analysis. However, swimmer's motion cannot be evaluated quantitatively by the quasi-steady analysis, because of extremely unsteady characteristics. Unsteady lift force is generally greater than steady one. Top swimmers are expected to swim by using effectively the unsteady flow force. Counsilman (2) found S-shaped pull as a result of the motion analysis for top swimmers and proposed it as an efficient one. We paid our attention to a phase turning from In-sweep to Out-sweep of S-shaped pull. Fig. 1 shows a palm trace in a horizontal plane. The flow direction is in the positive X-direction. The palm of the swimmer reverses the orientation of the circulation in the two places denoted by (α) and (β) in Fig. 1 (a). In these places, a hand gains larger propulsion by shedding a strong and large vortex by the conservation law of circulation.
A motion analysis can evaluate the unsteady motion of swimmers quantitatively on digitizing the motion of the swimmer. Fig. 1 (b) shows the definition of the angles using in the motion analysis. Let $\vec{v}$ and $\vec{u}_0$ be the hand velocity and the forward velocity of a swimmer. The velocity of hand relative to water is written as $\vec{v}+\vec{u}_0$.
We defined a palm inclination angle (θ) as an angle between the palm and the flow direction. We defined an attack angle (α) as an angle between the palm and the relative velocity, $\vec{v}+\vec{u}_0$ (3).
In addition, PIV (Particle Image Velocimetry) was used to visualize the unsteady flow field around a swimmer (4, 5). With this method, vortex motion around the hand can be evaluated quantitatively. We referred the vortex rotating clockwise to positive and the one rotating counter clockwise to negative. Our study is to clarify a relationship between the vortex behavior and the motion of the palm in crawl swimming by using a motion analysis combined with PIV.
Table 1 shows the data of the subjects. The flow velocity of a flume is set at their top speed for the subjects. The flow velocities are 0.8 m/s for subject 1 and 1.5 m/s for subject 2.

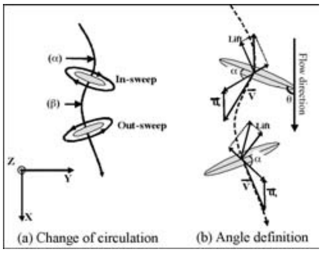

Figure 1. (a) : the position where the hand reverses the orientation of the circulation in (α) and (β). (b): the definition of the angle for the motion analysis.

Table 1. Data of the subjects.

Subject	Sex	Flow velocity(m/s)	Stature (cm)	Weight (kg)
1	Male	0.8	168	72
2	Female	1.5	166	55

METHODS

Motion analysis

Fig. 2 shows the experimental configuration of the motion analysis. It determines the geometry of the palm in space viewed from the bottom and the side of the flume installed at Tsukuba University with two synchronous high-speed cameras. Let the camera installed at the bottom and at the side of the flume be camera 1 and camera 2, respectively. The camera 1 was used in combination with a mirror inclined at 45deg. Our system can get 250 planes per second.

Several points on the hand are digitized using a video motion analysis system Frame-DIAS 2 version 3. For the image captured by camera 1, we digitized the tips of a thumb and a little finger, because we regard a segment joining the two points as a palm. For the image captured by camera 2, we digitized the tip of a third finger and a wrist, because we regard a segment joining the two points as a palm. A trajectory of the palm is calculated by connecting the digitized points at each time. The palm inclination angle was calculated from the coordinates of the thumb, the little finger and an arbitrary point drawn from the little finger parallel to the flow direction (see Fig. 1(b)) using the cosine theorem. The magnitude of the hand velocity is calculated as the average of the velocity of the middle point of the palm. The attack angle (α) is determined by the angle between the palm viewed from camera 1 and the direction of the relative velocity ($\vec{v}+\vec{u}_0$).

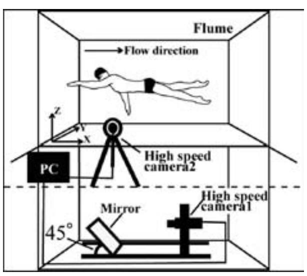

Figure 2. Experimental configuration of the motion analysis.

PIV (X-Y plane)

PIV system measures the flow velocity from the movement of tracer particles irradiated with YAG laser sheet. The laser sheet is set in the horizontal plane located at a depth of 0.6m below the free surface. The image of the tracer particles is reflected by a mirror and captured by a CCD camera set at the bottom of the flume and then the image is transferred to a computer for the determination of the velocity. The interval of the laser pulse is controlled using a pulse generator. The measurement region is set 0.5_0.5 m. Our PIV system can get 15 planes per second. Fig. 3 shows the experimental configuration for the PIV.

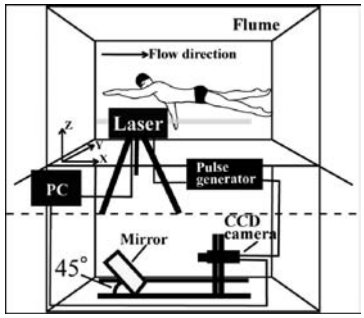

Figure 3. Experimental configuration of PIV.

RESULTS AND DISCUSSION

Motion analysis

Fig. 4 and 5 show the change of palm and palm inclination angle (θ) of the subjects 1 and 2, respectively. The left shows the digitized points of the tips of the thumb and the little finger every 4 ms. The right shows the digitized points of the tip of the third finger and wrist at the same instants as the left. The angles shown in both figures are the palm inclination angle. The flow is in the X-direction. The trajectory of the palm of the subject 2 was in somewhat S-shaped motion while that of the subject 1 was almost straight. From the palm inclination angle, we confirmed that the palm of the subject 2 reverses the orientation of the circulation in the phase turned from In-sweep to Out-sweep. From these observations, it is supposed that the subject 1 generates no vortex pair.

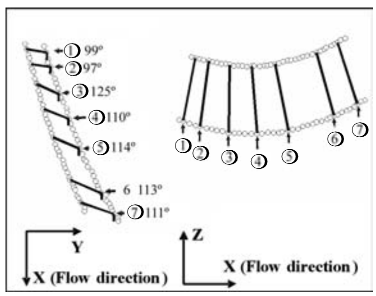

Figure 4. Change of palm and palm inclination angle of subject 1 (left: camera 1, right: camera 2).

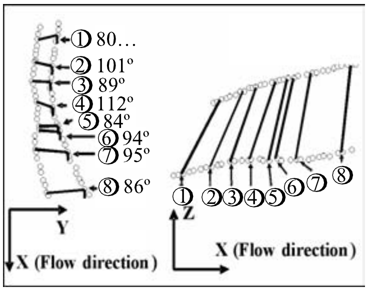

Figure 5. Change of palm and palm inclination angle of subject 2 (left: camera 1, right: camera 2).

PIV (X-Y plane)
From the data of particle positions we calculated the velocity. Fig. 6 and 7 show the velocity and vorticity distributions of the subjects 1 and 2, respectively. The gray scale on the right column of these figures denotes the vorticity measured in 1/s. In the velocity vectors shown in Fig. 6 and 7 the mean velocity have already been subtracted to clarify the vortex behavior. Two ovals denoted by dotted line show the position of the palm at the previous two planes. Fig. 6 shows that the subject 1 does not shed any clear vortices. In contrast, Fig. 7 shows that the subject 2 generates two vortex pairs after the phase turned from In-sweep to Out-sweep. In addition, the shed vortex pair produces a jet flow in the direction of the flume velocity. Hereafter, we designate the left vortex pair as vortex pair 1, the right vortex pair as vortex pair 2. Table 2 shows the characteristics of the vortex pairs. In the table, the values of the induced velocity and momentum predicted by supposing the pair as a vortex ring are listed in comparison with the experimental data. Γ, b, Ve, Vt(=Γ/b) and M(=ρbΓ) are the circulation of vortex pair, the diameter of the vortex ring, the value of jet flow velocity determined by the experiment, the values of jet flow velocity and momentum predicted as a vortex ring. These values of the vortex pair 2 are greater than those of the vortex pair 1. The increase in the diameter (b) and the circulation (Γ) resulted in the great increase of the momentum (M) from 15.6 kg/s to 22.6 kg/s

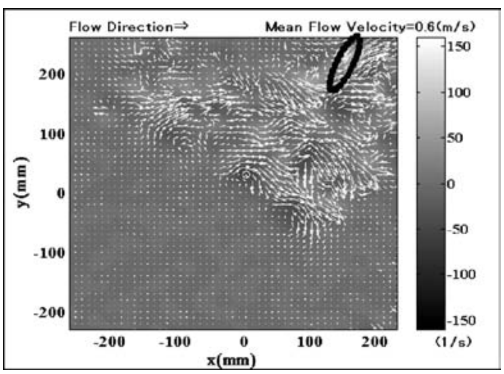

Figure 6. Distribution of velocity vectors and vorticities (subject 1).

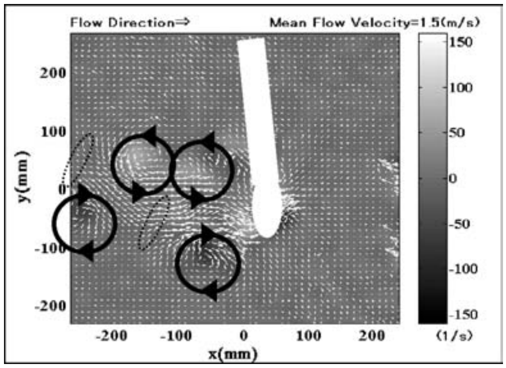

Figure 7. Distribution of velocity vectors and vorticities (subject 2).

Table 2. Characteristics of vortex pair shed by subject 2.

Vortex pair	$\Gamma(m^2/s)$	b(m)	Ve(m/s)	Vt(m/s)	M(kg/s)
1	0.13	0.12	1.0	1.0	15.6
2	0.15	0.15	1.0	1.0	22.6

CONCLUSION
We could evaluate the hand motion of crawl swimmers by the trajectory and the palm inclination angle using the motion analysis method. PIV could visualize and see the pair vortex suggested by the variations of the palm inclination angle.
We concluded that the subject 2 swam by using effectively the unsteady flow force by changing the palm inclination angle. From the motion analysis combined with PIV, it was found that the hand motion in swimming was closely related to the vortex behavior and momentum generation.

ACKNOWLEDGEMENTS
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SWIMMING PHYSIOLOGY AND BIOCHEMISTRY

INVITED CONTRIBUTION

ENERGETICS IN COMPETITIVE SWIMMING AND ITS APPLICATION FOR TRAINING

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Competitive swimming events consist of different distances from 50m to 1500m. Since the exercise intensity and the relative importance of aerobic and anaerobic energy processes vary depending on the exercise time (and thus swimming distance), training regimen should be developed in accordance to time dependent metabolic profile. To understand the time dependent metabolic profile of arm stroke (A), leg kick (K) as well as whole body (S) swimming, the accumulated O_2 uptake (AOU) and the accumulated O_2 deficit (AOD) were determined at six different water flow. The AOU increased linearly with exercise time in all strokes, and the increased rate of AOU in A and K corresponded to 70, and 80% in S, respectively. The AOD in A and S significantly increased until 2-3min of exercise time, while the AOD in K more rapidly increased and the AOD at 30 s was not significantly different from those at 1 min and 2-3min. These results concerning time dependent metabolic profile in A, K, and S, would give a helpful information to plan training successfully to improve the metabolic capacity for each stroke.
Training effects of a moderate–intensity continuous training (CT) and a high-intensity intermittent training (IT), which are the most popular training regimens in competitive swimming, on $\dot{V}O_2$max and maximal accumulated O_2 deficit (MAOD) were evaluated. After the training, $\dot{V}O_2$max increased significantly in both training modes. On the other hand, MAOD did not increase significantly in CT, but in IT. These results indicate that CT can improve only aerobic power but that adequate IT can improve both aerobic power and anaerobic capacity.
Aerobic and anaerobic energy release in supramaximal swimming lasting 2-3 min were determined under different levels of hypobaric hypoxic condition. The exercise intensity (water flow rate) decreased with decrease in atmospheric pressure. During the exhaustive swimming, rate of aerobic energy release diminished with increase in hypobaric hypoxia, while not only AOD but also rate of anaerobic energy release throughout the exercise were unaffected despite the decreased O_2 demand caused by diminished exercise intensity due to hypobaric hypoxia.
Furthermore, the effects of high-intensity exercise training under a normal condition (C) and hypoxic conditions (H) on metabolic capacity were examined. After the training, $\dot{V}O_2$max significantly increased in both N and H, and no significant difference was observed in the increase ratio of $\dot{V}O_2$max between C and H. MAOD also significantly increased in both groups, however, the increase ratio of MAOD was significantly higher in H than C. The results suggest that the hypoxic training would be favorable for the improvement of the ability to supply anaerobic energy such as MAOD rather than $\dot{V}O_2$max.

Key Words: metabolic profile, specific training effect, energy dynamics, hypoxic training.

INTRODUCTION
Competitive swimming events consist of different distances from 50m to 1500m, and it takes approximately 23 seconds to 14 minutes 30 seconds to complete swimming those distance events. The required energy to swim a certain distance is supplied by aerobic and/or anaerobic energy processes, however, the relative importance of each energy process and also exercise intensity vary depending on the exercise time (and thus swimming distance) (Medbø 1989, Ogita 1996, 1999, 2003). Therefore, it is considered that coaches and swimmers should understand metabolic profile of each swimming distance event, what is more required for the swimmer, and how to strengthen the weak point, in order to develop effective and distance specific training program. By doing so, the performance could be improved more successfully.
This paper is summarized concerning to energetics in competitive swimming and its application for training. In particular, I would like to focus on following 4 topics using some of the recent our results; 1) metabolic profile corresponding each distance event, 2) specificity of training effect to various training program, 3) energetics during swimming under a normal and hypoxic conditions, and 4) new idea of hypoxic (high-altitude) training.

TIME DEPENDENT METABOLIC PROFILE
The propulsion during whole body swimming is generated by the action of both arms and legs. Therefore, daily swimming training is conducted not only by whole body swimming but also by arm stroke or leg kicking only, because it has been considered that to strengthen metabolic capacity in local muscles would improve more effectively whole body swimming performance. Therefore, if time dependent metabolic demands of arm stroke (A), leg kick (K) as well as whole body (S) swimming are clarified, the knowledge would provide an important implication for specific training of each distance event. So, the aerobic and anaerobic energy release were determined the at six different intensities, which were estimated to cause exhaustion in 15 s, 30 s, 1 min, 2-3 min, 4-5 min, and 8-10 min simulating from 25m sprint to 800m.

Aerobic and anaerobic energy release
The AOU increased linearly with exercise time in all strokes (Fig. 1). This means that the longer the duration (and thus the distance), the larger the total amount of aerobic energy release. Also, the increased rate of AOU related to exercise duration was the highest in S, and those in A and K corresponded to 70 and 80% of that in S, respectively. The ratio was similar to those when $\dot{V}O_2$max among strokes was compared (A: 2.80 $l \cdot min^{-1}$, K: 3.34 $l \cdot min^{-1}$, S: 3.92 $l \cdot min^{-1}$). Therefore, it is suggested that the increased rate of AOU is highly dependent on the magnitude of $\dot{V}O_2$max, supporting a general concept that a higher maximal aerobic power can be a more beneficial to accomplish a good performance for the endurance swimmer.
With increasing duration, the AOD in A and S significantly increased until 2-3min of exercise, and the AOD gradually decreased when the exercise duration was longer than 4-5min (Fig. 1). The AOD at 30s was not significantly different from those at 1 min and 2-3min. Several studies used running and cycling have also reported that the AOD reached maximal levels with exercise bouts lasting 2-3 min (Medbø 1988. Medbø 1989). Actually, it was revealed that the anaerobic ATP production estimated by lactate production and PCr break down was the highest in 2-3 min exhaustive exercise (Medbø 1993). These findings indicate that both the ATP-PCr system as well as the lactate producing system are stressed maximally with 2-3 min exhaustive exercise. Therefore, it is suggested that the

anaerobic energy system is recruited maximally in 200m swimming event, and consequently maxima AOD (MAOD) is recognized as an important factor determining the performance of this event.
On the other hand, the AOD in K increased more rapidly, and reached almost maximal levels in 30 s (>90% of maximal AOD). In addition, this level was observed in bouts lasting up to 2-3 min. Therefore, it is implies that the anaerobic energy release in K is different from the other strokes and that the swimmer can induce a maximal stimulus for the anaerobic energy process in leg muscles by maximal leg kicks of 50 m to 200 m. Consequently, this stimulus would induce the improvement of the anaerobic capacity in K, due to an increase in buffering capacity of leg muscles *per se*.

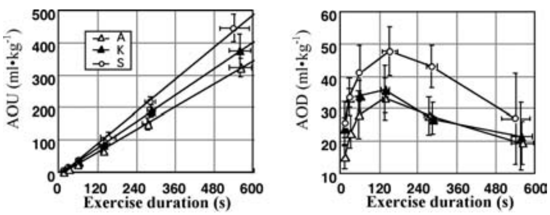

Fig. 1. The accumulated O2 uptake (AOU) and deficit (AOD) in relation to exercise duration in arm stroke (A), leg kicking (K), and whole swimming (S). (Ogita 2003)

Relative contribution of aerobic and anaerobic energy processes
The relative importance of anaerobic energy process in three strokes decreased from 78-85% for 15 s to 50 % for 1min, 30% for 2-3min where the anaerobic energy supply was at a maximum. Furthermore, it was only ~5% for 8-10min duration (Table 1). In general, short lasting exhaustive bout is recognized as so called "anaerobic exercise". However, our results reveal that even in exercise bout of 15s, the aerobic energy supply covered at least 15-20% of energy demand, while it covered more than 65% in 2-3 min bouts. Therefore, the contribution of the aerobic energy process even in short lasting bout should not be neglected. Also, the relative contribution of the aerobic and the anaerobic energy system was almost equal for 1 min exercise bouts. This suggests that both energy processes should be strengthened to improve the performance in 100m and 200m event.

Table 1. Accumulated O2 demand, uptake, deficit for exhausting bouts of different durations during A, K, and S.

		durations (s)	water flow rate (m•s-1)	accmulated O2 demand (l)	accmulated O2 uptake (l)	accmulated O2 deficit (l)	accmulated O2 deficit/ accmulated O2 demand (%)	O2 demand (%VO2max)
15s	A	14.4±0.4	1.49±0.05 **##	1.28±0.21 **##	0.27±0.07 **	1.02±0.24 **##	78.4±7.9	190±20 #
	K	14.2±1.4	1.19±0.08 **	1.91±0.34	0.26±0.07	1.64±0.21	85.9±6.2	243±23
	S	15.5±1.4	1.69±0.06	2.08±0.43	0.36±0.03	1.73±0.45	82.1±6.3	205±32
30s	A	30.7±2.4	1.42±0.04 **##	2.38±0.39 **##	0.83±0.16 **	1.54±0.34 **##	64.4±7.9	166±17 #
	K	30.0±1.5	1.09±0.05 **	3.18±0.34	0.92±0.24	2.26±0.20	71.3±6.2	191±17
	S	29.7±1.8	1.59±0.05	3.36±0.30	1.08±0.13	2.28±0.38	67.4±6.3	175±23
1min	A	58.3±2.4	1.33±0.04 **##	3.77±0.55 **#	1.85±0.19 **##	1.91±0.51 **#	50.0±8.2	138±12
	K	61.5±3.7	0.95±0.05 **	4.51±0.32 **	2.19±0.28 **	2.32±0.31	51.3±6.2	133±13
	S	61.3±3.4	1.45±0.04	5.50±0.59	2.72±0.28	2.78±0.59	50.1±7.3	138±14
2-3min	A	137.8± 8.1	1.21±0.03 **##	6.96±0.61 **##	4.71±0.36 **#	2.25±0.44 **	32.2±4.9	109±6
	K	138.7±10.8	0.88±0.05 **	8.28±1.16 *	5.84±0.90	2.44±0.49 *	29.5±5.1	107±6
	S	152.3±22.7	1.31±0.04	10.58±1.33	7.35±1.14	3.23±0.51	30.7±4.7	107±9
4-5min	A	272.7±12.2	1.15±0.04 **##	12.24±1.49 **##	10.36±1.16 **	1.88±0.40 **##	15.3±7.9	96±6
	K	284.6±11.2	0.84±0.05 **	14.81±1.72	12.98±1.28	1.82±0.53	12.1±6.2	93±4
	S	282.7±17.7	1.25±0.02	17.71±1.30	14.79±1.09	2.92±0.45	16.5±6.3	96±4
8-10 min	A	560.0±33.6	1.12±0.05 **##	23.34±1.91 **#	22.02±2.02 **##	1.32±0.45 **#	15.7±8.2	90±7
	K	557.9±33.2	0.81±0.06 **	26.96±3.08 **	25.51±3.51 **	1.45±0.70	15.6±6.2	87±2
	S	540.4±44.9	1.22±0.03	32.03±2.97	30.21±2.84	1.83±0.96	15.7±7.3	91±3

** P<0.01 vs S * P<0.05 vs S, ## P<0.01 vs K # P<0.05 vs K A : arm stroke, K : leg lick, S : whole body stroke

Exercise intensity
The relative exercise intensities expressed as $\%VO_2max$ in relation to exercise duration longer than 1 min were comparable among A, K and S, and corresponded to $135\%\dot{V}O_2max$ for the 1 min bout, $105\text{-}110\%\dot{V}O_2max$ for the 2-3 min bout, and $95\text{-}100\%\dot{V}O_2max$ for the 4-5 min bout. These results indicate that the 400m event is competed at almost $100\%\dot{V}O_2max$ level, and that the shorter distance events are done at supramaximal intensities. This finding points out that the anaerobic training should be very important for most swimmers. In addition, in the 15 s and 30 s bout, the intensity in K was much higher than those in A and S (15 s : K 240%, A 190%, 30 s : K 190%, A 165% $\dot{V}O_2max$), and the intensities in S were intermediate between A and K (Table 1). Therefore, when the training consists of 25 m or 50 m sprints, it should be heeded that the exercise intensity expressed as $\%\dot{V}O_2max$ differ between A, S and K. Conventionally, the magnitude of the training effect on metabolic capacity depends on the exercise intensity (Fox 1975). In other words, in order to improve the total metabolic capacity, adequate exercise intensity, taxing both aerobic and anaerobic energy processes, must be set. Therefore, the reported metabolic profiles (i.e. aerobic and anaerobic energy release and their relative contributions, relative exercise intensity and so on) in relation to exercise time in A, K, and S, gives helpful information to plan training successfully.

EFFECTS OF TRAINING MODES (OR INTENSITY) ON $\dot{V}O_2$max AND MAOD
Metabolic capacity has been considered to be one of important determinants of swimming performance. Therefore, the swimming training should be designed to improve the ability to release energy both aerobically and anaerobically. The most popular training regimens in competitive swimming are an intermittent (interval) training and a continuous (endurance) training. In general, the success of the training effect can and should be evaluated not only by an exercise performance but also by metabolic capacity such as $\dot{V}O_2max$ and MAOD. So, we compared the specific training effect of different training protocols: a moderate-intensity endurance training and high-intensity intermittent training.
In this study, continuous training (CT) was performed at the intensity of $70\%\dot{V}O_2max$ for 60 $min \bullet session^{-1}$, on the other hand, intermittent training (IT) consisted of 7-8 sets of 20-s exercise at an intensity of 170% $\dot{V}O_2max$ with a 10-s rest between each bout. Both trainings were done 5 days a week for 6 weeks.

The effect on $\dot{V}$O2max and MAOD
After the training, $\dot{V}O_2max$ increased from 53 to 58 $ml \bullet kg^{-1} \bullet min^{-1}$ in CT, and 48 to 55 $ml \bullet kg^{-1} \bullet min^{-1}$ in IT (Fig. 2). On the other hand, MAOD did not increase significantly in CT, but it increased by 28% in IT (Fig. 2). These results indicate that CT at moderate- intensity can improve aerobic power but not MAOD and that IT at high-intensity can improve both $\dot{V}O_2max$ and MAOD simultaneously.

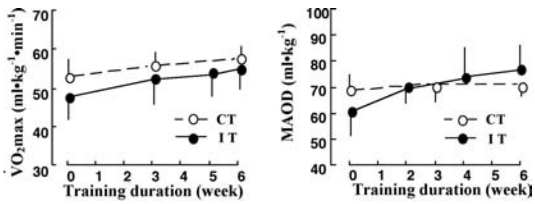

Fig. 2. Effect of moderate-intensity continuos training (CT) and high-intensity in termittent training (IT) on $\dot{V}O2$ max and maximal accumulated O2 deficit (MAOD) (Tabata 1996).

These results suggest that CT at moderate-intensity is not intense enough training to improve anaerobic power. In fact, it has been proved that the used IT training protocol can tax maximally stimulus not only to aerobic but also to anaerobic energy process but that CT at moderate intensity does not (Tabata. 1996). As previously suggested, the greater stimulus to aimed energy system, the larger improvement of metabolic capacity. Accordingly, for short to middle distance swimmers who are proposed to be strengthened both energy processes, IT at high intensity must be more adequate training mode compared to CT at moderate intensity.

ENERGETICS IN SUPRAMAXIMAL SWIMMING UNDER HYPOXIC CONDITIONS

It has been well documented that $\dot{V}O_2$max reduces with decrease in atmospheric pressure, i.e. O_2 fraction. In addition, several investigations have shown that hypoxia results in slower O_2 uptake kinetics during exercise (Engelen 1996, Hughson 1995). Since steady-state $\dot{V}O_2$ during submaximal exercise is identical between normoxic and hypoxic conditions, this means that AOD is greater in hypoxia than in normoxia (Knuttgen 1973, Linnarson 1974). Indeed, a greater reduction in muscle phosphocreatine levels and greater increases in blood and muscle lactate concentrations have been observed during submaximal exercise in hypoxia compared with normoxia (Knuttgen 1973, Linnarson 1974).

On the other hand, there are few studies that investigated the effect of anaerobic energy release during exercise, especially supramaximal bout, on hypoxia. As mentioned in the first section, to improve MAOD as anaerobic capacity is very important for most swimmers. So, we attempted to clarify the aerobic and anaerobic energy release during supramaximal exhaustive swimming lasting 2-3 min, where anaerobic energy process is recruited maximally, under different hypoxic conditions (a normal condition; 999hPa, 800 m; 912hPa, 1600 m; 836hPa, and 2400 m above sea level; 751hPa).

$\dot{V}O_2$max in each condition

$\dot{V}O_2$max was significantly reduced as atmospheric pressure decreased. Compared to mean values of $\dot{V}O_2$max at sea level (4.28 ± 0.53 l•min^{-1}), values were at 96% for 800 m (4.11 ± 0.49 l•min^{-1}), 88% for 1600 m (3.76 ± 0.44 l•min^{-1}), and 85% for 2400 m (3.63 ± 0.44 l•min^{-1}).

Aerobic and anaerobic energy release during supramaximal exhaustive swimming

Mean water flow rate in the supramaximal swimming diminished significantly with decreased atmospheric pressure. However, when O_2 demand estimated from water flow rate was expressed as a percentage of $\dot{V}O_2$max, no significant differences were observed (Table 2). This means that even though absolute exercise intensity in hypoxic condition decreased due to a decrease in $\dot{V}O_2$max, the swimmers could swim relatively at the same intensity.

Table 2. Exercise duration, water flow rate, accumulated O2 demand, uptake, deficit, for supramaximal axhausting bout lasting 2-3 min.

		Sea level	800m	1600m	2400m
Exercise durations	(min)	2.26 ± 0.15	2.23 ± 0.13	2.27 ± 0.14	2.34 ± 0.24
Water flow rate	(m•s^{-1})	1.25 ± 0.03	1.23 ± 0.02 *	1.21 ± 0.02 *#	1.19 ± 0.02 *#$
Relative exercise intensity	(%VO2max)	110 ± 7	111 ± 7	117 ± 11	115 ± 12
Accumulated O2 demand	(l)	10.67 ± 1.62	10.28 ± 1.97	10.02 ± 1.82	9.73 ± 1.98
Accumulated O2 uptake	(l)	7.30 ± 1.09	7.04 ± 1.11	6.88 ± 1.33	6.56 ± 1.15
Accumulated O2 deficit	(l)	3.36 ± 0.74	3.24 ± 0.92	3.14 ± 0.55	3.17 ± 0.99
Accumulated O2uptake/ Accumulated O2 demand	(%)	68.5 ± 4.7	68.5 ± 4.2	68.6 ± 2.3	67.4 ± 5.7
Accumulated O2 deficit / Accumulated O2 demand	(%)	31.5 ± 4.7	31.5 ± 4.2	31.4 ± 2.3	32.6 ± 5.7

* Indicates a significant difference vs normal condition ($P<0.05$).
\# Indicates a significant difference vs 800 m above sea level ($P<0.05$)
$ Indicates a significant difference vs 1600 m above sea level ($P<0.05$)

VO_2 during the supramaximal swimming quickly increased at the beginning of exercise and almost reached a plateau within 2 min in all conditions (Fig. 3). However, mean VO_2 determined every 30 s as well as VO_2peak decreased with increasing hypoxia, and thus AOU tended to decrease with increased altitude (although no significant differences were identified) (Table 2). Also decrease in VO_2peak under hypoxic conditions was quite comparable to the decrease in $\dot{V}O_2$max under each hypoxic condition. Therefore, VO_2 during supramaximal exercise also appears to be directly affected by the level of hypobaric hypoxia throughout the exercise.

Conversely, changes in O_2 deficit determined every 30 s during the bout were quite comparable in all conditions (Fig. 3). Consequently, no significant differences were observed in MAOD between the conditions. This implies that the rate of anaerobic energy release during exercise is strongly associated with relative physiological stress regardless of inspiratory O_2 fraction, although underlying mechanisms remain unclear.

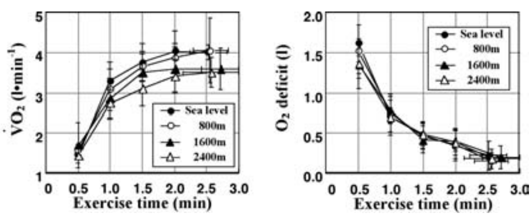

Fig. 3 Time course of Vo2 and O2 deficit measured every 30 s during supramaximal swimming under normal (sea level) and hypobaric hypoxic conditions corresponding to 800 m, 1600 m and 2400 m above sea level. (Ogita 2000)

Our results suggest that during supramaximal swimming, rate of aerobic energy release diminished with increase in hypobaric hypoxia, while not only AOD but also rate of anaerobic energy release throughout the exercise were unaffected despite the decreased O_2 demand caused by diminished exercise intensity due to hypobaric hypoxia. If so, hypoxic condition such as high altitude might be a better condition to tax easily a greater stimulus to anaerobic energy process regardless of the decrease in absolute exercise intensity.

ALTITUDE TRAINING – AEROBIC OR ANAEROBIC?

As altitude acclimatization occurs, hemoglobin concentration and thus arterial oxygen content increases. This physiological adaptation would expect also to increase maximal oxygen transport to active muscles during exercise. Therefore, training at altitude has been primarily performed for the purpose of improving $\dot{V}O_2max$, and thus, endurance exercise performance. However, according to the evidence that the higher the training stimulus to the aerobic or anaerobic energy process, the greater the increase in metabolic capacity (Fox 1975, Tabata 1996), the metabolic stimulus to the aerobic process under hypoxic conditions is lowered due to the reduction in $\dot{V}O_2max$, compared to that under normoxia (Levine 1992). Conversely, the capacity to supply anaerobic energy (MAOD) would not be limited by hypoxia (Medbø 1988, Ogita 2000). In addition, rate of anaerobic energy release during supramaximal swimming is unaffected by hypoxia despite the reduction in absolute exercise intensity. Furthermore, Weyand (1999) reported that sprint performance lasting ≤ 60 s was unaffected by hypoxia, even though aerobic power during hypoxia was significantly lower than that under normoxia, suggesting that reductions in aerobic energy during hypoxic sprints would be compensated by an increased rate of anaerobic energy release. All this suggests that anaerobic energy can achieve maximal release at a lower exercise intensity compared to that under normoxia, or may be more rapidly released when exercise is performed at the same absolute intensity as normoxia. In other words, hypoxic training can readily create the same or greater stimulus on the anaerobic energy process, and thus could more effectively improve MAOD as anaerobic capacity. Several investigations have actually reported increased MAOD after high-altitude training (Mizuno 1990, Ogita 1999), which would be associated with improvements in muscle buffering capacity (Mizuno 1990).

To examine above hypothesis, 12 well-trained college male swimmers were matched for physical fitness level into two groups and then randomized to control group (C) and hypoxic training group (H). C had training under a normal condition and H performed under hypoxic conditions that simulated atmospheric pressure of 1600m and 2400m above sea level. Both groups conducted three types of high intensity intermittent or endurance training; 1) a 2-min bout at OBLA separated by 15-s recovery were repeated 15 times, 2) a 2 min bout at 50% $\dot{V}O_2max$ and a 3 min bout at 100% $\dot{V}O_2max$ were continuously repeated 5 times, 3) a 20-s bout at 170% $\dot{V}O_2max$ separated by 10s recovery was conducted at least eight sets or more. Training 1) and 2) were done in the hypobaric condition corresponded to 1600m above sea level, and training 3) was done in 2400m above sea level. The training was done 2 sessions daily, 5 days a week for 3 weeks. Before and after the training period, $\dot{V}O_2max$ and MAOD, and swimming performance in 100m and 200m free style were determined.

The effect on $\dot{V}O_2max$ and MAOD

After the 3 weeks of training, mean values of $\dot{V}O_2max$ increased significantly 56 to 62 ml $\cdot kg^{-1} \cdot min^{-1}$ in C, and 56 to 63 ml $\cdot kg^{-1} \cdot min^{-1}$ in H (Fig. 4). However, when compared the increase ratio of $\dot{V}O_2max$, no significant difference was observed between C (12%) and H (12%). This suggests that training under hypoxic conditions would not elicit necessarily the greater increase in $\dot{V}O_2max$, and dose not support the hypothesis that high altitude training is more beneficial to improve $\dot{V}O_2max$ as suggested for a long time.

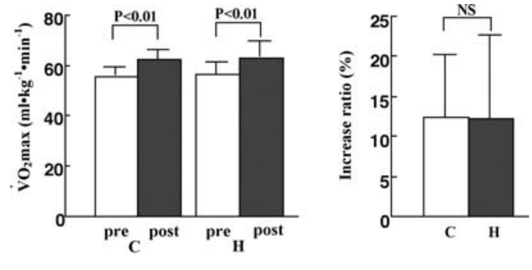

Fig. 4 Comparison of V̇O2 max between pre- and post- training in control group (C) and hypoxic group (H), and comparison of the increase ratio in V̇O2 max between C and H. (Ogita 2003)

Contrary, mean values of MAOD increased significantly 61 to 70 ml $\cdot kg^{-1}$ in C, and 56 to 72 ml $\cdot kg^{-1}$ in H (Fig. 5). When the increase ratio of MAOD between two groups were compared, it was significantly greater in H (29%) than in C (14%). Furthermore, such great increase in MAOD only for the 3 weeks training has been never seen in our knowledge. Therefore, our result suggests that adequate high intensity training under a hypobaric hypoxic environment would improve more effectively anaerobic metabolism such as MAOD.

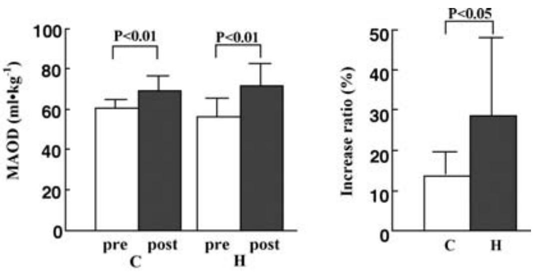

Fig. 5 Comparison of MAOD between pre- and post-training in control group (C) and hypoxic group (H), and comparison of the increase ratio in MAOD between C and H. (Ofita 2003)

Swimming performance

After the training, the swimming performance in 100m and 200m was significantly improved in both groups, and 10 of 12 subjects obtained their personal best records. When the improvement of swimming time was compared between groups, no significant difference was observed (Table 3). However, for the reason that swimming performance in pretest was rather higher in H and the energy demand during swimming increase in relation to the cube of swimming speed (Toussaint 1988, Ogita 1996, 1999, 2003), it is conjectured that the greater energy demand in H should be required to induce the same degree of improvement. Thus, the greater increase in MAOD would contribute successfully for the improvement of the swimming performance in H.

Table 3. Comparison of swimming performance in 100m and 200m event between pre- and post-training

	Contorol Group		Hypoxic Group	
	pre	post	pre	post
100m	56.92±1.81	56.09±1.71	55.86±1.44	55.09±1.71
200m	123.68±2.62	121.26±3.03	121.27±2.27	119.27±2.37

These results suggest that the high-intensity training could induce a large improvement of metabolic capacity and high-intensity exercise performance in both conditions but that high-intensity training in hypoxic condition would be more favorable for the improvement of MAOD rather than $\dot{V}O_2$max.

CONCLUSION

It is concluded that metabolic capacity and swimming performance can be improved more effectively if you understand energetics in competitive swimming of each distance event and you can tax an appropriate training stimulus to the aimed energy system.

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APPLICATION OF THE CRITICAL POWER CONCEPT IN SWIMMING?

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The concept of Critical Power (CP) has been extended to running, cycling, and swimming. However, applying the CP concept to cyclic activities imposes several assumptions (di Prampero, 1999) not always apparent to scientists and coaches. Their understanding would allow a better appreciation of the potential of this concept when applied as a tool for training.

Key Words: critical velocity, assumptions, assessment, training.

INTRODUCTION

The critical power concept originally introduced by Monod and Scherrer (13) attempted to improve the understanding of the local work capacity of one muscle or one synergistic muscle group. The authors highlighted that local work (*W*) and time to exhaustion (*t*) were linearly related (Equation 1). The slope of the relationship, called Critical Power (CP), was defined as a 'threshold of local fatigue' while the y-intercept (a) was corresponding to a reserve of energy.

Equation 1: $W = a + CP.t$

The concept of CP has since been extended to activities involving larger muscle masses such as running (11), cycling (14), and swimming (24). However, applying the CP concept to cyclic activities requires the consideration of several assumptions (6, 16, 22) not always apparent to scientists and coaches. Understanding the underlying theory of the whole-body CP concept would allow a better appreciation of its potential when applied as a tool for training.

ASSUMPTION 1 – A 2-COMPONENT MODEL
There are only two components to the energy supply system for human exercise. When performing a fatiguing exercise, energy is generated via both the anaerobic and aerobic pathways (Equation 2).

Equation 2: $e = e_{anae} + \dot{V}O_2max.t$

Several authors have evocated the limits of such a simple model based on only two energetic systems to characterise a very complex energy release - time relationship (1, 16). Other models that incorporate a few more physiological variables (15, 18) have been presented and validated in the literature (Billat et al., 1999). However, these models could appear too complex to be used in training. Moreover, no study has yet been conducted to test their effectiveness as a training tool.

ASSUMPTION 2 - ENERGETIC COST OF SWIMMING
It is assumed that the energetic cost of the activity, i.e. the amount of energy required to travel a metre (ml of $O_2.m^{-1}$), is constant in order to allow Equation 2 to be expressed as followed:

Equation 3 : $d = ADC + CV.t$ (d, distance; t, exhaustion time),

Accordingly, distance (d) and time required to cover it (t) are linearly related, with Critical Velocity (CV) and Anaerobic Distance Capacity (ADC) represented by the slope and the y-intercept of the d-t relationship, respectively (Figure 1).

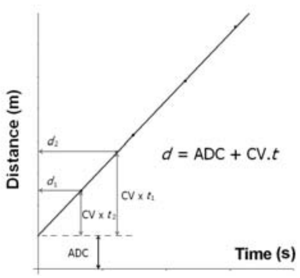

Figure 1: Schematic of the 2-parameter model. The distance covered during two events (d_1 and d_2) is represented. It is equal to the sum of ADC plus the product of CV and t (t_1 and t_2).

In swimming, the observation of a linear relationship linking *d* and *t* has been used to validate the application of the CP concept (Wakayoshi et al., 1992). A low sensitivity of CV (and CP) to large errors in exhaustion times has also been demonstrated (10, 22). However, it is known that the *d-t* relationship is not strictly linear. This has been demonstrated for work involving the whole body or part of the body (5, 23) and is mainly explained by a change in the energetic cost across the range of *t* used to plot the relationships (6, 22). The energy cost of swimming is indeed not constant with increasing swimming speed, due to changes in efficiency, energy contribution and hydrodynamics. Rather, the relationship is exponential resulting in proportionately greater increases in energy cost for changes in swimming speed at the high intensity first part of the *d-t* relationship (3). The lower the values of exhaustion times, the higher the slope, the lower the y-intercept, and vice versa (5, 22). CV and ADC values are therefore dependent on the exhaustion times used to plot the *d-t* relationship. Further studies are needed to determine the effect of this change in the energetic cost on the *d-t* relationship and its parameters.

ASSUMPTION 3 – AEROBIC RELEASE OF ENERGY
The aerobic supply is unlimited in its capacity but is rate limited. It would be solicited at its maximal power ($\dot{V}O_2max$) throughout the duration of the exercise to enable the energy demand to be covered. It is represented in Equation 2 by the second term $\dot{V}O_2max.t$.

This assumption is often forgotten leading to a misapplication of the CP concept and misunderstanding of its parameters. First, the CP concept assumes an attainment of $\dot{V}O_2$max at the beginning of exercise. This will never be fulfilled and the slope and y-intercept of the *d-t* relationship will always slightly overestimate and underestimate the ‘true’ CV and ADC (4). The error in the estimation of an ‘anaerobic energy reserve’ has been shown to be relatively great (around 20%; (4, 21) while those in the estimation of CV has not been yet estimated and can be expected to be lower.
Second, it is known that $\dot{V}O_2$max cannot be reached from the start of exercise, as assumed. In order to partially fulfil assumption 3, when choosing the range of exhaustion times that will be used to plot the *d-t* relationship, it has to be considered that $\dot{V}O_2$max should be attained during each trial. In other words, the 2-component model explains the *d-t* relationship for intensities eliciting $\dot{V}O_2$max (6). Exhaustion times have to range between about 2 minutes (9) and the time to exhaustion at CV (not measured yet in swimming but values of 20-40 min have been recorded in cycling) (2). Therefore, in swimming, the competitive distances ranging the 200m and 1500m can be advised (12, 26). Some authors attempted to simplify the application of the CP concept in swimming by determining which combinations of only two competitive distances should be used to derive CV and ADC (5, 19, 26). The suggestion of using only the 200m and 400m seems to most pertinent (5).
Consequently, CV can be defined as the upper limit of the heavy intensity domain, i.e. the highest intensity that does not allow $\dot{V}O_2$max to be attained during a constant load exercise (8). Above CV, because of the slow component phenomena, $\dot{V}O_2$max would be achieved. CV is therefore lower than the end velocity of an incremental test, often identified as the Maximal Aerobic Power. The first belief that CV was sustainable for a very long period of time was a misinterpretation of the mathematical (and not physiological) definition of CV, i.e. the intensity that can be maintained indefinitely (asymptote of the velocity-time relationship).

ASSUMPTION 4 – ANAEROBIC RELEASE OF ENERGY
The anaerobic metabolism is not rate but capacity limited. It generates a finite amount of energy termed e_{anae} in Equation 2.

This energy store (E_{anae} in Equation 2 or ADC in Equation 3) is assumed to be depleted at exhaustion and is independent of the exhaustion time. This is probably not valid in all cases and especially for short and very long exercises (22) but should be during exercise enabling $\dot{V}O_2max$ to be attained. This assumption remains difficult to test since the measurement of anaerobic work capacity is a theoretical construct that is fraught with measurement errors (7). Today, the 'anaerobic' parameter of the CP concept has been the object of several studies whose conclusions are conflicting. In swimming, ADC does not seem to provide a valid estimation of an 'anaerobic reserve of energy' (5) although it is not sure the measurements error inherent to the CP concept is not as great as those of any other methods of estimation of an Anaerobic Work Capacity (4).

ASSUMPTION 5 – END OF EXERCISE
Termination of exercise occurs when all of e_{anae} has been utilised.

The CV/CP concept assumes that performance is determined by metabolic factors relying on the classical and traditional model of fatigue. The explanation for a decrease in velocity during all-out effort or the inability to maintain a velocity during time to exhaustion trials refers to action potential failure, excitation-contraction coupling failure, or impairment of cross-bridge cycling, in the presence of unchanged or increasing neural drive (20), all of these causes being peripheral. However, the origin of fatigue could be quite different. Another model of fatigue (central in its origin) has recently been presented by Noakes and co-workers (17).

CONCLUSION
Despite these several limits, the CV concept has raised lots of interest from the scientific and non scientific communities. The 2-component model is a simple tool enabling to characterise individual *d-t* relationships. CV in swimming is reliable and offers the coach a tool with some precision. Competitive distances ranging from the 200m to the 1500m can be used to plot the *d-t* relationship and would lead to good estimates of CV. CV can be defined as the upper limit of the heavy intensity domain, i.e. the highest intensity that does not allow $\dot{V}O_2max$ to be attained during a constant load exercise. ADC corresponds to an anaerobic energy reserve.
The model may provide an interesting way of investigating the energetic contributions to swimming. Coaches and swimmers could also appreciate the ease in using the model to predict performance from the *d-t* relationship, to set training loads, to discriminate effects of training, and to establish energetic potentials of swimmers. The model offers potential to swimming in that it is non-invasive and easy to administer however coaches and scientists should be aware of the assumptions outlined above.

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THE STRUCTURE OF EVALUATION INDICATORS OF VERTICAL SWIMMING WORK ABILITY OF TOP WATER POLO PLAYERS

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The aim of this research is to define a simple method for assessing the level of basic fitness of water polo players (WPP) in the vertical swimming position (VSP). The sample consisted of 35 players, and each subject was tested four times in different training session with four different weights (one weight per session). The task of players was to stay in VSP as long as possible using the standard vertical swimming technique until full exhaustion. On the basis of raw data for each subject the function of dependence Power-Time equation has been calculated for the following nine time intervals (three time intervals per energetic system): 5, 10, 15 seconds for CP , 30, 60, 120 seconds for glycolytic, and 300, 600, 1800 seconds for aerobic energetic system. From the bases of factorial analysis we can conclude that in the context of vertical swimming work ability of top WPP, it is advisable to do tests for VSP in relation to glycolitic and aerobic load realized within 30 seconds (23.95±3.90 kg), and 300 seconds (14.53±1.70 kg), respectively.

Key Words: water polo players, vertical swimming, basic vertical work ability.

INTRODUCTION
Water polo is physically a very demanding sport game, with an “intermittent” nature of playing. Intense bursts of short activity in horizontal and vertical technical and tactical elements are varied with intervening lower intensity intervals (8, 10). On average, a water polo game lasts approximately 55 minutes, whereas actual mean playing time amounted to approximately 48 minutes (8, 10). At the senior top-performance level, a water polo player spends 45-55% up to 66.9% in the vertical swimming position in which he executes different tactical and technical tasks (4, 8). The data indicate the vertical swimming position to be the dominant position in the game. The given data regarding the duration and the structure of the game, the distribution of intensity and the positions during the game implicate that water polo players require fitness for execution of tasks both in the horizontal as well as the vertical direction in all three energetic regimes of exertion and work.
With horizontal swimming as reference, for the control of the fitness level, reliable methods have been defined and then adapted for a simple application (2). However, methods for the control of fitness level in the vertical swimming position have not been adequately developed. The current methods require special lab equipment and conditions of testing that make them practically unusable in the training system and process (11). This brings about the necessity to define a simple, easy-to-apply and reliable method for assessing the level of basic and competitive fitness of water polo players in the vertical swimming position.

METHODS
The sample of water polo players (SCG_{WP}) was made of 35 members of the SCG under-20 and B-national team (Age=19.3±2.6 years; BH=1.914±0.048 m; BM=88.2±7.5 kg). In order to establish fitness level in the vertical swimming position, we have used the following procedure (3, 4). After the usual warm-up procedure (≈ 600 m), the subject was harnessed around the waist with the weights (as a given load, i.e. the intensity of work) hanging on a rope between the legs. The rope was fixed to his lumbar and stomach side. The subject would then get into the water trying to stay in the vertical swimming position between 10-15 seconds in order to check out the gear, and after a one-minute break with assistants in the position of preventing any mishap, the trial would start. The task was to stay in the vertical swimming position as long as possible, i.e. until full exhaustion necessitated trial termination. The subjects were allowed to use egg-beater kick, while their hands performed the semi-circle movements (“the horizontal eight”). Also, the subjects were requested to keep their neck and head constantly in the vertical position and the water level not to go above the lowest part of their chin. The time was measured from the beginning of the subject’s vertical swimming with the given weights in position till its end.
Each subject has been tested four times in different training session with different weights (one weight per session - 12, 14, 16 and 18. Each working weight is meant to hypotheticaly represent a strain (work intensity) exerting different energy mechanisms of the body. Thus, for each subject the data we obtained, show the duration in which the vertical swimming position can be maintained with a minor, medium, major and sub-maximal load (4, 5, 12). Applying the described trial method, a set of four specific points for each subject has been established and it defines the fitness level for the vertical swimming position, as a function: the level of load, i.e. the intensity of work (in kilograms of weight’s mass) in function of duration, i.e. the capacity of work (7, 12).
On the basis of raw data obtained through testing for each subject the function of dependence Power-Time (P-t) equation has been calculated applying the general equation: $y = a \_ b^{x}$. Following which, for each subject, and on the basis of his P-t equation, we synthesised the value of the weight mass (all synthesized data are presented in absolute terms - in kg of weight mass), for the following nine time intervals (three different time intervals per energetic system): 5, 10 and 15 seconds - anaerobic alactic, 30, 60 and 120 s - anaerobic lactic, 300, 600 and 1800 s - aerobic energetic system. The given time intervals have been chosen in accord with the theoretical preposition that they are capable of describing the working capacity of players with three hypothetically possible features of the tested energetic systems – intensity, power and capacity (5, 7, 12). All data have been treated with the descriptive statistical method and multivariant statistics, i.e. factorial analysis – explorative model of extraction with Oblimin rotation method (6).

RESULTS
Table 1 displays the results of the basic descriptive statistic of vertical swimming work abilities (in kg of weight mass) in

function of observed time intervals (in seconds). On the average, the results showed that the players were able to sustain vertical position for the following times and weights: 5, 10, 15 s – 36.43, 30.87 and 28.08 kg; 30, 60, 120 s – 23.95, 20.52 and 17.64 kg; 300, 600, 1800 s - 14.53, 12.59 and 10.11 kg, respectively.

Table 1. The basic descriptive statistics of vertical swimming work abilities in function of observed time intervals.

	Vertical swimming work ability – time intervals (s)								
	5	*10*	*15*	*30*	*60*	*120*	*300*	*600*	*1800*
Mean (kg)	36.43	30.87	28.08	23.95	20.52	17.64	14.53	12.59	10.11
SD (kg)	12.17	8.09	6.27	3.90	2.37	1.65	1.70	1.98	2.32
cV (%)	33.40	26.21	22.32	16.30	11.56	9.35	11.73	15.73	22.95
Min (kg)	23.43	21.59	20.57	18.95	17.46	14.10	10.26	8.06	5.09
Max (kg)	77.96	56.54	46.85	34.37	27.24	21.59	17.42	15.23	12.89

Figure 1 displays the equation function of the model defined in relation to the vertical swimming working capacity of the tested sample. The equation function of the model yielded: Power (kg) = 50.7389 •time$^{-0.2179}$.
Kaiser-Meyer-Olkin measure of sampling adequacy has shown the reliability of the measurement method to be at 0.7481 (74.81%), at a statistically significant level, F_{ratio} = 2431.75, and p = 0.000. Factorial analyses extracted two factors (table 2), the first factor explaining 63.31%, and the second 36.15% of total variance of vertical swimming work ability in players. The former is best represented by the variable which described vertical swimming ability for 30 s (VERT30s), and the latter by the variable for 300 s (VERT300s).

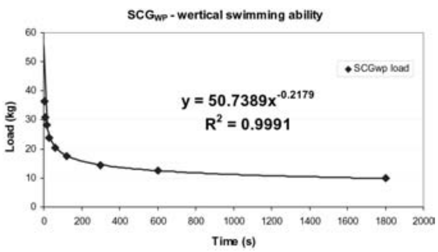

Figure 1. The equation function of the model defined in relation to the vertical swimming working capacity of the tested sample.

Table 2. The results of factorial analysis of structure of evaluation indicators of vertical swimming work abilities in function of observed time intervals.

	Component	
	1	2
VERT30S	.999	-.099
VERT15S	.985	-.275
VERT10S	.970	-.339
VERT5S	.944	-.413
VERT60S	.939	.231
VERT300S	-.070	.999
VERT600S	-.345	.969
VERT1800	-.536	.888
VERT120S	.607	.719

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

DISCUSSION

In relation to the tested sample and the used method of evaluation, the results of the factorial analysis have shown the existence of two hypotetical/theoretical predominant aspects of the working fitness of water polo players from the vertical swimming position aspect. The first factor is defined by the capacity to withstand work of maximal intensity in the vertical swimming position in the time interval of 30 seconds. The tested sample has shown the hypotetical/theoretical capacity to stay afloat with the load of 23.95±3.90 kg (Min – Max = 18.95 to 34.37 kg).
It is well known that the work of maximal intensity in the time interval of 30 seconds from the physiological aspect, i.e. the energetic criteria, belongs to the space of anaerobic power (5, 7, 12).
As water polo players have been noted to perform many intense activities in a vertical or semy-vertical position for a large portion of duration of a match, and if we know that lower limbs play a crucial and predominant role in maintaining the upward propulsion of the body, such as jumps, blocks, in active contact defence situation, grappling for possession, and during the overhead forward throwing - the first defined factor sugest that high or well developed anaerobic power are very important for water polo performance (1, 8, 9).
The second factor is defined by the hypotetical/theoretical capabillity to withstand work of maximal intensity in the vertical swimming position in the time interval of 300 seconds. The tested subjects were able on average to stay afloat with the load of 14.53±1.70 kg (Min – Max = 10.26 to 17.42 kg). It is accepted that the work of maximal intensity in the time interval of 300 seconds from the physiological aspect, i.e. the energetic criteria, belongs to the space of aerobic power (5, 7, 12).
Earlier research has also established that water polo players have a moderately high levels of anaerobic power and possessed a high aerobic fitness capacity (1, 8).
The given capacity is probably the consequence both of the players' selection on the one hand and of the bodily adaptation to the training and competition exertion (10).
Pininton and his collaborators have established that the pulse of water polo players during the fourteen different technical and tactical tasks they realize during a game, goes from 162 to 175 HR/min, or that the game is played at the intensity which is on average at the level of 74.2 to 86.8 % of $\dot{V}O_2$ max (10).

CONCLUSION

These results draw upon the conclusion that in the context of vertical swimming work ability of top water-polo players, it is possible to say that, on the hypotetical/theoretical level, the basic evaluation should be carried out in relation to anaerobic lactic load (anaerobic power) realized within 30 s (23.95±3.90 kg), and aerobic load (aerobic power) realized within 300s (14.53±1.70 kg).

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CHARACTERISTICS FOR SUCCESS IN ELITE JUNIOR AND SENIOR SWIMMERS

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The aim of this study was to describe and compare key anthropometric, physiological and socio-demographic characteristics of junior and senior elite swimmers at two performance levels and to determine the importance of these attributes to successful swimming performance. Sixty-five (34 males and 31 females) senior and 561 (305 males and 256 females) junior elite swimmers undertook a battery of anthropometric and physiological tests, and additional family background assessment. The combination of variables was able to differentiate between the two levels of senior performance in males ($P<0.05$). Significant predictors of swimming performance ($P<0.05$) differed from junior to senior level in both males and females. A longitudinal approach is required to track the importance of certain characteristics during growth and development.

Key Words: Characteristics, performance, elite, junior, senior, talent identification.

INTRODUCTION

Structured talent identification schemes are not new, having been employed widely in Australia and in Eastern Europe, but only in recent years have the UK seriously considered sports science as an aid to identifying and selecting talent for high performance sport development programmes. Past schemes have typically focused on certain physiological and anthropometric attributes, assuming that specific sporting talent and performance are largely based on an innate or genetic predisposition that is responsive to training (2). The alternative view is that genetics or innate ability are not involved in the development of sporting expertise, and that success is determined by the amount of deliberate practice acquired by an individual (4, 7). However, this theory of deliberate practice has been questioned in relation to sport (5) and if a successful talent identification, selection and development (TISD) system is to be formed, these two theoretical positions should not be seen as mutually exclusive, rather that both genetics and sociological/environmental factors contribute to sporting success (6).
A paucity of multidisciplinary research exists in talent identification, with researchers traditionally approaching the problem from a unidimensional perspective. Previous attempts to quantify the importance of certain characteristics to swimming performance have focused on either elite senior (3) or junior swimmers (1) and little is known about the degree to which physiological and anthropometric indices of performance capability prevail through growth and maturation into adulthood (8). Therefore, investigating the construction of a successful talent identification and selection programme should attempt to describe talent from junior to senior level.
The purpose of this study therefore, was to describe and compare key anthropometric, physiological and socio-demographic characteristics of elite and sub-elite junior and senior swimmers across four competitive strokes and to assess the degree to which some of these characteristics might predict elite swimming performance.

METHODS

Subjects included thirty-four swimmers from the 2004 British Olympic team (19 males and 15 females; Olympic group) and a matched sample of 31 swimmers (15 males and 16 females; sub-Olympic group) from the Loughborough University High Performance squads, and 559 junior swimmers (304 males and 255 females) aged eleven to eighteen, from the 2004 British Age and Youth Championships. All procedures were approved by the Amateur Swimming Association's Ethics Department and informed consent was obtained from all subjects or their parents/ guardians.
A battery of anthropometric measurements included: height and sitting height, standing reach, arm span, body mass, torso and waist circumferences, right foot and hand lengths, and right acromiale-radiale (upper arm) and radiale-stylion (lower arm) lengths. Counter movement jump (CMJ) was also measured. Body mass index (BMI; body mass (kg) / standing height (m)^2), sitting height percentage (sitting height (cm) / standing height (cm) x 100), torso to waist ratio (expressed as the number of centimetres of torso circumference to one centimetre of waist circumference) and difference between arm span and height (arm span (cm) – standing height (cm)) were calculated and added to the list of variables to be used in later analyses.
Anthropometric tests were selected based on previous

research into talent identification and selection in swimming (1, 3, 11), the rationale being that a swimmer's morphology influences the horizontal components of lift and drag and thereby affects the swimmer's potential to generate optimum propulsion and to minimise resistance (9). Counter movement jump was selected as a measure of explosive leg power, closely related to maximum power in swimming (11). The family background of the senior subjects was assessed using a questionnaire designed to gather information on the family sporting background and the types and levels of family support received by elite swimmers through their development as age group swimmers. Data were analysed using the Statistical Package for Social Scientists (SPSS, version 11.0) and statistical significance was accepted at the 5 percent level for all analyses. Males and females were analysed separately with the exception of the family background analyses. Senior and junior subject data were analysed using multivariate analysis of variance (MANOVA) with follow up univariate analysis of variance (ANOVA) and discriminant analysis used where appropriate. Age group classifications used for the junior male and female subjects reflect those used at the British Age and Youth Championships. Multiple linear regression was used to determine the predictive power of the anthropometric and physiological variables using personal best swim time as a percentage of the world best swimming time (for 2003) as the criterion of performance for all senior and junior swimmers (reliable for predicting Olympic swimming performance, 10). A descriptive approach employing both quantitative and qualitative techniques was used to analyse the family background questionnaire data.

RESULTS AND DISCUSSION

Table 1 shows the male and female anthropometric measurements and CMJ for Olympic and sub-Olympic swimmers. Both MANOVA and discriminant analysis showed that the combination of anthropometric and CMJ could successfully differentiate between the two levels of performance in senior male swimmers. The individual variables best able to discriminate between groups were standing height, sitting height, torso circumference, torso to waist ratio and CMJ. Multiple regression analysis yielded a significant model ($P<0.01$) accounting for 79% of the variance in swimming performance. The significant positive predictor variables in males were standing reach and CMJ ($P<0.05$) suggesting that greater standing reaches and higher CMJ scores predict faster personal best swimming times. Sprinters usually display higher vertical jump parameters than distance swimmers (11) and therefore, CMJ has been used to predict distance orientation. However, as CMJ focuses on the leg extensor muscles which are important for the start element of the swimming race, it could be seen as a performance predictor for all swimming strokes (the Olympic group scored more highly than the sub-Olympic group on this test). Therefore, CMJ measure might be a simple, useful tool to predict both event orientation and aid talent selection. Although standing reach was unable to differentiate between the two performance levels, the regression analysis showed that standing reach is an important predictor of swimming performance due to its relationship to the streamline position (important for all swimming strokes) and supports its inclusion in the test battery.

Table 1. Anthropometric measures and CMJ (mean ± SD) for senior male and female swimmers.

Parameter	Males Olympic (n = 19)	Males Sub-Olympic (n = 16)	Females Olympic (n = 15)	Females Sub-Olympic (n = 16)
Height (cm)	186.7 ± 4.0*	182.7 ± 5.3*	173.1 ± 4.9*	169.3 ± 5.1*
Sitting Height (cm)	97.3 ± 3.1*	93.7 ± 3.2*	91.2 ± 3.6*	87.4 ± 2.8*
Sitting Height Percentage (%)	52.1 ± 1.1	51.3 ± 1.4	52.6 ± 1.1*	51.6 ± 1.2*
Standing Reach (cm)	245.6 ± 5.6	241.2 ± 8.4	229.0 ± 10.9	224.7 ± 8.0
Arm Span (cm)	193.8 ± 5.6	193.4 ± 6.7	178.4 ± 6.8	176.9 ± 6.0
Arm Span minus Height (cm)	7.2 ± 5.1*	10.7 ± 4.0*	5.3 ± 4.7	7.5 ± 5.0
Mass (kg)	79.2 ± 6.0	76.5 ± 5.9	63.2 ± 6.4	63.4 ± 5.2
BMI	22.7 ± 1.3	23.2 ± 2.3	21.1 ± 1.8	22.1 ± 1.3
Torso Circumference (cm)	102.6 ± 5.4*	96.5 ± 4.1*	93.0 ± 4.2*	90.0 ± 3.7*
Waist Circumference (cm)	79.5 ± 4.0	78.4 ± 4.5	70.9 ± 3.8	70.6 ± 3.4
Torso to Waist Ratio	1.29 ± 0.05*	1.23 ± 0.04*	1.31 ± 0.05*	1.28 ± 0.04*
Foot Length (cm)	27.3 ± 0.9	26.9 ± 1.7	24.9 ± 1.1	25.0 ± 1.0
Hand Length (cm)	19.8 ± 0.8	19.8 ± 0.9	18.3 ± 0.6	18.2 ± 0.7
Acromiale-Radiale Length (cm)	35.4 ± 1.6	35.0 ± 1.6	32.9 ± 1.3	31.8 ± 2.5
Radiale-Stylion Length (cm)	27.0 ± 1.0	26.6 ± 1.3	24.5 ± 1.0	24.7 ± 1.1
CMJ (cm)	43.3 ± 5.2*	39.3 ± 3.7*	33.9 ± 4.5	30.9 ± 4.3

MANOVA shows significant difference between profile of Olympic and Sub-Olympic groups in males ($P<0.01$). Discriminant analysis shows significant difference between profile of Olympic and Sub-Olympic groups in males ($P=0.000$) and females ($P<0.05$). ANOVA shows significant group differences between variables indicated *($P < 0.05$).

The relationship between anthropometric measures and CMJ and performance level was less clear in senior females. Only discriminant analysis showed significance, indicating that the set of variables was less able to differentiate between the two performance levels in senior female than in senior male swimmers. A possible reason for this may be the smaller range in performance ability in the group of senior females as a whole. Individual variables that were able to discriminate between groups were standing height, sitting height, sitting height percentage, torso circumference and torso to waist ratio. Individual discriminatory variables for senior female swimmers match closely with the results for senior male swimmers, indicating that the important anthropometric attributes of elite swimmers are similar for both genders. Multiple regression analysis yielded a significant model ($P<0.05$) accounting for 74% of the variance in senior female swimming performance, although no individual predictor variables were significant. The regression analysis produced a performance ability range between 0% and ~10% away from the world best time and therefore, the extreme homogeneity of the female group may have masked regression effects. To more accurately assess the predictive value of the variables, it is necessary to collect data from a larger range of performance abilities.

Key results of the family background analysis showed: 77% of families owned 2 or more cars; 86% of families provided transport to training/competition at least 4 times per week (81% estimated the annual travel cost in excess of €400); family activities frequently had to be adapted to accommodate swimming with meal times (92%) and the family weekend (94%) adapted most often. Results indicate that it is only possible to succeed in elite swimming in Great Britain with significant financial outlay and family support; opportunities to identify and develop talent therefore, may be missed.

The test battery was unable to significantly discriminate between the two performance levels in any junior male or female age group, although multiple regression analysis yielded significant models for junior males ($P=0.000$) and females ($P=0.000$) accounting for 74% and 47% of the variance in swimming performance respectively. In junior males, arm span, waist circumference, torso to waist ratio and CMJ were significant predictors of performance ($P<0.05$) and in junior females, arm span, sitting height, sitting height percentage and CMJ were significant predictors of performance ($P<0.05$). Several of the characteristics identified as important for junior swimming performance are those that individually differentiate between performance level in senior swimmers (in males, torso to waist ratio and CMJ and in females, sitting height and sitting height percentage). Hence, some characteristics possessed by elite junior swimmers may also be important for elite senior swimming performance.
All regression analyses were unable to explain 100% of the variance in swimming performance indicating that some of this variance must be attributed to other factors such as more detailed physiological measures, swimming technique, psychological and/or environmental characteristics. It seems likely that the inclusion of swimming specific tests in the battery would provide additional predictive power to this analysis, although further multidisciplinary research is required to establish any contribution these factors may have to elite swimming performance.

CONCLUSION
The characteristics that predict swimming performance differ from junior to senior level in both males and females. A longitudinal approach to this type of research would provide valuable information about the importance of certain characteristics to performance during growth and development and at senior level. This type of approach suggests that an appropriate multidisciplinary test battery combined with multivariate analyses could be useful as an important predictive and diagnostic tool for talent identification and development in elite junior swimmers.

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ASSESSMENT OF TIME LIMIT AT LOWEST SPEED CORRESPONDING TO MAXIMAL OXYGEN CONSUMPTION IN THE FOUR COMPETITIVE SWIMMING STROKES

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Time limit at lowest speed of maximal oxygen consumption (TLim-v$\dot{V}O_2$max) was characterized in the 4 swimming strokes, and related with $\dot{V}O_2$max and anaerobic threshold (AnT). 23 elite swimmers performed an incremental protocol for v$\dot{V}O_2$max assessment. 48 hours later, Tlim-v$\dot{V}O_2$max was assessed. $\dot{V}O_2$ was directly measured BxB (K4 b_2, Cosmed, Italy) and AnT was assessed individually (YSI 1500L Sport, USA). Tlim-v$\dot{V}O_2$max values were 238.8±39.0, 246.1±51.9, 277.6±85.6 and 331.4±82.7 s in crawl, backstroke, butterfly, and breaststroke (no differences observed). No correlations were found between Tlim-v$\dot{V}O_2$max and $\dot{V}O_2$max, and AnT. However, inverse relationships were observed between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max ($r=-0.63$, $p<0.01$) and vAnT ($r=-0.52$, $p=0.01$), pointing out that the higher the velocities commonly related to aerobic proficiency, the lower the TLim- v$\dot{V}O_2$max.

Key Words: time to exhaustion, competitive strokes, oxygen consumption, anaerobic threshold.

INTRODUCTION
Time limit at lowest speed of maximal oxygen consumption (TLim-v$\dot{V}O_2$max) was studied both in swimming flume (1, 2, 3) and in normal swimming pool conditions (4, 6, 13). While no studies have been carried out based on other swimming techniques than front crawl, the purpose of this experiment was to characterize, and compare, TLim-v$\dot{V}O_2$max in the four competitive strokes, as well as to observe its relationships with two major performance determinants: $\dot{V}O_2$max and anaerobic threshold (AnT). Complementarily, knowing that top-level swimmers have their specificities (11) and that TLim-v$\dot{V}O_2$max was never assessed in elite swimmers, the pertinence of this study is clearly stated.

METHODS
Subjects
Twenty-three elite swimmers (15 males of 19.4 ± 2.1 yy, 178.1 ± 6.2 cm and 71.8 ± 7.4 kg, and 8 females of 17.2 ± 1.4 yy, 166.0 ± 3.7 cm and 59.7 ± 4.3 kg) from the Portuguese National Swimming Team volunteered to participate in this study and signed an informed consent form.

Test protocol

Each subject performed, in their best technique, an individualized intermittent incremental protocol for v$\dot{V}O_2$max assessment, with increments of 0.05 m.s^{-1} each 200 m stage and, 30 s intervals, until exhaustion (4). $\dot{V}O_2$ was directly measured using a telemetric portable gas analyzer (K4 b^2, Cosmed, Italy) connected to the swimmers by a respiratory snorkel and valve system (9, 14). Expired gas concentrations were measured breath-by-breath. Swimming velocity was controlled using a visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. $\dot{V}O_2$max was considered to be reached according to primary and secondary traditional physiological criteria (8). v$\dot{V}O_2$max was considered to be the swiming velocity correspondent to the first stage that elicits $\dot{V}O_2$max. If a plateau less than 2.1 ml.min^{-1}.kg^{-1} could not be observed, the v$\dot{V}O_2$max was calculated as proposed by Kuipers et al. (9):

v$\dot{V}O_2$max = v + Δv · (n.N^{-1}), (Eq. 1)

where v is the velocity corresponding to the last stage accomplished, Dv is the velocity increment, n indicates the number of seconds that the subjects were able to swim during the last stage and N the pre-set protocol time (in seconds) for this step. Capillary blood samples for lactate concentrations ([La$^-$]) analysis were collected from the earlobe at rest, in the 30 s rest interval, at the end of exercise and during the recovery period (YSI1500LSport auto-analyser - Yellow Springs Incorporated, Yellow Springs, Ohio, USA). Those data allowed to assess individual AnT, that was determined by [La$^-$]/velocity curve modelling method (least square method) (5). HR was monitored and registered continuously each 5 s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). Forty-eight hours later, subjects swam until exhaustion at their pre-determined velocity, to assess Tlim-v$\dot{V}O_2$max. This protocol consisted in two different phases, all paced: (i) a 10 min warm-up at an intensity correspondent to 60% v$\dot{V}O_2$max, followed by a short rest (20 s) for earlobe blood collection, and (ii) the maintenance of that swimming v$\dot{V}O_2$max until volitional exhaustion or until the moment that the swimmers were unable to swim at the selected pace. TLim-v$\dot{V}O_2$max was considered to be the total swimming duration at the pre-determined velocity. HR was registered continuously using the same procedure previously described.

Statistical analysis

Mean (±SD) computations for descriptive analysis were obtained for all variables (all data were checked for distribution normality with the Shapiro-Wilk test). One-way Anova, with a Bonferroni post-hock test, was also used. A significance level of 5% was accepted.

RESULTS

Data concerning the variables obtained in the incremental test: $\dot{V}O_2$max, [La$^-$]max, HRmax, AnT (velocity and [La$^-$] values) and v$\dot{V}O_2$max, and the parameters assessed in the Time Limit test: TLim-v$\dot{V}O_2$max, [La$^-$]max and HRmax, are reported in Table 1 for each competitive stroke.

The values of $\dot{V}O_2$max obtained in the incremental test are in accordance with those previously published for elite front crawl swimmers for a number of authors (1, 3, 7). Studies that aim to compare $\dot{V}O_2$max in elite front crawl, backstroke, butterfly and breaststroke swimmers are very scarce, so it is difficult to make valid comparisons. However, the observation of no differences between $\dot{V}O_2$max values between techniques is in accordance with Troup (15). The obtained values of HRmax are in agreement with the literature since that, for this kind of intensity of exercise (aerobic power zone), values ranging from 180 to 200 b.min^{-1} are consensual (12). Likewise, the [La$^-$]max mean values are in agreement with the typical requirements for $\dot{V}O_2$max swimming intensities (8).

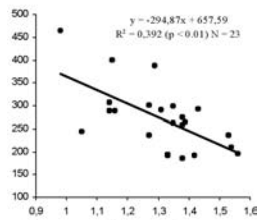
While no significant differences were observed between competitive strokes in TLim-v$\dot{V}O_2$max, pooled data were correlated with $\dot{V}O_2$max (ml/kg/min) and AnT (mmol/l), being observed no significant interrelationships. However, moderate inverse correlation values were observed between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max (r=-0.63, p=0.001, Figure 1A) and vAnT (r=-0.52, p=0.012, Figure 1B).

Table 1. Mean (±SD) values for v$\dot{V}O_2$max (absolute and relative), [La-]max, HRmax, AnT (velocity and [La-] values) and v$\dot{V}O_2$max (incremental test), and TLim-v$\dot{V}O_2$max, [La-]max and HRmax (Time Limit test), for each competitive stroke. Significant differences are shown through pairs of (1), (2), (3), (4), (5), (6), (7), (8), (9) and (10), $p \leq 0.05$.

Parameters	Front crawl (n = 8)	Backstroke (n = 5)	Butterfly (n = 4)	Breaststroke (n = 6)
$\dot{V}O_2$max (ml.kg^{-1}.min^{-1})	64.28 ± 10.27	66.78 ± 11.40	53.95 ± 4.82	63.21 ± 8.14
$\dot{V}O_2$max (l.min^{-1})	4.34 ± 1.32	4.69 ± 1.11	3.57 ± 0.54	4.33 ± 0.71
[La$^-$]max (mmol. l^{-1})	8.34 ± 3.02	11.22 ± 3.63	8.22 ± 1.60	9.13 ± 1.99
HRmax (b.min^{-1})	182.50 ± 5.73	190.00 ± 6.60	179.25 ± 6.50	190.83 ± 7.33
AnT (mmol.l^{-1})	2.59 ± 0.97 (1)	4.56 ± 2.10	5.56 ± 2.30 (1)	3.03 ± 1.50
vAnT (m.s^{-1})	1.33 ± 0.10 (2)	1.25 ± 0.06 (3)	1.21 ± 0.07 (4)	1.01 ± 0.08 (2,3,4)
v$\dot{V}O_2$max (m.s^{-1})	1.45 ± 0.08 (5,6)	1.35 ± 0.04 (7)	1.29 ± 0.03 (5,8)	1.10 ± 0.07 (6,7,8)
TLim- v$\dot{V}O_2$max (s)	243.17 ± 30.49	246.08 ± 51.93	277.63 ± 85.64	331.43 ± 82.73
[La$^-$]max TLim (mmol.l^{-1})	6.92 ± 2.53 (9,10)	10.65 ± 2.40 (9)	9.04 ± 0.91	10.76 ± 1.34 (10)
HRmax TLim (b.min^{-1})	180.00 ± 6.44	176.60 ± 8.56	179.50 ± 4.44	185.67 ± 7.97

$\dot{V}$O2max: maximal oxygen consumption; [La-]max: maximal blood lactic acid concentrations; HRmax: maximal heart rate; AnT: anaerobic threshold; vAnT: velocity corresponding to anaerobic threshold; v$\dot{V}$O2max: lowest speed of maximal oxygen consumption; TLim-v$\dot{V}$O2max: time limit at v$\dot{V}$O2max; n: number of subjects.

The observed inverse relationships between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max, and/or vAnT, confirms previous findings obtained in national level freestyle swimmers (4, 6), and point out that, whatever the swimming techniques the higher the swimming velocities commonly related to aerobic proficiency, the lower the TLim-v$\dot{V}O_2$max. This observation seems to be justified by the fact that higher swimming velocities indicates more strenuous efforts, with probably more pronounced recruitment of anaerobic energy pathways, leading to earlier fatigue stages and, consequently, to lower TLim-v$\dot{V}O_2$max. However, no relationship was found between Tlim-v$\dot{V}O_2$max and [La$^-$]max, in opposition with some previous findings (3, 6).



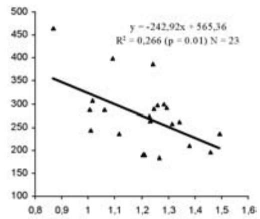


Figure 1. Relationshisp between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max (A panel), and vAnT (B panel).

CONCLUSIONS

TLim-v$\dot{V}O_2$max did not differ between swimming strokes, pointing out that the phenomenon is similar in all four strokes. TLim-v$\dot{V}O_2$max was lower in the swimmers who presented higher v$\dot{V}O_2$max and vAnT, which could be explained by the higher anaerobic rate in that specific exercise effort. $\dot{V}O_2$max and [La$^-$] values are poor predictors of TLim-v$\dot{V}O_2$max performance.

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OXYGEN UPTAKE AND VENTILATORY THRESHOLD IN SWIMMING

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The purpose of this study was to identify, in terms of percentage of maximal oxygen uptake (%$\dot{V}O_2$max), the intensity of swimming associated with a non linear increase of minute ventilation (Ve), also described as ventilatory threshold (VT). Twenty nine trained swimmers participated in our study: 15 males and 14 females. Each subject performed a intermittent incremental protocol of 200m stages, with increases of 0.05m.s^{-1}, and 30s intervals between each stage. VT was assessed by Ve/$\dot{V}O_2$ curve modelling method (least square method). It was assumed VT to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential). The analysed values of $\dot{V}O_2$ and Ve were cropped by direct oximetry. The present study demonstrated that the non linear increase of Ve corresponding to VT in a specific swimming situation seems to happen at 84.3±8.7 %$\dot{V}O_2$max.

Key Words: ventilatory threshold, oxygen uptake, minute ventilation, evaluation.

INTRODUCTION

The concept of whole body maximal oxygen uptake ($\dot{V}O_2$max) has received much attention in the specialized literature, especially on its relevance to endurance performance and adaptation to training, being frequently viewed as one of the most relevant factors of performance [2]. However, di Prampero et al. [9] observed that, besides $\dot{V}O_2$max, other parameters are crucial for the athlete endurance performance, such as motor economy and the capability to sustain a high percentage of $\dot{V}O_2$max (%$\dot{V}O_2$max) along the exercise. On the same perspective, Svedahl et Macintosh [17] support that an athlete with a

lower absolute $\dot{V}O_2max$ in comparison with other athletes, can compensate that difference, using a higher $\%\dot{V}O_2max$ to reach the same oxygen uptake (ml/min/kg) along the exercise. According to this, sub-maximal physiological parameters started to be considered as determinant parameters as $\dot{V}O_2max$ for the assessment of athlete's endurance performance potential. Gradually, the Anaerobic Threshold (AT), and its multiple expressions, i.e., lactate threshold (LT), heart rate threshold or ventilatory threshold (VT), became used on training and perceived as determinant parameters on the athlete's performance, once they highly correlate with the $\%\dot{V}O_2max$ related to aerobic performance [3]. Although the importance given to the capacity to sustain a higher $\%\dot{V}O_2max$ related to VT [2], due to the difficulties associated with the evaluation of ventilatory parameters in swimming pool conditions, the assessment of the VT in swimming has been less investigated and used than the metabolic parameters, such as LT.
The purpose of this study was to identify the intensity associated with a non linear increase of the minute ventilation (Ve) described as VT [20], expressed as a $\%\dot{V}O_2max$, in swimming pool conditions.

METHODS

Subjects

Twenty nine trained swimmers were studied: 15 male (21.4±3.0 yy, 177.3±7.0 cm, 68.3±7.1 kg and a $\dot{V}O_2max$ of 70.9±10.2ml/min/kg) and 14 female (18.7±2.4 yy, 164.9±2.3 cm, 55.1±3.9 kg and a $\dot{V}O_2max$ of 59.8±8.0ml/min/kg). All subjects were informed about the details of the experimental protocol before beginning the measurements procedures, and volunteered to participate in this study.

Test protocol

The test sessions took place in a 25m indoor poll. Each subject performed an intermittent incremental test for $\dot{V}O_2max$ assessment. This test had increments of $0.05m.s^{-1}$ each 200m stage, with 30s intervals until exhaustion [10]. Initial velocity was established according to the individual level of fitness, and was set at the swimmer's individual performance on the 400m freestyle minus seven increments of velocity (for more details see Cardoso et al [6]). $\dot{V}O_2$ and Ve were directly measured using metabolic cart (Sensormedics 2900 oxymeter, Yorba Linda – Califórnia, USA) mounted on a special chariot running along the pool [19], and connected to the swimmer by a special respiratory valve [18]. Exhaled air was continually measured during the entire test on each 20s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. $\dot{V}O_2max$ was considered to be reached according to primary and secondary traditional physiological criteria [1, 11]: (i) occurrence of a plateau in oxygen uptake despite an increase in swimming velocity, and (ii) high levels of blood lactic acid concentrations ($[La^-] \geq 8mmol.l^{-1}$), elevated respiratory exchange ratio ($R \geq 1.0$), high heart rate (HR) (>90% of [220bpm-age]) and exhaustive perceived exertion (controlled visually, and case to case, by the respective coaches and scientific staff).
Capillary blood samples for $[La^-]$ analysis were collected from the earlobe at rest, in the 30s rest interval, immediately after the end of each exercise step, and at 3 and 5 min of the recovery period. These blood samples were analysed using an YSI1500LSport auto-analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). HR was monitored and registered continuously each 5s through a HR monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). Swimmers were instructed to perform an open turn, always performed to the same lateral wall side, without underwater gliding, and were verbally encouraged to swim as long as possible during the test period. The test was carried out in same conditions for each subject, i.e., temperature and humidity.

Statistical analysis

Statistical procedure includes mean and standard deviations for all variables. All data was checked for normality. VT was assessed by $Ve/\dot{V}O_2$ curve modelling method (least square method) and was assumed as the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential) [13]. Intensity related to VT was expressed on $\%\dot{V}O_2max$.

RESULTS AND DISCUSSION

The ability to sustain a high $\%\dot{V}O_2max$ during an endurance exercise appears to be related to $\%\dot{V}O_2max$ at VT [2]. Although this fact, due to the difficulties associated with the evaluation of the ventilatory parameters in swimming pool conditions, the VT assessment has been scarcely investigated [16].
The results obtained in our study show that the non linear increase of Ve seems to occur at $88.1\pm31.3\ l.min^{-1}$. This value corresponds to 84.3±8.7% $\dot{V}O_2max$. These findings seem to be in agreement with other studies conducted in running and cycling ergometers (82.3±3% [14], and 84.6±5.1% [7]), pointing out that, despite the specificity of the aquatic environment, the VT occurs at a similar absolute intensity as in running and cycling. This seem to be so, nonetheless the different haemodinamics (because of the horizontal body position), the decreased effects of gravity, and reflex bradycardia [12], in swimming. It also seems that the variation on training patterns in swimming and other sports, such as running and cycling, does not influence the value of $\%\dot{V}O_2max$ at that appends the VT. In the study conducted by Roels et al [16], there weren't found differences on the subjects' VT when performing an incremental test on water and on cycle ergometer, or between the two groups observed, swimmers and triathletes.
Although the obtained value of $\%\dot{V}O_2max$ associated to VT, does not represent the maximal work rate that can be maintained for a long period of time without a continuous rise of blood $[La^-]$ (because, like many studies demonstrate [4, 15], the VT appends to an higher intensity than the intensity associated to the non linear increase in blood $[La^-]$), this exercise intensity should not be ignored in the swimming training, once it is associated to a group of physiologic mechanisms (like the bicarbonate buffering of the lactic acidosis) [5, 8, 20], determinant for the impairment of muscle contractility and its capacity to generate energy.

CONCLUSION

To our knowledge, this is one of the first studies in which $\%\dot{V}O_2max$ and VT are related, in swimming pool conditions. Thus, it is expected to provide additional data to better understanding of VT in swimming. The obtained results seem to indicate that the swimming training should include more intense sets on the aerobic capacity training, than the more "traditional" sets of moderate intensity, normally based or associated to the LT, which only represents one of many parameters associated to the AT. Our results indicate that to fully train the aerobic capacity, sets with intensity close to

85%$\dot{V}O_2$max should also be included, because of the importance of the mechanisms related to VT, on the rapid adjustment of the body's acid-base status during and immediately after exercise.

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LACTATE AND HEART RATE RESPONSES DURING SWIMMING AT 95% AND 100% OF THE CRITICAL VELOCITY IN CHILDREN AND YOUNG SWIMMERS

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The purpose of this study was to compare the lactate and heart rate responses of children (n=8, 11.5±0.6 yrs) and young swimmers (n=7, 16.0±1.7 yrs) when swimming at 95% (V95) and 100% (V100) of their critical velocity (CV). On a series of 4x400m, blood lactate concentration [La] of young swimmers increased at V100 after the 3rd and 4th 400m repetition compared to the 1st (1st:5.55±0.65 vs. 3rd:7.27±1.01 and 4th: 8.02±1.47 mmol/l, $p<0.05$) but remained unchanged at V95 ($p>0.05$). On a series of 4x300m, performed by children, [La] was unchanged after each 300m repetition in both trials (V95 and V100, $p>0.05$). Heart rate was higher in V100 compared to V95 trial ($p<0.05$, between groups $p>0.05$). Swimming at velocity equal to CV increased over time [La] in young swimmers but not in children. This may be attributed to different energetic responses or altered rates of lactate removal in children compared to young swimmers.

Key Words: Endurance training, training intensity, exercise domains.

INTRODUCTION

Metabolic responses during swimming at critical velocity (CV) have been previously reported (8). These early findings suggested that CV and maximum lactate steady state (MLSS) may represent the same exercise intensity. After a more careful examination it was found that CV represents exercise intensity higher than MLSS (2, 3). Energetics of children may differ from those of young swimmers and the metabolic responses have never been examined in children when swimming at this velocity. Even further, it is likely that CV may represent a different exercise domain for children and young swimmers compared to adults (7). The purpose of the present study was to compare the blood lactate and heart rate responses of children and young swimmers when swimming at 95% and 100% of the CV.

METHODS

Seven young swimmers and eight children (male swimmers) (x±SD, age:16.0±1.7 vs. 11.5±0.6years, height:177±6 vs. 149±5cm, body mass:68.9±5.4 vs. 42.9±5.8kg) participated in

the study, after parental agreement. The stage of biological maturation was assessed according to pubic hair development (6). All swimmers covered a distance of 3-3.500m (children) or 4.5-5.500m (young) on a daily basis. Initially, the CV was calculated from performance time on distances of 50-100-200-400m (8). Each swimmer performed a series of 4x400m (young) or 4x300m (children) with a velocity corresponding to 95% (V95) and 100% (V100) of CV in two different days a week apart, randomly assigned with a counterbalanced order. Swimmers had been familiarized with the required velocity two-three days before testing. To avoid any inconsistency with the prescribed velocity, one of the experimenters walked to the side of the pool and gave instructions when necessary.
The time to complete three stroke cycles was recorded during the last 25m of each 100m of the 400 or 300m in each trial for the calculation of the stroke frequency (SF). Stroke length (SL) was calculated from the mean velocity of each repetition divided by the mean SF. The resting interval between repetitions was kept as short as possible (35-45s) to allow for capillary blood sampling. Capillary blood samples were obtained from the finger-tip (10μl) after each 400 or 300m repetition and were enzymatically analyzed for blood lactate concentration ([La]) (Dr Lange M8). Heart rate (HR) was continuously recorded during each trial (Polar xTrainer-plus). Diet and training were controlled two days proceeding each testing session. The front crawl swimming style was used during all testing sessions and controlled warm-up was applied before each trial. All procedures took place in a 50m indoor swimming pool with a water temperature of 26 ^{o}C. Analysis of variance for repeated measures was applied for statistical analysis (group x trial x repetitions). The Tukey post-hoc test was applied to locate the differences between variables. The level of significance was set at $p<0.05$ and the results are presented as mean ± SD.

RESULTS

The CV of young swimmers was higher compared to children (1.34 ± 0.04 vs. 1.17 ± 0.04 m/s, $p<0.05$) and corresponded to 96 ± 0.7% and 97 ± 0.3% respectively of their individual 400m best time. Children were at 2.3 ± 0.5 and young at 4.4 ± 0.8 of Tanner's stage. In young swimmers, blood lactate was higher at V100 compared to V95 (5.95 ± 0.95 vs. 3.91 ± 1.11mmol/l, $p<0.05$) increased at V100 after the third and fourth 400m repetition compared to the first (1st:5.55 ± 0.65 vs. 3rd:7.27 ± 1.01 and 4th: 8.02 ± 1.47 mmol/l, $p<0.05$) but remained unchanged at V95 (1st: 3.80 ± 0.91, 2nd:4.41 ± 1.08, 3rd:4.52 ± 0.94, 4th:4.61 ± 1.03 mmol/l, $p>0.05$, fig. 1).

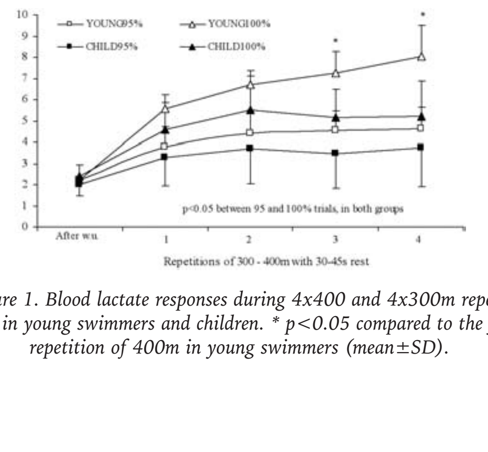

*Figure 1. Blood lactate responses during 4x400 and 4x300m repetitions in young swimmers and children. * p<0.05 compared to the first repetition of 400m in young swimmers (mean±SD).*

In children, blood lactate was unchanged after each 300m repetition in both trials (V95; 1st:3.27 ± 1.31, 2nd:3.70 ± 1.67, 3rd:3.48 ± 1.64, 4th:3.74 ± 1.82 mmol/l and V100; 1st:4.56 ± 1.32, 2nd:5.49 ± 1.89, 3rd:5.15 ± 1.35, 4th:5.21 ± 1.68 mmol/l, $p>0.05$, fig. 1). Blood lactate concentration was higher at V100 compared to V95 in both groups ($p<0.05$).

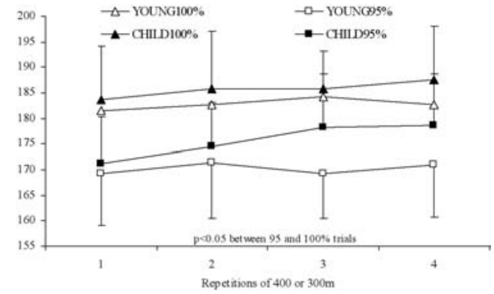

Figure 2. Heart rate responses during each repetition of the 4x400 and 4x300m swimming set (mean±SD).

HR was higher in V100 compared to V95 trial (184 ± 8 vs. 173 ± 8 b/min, $p<0.05$) and no difference was observed between groups ($p>0.05$, fig. 2). SF was increased in children compared to young swimmers (90 ± 13 vs. 77 ± 14 str/min, $p<0.05$). Both groups showed higher SF during the V100 compared to V95 trial ($p<0.05$). However, this increment was statistically significant for children but not for young swimmers (children, V95:79 ± 6 vs. V100:101 ± 6 str/min, $p<0.05$). Conversely SL decreased in children compared to young swimmers as well as during the V100 compared to the V95 trials ($p<0.05$).

DISCUSSION

The findings of the present study indicate that blood lactate responses during swimming at a velocity corresponding to the critical velocity (V100) are not similar between young boys and children. Swimming at V100 caused a rise of blood lactate after the second 400m repetition in young swimmers. In children lactate accumulation did not change after each 300m repetition in the corresponding velocity. Both groups completed the swimming repetitions at a velocity corresponding to 95% of the CV (V95) without blood lactate accumulation (fig. 1).
Blood lactate concentration is a widely used blood marker of metabolic responses during exercise and represents the difference of lactate release and the removal from circulation, but gives us no evidence of the events at the muscle cell. Therefore, increased blood lactate concentration after each repetition in young swimmers but not in children may be attributed to at least two factors. Firstly, anaerobic contribution which may be expressed by increased lactate concentration is higher in young swimmers compared to children when swimming at the same relative intensity (5). Secondly, the rate of lactate removal may be different between the groups tested in the present study. In fact, recent findings suggest that children and adults do not show the same rate of lactate removal following maximal exercise (1). However, exercise at V100 cannot be considered as maximal since it represents exercise intensity below maximum oxygen uptake (2). Moreover, the rest interval between repetitions may have allowed for some blood lactate removal but this period (30-45s) was similar for both groups.

Even with different rates of removal, therefore, it is unlikely that this short recovery period was responsible for the lower lactate concentration in children compared to adults. On the other side, a different turnover rate of lactate during swimming between young swimmers and children is not improbable if we consider the difference in the training background of both groups (i.e. young 6 years, children 1-2 years of competitive training).
Increased blood lactate accumulation at V100 in young swimmers may indicate exercise at a severe intensity domain. On the other side, the stability of blood lactate concentration on the corresponding trial may indicate exercise at a heavy intensity domain in children. The procedures followed in the present study did not allow us to speculate whether the critical velocity represents different exercise domains in these swimmers. However, our results are in agreement with earlier findings which reported that critical velocity represents exercise intensity above the maximal lactate steady state (MLSS) for adult swimmers (2). Research which focused on the location of CV on the exercise intensity domains should take into account that this parameter is estimated with different protocols on the number and duration of the tested distances. In a previous study (2) the trial duration was 1.4 to 7.1 min compared to 27s to 5.6 min in the present study. The shorter duration of our testing trials may have overestimated the CV. It is not surprising then that CV corresponds to 96 and 97% of the 400m velocity in the present study compared to 93% of the velocity at maximum aerobic power (2). Moreover, CV in children may represent exercise intensity similar to lactate threshold (7) while it is far above this level in mature triathletes during swimming (4). The difference in metabolic responses may indicate that CV expresses different exercise intensity domains for young swimmers and children.
HR increased in the V100 compared to V95 trial and was similar between groups. The values are similar to those reported for exercise intensity at 95% of the maximum aerobic speed and this represents exercise intensity above the MLSS (88% of maximum aerobic speed, Dekerle et al. 2005). The HR during the V95 trial (169-179 b/min) is comparable to that observed when swimming at MLSS (i.e. 179 b/min, 2). However, similar HR values between groups corresponded to different metabolic responses.
SF increased and SL decreased during the V100 compared to V95 trials. The SL did not decrease significantly during the 400m or 300m repetitions as it was expected (3) and this may be explained by the intermittent nature of the test which allowed for some recovery and maintenance of performance.

CONCLUSION
The present findings indicate that swimming at CV will induce an increased blood lactate concentration over time in young swimmers. However, this was not observed in children swimmers, and it may be attributed to different energetic responses or altered rates of blood lactate removal between groups. Coaches are advised not to focus on HR responses only but also take into consideration the fact that swimming at a velocity corresponding to CV may lead to different lactate responses and may represent different levels of exercise intensity in children or young swimmers.

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STROKE RATES CORRESPONDING TO CRITICAL SPEED AND THE MAXIMAL SPEED OF 30 MIN IN SWIMMERS OF DIFFERENT TRAINING STATUS

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The objective of this study was to verify the effect of aerobic performance level on the relationship between stroke rates at critical speed (SRCS) and at maximal speed of 30 min (SRS30). Twenty-three male swimmers of 15 to 20 yr were divided by aerobic performance level (S30) into G1 (n = 10) and G2 (n = 13) groups. SRCS was determined by the slope of the regression line between the number of stroke cycles and time. SRS30 was determined trough the mean value of stroke rate obtained during 30 min test. CS was higher than S30 in G1 (1.30 ± 0.04 and 1.23 ± 0.06 $m.s^{-1}$) and G2 (1.17 ± 0.08 and 1.07 ± 0.06 $m.s^{-1}$). CS and S30 were higher in G1 than G2. There was no difference between SRCS and SRS30 in G1 (33.07 ± 4.34 and 31.38 ± 4.15 $cycles.min^{-1}$) and G2 (35.57 ± 6.52 and 33.54 ± 5.89 $cycles.min^{-1}$). In conclusion, SRCS can be used to predict the SRS30 irrespectively of the aerobic performance level.

Key Words: Stroke rate, swimming, aerobic capacity.

INTRODUCTION
In competitive swimming, biomechanical aspects representing the swimming technique and skill may equally contribute to performance when compared to aspects related to the energy production systems. These biomechanical aspects include the level of application of propulsive force and passive and active drag (9, 14).

Studies have shown that these aspects interfere with variables such as energy expenditure and propelling efficiency, with these factors being fundamental for human locomotion in water (3, 18). Among the indices that express the biomechanical skill in swimming is the stroke rate (SR), which corresponds to the number of strokes or stroke cycles performed per unit of time. In addition, the relationship between this variable and stroke length (SL) also seems to express the swimming ability level (3). The mean speed in swimming is equal to the product of SR and SL (16). To maintain a given speed, swimmers generally adopt a combination of SR and SL which they judge to be most efficient. These variables have shown a significant correlation with oxygen uptake at a given submaximal speed and with performance at different swimming distances (100, 200, 368 and 400 m) (2, 3, 10, 18).
With respect to the physiological indices that can estimate aerobic capacity, the critical speed (CS) and the maximal speed of 30 minutes (S30) are among the noninvasive methods most widely used for aerobic assessment during swimming (7, 15). These speeds (CS and S30) have shown high correlations with speed at maximal lactate steady state and with aerobic performance in this modality (5, 8). Recently, Dekerle et al. (4) showed that the SR determined based on the slope of the regression line between the number of stroke cycles and time obtained at different distances (critical stroke rate – SRCS), similar to the method proposed for the determination of CS, is valid to estimate the SR maintained in an S30 test (SRS30) (4). One advantage of this method is that shorter tests (e.g., 200 and 400 m) can be used, since longer tests such as the S30 require more time for assessment and are difficult to perform by less skilled swimmers.
Since the CS depends on the duration of predictive loads (1), a fact that might interfere with the relationship between this variable and the anaerobic threshold (4 $mmol.l^{-1}$ blood lactate) (8), it is possible that the physiological and biomechanical meaning of CS depend on the performance level of the swimmers, since high performance athletes swim the same distances (e.g., 200 and 400 m) in less time. Still regarding the performance level, elite swimmers may adopt combinations of stroke parameters which are very different from those used by their less proficient counterparts (4). Thus, it is possible to hypothesize that the level of aerobic performance may modify the relationship between SRCS and SRS30. On the basis of this hypothesis, the central objective of the present study was to determine the effect of the aerobic performance level on the relationship between SRCS and SRS30.

METHODS

Subjects

Twenty-three male swimmers with similar physical characteristics were divided by aerobic performance level (S30) into G1 (n = 10) (Age = 16.22 ± 2.72 yr., Body mass = 64.74 ± 11.45 kg, Stature = 174.08 ± 7.42 cm, Body fat = 12.80 ± 2.99 %) and G2 (n = 13) (Age = 14.60 ± 1.35 yr., Body mass = 61.56 ± 15.76, Stature = 169.80 ± 10.37, Body fat = 14.80 ± 5.27). They had at least 4 years of experience in the modality and a weekly training volume of 30,000 to 45,000, and were competing in regional and national level. Before participation in the study, the swimmers and their parents or guardians were informed of all test procedures and they provided voluntary written informed consent to participate in the study. The protocol was approved by the university's ethics committee.

Experimental design

The anthropometric characteristics were measured in the first experimental session. Then, the performances of 200 m, 400 m, and 30 min in front crawl were determined in a random order. All tests were performed in a 25 m pool, with at least 48-72 h of rest. Swimmers were divided in groups G1 and G2 based on the maximal speed of 30 min (S30), which was different between groups ($p < 0.05$). For each swimmer, all tests were conducted at the same time of day and after at least 2 h of a meal.

Determination of critical speed (CS)

During training sessions, the participants were instructed to swim distances of 200 and 400 m as quickly as possible. The time taken to swim each distance was recorded using a manual chronometer. Participants swam one event per day in random order. CS was determined using the slope of the linear regression between swimming distances and the time taken to swim them.

Determination of maximal speed of 30 min (S30)

S30 was determined through a maximal 30 min test, recording the distance in m, and calculated dividing the distance by time. At the 10th min and at the completion of the test, 25 μl of arterialized blood were collected from the ear lobe through a heparinized capillary and immediately transferred to microcentrifuge tubes containing 50 μl NaF (1%) for lactate [La] measurement (YSL 1500 STAT, Yellow Springs, OH).

Determination of the stroke rates corresponding to SC (SRCS) and S30 (SRS30)

During the 200 and 400 m tests, the time necessary to complete 5 strokes was measured along the pool, at each passage of 50 m, and the mean value was calculated. SRCS was calculated by the linear slope of the regression line between the number of stroke cycles and time. During the 30 min test, the time necessary to complete 5 strokes was measured along the pool, at each passage of 400 m. To determine SRS30, the mean value was calculated. These measurements were made after 10 m of the turn to avoid its influence in swimming speed.

Statistical Analysis

The values were expressed as mean ± SD. The effect of method (CS and S30) and group (G1 and G2) on the relationship between SRCS and SRS30 was made through ANOVA TWO WAY, with Tukey HSD post-hoc tests where appropriate. The comparison of the physical characteristics between groups was made through Student *t* test for unpaired data. The correlation between CS and S30 was made through Pearson product moment correlation coefficient. Significance was set at $p \leq 0.05$.

RESULTS

Table 1 presents the mean ± SD values of SRCS, SRS30, CS and S30 obtained in G1 and G2. There was no significant difference between SRCS and SRS30 in G1 and G2. The SRCS and SRS30 were similar between groups. CS was higher than S30 in G1 and G2 ($p < 0.05$). CS and S30 were higher in G1 than G2 ($p < 0.05$). There was no significant difference in the blood lactate levels obtained at 10th min and the completion of the 30 min test between G1 (4.37 ± 1.53 and 3.58 ± 1.57 $mmol.l^{-1}$, respectively) and G2 (4.09 ± 1.57 and 3.66 ± 1.56 $mmol.l^{-1}$, respectively) ($p > 0.05$). The correlation between CS and S30 (G1 – r = 0.68 and G2 – r = 0.84) and SRCS and SRS30 (G1 – r = 0.84 and G2 – r = 0.88) was statistically significant in both groups.

Table 1. The mean ± SD values of SRCS, SRS30, CS and S30 obtained in G1 and G2.

	G1 (n = 10)	G2 (n = 13)
CS ($m.s^{-1}$)	1.30 ± 0.04	1.17 ± 0.08*
S30 ($m.s^{-1}$)	1.23 ± 0.06	1.07 ± 0.06*
SRCS ($cycles.min^{-1}$)	33.07 ± 4.34	35.57 ± 6.52
SRS30 ($cycles.min^{-1}$)	31.38 ± 4.15	33.54 ± 5.89

** $p < 0.05$ in relation to G1. SRCS – stroke rate at critical speed, SRS30 – stroke rate at maximal speed of 30 min, CS – critical speed, S30 – maximal speed of 30 min.*

DISCUSSION

The central objective of the present study was to determine the effect of aerobic performance on the relationship between SRCS and SRS30 during swimming. The main finding was that the relationship between SRCS and SRS30 was similar in G1 and G2, suggesting that, irrespective of the aerobic performance level, the determination of CS may simultaneously provide information about aerobic capacity and biomechanical skill in this modality.

In a study conducted on trained swimmers, Dekerle et al. (4) found values of SRCS (37.79 $cycle.min^{-1}$), SRS30 (36.41 $cycles.min^{-1}$), CS (1.35 $m.s^{-1}$) and S30 (1.31 $m.s^{-1}$) higher than those observed in the present study for G1 and G2 (Table 1). These authors also observed no significant difference and a high correlation ($r = 0.86$) between SRCS and SRS30, in agreement with our data showing that the relationship between SRCS and SRS30 seems to be independent of aerobic performance. However, in contrast to the above study, in the present investigation CS overestimated S30 in both groups. One aspect that might explain in part this behavior is the small experience of the swimmers, a fact that may have underestimated the S30, since the experience level seems to influence the capacity to perform endurance tests (5). Therefore, modifications in the technical pattern (SRCS x SRS30) seem to occur to an extent differing from the variations in swimming speed (CS x S30), at least at the level of experience and aerobic performance analyzed in the present study.

With respect to the measurement of SR at intensities close to the CS or S30, studies have shown a significant change in the stroke pattern when the individual exercises above the intensity corresponding to the maximal lactate steady state (12), or above the anaerobic threshold (11, 12, 13), suggesting a relationship between metabolic fatigue and a fall in swimming skill (6). In cyclic sports, the fatigue is associated with a reduction in the frequency of the movements (17). Therefore, since biomechanical skill may be compromised as a function of physiological mechanisms associated with fatigue, the measurement of SRCS or SRS30 and of CS or S30 might be an important tool to determine the biomechanical and physiological aspects associated with aerobic capacity.

CONCLUSION

Based on the present data we conclude that the aerobic performance level does not seem to influence the relationship between SR corresponding to CS and S30. Thus, the protocol of determination of CS may simultaneously provide information regarding physiological aspects (aerobic capacity) and an index associated with biomechanical skill, thus representing an important tool for the assessment, control and prescription of aerobic training in swimming, since less skilled athletes might underestimate the distance to be covered for 30 min as a result of lack of experience and high motivation.

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THE FUNCTION OF NASAL PRESSURE FOR BREATHING IN THE BREASTSTROKE

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The purpose of this paper is to discuss the function of the sensation of water touching the face and the effects of nasal pressure on breaststrokers. For examining facial sensation, skin around the nose was covered with film. To study effects of nasal pressure, the nostril was covered with film. Then the pressure data and other data were analyzed using the Student T-test. There was no difference (t=0.40) in depth pressure with swimmers covered with film and not covered. When the nostrils were closed, face depth (average: 30.3cm) was shallower (t=0.006) than in the controlled setting (28.0cm). There were no significant differences (t=0.62) between the experimental and controlled settings with regards to face-sustaining duration above water surface and subjects' breathing.

Key Words: breath control, nasal pressure, water pressure, facial sensation.

INTRODUCTION
Two study discuss in the paper illustrate the importance of facial sensation on swimmer's sense of safety and swimming continuity, which are two important factors in swimming. Using nasal pressure measuring method (3), the result from the experiment revealed that intranasal pressure was a little higher than the pressure in water at the depth where subjects were swimming while exhaling and holding their breath. Novice swimmers often have problems controlling breathing while swimming. As a result, the water is swallowed or swimming is cut short due to breathing problems. This is directly linked to how the swimmer times exhalation or inhalation appropriately.
The purpose of this paper is to discuss the results of two experiments. The first experiment was to determine the sensation of water touching the face, especially the cheek area. The second examines how nasal pressure sensation affects the timing of exhalation and inhalation.

METHODS
The purpose, methods and risks were explained to the subjects in verbal and written form and consent was given prior to carrying out the experiments. The methods used were approved by the Department of General Planning Research Cooperation Section of Kokugakuin University. The characteristics of subjects are shown in Table 1.

Table 1. Characteristics of Subjects (average).

Experiment	N	Age (yrs)	Body Fat(%)	Sex	Swim Experience
#1) Cheek covered	6	23.0	17.3	male	recreational
#2) Nostril closed	6	23.2	18.0	male	recreational

Nasal pressure was measured during ten strokes with two sensors. One sensor was inserted in the nasal passage and the other was placed outside the nostril wall with surgical tape. The outside pressure was measured at face depth (fig. 1). All pressure measurements were performed in a swim-mill. To cover the facial area and close the nostril, see-through protector film was used. The film was 0.03 mm thick, made of polyurethane, which is primarily used for covering lesions. Differences in water pressure and nasal pressure were analyzed by the Student T-test (probability = 0.05).

Figure 1. Lowest stroke position; the arrow (from the surface to the sensor) shows the depth where measurements were taken.

Figure 2. Cheeks were covered with film around the nose and below the nose (The area inside the black line).

Experiment #1 attempted to determine the function of the sensation of water touching the face. To do this we compared facial depth of breaststroke swimming in normal conditions (controlled condition) to film-covered trials, which included subjects' cheeks, nose, and the part below the nose being covered with protector film (fig. 2). In both the conditions, the nostrils were not closed with film. To measure intranasal pressure and water depth pressure, two interface tubes were attached by surgical tape.
Experiment #2 compared facial depth when influenced by the closing of the nostrils with film. Facial depth was measured while subjects swam the breaststroke under normal conditions (controlled condition) and when nostrils were closed (experimental condition).

Pressure was measured with a pressure transducer (SPC-464:Millar) connected to a control unit (TCB-500:Millar). This was also used to measure arterial blood pressure and to obtain reliability (1, 4). Data was recorded on LogWorx (Distributed Design Concepts) and measured pressure was analogically curved (fig. 3).

RESULTS

This section discusses the statistical data of two experiments. In experiment #1 (facial depth pressure study) there was no significant difference between the control condition and the film-covered condition (Fig. 4-left). The Student T-test result was t=0.40. In the second experiment, a difference in the depth pressure was found (Fig.4-right). In the control condition, the average pressure was 28.0 cmH2O, and in nostrils-closed condition, it was 30.3 cmH2O, and the result of Student T-test was t=0.62. On the pressure curves, the face-sustained duration was also measured (Fig.3), which was detected between depth pressure curves (fig. 2). Then it rose once again when the sensor went below the water. The duration of the curve was measured while at the bottom. No significant difference was found between experiments pertaining to face-sustained duration.

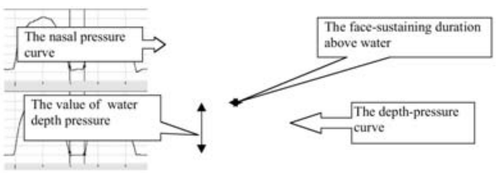

Figure 3. The pressure curves obtained from the experiment and an explanation of sections analyzed.

DISCUSSION

In an earlier study, it was reported that nasal pressure is higher, albeit minutely, than water depth pressure when the face is immersed in water (2). This pressure is required to protect the nose from incoming water. Another consideration, while swimming, aside from pressure, is the timing of breath inhalation and the intake of water. Intake of unwanted water occurs due to a lack of sensation when water touches the skin, and/or due to a lack of sensing nasal pressure. When exhaling while swimming, there is a tendency to inhale from the nose and mouth as soon as possible, at the moment the face is above water. This is done in an effort to avoid holding one's breath longer than is deemed necessary. For the purpose of quick breathing, the cutaneous sensor and pressure sensor in the nasal area must perform their roles effectively.

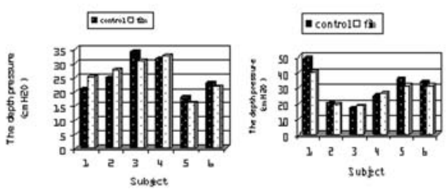

Figure 4. Comparison of average depth pressures in the first experiment (LEFT: film covered the cheek area) and the second experiment (RIGHT: the film closed the nostrils).

Based on the results of the two experiments, safe breathing exhalation from nose appears to be more important than the sensation on the cheeks. Previous research supports this hypothesis. Tsubone (5) reports that negative pressure receptors are found in the nasal passage of rats. Similar receptors may exist in humans. Wheatley (6) describes breathing routes; one through the mouth and the other via the nose. Therefore, nasal exhalation while swimming is very important for breath control. The pressure receptor might have an important role in pushing the switch on to start inhalation at the moment of when a positive amount of pressure changes to state of near zero pressure in the air.

In the case of swimming instruction, knowledge about timing sensory mechanisms can enhance successful swimming, especially for beginners. While swimming, novice swimmers usually have two kinds of difficulties in regards to breathing. One is difficulty in timing inhalation, for fear of swallowing water at the moment of inhalation. Negative pressure in the nose reassures the swimmer that inhalation can be carried out without fear of swallowing water because their face is in the air. To alleviate such a fear, exhaling while the nose is still in the water is effective. To keep the face in the air, the face must be held in a high position for a longer period of time. To avoid having the face out of the water for too lengthy a duration, early inhalation is very important.

The other difficulty surrounding exhalation for a novice swimmer is the fear of not being able to be inhale on the next breathing motion opportunity. To combat this fear while swimming, it is important to be conscious of one's facial position, both in and out of water. When cutting the surface with a quick vertical head motion, the cutaneous sensation on the face is confusing for breath control. With slow head rises, one can easily recognize whether one's mouth and nose are still in or out of water.

ACKNOWLEDGEMENT

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CONCLUSION

When instructing beginners, breathing is the most important factor to assure safety and to make them psychologically comfortable. Therefore, investigating the breathing mechanism of the breaststroke is meaningful in developing physiological grounds for instruction of novice swimmers.

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MIXED-MODEL ANALYSIS OF THE RELATIONSHIPS BETWEEN TRAINING LOADS AND HEART RATE VARIABILITY IN ELITE SWIMMERS

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INTRODUCTION
Heart rate variability (HRV) analysis is a well-recognized method to assess autonomic nervous system perturbations, and was shown to be influenced by the fitness and the fatigue in endurance athletes (6). The relationships between HRV and training loads were shown to be highly individualized (6), and dependent of several factors, including gender (G), training level (L) and specialty (S) (1). Indeed, the HRV responses could probably be influenced by long-term effects (LTE) (6). When only few repeated measurements are available for several subjects characterized by a large inter-individual variability, mixed models provide an attractive solution (2). Instead of constructing a personalized model for each subject, a model of common behavior is constructed, allowing parameters to vary from one individual to another, to take into account the heterogeneity between subjects. The aim of this study was to investigate the immediate and differed effects of training loads on HRV taking into account: (a) the mean structure of the covariates G, L, S; (b) individual profiles, and (c) subpopulation profiles.

METHODS
Twenty one (11 females, 10 males) national and international level French swimmers were studied, (20±3 yr, 179±6 cm, and 65±11 kg). HRV was monitored during 1 to 3 years, twice a month, during each period of the training cycle. The mean number of recordings per subject was 23±12. Each test lasted 12 min, in supine position. The RR interval (time between two R waves of the recorded cardiac electric activity) was measured with a Polar S810 HR monitor (Polar®, Kempele, Finland). Fast Fourier Transform (FFT) was then applied to calculate the spectral power using Nevrokard HRV software (Nevrokard® Medistar, Ljubljana, Slovenia). Peaks were extracted from the spectrum and determined on low frequency (LF between 0.04 Hz and 0.15 Hz) and high frequency (HF between 0.15 Hz and 0.5 Hz). This allows us the determination of LF and HF powers, total power (TP) and computing the LF/HF ratio. Quantification of the training stimulus was performed as proposed by Hellard et al. (5). Three training loads were determined according to 3 training zones. Low intensity training (LI), represented swimming speeds below the onset of blood lactate accumulation (OBLA), and high intensity training (HI), represented swimming speeds above OBLA. Strength training (ST) was quantified in minutes of active exercise, excluding resting periods. Then, 3 training phases were identified during each training cycle: the short term phase (STP) was defined as the last week before each HRV measure; the intermediate (ITP) and long term phase (LTP) were defined as week 1 and week 2 prior each HRV measure. Finally, 9 distinct independent variables were defined STP_{LI}, ITP_{LI}, LTP_{LI}, STP_{HI}, ITP_{HI}, LTP_{HI}, STP_{ST}, ITP_{ST}, LTP_{ST} and linked to HRV measures using mixed models.

RESULTS
TP and LF were higher in male than in female (18687±2888 vs. 8227±1857 ms^2; 3885±2888 vs. 1857±2269 ms^2, respectively $p\leq 0.01$). TP and LF were higher for international swimmers than for national (14475±12407 vs. 10655±14712 ms^2; 8392±9483 vs. 5752±9445 ms^2, respectively $P < 0.01$). TP and LF increased significantly from the first to the second part of the season (16512±14166 vs. 10109±12115 ms^2; 10246±10657 vs. 5005 vs. 7772 ms^2). The mixed model described a significant relationship between training and HRV HF=0.18L [0.09-0.26] + 0.16SU [0.06-0.23] + 0.16 STP_{LI} [0.06-0.23] + 0.11G [0.03-0.21] – 0.10 STP_{ST} [0.02-0.18], R_=0.1, F=7.71, $p\leq 0.0001$. In the model the inter-subject differences were statically significant. The fit between real and modelled HRV values was significant for all swimmers ($0.10\leq R^2\leq 0.47$, $p\leq 0.05$). For instance, for subject 4, LF/HF= -0.32 STP_{LI} [-0.58;-0.06] - 0.48 STP_{HI} [-0.73;-0.23] + 0.59 STP_{ST} [0.33;0.85] + 0.60 ITP_{HI} [0.39;0.81], R_=0.40, F=3.11, $p\leq 0.05$. The number of measured LF/HF data included into the 95% CI was 15 in 21 measured (Figure 1).

DISCUSSION
The four main observations emerging from these analyses were: 1) HRV was higher for international level swimmers. 2) The impacts of training on HRV increase significantly from the first to the second part of the season. 3) Considering the overall sample, the training variables explained only a weak part of HRV variance. 4) Finally the variations of HRV were specific to the interactions of the various types of training loads during the course of time.
HRV was higher for international level swimmers. Several researches pointed that basic characteristics of the autonomous nervous system would largely induce the nature of the responses to training. Hautalla et al. (3) highlighted in 39 sedentary subjects (ages 36 ± 6 years) a relationship between the improvement of the aerobic power after a 8 weeks training course and the night power parasympathetic HF at the beginning of the study. Hedelin et al. (4) showed in seventeen cross-country skiers and canoeists that those having improved their $\dot{V}O_2max$ were characterized by higher initial power HF values. These results let suppose that initial high levels of variability prelude to the increase in the VO_2max (3, 4).
The impacts of training on HRV increase significantly from the first to the second part of the season. These higher values of variability could be one consequence of the more intense and prolonged training as well as of the delayed effects of the first part of the year. Indeed, the HF rhythmic component responses could probably be influenced by long-term effects. For instance, (Furlan et al. 1993) showed that high level swimmers examined after a six weeks detrained period were characterized by slight bradycardia accompanied by a spectral profile suggestive of a prevailing vagal tone. In the same trend Pichot et al. (6) observed a persistence of the parasympathetic prevalence after a 7 weeks period of detraining following a two months training period.

For the group as a whole the training variables explained only a weak part of the measurements HRV variance. Indeed, large inter individual variations were observed in the autonomic cardiac regulation (7). Several researches showed that the genetic factors determined a broad proportion (~ 20%) of the HRV inter individual variations (7, 8). Moreover, several factors (quality of the sleep, psychological states) are likely to influence diurnal measurements of HRV (1).
Figure 1 shows for subject 4 the real and modelled LF/HF ratio evolution compared to the swimming training load (n=21, r=0.28, p=0.2). This figure highlights the difficulty to interpret the HRV measures evolution from only one training parameter. Indeed the solution of the regression for this subject points that the training swimming load during the week of the test decreases ratio LF/HF, whereas two weeks weight and water severe training loads tends to increase this ratio.
Finally the HRV variations were specific to the various types of training loads, to their interactions and distribution in the course of time. Moreover the cardiovascular responses during training were specific to the nature and intensity of exercise (1).

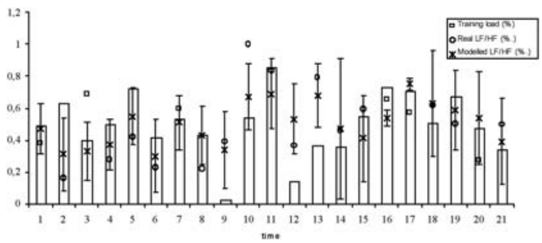

Figure 1. Real and modelled LF:HF ratio associated with the weekly training swimming load for subject 4. Values in vertical axis are expressed in normalised values. In horizontal axis are expressed the number of HRV measures. Real LF:HH measures is indicated with circles and modelled LF:HF measures with crosses. Weekly swimming training loads are represented with yellow rectangles.

CONCLUSION
In conclusion, the HRV was higher in high-level swimmers and increased throughout the sporting season. It could be interesting to model the individuals training loads/HRV relationships in order to control the training impact on autonomic nervous system.

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THE VALIDITY OF A NON-PACED LACTATE PROFILE TEST FOR SWIMMERS

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The aim of this study was to examine whether swimming without pace-lights affects lactate test results compared to swimming with pace-lights. Each of the 11 competitive swimmers performed, in a randomized order, on one day with paced workloads and one day without. The test protocol consisted of five 400m front crawl workloads with increasing velocity. Predetermined velocities for each swimmer were either paced using a set of 14 pace-lights moving below the swimmer or self paced. Mean velocities of paced or unpaced workloads at lactate values of 2, 3, 4 and 5 mM showed no statistical differences (p>0.05), and mean standard deviation of lap times was 0.60±018 and 0.57±0.17s for the paced and unpaced trials respectively (p>0.05). This study shows that during lactate testing, competitive swimmers are able to hold an even pace and meet predetermined workloads without the use of external pacing.

Key Words: lactate testing, validity, pace lights, testing methodology, pacing.

INTRODUCTION
On the contrary to maximal oxygen uptake testing, blood lactate profile testing has several suggestions for test protocols. The whole concept rests on different theoretical backgrounds, like ventilatory threshold (8), onset of blood lactate accumulation (OBLA) (3) or a fixed 4 mM lactate threshold (4). These different concepts make it difficult to establish a gold standard for lactate profile testing. However, the concept of maximal lactate steady state (MaxLass) (e.g. 2) seems to establish a standard, and lactate testing often aims at finding the MaxLass in an indirect way. However, research has shown differences in test results due to only small differences in testing protocol, for instance by different lengths of workloads, different rest intervals and different intensity increases between the workloads (2).
The important features of indirect lactate testing protocols to find MaxLass are the ability to 1) keep a even pace during the workload, and 2) keep the increase in intensity from workload to workload at reasonable steps and 3) to have a short but standardised rest interval (2). In a dry-land laboratory the use

of workload control by a motorised treadmill or an electrically controlled ergometer cycle is a certainty. In the pool laboratory this control is not often an option and the use of pacing lights has been suggested to control workload when testing swimmers (5). Whether the pacing by moving underwater lights really is necessary has not yet been investigated. The question is whether competitive swimmers, who often use pace-clocks in their training and have been doing so for many years, are able to keep an even pace without the use of pace lights. The aim of this study was to examine whether swimming without pace-lights affects lactate test results compared to swimming with pace-lights.

METHODS

A randomized crossover design was conducted, where each of the 11 swimmers (mean age 20 years (range 16-24)) was their own control. All subjects were competitive swimmers, and consisted of 3 females and 8 males. Their performance level ranged from one Olympic swimmer, through Norwegian Championship medallists and club level swimmers. Average weekly training volume for the last 6 months before the study was 36 000m.

The test protocol was performed once with and once without paced workloads on two different days, at the same time of day, and with one resting day between the two tests. The order of the two test days was randomized. A stepwise test protocol consisted of five 400m front crawl workloads with increasing velocity and a 60s rest interval. Working times ranged from slowest swimmer and slowest workload with 362s (6:02 min) to 250s (4:10 min) for the fastest workload on the fastest swimmer. Predetermined velocities for each swimmer were either controlled by the swimmer himself or paced using a set of 14 pace-lights (Optimal Controlbox Corp., USA) moving below the swimmer (fig. 1). During the paced trials the subjects were excluded from using the pace clock. A standardised warm-up procedure was used, and before the paced test subjects were familiarized with using the pace lights.

Lactate data was collected using an YSI 23L lactate analyser (Yellow Springs Instruments, Yellow Springs, USA). The analyzer was calibrated according to standard procedures (using 5 and 15mM standard lactate solutions). True velocity was calculated in $m \cdot s^{-1}$ using a stopwatch and the pool length. A paired t-test was used for statistical comparisons.

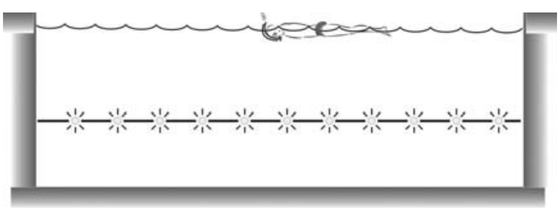

Fig 1: Pace- lights controlling the velocity of the swimmer.

RESULTS

The mean velocities of paced or unpaced workloads at lactate values of 2, 3, 4 and 5mM showed no statistical difference and are shown in fig. 2. The mean absolute difference between paced and un-paced velocities at lactate values of 2, 3, 4 and 5 mM are all 0.02 (± 0.01) $m \cdot s^{-1}$.

Standard deviation of the mean times for each pool lap in each workload (16 laps) was chosen as the measurement of how evenly paced each workload was conducted. The mean standard deviation for each workload number is shown in fig. 3. For all trials and all subjects the mean standard deviation was 0.60±018s using pace lights and 0.57±0.17s swimming freely ($p=0.32$). A two-way ANOVA test for the effects of pacing and workload number showed no statistical effect of pacing, a significant effect of workload number ($p=0.03$) and no interaction effect. A Bonferroni corrected post hoc test revealed a significant smaller mean standard deviation of lap times for unpaced workload nr 4 compared to workload nr 1.

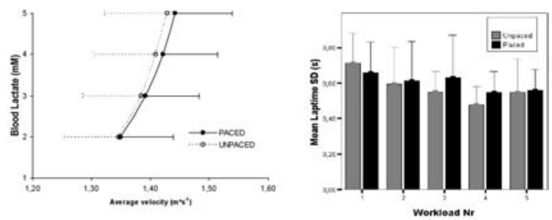

Figure 2. Average velocities (±SD) for Fig. 3: Mean (error bars show SD) lap paced and non-paced workloads time standard deviation (s) for paced (n=11) at lactate levels of 2, 3, 4 an and unpaced workloads. 5mM

Furthermore, no statistical difference was found between the average decrease in swimming time from workload to workload in paced compared to unpaced swimming (mean± SD of 14.4±1.66 and 13.0±1.14s respectively $p>0.05$).

DISCUSSION

The use of lactate testing in swimming without any form of pacing control is a widespread custom. This custom is justified by the present results, showing that competitive swimmers are able to keep an even pace and that they are able to work at the prescribed workload (velocity) without pacing help. The results show that mean difference of velocities at 2, 3, 4 and 5 mM lactate values is 0.02 $m \cdot s^{-1}$. This must be considered a low difference and was found to be statistically not significant. For comparison, a common velocity step when testing swimmers for sub maximal VO_2 is 0.05 $m \cdot s^{-1}$, and the mean decrease in velocity from lap 3 to lap 4 during international short course 100 m races may be in the area of 0.04 $m \cdot s^{-1}$ (unpublished results from race analysis). The relatively large standard deviations shown in fig. 2 are due to a relatively vide range in performance of the subjects.

Looking at the variations in lap times for each workload it seems that a pacing device for swimmers is not necessary. In laboratory testing on dry land, keeping an even pace to attain a representative steady state workload is important (2). For the unpaced swimming lactate test the mean standard deviation of the lap times was no different from the paced test. This means that swimmers are able to keep an even pace without external pacing help. As the lactate measured at the end of the workload depends on a reached steady state, the evenly performed unpaced workload strengthens the validity of this testing protocol.

There are few scientific studies on external pacing for swimmers. One study investigated the physiological effects of even, positively or negatively paced 200m breaststroke swims, and

found that the evenly paced swim produced lower physiological stress (lower post exercise blood lactate concentration) (6). The accuracy of pacing using paced and unpaced swims has also been investigated by this group of researchers. However they used an acoustic pacing device. This form of pacing gave a pacing signal for each 12.5m of the pool and is quite different from the moving pace lights where the pacing is continuous and the swimmer instantly gets visual feedback on the pacing position. The results from the study on the acoustic pacing situation show that swimmers are able to pace a 200m sub maximal breaststroke swim accurately without external pacing within 2.2-2.7s (95% level of agreement) of their target time (7) (no significant bias was found). Moreover, in the same study these authors also concluded that external acoustic pacing produced a more accurate final time, from -1.8 to +1.3s of target time, in a group of less well trained and less homogenous swimmers. However in this study no measurements were done to assess the within-trial pacing for sub maximal swimming, so it is not known whether the subjects were able to hold an even pace for the whole 200m.
Our findings are further supported by results obtained on runners. Billat et al. (1) found that long distance runners produced only small variations in velocity during free paced runs, and there were no significant difference in pacing compared to paced runs. Possibly, swimmers are accustomed to swimming at prescribed paces due to the use of pace clocks in daily training routines. We assume that after many years of swimming training this ability have been developed to a high degree in swimmers. It would be logical to assume that this effect would be strongest at the training paces most often used by the swimmers.
Looking more closely on the lap time variations, it may seem that a pacing device is more needed when the velocities are low (fig.3). The mean standard deviation of lap times for the first workload on both the unpaced and the paced trials showed the highest variation. The results of the ANOVA test revealed that lap time variations decrease as workload number increase for paced and unpaced trials together. However post hoc testing (Bonferroni corrected) revealed only a statistically difference between workload number 1 and 4 for the paced trials, and this means that the lap time variations of the unpaced trials can be considered to be independent of workload number.
However measurements of oxygen uptake and other physiological parameters may still require the use of pace-lights. Wearing breathing masks and other types of apparatuses may alter the relationship between the physiological intensity and the velocity, thereby reducing the swimmers feel for the right speed. Furthermore, at maximal VO_2 test protocols the workload is not at steady state or at an even intensity, thereby justifying the necessity for external pacing. Additionally, and as indicated by the results, but not confirmed statistically, when the velocity of swimming differs widely from the normal training paces a pacing device may have its function.

CONCLUSION
The use of lactate testing in swimming without some form of pacing control has become a widespread custom. The results of this study support the common practice of lactate testing in the pool for swimmers, without the use of paced workloads. The validity of this form of lactate testing is supported. Competitive swimmers are able to hold an even pace and meet predetermined workloads without this form of assistance.

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ASSESSING THE INDIVIDUAL ANAEROBIC THRESHOLD: THE MATHEMATICAL MODEL

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This work presents a mathematical method based on a fit to the observed velocity/[La^-] data points for swimmers that allows the determination of the anaerobic threshold individually. In the present method a straight line is fitted to the lower velocity data points, while an exponential line is fitted to the higher velocity data points. The point of interception of both lines is considered as the point of beginning of the anaerobic threshold. Some practical examples are shown.

Key Words: mathematical model, anaerobic threshold, swimming.

INTRODUCTION
Several methods have been developed to assess the exercise intensity after which the lactate production exceeds its removal, i.e., the anaerobic threshold (AnT) (1). One of the most used methods for AnT assessment is based on the averaged value of 4 mmol/L of blood lactate concentration [La^-], proposed by Mader et al. (4). However, the [La^-] corresponding to AnT has been reported to have great variability between swimmers. Other methodologies for AnT determination have been proposed to find more specific and individualized values for this parameter. These methods also contain some limitations, namely: (i) the subjectivity of the observation of the [La^-]/velocity curves' inflection point; (ii) the use of long test distances with significant velocity differences between steps (MaxLass) and (iii) the necessity of very high values of [La^-]

(15 mmol/L), which implies strenuous exercise intensities (cf. Bunc et al. (2)).
This work presents in detail a mathematical model to obtain a particular value for the anaerobic threshold for each swimmer. This model has been used by Fernandes et al. (5) to assess the individual AnT (IndAnT) for 32 swimmers.

METHODS
Consider a set of N distinct data points (x_i,y_i). These points may be fitted by a straight line with equation:

$$y = m \cdot x + c, \tag{1}$$

where *m* and *c* are constants to be determined, based on the observed data points. They may also be fitted by other functions, for example the exponential function, with equation:

$$y = a \cdot \exp(b \cdot x), \tag{2}$$

where a and b are constants to be determined, also based on the observed data points. One method to find the unknown coefficients of the fitting curve is the Method of Least Squares, where the vertical distance between the observed data points and the fitted ones is minimized. Symbolically, the quantity

$$\sum_{i=1}^{N} \left(y_i - f(x_i)\right)^2 \tag{3}$$

is minimized. For the case of a straight line, this corresponds to finding

$$\min\left(\sum_{i=1}^{N} \left(y_i - m \cdot x_i - c\right)^2\right);$$

while for an exponential, it corresponds to finding

$$\min\left(\sum_{i=1}^{N} \left(y_i - a \cdot \exp(b \cdot x_i)\right)^2\right).$$

It is a well known result that to adjust a function with p different parameters to N data points we must have: $N \geq p$. When $N = p$, the fitting reduces to an interpolation, and there is no difference between the observed points and the adjusted function, that is, the result of the sum in equation 3 is zero.
Due to the nature of the observed data points for the lactate concentration as function of the swimming velocity, the lactate concentration has two different regimes: at low values of the velocity the lactate concentration increases linearly with the velocity; after the velocity corresponding to the anaerobic threshold[1] the increment is exponential. Therefore a given observed set of N velocity-[La^-] data points were split in two groups: points 1 to k for the first group and points k+1 to N for the second group, where k ranged from 2 to N-2. Two separate least squares fits were made: a straight line fit to the first group; and an exponential fit to the second group. These two separate fits were computed for all N-2 possible values of k. From the values of k it is found that in some cases the fit was indeed an interpolation since the number of data points and the number of coefficients of the fitting function are the same. This occurs for the straight line when k=2, while for the exponential line it occurs when k=N-2, in both situations the numbers of points to be fitted by one of the lines is 2.
The computer program implementing these lines of action was written in the language MatLab[2].

The output of the program are N-2 plots (loosely called samples) of the two distinct fits superposed on the observed velocity-[La^-] data points. To these plots is added another plot with all data points being fitted by a straight line or by an exponential. Examples of the graphical output can be seen in figures 1 and 2. The program also creates a text file with the fitting parameters for both curves, the point of interception of the curves and the value of the residue[3] for each of the samples. Both the partial and the total residues are printed, as well as the corresponding residues normalized to the mean value of the [La^-], as these allow a more direct comparison of the values from different samples.

RESULTS
The figures 1 and 2 show examples of the graphical output from the program for two different swimmers chosen such one (swimmer 1) has the anaerobic threshold below 4mmol/L, while the other (swimmer 2) exceeds this value.
These swimmers have participated in a study where each subject performed, in a 25 m indoor swimming pool, an intermittent incremental test for freestyle $\dot{V}O_2max$ assessment, with increments of 0.05 m/s each 200 m stage and 30 s intervals, until exhaustion (Fernandes et al., (3)). The velocity was controlled using a visual pacer with flashing lights on the bottom of the pool. In-water starts and open turns were used. The blood lactate concentrations were assessed at rest, during the 30 s intervals, immediately after each step, and at minutes 3 and 5 of the recovery period (using the YSI1500LSport auto-analyser).

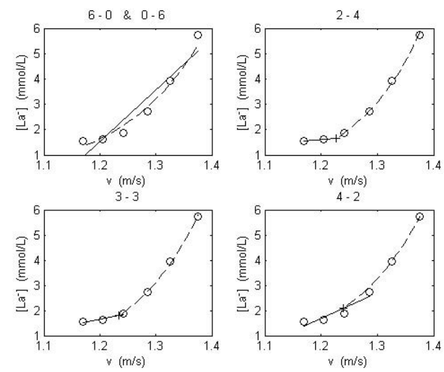

Figure 1. Example of the output plots from the program, for swimmer 1. The circles are the observed velocity-[La-] data points, the solid line is the fitted straight line, the dashed line is the fitted exponential line, and the cross marks the position of the interception of both lines, when applicable.

Analysis of figures 1 and 2 shows that the best fitting situations occur for the adjustment of a straight line for the low velocity points and by an exponential for the high velocity ones. This visual inspection also reveals that the value of 4mmol/L of [La^-] to access the velocity at the anaerobic threshold is not valid in these two examples: for swimmer 1 the exponential increase of the [La^-] starts around 2mmol/L, well below the 4mmol/L value, while swimmer 2 has blood concentrations of La^- always above 4mmol/L, effectively preventing the use of this value to access the anaerobic threshold.

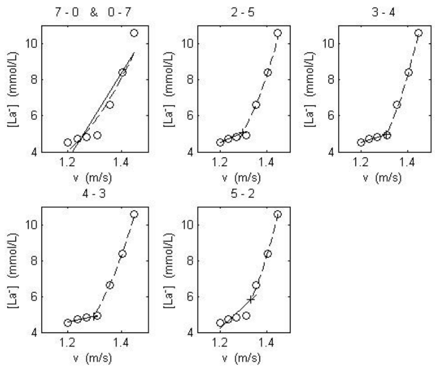

Figure 2. Same as figure 1, but for swimmer 2.

A pair of numbers above each plot represents the number of points used for the straight line fit (first number, which equals the value of k, see above) and for the exponential line fit (second number). This is important to help choosing the best fitting sample since the interception point must be between the last data point used for the straight line and the first one used for the exponential line, otherwise one of the fitting lines must be prolonged out of its region of validity. This can be seen in figure 1, for example, where the 3-3 and the 4-2 samples are ruled out since the interception point is found in the straight line after having prolonged the exponential line away from its region of validity, in order to intercept the straight line. This effect is most evident in the 4-2 sample.
After a visual inspection of the plots for each sample and taking into account the value of the respective residue, the user chooses the most suitable sample for the swimmer under study. The value of the residue shall not be the only parameter to be considered in this choice, as sometimes the interception point is in the wrong place, as was discussed in the previous paragraph. Furthermore, due to the fact that for two of the samples (k=2 or k=N-2) the residue from one of the lines being zero, since it is an interpolation as referred in the Methods section, which may result in a mistaking small value for the residue.
With all these considerations in mind, the user chooses the most suitable sample, and from the point of interception of both lines can determine the velocity at the anaerobic threshold.
Fernandes et al. (5) found that the velocity obtained using the 4 mmol/L of [La-] was significantly different from that obtained using the present method, in a test involving 32 swimmers.

DISCUSSION
The main conclusion of this work is that this method seems to model in an adequate and individual way the anaerobic threshold of swimmers. The use of the value of 4mmol/L of [La-] to identify the anaerobic threshold and the corresponding velocity is a valid method on average terms, but is unable to respond to the individual values of an athlete. The method of the present work is flexible enough to adjust and determine the anaerobic threshold, even in situations where the measured value of [La-] is always above 4mmol/L (cf. figure 2).

NOTES
[1] For high intensity exercises the anaerobic mechanisms for providing energy to the muscle cells account for a significant fraction of the total. As the anaerobic mechanisms produce lactate, its concentration starts increasing, the lactate being produced faster than it can be removed. The minimum exercise intensity for this to occur corresponds to the anaerobic threshold.
[2] www.mathworks.com
[3] The residue is the square root of the sum in equation 3.

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MATHEMATICAL MODELLING OF THE SLOW COMPONENT OF OXYGEN UPTAKE KINETICS IN FRONT CRAWL

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This work presents a mathematical method to model the $\dot{V}O_2$ kinetics during heavy exercise. This methods is able to discriminate between the different components of the oxygen uptake, including the basal, cardiodynamic, fast and slow components. Each of these components is fully characterized, not only in amplitude, but also in time of start of that component. The method is applied to two swimmers, and the results are presented, resulting in both cases in a good description of the slow component for oxygen uptake.

Key Words: mathematical model, $\dot{V}O_2$max, slow component, swimming.

INTRODUCTION
The $\dot{V}O_2$ kinetics has been the subject of several studies since the early 40's. In 1961 Astrand and Saltin (1) observed the so called 'slow component' of oxygen uptake arising in heavy exercises, which has been since then the subject of several works. Most of these works are for exercises performed in cycle ergometers, and yet the first work dealing with swim only appeared in 2001 (4). The present work follows this line of study, and tries to model the $\dot{V}O_2$ kinetics for front crawl

swimming, paying particular attention to the slow component. The data points for maximal $\dot{V}O_2$ used in this work were determined through direct ventilatory oxymetry, using a portable breath-by-breath gas analyser (K4b[2], Cosmed, Italy) connected to the swimmers by a respiratory snorkel with low hydrodynamic resistance, in a test where the swimmers swam until exhaustion, at the previously determined velocity corresponding to $\dot{V}O_2max$ (cf. (5)).
The typical aspect of the recorded breath-by-breath values of the oxygen uptake during heavy exercise is shown in fig. 1.

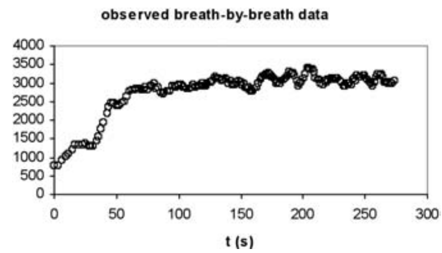

Figure 1. Observed breath-by-breath oxygen consumption by a swimmer during an exercise at maximal intensity. The origin of the time is set at the beginning of the exercise.

From the comparative analysis of the data collected through the years by different authors, it eventually turned out that the behaviour of the $\dot{V}O_2$ kinetics may be described by several components, as is schematically presented in figure 2 (for example, (3)). In the $\dot{V}O_2$ kinetics we may identify three distinct regions/components, apart from the constant basal value. The first component starts at the onset of the exercise, and is called the cardiodynamic component. A few seconds later starts the so called 'fast component', while the 'slow component' starts 2 to 3 minutes afterwards.

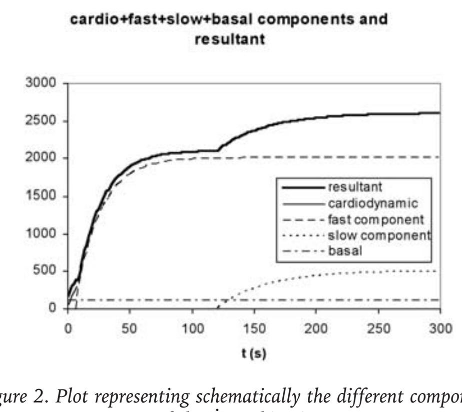

Figure 2. Plot representing schematically the different components of the $\dot{V}O2$ kinetics.

The cardiodynamic component is caused by the increase of the heart rate, as demanded by the exercise, while the fast component is caused by the need of oxygen by the body, mainly the muscle fibres, as the exercise proceeds (for example (2)). The cause of the slow component is still a matter of debate, the activation of the type II fibres being frequently referred as its cause (see for example (8) for a review of several different hypothetical causes for its origin).

METHODS

The $\dot{V}O_2$ kinetics is usually fitted by the following model:

$\dot{V}O_2(t) = \dot{V}_b$	(basal $\dot{V}O_2$)
$+A_0 \text{ x } (1 - e^{-(t/\tau 0)})$	(phase 1: cardiodynamic component)
$+ A_1 \text{ x } (1 - e^{-(t-TD1)/\tau 1})$	(phase 2: fast component)
$+ A_2 \text{ x } (1 - e^{-(t-TD2)/\tau 2})$	(phase 3: slow component)

Where t is the time; A_i represents the various components amplitudes; TD_i are the times for the onset of the different components; and τ_i stands for the transition period needed for the component to attain the steady state, during which physiological adaptations adjust to meet the increased metabolic demand (6).
Analysis of the above mathematical expression shows that the $\dot{V}O_2$ kinetics is characterized by a constant value, the basal $\dot{V}O_2$, by an exponential function modelling the cardiodynamic component, and by two exponentials modelling the fast and slow components. These later components start after the time delays TD1 and TD2, respectively. The model cardiodynamic component acted from the beginning of the exercise until TD1, moment at which it was replaced by the fast component, which acted from this instant until the end of the exercise. The slow component started at TD2, being added to the fast component, and remained active until the end of the exercise. In figure 2, above, we can see a scheme with the four different components – cardiodynamic, fast, slow and basal –, as well as their sum, the resultant, that ultimately adjusts/models the observed data for the oxygen uptake.
The characteristics of the fitting function above, in particular the fact of being the sum of several exponentials, confers a nonlinear nature to it, which in this case is not removable, preventing its linearization. Consequently, for the adjustment of this function to the data points we used a nonlinear least squares method implemented in the MatLab[1] program, using the routine LSQCURVEFIT.
Prior to start the curve fitting we must perform some mathematical operations on the $\dot{V}O_2$ data. First of all, the oxygen consumption must be normalized to the body mass, such that it is presented as oxygen consumption per unit mass (ml/min/kg). In this way we can compare directly the amplitudes of the various components found for different persons. Dividing the oxygen consumption by the body mass is an operation performed simultaneously at all data points that does not alter the shape of the plot, it merely changes its scale.
Since this curve fitting uses a non-linear least squares method we must provide an initial guess for all the parameters (nine in this model), based on a visual inspection of the colleted data values. To further constrain the amplitude of variation the computational model parameters can have, we should impose the minimum (LB) and maximum (UB) ranges of variation for all parameters. Since all the parameters are positive, we must set the lower bound for all parameters to zero, with the exception of TD2 which clearly begins at a later time. Considering the upper bounds, they depend on the individual parameters, being conditioned by the collected data values for the oxygen uptake.

RESULTS

We present two real situations for the adjusting of this model to data collected in front crawl swimming. These two swimmers were chosen such that one has a large amplitude slow component while the other has a small amplitude slow component, as is shown by the values of A2 in the following table. This table also displays the values of the remaining model parameters.

Table 1. Values for the remaining model parameters.

Swimmer	$\dot{V}_b$ (ml/ kg/min)	A0 (ml/kg /min)	τc (s)	A1 (ml/ kg/min)	TD1 (s)	τ1 (s)	A2 (ml/ kg/min)	TD2 (s)	τ2 (s)
1	8.6	20.3	57.2	42.6	21.9	20.5	3.0	105.0	59.7
2	22.9	23.2	25.5	37.9	6.7	21.2	12.0	95.0	14.1

Figures 3 and 4 display the graphics for swimmers 1 and 2, respectively. Both graphics show the collected data points normalized to the body mass, as well as the adjusted function, whose model parameters were already displayed in the table above.

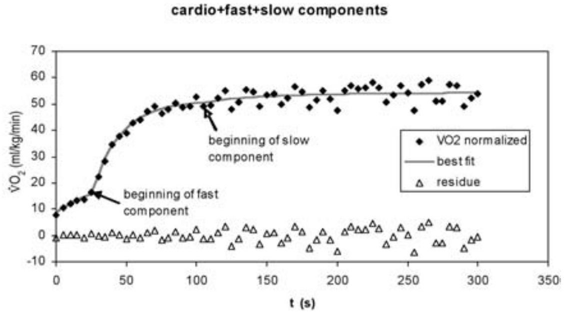

Figure 3. Curve fitting for swimmer 1, displaying a low amplitude slow component.

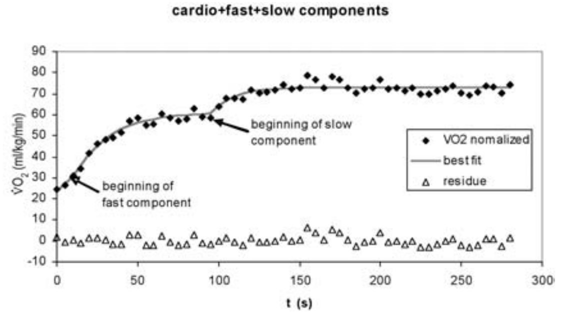

Figure 4. Curve fitting for swimmer 2, displaying a high amplitude slow component.

Analysis of these graphics shows that the implemented mathematical model is able to conveniently adjust the collected values for the oxygen uptake, regardless of the amplitude of the slow component.

DISCUSSION

The main conclusion of this work is that this method seems to model in an adequate way the collected data for $\dot{V}O_2$ in swimming, being possible to characterize the different components of the oxygen consumption, namely, the basal, the cardiodynamic, the fast and the slow components. This method describes the slow component in terms of amplitude, time of beginning and duration of the transition phase.

There are other methods to estimate the oxygen uptake components, particularly the slow component amplitude, some of them being described in (7). Nevertheless, comparison of those methods with the present mathematical model shows that the later gives the possibility to discriminate the different components of the $\dot{V}O_2$ kinetics, including the amplitude of the slow component, while the others usually fail in this respect.

NOTES

[1] http://www.mathworks.com/

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RELATIONSHIP BETWEEN LEFT VENTRICULAR DIMENSIONS AND FUNCTION AND MAXIMAL OXYGEN UPTAKE IN YOUNG SWIMMERS

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The purpose of this study was to analyse the relationship between left ventricular (LV) dimensions/function and maximal oxygen uptake ($\dot{V}O_2$max) in young swimmers. Twelve well trained swimmers (15.9±0.2years; 64.2±6.8kg; 1.75±0.06m) underwent anthropometric measurements, resting M–mode/Doppler echocardiography and a treadmill running

protocol. Allometric scaling of heart morphological characteristics by body dimensions was performed. Heart size was highly correlated with $\dot{V}O_2max$ and end–diastolic LV internal chamber dimension was the main determinant factor. Ejection fraction and $\dot{V}O_2max$ were uncorrelated suggesting that the systolic function at rest does not reflect cardiac function at maximal exercise. Conclusion is that $\dot{V}O_2max$ determined by a non-specific maximal protocol can be an indicator of cardiac adaptations to aerobic exercise.

Key Words: LV hypertrophy, athlete's heart, cardiac function, echocardiography, $\dot{V}O_2max$.

INTRODUCTION
In well-trained endurance athletes, the heart has to adapt to both volume and pressure loads, by increasing, respectively, left ventricular (LV) internal diameter and wall thickness. The increase in stroke volume is a prerequisite for the increase in maximal oxygen uptake ($\dot{V}O_2max$) resulting from training. Notwithstanding being a poor predictor of race performance in elite swimmers, $\dot{V}O_2max$ is considered as a useful indicator of aerobic adaptations to exercise in broader populations, including age-group swimmers.
Little attention has been given to young athletes with respect to factors controlling $\dot{V}O_2max$ and their influence on the adaptation of cardiac morphology and function in swimming training. Few data are available about the possible impact of left ventricular structure on cardiac performance during physical effort (1, 4, 5, 8, 10).
The purpose of this study was to analyse the relationship between left ventricular (LV) dimensions and function at rest and $\dot{V}O_2max$ in young swimmers.

METHODS
Twelve young swimmers (table 1) took part in this study. They performed 7 – 8 training sessions a week in water (about 110 min each), 5000 m per session, 85/90% of total volume in the aerobic zones together and with out of water endurance weight training.

Table 1. Age, physical characteristics, body composition and maximal oxygen uptake of the young swimmers.

	M	SD	Max	Min
Age (years)	15.9	0.2	16.2	15.5
Height (m)	1.75	0.06	185	167
Body mass (kg)	64.2	6.8	75	52.9
Body surface area (m^2)	1.77	0.12	1.94	1.57
Body mass index ($kg.m^{-1}$)	20.9	1.4	22. 9	19.0
Body fat percentage (%)	9.4	1.3	11.8	7.7
Body fat mass (kg)	6.0	1.2	8.9	4.7
Fat free mass (kg)	58.2	6.0	66.1	48.1
$\dot{V}O_2max$ ($l.min^{-1}$) 4. 10	0.66	4.74		3.42
$\dot{V}O_2max$ ($ml.kg^{-1}.min^{-1}$)	63.8	9.2	72.2	57.4

Body mass (BM), height (H), body surface area (BSA), body fat percentage (BFP) and fat free mass (FFM) were measured according to standard procedures.
Two dimensionally guided M mode recordings were obtained parasternally in accordance with the recommendations of the American Society of Echocardiography (16). All the measurements were performed by the same investigator. Left ventricular (LV) wall thickness and internal diameter were obtained by positioning the trackball cursor on the screen. The echocardiographic parameters measured included: end–diastolic LV internal chamber dimension (LVIDd), end–systolic LV internal chamber dimension (LVIDs), posterior wall thickness (PWT), septal wall thickness (ST), LV end-diastolic volume (LVedV), LV end-systolic volume (LVesV), resting heart rate (HRr), and cardiac output (Qc). Derived parameters were calculated as follows: relative end–diastolic wall thickness (RWTd) by the quotient (PWT+ST)/LVIDd, LV mass by $0.8 \times (1.04\ (ST+PWT+LVIDd)^3–LVIDd^3)+0.6$ (7), LV volumes were obtained according to Teicholz formula ($7/(2.4+LVIDd) \times LVIDd^3$), LV shortening fraction (FS %) by the quotient (LVIDd–LVIDs)/LVIDd) x 100 and the ejection fraction (EF %) by (TDV–TSV)/TDV) x 100 stroke volume (SV). Early (E) and late (A) diastolic peak filling velocities, disacceleration E time (DT) and E/A ratio were estimated by pulse wave Doppler measurements in the four chamber apical view. Echocardiographic data was expressed in absolute units and then scaled allometrically for anthropometrical data.
$\dot{V}O_2max$ was determined using the modified Balke treadmill protocol. The initial work was set at 5.25 km/h (0% of inclination) and the exercise intensity was increased by 2.5 % each two min. (6). The athletes were encouraged to reach maximal effort. $\dot{V}O_2max$ was defined as peak VO_2. $\dot{V}O_2max$ was expressed in absolute units and then scaled allometrically for individual differences in anthropometrical data. A body mass exponent of 0.67 for scaling $\dot{V}O_2max$ was also used, as a standard value supported by literature (2).
Pearson product–moment correlation coefficients were calculated to evaluate the relationships between LV dimensions and function and $\dot{V}O_2max$. Results of all statistical testes were considered significant at $p \leq 0.05$.

RESULTS AND DISCUSSION
The results suggest that young swimmers with large LVIDd have a higher $\dot{V}O_2max$ and a greater development of the LV morphology have a better cardiorespiratory performance. Absolute $\dot{V}O_2max$ and $\dot{V}O_2max$/BFP correlated significantly with LVIDd, LVM, LVIDs, LV volume at end–diastole, LV volume at end–systole, SV and Q. $\dot{V}O_2max$/BM correlated significantly with LV volume at end-diastole and SV, $\dot{V}O_2max/BM^{0.821}$ correlated significantly with LVIDd, LV volume at end-diastole and SV, $\dot{V}O_2max/BM^{0.67}$ correlated significantly with LVIDd, LV volume at end–diastole, LV volume at end–systole, SV and Q, $\dot{V}O_2max$/FFM correlated significantly with LV volume at end–diastole and SV.
No significant correlation was observed between absolute and relative $\dot{V}O_2max$ and fractional shortening (FS), ejection fraction (EF) and ratio of early passive (E) to late atrial contraction (A) filling of LV (E:A ratio) (table 2).
SV and LVedV correlated significantly with absolute and relative $\dot{V}O_2max$. LVedV and SV should be the critical determinants of the high $\dot{V}O_2max$ in young swimmers and factors that influence resting SV are important in defining $\dot{V}O_2max$. SV response to exercise depends on changes in cardiac filling, intrinsic myocardial contractility and LV afterload (7). Thus, higher SV obtained in young swimmers depends on factors influencing resting SV, such as cardiac hypertrophy, augmented myocardium relaxation properties or expanded blood volume (3).

*Table 2. Correlation between $\dot{V}O_2$max and echocardiographic measurements. LVIDd - end–diastolic LV internal chamber dimension; LVIDs - end–systolic LV internal chamber dimension; ST - septal wall thickness; PWT - posterior wall thickness; LVM - LV mass; BM - body mass; BSA - body surface area; FFM - fat free mass; BFP - body fat percentage; HRr - rest heart rate; Qc - cardiac output; SV - stroke volume; E/A - filling of LV; EF - ejection fraction; LVesV - LV end - systolic volume; LVedV - LV end - diastolic volume; Peak E - early (E) diastolic peak filling velocitie; Peak A - late (A) diastolic peak filling velocitie; FS - LV shortening fraction. * p< 0.05; ** p< 0.01; n.s.: non significant.*

(l/min)	$\dot{V}O_2$max /BM	$\dot{V}O_2$max /BFP	$\dot{V}O_2$max /FFM	$\dot{V}O_2$max /BFM	$\dot{V}O_2$max /$BM^{0.821}$	$\dot{V}O_2$max	$\dot{V}O_2$max /$BM^{0.67}$
LVIDd (mm)	0.65**	n.s	0.73**	n.s	0.56**	0.46*	0.51*
LVIDs (mm)	0.45*	n.s	0,60**	n.s	0,48*	n.s	n.s
ST (mm)	n.s	n.s	n.s	n.s	n.s	n.s	n.s
PWT (mm)	n.s	n.s	n.s	n.s	n.s	n.s	n.s
LVM (gr)	0.47*	n.s	0.517**	n.s	n.s	n.s	n.s
EF (%)		n.s	n.s	n.s	n.s	n.s	n.s
LVesV (ml)	0.57**	n.s	0.67**	n.s	0.53**	n.s	0.45*
LVedV (ml)	0.71**	0.41*	0.76**	0.41*	0.58**	0.52**	0.57**
PeakE (ms)	n.s	n.s	n.s	n.s	n.s	n.s	n.s
PeakA (ms)	n.s	n.s	n.s	n.s	n.s	n.s	n.s
E/A	n.s	n.s	n.s	n.s	n.s	n.s	n.s
FS (%)	n.s	n.s	n.s	n.s	n.s	n.s	n.s
SV (ml)	0.73**	0.42*	0.74**	0.43*	0.56**	0.54**	0.59**
HRr (bpm)	-0.43*	n.s	n.s	n.s	n.s	n.s	n.s
Qc (l/min)	0.56**	n.s	0.58**	n.s	0.42*	n.s	0.43*

CONCLUSION

The results of this study indicate that heart size is highly correlated with $\dot{V}O_2$max in young swimmer athletes and LVIDd is the main determinant factor. The relationship between estimated diastolic function and $\dot{V}O_2$max suggests that the maximal heart pumping capacity during exercise is associated by LV volume at end–diastole at rest. On the contrary, EF and $\dot{V}O_2$max are unrelated, possibly because the systolic function at rest does not have a relevant connection with cardiac function during maximal exercise and LV volume at end–systole is related to LV size and not to ejection performance.

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EFFECTS OF ACUTE MODERATE ALTITUDE EXPOSURE ON PHYSIOLOGICAL AND TECHNICAL PERFORMANCE IN FRONT CRAWL SWIMMING.

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The aim of this study was to analyse how acute moderate altitude exposure affects technique during a sub-maximal swimming protocol. Eleven subjects swam two steady-state test of 400 m front crawl, under normoxia (N, 690 m) and acute hypoxia (H, 2320 m). Stroke rate (SR) and stroke length (SL) was recorded during each lap. Blood lactate concentration (BLa), heart rate (HR) and rating of perceived exertion (RPE) were also measured after each trial. Results showed a reduction in SL with an increase in SR by altitude effect (p<0.05). HR, BLa and RPE were increased during altitude test respect normoxia (p<0.05). The obtained results did not show relation between physiological and technical variables in N and H. Technical parameters, like physiological ones, should be considered in altitude training camps.

Key Words: Stroke length, stroke rate, lactate, heart rate, RPE.

INTRODUCTION

In swimming, velocity is defined as the product of the stroke rate (SR) and distance travelled in each cycle (SL). Various factors have been observed to influence this relationship as training, intensity or swimming distance (1). Therefore we could consider fatigue as one of the major factors that modify swimming technique (2).

During ascent in altitude, the barometric pressure falls together with the density of the surrounding air, so that the inspired partial pressure of oxygen is also reduced, diminishing the O_2 content of arterial blood. An increase in heart rate, stroke volume, tissue vasodilatation and bronchodilatation can be observed immediately, contributing to improve O_2 delivery especially during exercise (3).

Exposure to acute hypoxia produces a significant increase in lactate production (4, 5, 6, 7), an important reduction in

$\dot{V}O_2$max (8), and slower VO_2 kinetics during isolated work loads (3) with respect to normoxia. Performance during short-intensity exercises, majority sustained by anaerobic metabolism, seems not to be affected by altitude ascent (3, 9). However when the duration of effort lasts more than approximately 30 s, aerobic and anaerobic metabolism pathways are implicated (10). Several studies have shown an increased anaerobic contribution to exercise to compensate the lost of aerobic ATP production (4, 10). These changes could explain the expectation of limited performance during high-intensity exercise for more than 30 s executed at altitude respect normoxia due to a faster accumulation of anaerobic metabolites, such as lactate, which also could develop differences in technical parameters as has been observed in normoxia (11).
In the literature revised, very few studies have been developed to analyze the effect of altitude on technique. For this reason, the aim of this study was to investigate changes on technical parameters in swimming due to acute moderate altitude exposure.

METHODS
Eleven swimmers, six males and five females (22.7±1.8 and 19.8±2.2 years of age, 181.8±4.7 and 172.8±5.1 cm tall, 76.9±3.6 and 63.3±7.5 Kg of weight, respectively), physical education students and members of water-polo and swimming team clubs, participated in this study. They all lived in the city of Granada at 690 m altitude.
Before participation, all swimmers were fully informed about the demands and procedures of the study and provided their written consent to take part. The experiment was approved by the University Ethic Committee and was in compliance with Spanish Laws. To avoid compromising the results of this study all participants were instructed about food intake rules and not to participate in any exhaustive workouts on the days of testing. All swims were completed in randomized order and at the same time of the day (12 p.m. ± 60 min) to minimize biological variation.
Each subject was randomly assigned to two different groups (Groups 1 and 2), forty-eight hours after a preliminary test. The first experimental protocol was carried out by group 1 in hypoxia, in the swimming pool of the Altitude Training Centre of Sierra Nevada (Granada, Spain), located at 2320 m above sea level and 560 mmHg of barometric pressure (H). Tests were conducted during the first 3 or 4 hours after arrival (9). The experimental protocol was then repeated forty-eight hours later, in a 50 m pool of the Sport Complex of the University of Granada (Granada, Spain) at 690 m altitude and 717 mmHg barometric pressure (N). Group 2 performed both trials in reverse order.
The preliminary test consisted in a maximal 400 m front crawl trial from a water start after a standard 800 m warm-up in normoxia. To ensure the capability of all swimmers to attain the 400 m test in hypoxia, the time to complete a 400 m repetition during experimental protocols was reduced to 92.5% of the maximal speed (of 344±20 and 335±31 s time for males and females, respectively). Previous essays showed us to be the appropriate percentage to ensure the capability of all swimmers to conclude experimental test in H.
Light sequencing was used to control the right pace in all swimmers, maintaining swimming velocity constant in all laps. This system consisted in a lane of underwater successive lights (n=50) connected to a speed controller box (Swim Master). This lighting system was placed on the pool floor, as described in previous reports (12). The lighting time was individually adjusted in all turns. All participants were familiarized to the underwater lighting system with previous training sessions. During all testing trials, a sagital camera (mini DV) recorded each trial. SR was measured lap by lap (cycle·min^{-1}). It was calculated over five cycles. Its value was obtained as a quotient of number of cycles and time employed to finish five completed cycles, multiplied by sixty. SL was calculated dividing swimming speed by SR in Hz and expressed as the result of the distance swum during a complete cycle (m·cycle^{-1}).
HR was measured just at the end of the test with a Polar 610 heart rate monitor. Immediately after the end of each trial, an integrated perceived exertion value (15 grades Borg's rating - RPE) was registered (13). Blood lactate concentration (BLa) was analyzed three and five minutes after finishing the test from the fingertip, using a portable blood lactate analyser Lactate Pro. The highest BLa obtained was considered as the peak or maximum value.
SPSS 12.1 was used for statistics analyses. Descriptive data was obtained and expressed as mean and standard deviation (SD). Homogeneity and normality of data was analyzed before studying the variance. The difference between altitude conditions was tested by repeated measures (ANOVA). When a significant difference was detected this was further examined by Sidak post-hoc test. Pearson test was employed to analyze the correlation relationships between physiological and technical parameters. The interval of confidence accepted for all comparisons was less than 0.05.

RESULTS AND DISCUSSION
The results of physiological and technical parameters obtained in this study under normoxia and acute hypoxia are displayed in Table 1.
It was observed significant differences between SR and SL by altitude effect ($p<0.05$). After ascent, SR (cycle·min^{-1}) increased a 2.45% while SL decreased but with similar percentage as SR (2.62%). Certain studies have related changes in swimming technique due to physiological stress generated during swimming (14) and the implication of anaerobic metabolism on it (2). Thus, swimmers can keep a high level of SL values throughout exercises performed at slow and aerobic speed corresponding to moderate and heavy sub maximal intensities. However, when the intensity increases above the maximal lactate steady state, the reduction in SL becomes progressively greater (2, 11, 14), overcoming this lost in SL with an increase in SR to maintain the swimming speed during constant load tests. In this sense, our data reveal that there were significant differences between both experimental conditions in the physiological variables.
It was observed an increase in BLa, RPE and HR in altitude respect normoxia conditions of a 36.67, 8.48 and 4.57% respectively for the same work-load, which are consistent with previous studies (5, 6, 7) under similar conditions. The increase in lactate production is associated with a fall of blood and muscle pH (15, 16). These results are consistent with the RPE response obtained. As it has been described in others works (14, 16), a decrease in pH produces fatigue, which could be defined as a reduction of the capacity to deliver a high amount of work per stroke as well as the capacity to swim at a high propelling efficiency (14) in the presence of an increased perception of effort (17).

Although, previous studies have suggested that changes in technique variables could be connected to simultaneous changes in metabolic variables, such as BLa (2, 11); the results of this study have not showed any correlation between physiological and technical parameters in both conditions (Table 2). The found results can be interpreted as acute moderate altitude exposure affects directly both variables, technical and physiological, without necessarily a relation among them exists. Later studies will have to be focused in analyzing how affects environmental modifications due to altitude in the technical parameters.

Table 1. Mean and SD obtained in a 400-m test at 690 m (N) and 2320 m (H) above sea level. Where: BLa=Peak of maximum blood lactate concentration; RPE=Rating of Perceived Exertion; HR=Heart Rate; SR=Stroke Rate; SL=Stroke Length.

	BLa ($mmol \cdot l^{-1}$)	RPE (6-20)	HR (bpm)	SR ($cycle \cdot min^{-1}$)	SL ($m \cdot cycle^{-1}$)
690 m	6.44 (2.44)	15.00 (2.63)	161.27 (15.66)	31.75 (5.49)	2.29 (0.38)
2320 m	8.81* (2.63)	16.27** (1.10)	168.64** (13.66)	32.53** (5.74)	2.23* (0.39)
	Δ 36.8 %	Δ 8.5%	Δ 4.5%	Δ 2,4%	-Δ 2.6%

* Indicates $p<0.01$ ** Indicates $p<0.05$.

Table 2. "P" values obtain in correlation analysis between physiological and technical variables in Normoxia (N, 690 m) and acute Hypoxia (H, 2320 m). Where: BLa=Peak of maximum blood lactate concentration; RPE=Rating of Perceived Exertion; HR=Heart Rate; SR=Stroke Rate; SL=Stroke Length.

	BLa 690m	BLa 2320m	HR 690m	HR 2320m	RPE 690m	RPE 2320m
SR 690m	0,412 n.s.	0,213 n.s.	0,111 n.s.	0,135 n.s.	0,055 n.s.	0,164 n.s.
SR 2320m	0,533 n.s.	0,263 n.s.	0,213 n.s.	0,184 n.s.	0,347 n.s.	0,141 n.s.
SL 690m	0,577 n.s.	0,317 n.s.	0,345 n.s.	0,504 n.s.	0,310 n.s.	0,279 n.s.
SL 2320m	0,673 n.s.	0,379 n.s.	0,481 n.s.	0,570 n.s.	0,426 n.s.	0,262 n.s.

*n.s. = not significant * $p<0.05$*

CONCLUSIONS

We concluded on the base of the results analyzed, that stroking parameters are affected during front crawl swimming by acute moderate altitude exposure. The results also have shown an important effect of the altitude in the physiological respond to effort, especially in the level of registered acidosis, although it cannot explain directly the changes undergone in the technical parameters. However, we suggest the necessity of a period of stroke technique adaptations during the first days of altitude training camps, before acclimatization occurs.

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RED BLOOD CELLS SUSCEPTIBILITY TO PEROXIDATION IN SWIMMERS

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The purpose of this study was to evaluate the influence of training on red blood cells' (RBC) susceptibility to peroxidation induced *in vitro* by H_2O_2 and on RBC' antioxidant enzymes activities. Fiveteen high competition male swimmers and 16 active men not involved in any regular sport activity participated in the study. Nutritional information was collected and body composition and physical condition were assessed. Blood was collected at rest. RBC peroxidation and superoxide dismutase, catalase, glutathione peroxidase and reductase and methahaemoglobin reductase activities were evaluated by photometry. Swimmers showed higher RBC' resistance to oxidation even though antioxidant enzymes were not higher. This beneficial adaptation may result from an accelerated RBC' renewal, leading to more efficient O_2 delivery to tissues and to lower RBC' intracellular oxidant stress.

Key Words: oxidant stress, red blood cells oxidation, antioxidant enzymes, training.

INTRODUCTION

Moderate physical exercise is believed to have many health benefits (3). However, for intense and sustained exercise, such as that performed by high competition athletes, controversy about the protective effects still exists (2, 11, 12, 18). As physical exercise is associated with accelerated reactive oxygen species (ROS) generation (7) it may establish conditions where ROS production may overwhelm the antioxidant defences and consequently induce damage to macromolecules resulting in adverse effects on health.
The susceptibility of red blood cells (RBC) to oxidation is a result of the high polyunsaturated free fatty acid content of their membrane and the high cellular concentrations of oxygen and haemoglobin, a potentially powerful promoter of oxidative processes. ROS constantly generated from both internal and external sources, even under normal conditions, may target RBC to oxidative damage during exercise. However, these cells, as well as the whole body, contain very efficient protective antioxidant systems that include antioxidant enzymes such as superoxide dismutase, catalase, glutathione peroxidase, glutathione reductase and methahaemoglobin reductase and non-enzymatic antioxidants such as α-tocopherol, β-carotene, ascorbate, urate and reduced glutathione (8).
Nutritional habits may condition antioxidants availability as antioxidant enzymes are metalo-enzymes, and some of the non-enzymatic antioxidants are of exogenous sources (e.g. α-tocopherol, β-carotene and ascorbate) (14).
The purpose of this work was to evaluate the influence of training on RBC' susceptibility to peroxidation induced *in vitro* by H_2O_2 (RBC Px) and on RBC' antioxidant enzymes activities.

METHODS

Fiveteen high competition male swimmers (S) training between 17 and 23 $h.wk^{-1}$ for at least 5 years, and 16 active men (AM) not involved in any regular sport activity agreed to participate in the study. They were between 18 and 25 years old (S: 20.0±1.65 years and AM: 21.1± 1.47 years). Their mean weight and height were respectively 70.6±5.3 kg and 176±6.0 cm for the S group and 71.1±10.1 kg and 176±7 cm for the AM group. The mean body mass index (BMI), derived from weight and height, was 22.7±1.6 $kg.m^{-2}$ for the S group and 23.0±2.9 $kg.m^{-2}$ for the AM group. Medical and running histories obtained by questionnaire indicated no smoking habits or known coronary heart diseases. Informed written consent was obtained from all the subjects.
Nutritional information was collected using a 3 days food record. Subjects were previously informed of the most correct and complete form of fulfilment of the record and interviewed afterwards to compare the items recorded with real size photos in a Portuguese manual for analysing food records (Modelos Fotográficos para Inquéritos Alimentares do Instituto Nacional de Saúde Dr Ricardo Jorge). Macro and micronutrients intake were quantified with Food Processor (Nutrition Analysis Software version 7.4, made by ESHA, Research, Salem, Oregon, 1999).
An all body analysis by Dual-energy x-ray absorptiometry (DXA) was used to assess body fat mass percentage (FM%), free fat mass (FFM) and bone mineral content (BMC) (QDR-1500, Hologic, Waltman, USA, pencil beam mode, software version 5.67 enhanced whole body analysis). Appendicular muscle mass (AMM) was calculated according to Heymsfield and co-workers (9).
Subjects performed a continuous graded maximal run on treadmill (Quinton TM 55) until oxygen uptake stabilization or exhaustion with expired gas analysis (Cardiorespiratory Diagnosis System, Medical Graphics Corporation, St. Paul, MN) and heart rate monitorization (Polar® - Pacer ECG/Telemetry Finland).
Blood was collected by venopucture at rest, at fast. After separation from plasma, RBC were washed 3 times with NaCl 0.9 % (w/v). RBC' susceptibility to peroxidation induced *in vitro* by H_2O_2 (RBC Px) was evaluated by photometry with a method modified from the group of Rayssiguier (personal communication). The antioxidant enzymes activities were evaluated by photometry after hemolysis of RBC. Superoxide dismutase activity was determined according with Winterbourn et al. (19); catalase activity according with Aebi (1), glutathione peroxidase activity according with Paglia & Valentine (15); glutathione reductase activity according with Beutler (4) and methahaemoglobin reductase activity according with Board (5).
Results are presented as mean±standard deviation. Normal distribution of the samples was tested with Shapiro-Wilk's test (n<50). Results were compared between groups with unpaired t test or with Man Whitney's U. Micronutrients intakes for each group were compared with the respective RDAs with one sample t test. All statistical analysis was performed with SPSS for Windows, version 11.5, released in 2002 by SPSS Inc., Chicago, USA.

RESULTS

As expected, swimmers showed higher $\dot{V}O_2max$ (51.3±7.1 $ml.min^{-1}.kg^{-1}$ versus 43.2±5.7 $ml.min^{-1}.kg^{-1}$; $p < 0.01$), VO_{2AnaT} (38.0±4.4 $ml.min^{-1}.kg^{-1}$ versus 29.2±5.1 $ml.min^{-1}.kg^{-1}$; $p < 0.01$), FFM (62.6±4.4 kg versus 58.2±5.7 kg; $p < 0.02$) and AMM (24.8±2.3 kg versus 23.0±2.4 kg; $p < 0.05$) and lower FM% (10.4±3.3 % versus 17.5±6.9 %; $p < 0.01$) than active men. Food intake was similar between the two groups (table 1), with low percentage of carbohydrate intake and high percentage of fat intake. Iron, zinc, copper and selenium intakes were over the RDAs. Retinol and α-tocoferol intakes were under the RDAs in both groups and folate was under the RDA in the AM group.

Table 1. Discriptive analysis of nutritional parameters for the two groups (S: swimmers, AM: active men). Results of the comparison between groups (p) and with the respective RDAs.

Energy/Nutrients	S	AM	p
Calories (kcal.day-1)	2976±744	2845±450	0.57
Calories per kg of weight (kcal.day-1.kg-1)	42.8±10.2	40.6±7.34	0.51
Calories from fat (%)	34.2±5.23	33.6±5.32	0.76
Calories from saturated fat (%)	13.1±3.38	12.7±2.15	0.95
Calories from proteins (%)	18.4±3.74	18.2±1.86	0.90
Calories from carbohydrates (%)	48.3±6.19	48.8±4.79	0.82
Calories from sugar (%)	15.8±5.69	17.6±5.26	0.40
Iron (mg.day-1)	24.3±9.69**	20.7±6.93**	0.39
Zinc (mg.day-1)	14.5±4.69*	13.5±3.93*	0.55
Copper (µ.day-1)	1336±499**	1255±339**	0.62
Selenium (µ.day-1)	101±48.0**	102±39.1**	0.94
α-tocoferol - Vit E (mg.day-1)	5.75±3.00**	6.02±2.21**	0.79
Retinol - Vit A (µ.day-1)	433±289**	412±199**	0.63
Ascorbate - Vit C (mg.day-1)	136±120	108±70.4	0.77
Folate - Vit B9 (µ.day-1)	283±208	132±163**	0.06

*Comparison with the respective RDAs: * p≤ 0.05 : ** p≤ 0.01.*

Swimmers showed lower RBC susceptibility to peroxidation induced *in vitro* by H_2O_2 and methahaemoglobin reductase activity (Table 2).

Table 2. Discriptive analysis of biochemical parameters for the two groups (S: swimmers, AM : active men). Results of the comparison between groups (p).

Variable	S	AM	p
RBC susceptibility to peroxidation induced *in vitro* by H_2O_2 (%)	39.2±4.83	46.3±9.54	0.03
Superoxide dismutase activity (U.g Hb-1)	2222±411	2198±410	0.88
Catalase activity (s-1.g Hb-1)	192±46.5	207±31.8	0.34
Glutathione peroxidase activity (mol.min-1.g Hb-1)	103±24.2	115±25.2	0.21
Glutathione redutase activity (mol.min-1.g Hb-1)	89.7±14.1	86.6±13.9	0.41
Methahaemoglobin reductase activity (µ.min-1.g Hb-1)	7.45±2.07	9.14±2.29	0.03

DISCUSSION

The nutritional habits of the subjects don't seem to limit the activity of antioxidant enzymes, as the intakes of their co-factor metals are above the recommended dietary allowances. However, they may benefit from some changes in their foods as high intakes of fat associated with low intakes of fat-soluble vitamins increase susceptibility to oxidation.

Lower methahaemoglobin reductase activity in the group of swimmers may suggest lower production of methahaemoglobin in their RBC. Methahaemoglobin formation occurs along with the formation of superoxide radical. Such radical can originate other more reactive ROS and so induce damage to the RBC. The accumulation of methahaemoglobin in the RBC gives rise to the formation of Heinz bodies which render the RBC less flexible and deformable. As a consequence, RBC' half life tends to decrease, with premature reticulo-endotelial entrapment, especially by the spleen (6), and the probability of intravascular haemolysis increases, by osmotic pressure induced by the binging of these substances to the RBC' membrane (10, 13, 17). So, less methaemoglobin formation can be associated to more resistant RBC.

According to Smith (17), in athletes, the frequent oxidant pressure, in association with the osmotic and acid-base unbalances, can induce the decrease of RBC half life and the increase of eritropoiesis. A higher percentage of young RBC can make them less susceptible to oxidation. As long as anaemia doesn't occur, athletes can so be favoured as these are more efficient in the transport of oxygen to tissues (16).

CONCLUSION

Swimmers showed higher RBC' resistance to oxidation even though antioxidant enzymes were not higher. This beneficial adaptation may result from an accelerated RBC' renewal, leading to more efficient oxygen delivery to tissues and to lower RBC' intracellular oxidant stress.

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OXYGEN UPTAKE AT THE LACTATE THRESHOLD IN SWIMMING

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The purpose of this study is to identify, in terms of $\%\dot{V}O_2max$, the intensity of swimming associated with a non linear increase of blood [La^-]. Twenty nine swimmers participated in the study: 15 males and 14 females. Each subject performed a intermittent incremental protocol of 200m stages. The individual kinetics of the [La^-]/ velocity and VO_2 / velocity curves were taken in account for the assessment of lactate threshold (LT). The value of the [La^-] corresponding to LT was 2.99±0.80mmol.l^{-1}. In $\%\dot{V}O_2max$, LA was 73.54±0.8%. This result seems to confirm that the best single [La^-] value to predict LT, when testing trained swimmers, should be lower than the usual value of 4 mmol.l^{-1}.

Key Words: anaerobic threshold, lactate threshold, oxygen uptake, evaluation.

INTRODUCTION
Lactate Threshold (LT), the intensity above which it is observed an exponential increase in blood lactate concentrations ([La^-]), has been considered as a topic of great interest in swimming literature. This parameter is used on performance prediction, in assessment of aerobic capacity, in swimming training intensities prescription, and in exercise intensity control [6, 19]. The results from the most recent studies [10, 15] also stress out the importance of the aerobic metabolism on total energetic required for almost all the competitive exercise duration in swimming events. According to these previous findings, training at the intensity correspondent to LT consists on an important physiological goal in swimming training [14], in order to develop the swimmer's aerobic capacity [15]. The conventional approach of LT determination consists on the relationship between [La^-] and swimming velocity (v), based on the interpolation of the swimming velocity to a fixed value of [La^-] [13], or by an individualized method, finding a non linear increase on [La^-] [9]. In swimming, due to the difficulties usually imposed to the evaluation of $\dot{V}O_2max$ in normal swimming conditions, the definition of LT intensity expressed in $\%\dot{V}O_2max$ as not yet been accomplished, despite, in others sports, the determination of $\%\dot{V}O_2max$ correspondent to the LT received relevant attention [2, 3, 4, 7].
Wakayoshy et al. [19, 20] gave some attention to AT and LT related to VO_2, in their studies on critical swimming velocity, although they didn't define the percent value of $\dot{V}O_2max$ associated to the LT, they also didn't relate the intensity of LT to $\%\dot{V}O_2max$, or suggested a value of $\%\dot{V}O_2max$ representative of LT.
The purpose of this study was to identify, in terms of $\%\dot{V}O_2max$, the intensity associated with a non linear increase of [La^-] in normal swimming conditions.

METHODS
Subjects
Twenty nine trained swimmers were studied: 15 males (21.4±3.0 yy, 177.3±7.0 cm, 68.3±7.1 kg and a $\dot{V}O_2max$ of 70.9±10.2ml/min/kg), and 14 females (18.7±2.4 yy, 164.9±2.3 cm, 55.1±3.9 kg and a $\dot{V}O_2max$ of 59.8±8.0ml/min/kg). All subjects were informed about the details of the experimental protocol before beginning the measurements procedures and volunteered to participate in this study.

Test protocol
The test sessions took place in a 25m indoor poll. Each subject performed an intermittent incremental test for $\dot{V}O_2max$ assessment. This test had increments of 0.05m.s^{-1} each 200m stage, with 30s intervals until exhaustion [8]. Initial velocity was established according to the individual level of fitness and was set at the swimmer's individual performance on the 400m freestyle minus seven increments of velocity (for more details see Cardoso et al. [5]). VO_2 was directly measured using a metabolic cart (Sensormedics 2900 oxymeter, Yorba Linda – Califórnia, USA) mounted on a special chariot running along the pool [18], and connected to the swimmer by a special respiratory valve [17]. Exhaled air was continually measured during the entire test each 20s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool.
$\dot{V}O_2max$ was considered to be reached according to primary and secondary traditional physiological criteria [1, 11]: (i) occurrence of a plateau in the oxygen uptake kinetics, despite an increase in swimming velocity, and (ii) high levels of blood lactic acid concentrations ([La^-]≥ 8mmol.l^{-1}), elevated respiratory exchange ratio (R≥ 1.0), high heart rate (HR) values (>90% of [220bpm-age]) and exhaustive perceived exertion (controlled visually, and case to case, by the respective coaches and scientific staff).
Capillary blood samples for [La^-] analysis were collected from the earlobe at rest, in the 30s rest interval, immediately after the end of each exercise step, and 3min and 5 min of the recovery period. These blood samples were analysed using an YSI1500LSport auto-analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). HR was monitored and registered continuously each 5s through a HR monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland).
Swimmers were instructed to perform an open turn, always performed in the same lateral wall side, without underwater glid-

ing, and were verbally encouraged to swim as long as possible during the test period. The test was carried out in the same conditions for each subject, i.e., temperature and humidity.

Statistical analysis
The statistical procedure includes mean and standard deviations for all variables. All data was checked for normality. LT was assessed by $[La^-]/VO_2$ curve modelling method (least square method) and was assumed to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential) [12]. Intensity related to LT was expressed on $\%\dot{V}O_2max$.

RESULTS AND DISCUSSION
The use of an average value that represents the $[La^-]$ related to LT as been an area of great discussion among scientists. Our results showed that the non linear increase in $[La^-]$ occurred at a mean value of 2.99 ± 0.8 mmol.l^{-1}.This value seems to be in accordance with the results obtained by Beneke [3] who observed a mean $[La^-]$ correspondent to the maximal lactate steady state (MLSS) of 3.0 ± 0.6mmol.l^{-1}. Our results also seem to be in agreement with the results obtained by Wakayoshi et al. [19] (3.2mmol.l^{-1}) in a study conducted in swimming flume, relating the swimming critical velocity with $[La^-]$. Results also seem to confirm that the $[La^-]$ of 4mmol.l^{-1}, suggested by Mader et al. [13], does not satisfactory represent the LT of trained subjects, once it tends to be lower than that reference value. This observation seems to be in agreement with Stegmann et al. [16]. Our study also reveals that the non linear increase in $[La^-]$ occurred at $73.54\pm8.0\%\dot{V}O_2max$. To our knowledge, this is one of the first studies, conducted in swimming pool conditions were LT was related to oxygen uptake. However, similar approaches were already attempted in different ergometers. Our results seem to be in agreement with the finings of these studies, namely with the study conducted by Dekerle et al. [7], who tested swimmers in cycle ergometer ($74.3\pm84.0\%$), Baron et al. [2] ($73.0\pm4.1\%$) and Beneke et al. [4] ($71\pm7.0\%$).

CONCLUSION
The present study shows that the non linear increase of $[La^-]$ corresponding to LT in a specific swimming situation occurs at $73.54\pm8.0\%\dot{V}O_2max$. This value should be interpreted as the value upon what the aerobic capacity should be trained.
Our results also seem to confirm that, on the unavailability of an individual value correspondent to the LT, the best single $[La^-]$ value to predict this parameter, when testing trained swimmers, should be lower than the usual value of 4 mmol.l^{-1}.

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OXYGEN UPTAKE AND VENTILATORY THRESHOLD IN SWIMMING

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The purpose of this study was to identify, in terms of percentage of maximal oxygen uptake (%$\dot{V}O_2$max), the intensity of swimming associated with a non linear increase of minute ventilation (Ve), also described as ventilatory threshold (VT). Twenty nine trained swimmers participated in our study: 15 males and 14 females. Each subject performed a intermittent incremental protocol of 200m stages, with increases of 0.05m.s^{-1}, and 30s intervals between each stage. VT was assessed by Ve/VO_2 curve modelling method (least square method). It was assumed VT to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential). The analysed values of VO_2 and Ve were cropped by direct oximetry. The present study demonstrated that the non linear increase of Ve corresponding to VT in a specific swimming situation seems to happen at 84.3±8.7 %$\dot{V}O_2$max.

Key Words: ventilatory threshold, oxygen uptake, minute ventilation, evaluation.

INTRODUCTION
The concept of whole body maximal oxygen uptake ($\dot{V}O_2$max) has received much attention in the specialized literature, especially on its relevance to endurance performance and adaptation to training, being frequently viewed as one of the most relevant factors of performance [2]. However, di Prampero et al. [9] observed that, besides $\dot{V}O_2$max, other parameters are crucial for the athlete endurance performance, such as motor economy and the capability to sustain a high percentage of $\dot{V}O_2$max (%$\dot{V}O_2$max) along the exercise. On the same perspective, Svedahl et Macintosh [17] support that an athlete with a lower absolute $\dot{V}O_2$max in comparison with other athletes, can compensate that difference, using a higher %$\dot{V}O_2$max to reach the same oxygen uptake (ml/min/kg) along the exercise. According to this, sub-maximal physiological parameters started to be considered as determinant parameters as $\dot{V}O_2$max for the assessment of athlete's endurance performance potential. Gradually, the Anaerobic Threshold (AT), and its multiple expressions, i.e., lactate threshold (LT), heart rate threshold or ventilatory threshold (VT), became used on training and perceived as determinant parameters on the athlete's performance, once they highly correlate with the %$\dot{V}O_2$max related to aerobic performance [3]. Although the importance given to the capacity to sustain a higher %$\dot{V}O_2$max related to VT [2], due to the difficulties associated with the evaluation of ventilatory parameters in swimming pool conditions, the assessment of the VT in swimming has been less investigated and used than the metabolic parameters, such as LT. The purpose of this study was to identify the intensity associated with a non linear increase of the minute ventilation (Ve) described as VT [20], expressed as a %VO_2max, in swimming pool conditions.

METHODS
Subjects
Twenty nine trained swimmers were studied: 15 male (21.4±3.0 yy, 177.3±7.0 cm, 68.3±7.1 kg and a $\dot{V}O_2$max of 70.9±10.2ml/min/kg) and 14 female (18.7±2.4 yy, 164.9±2.3 cm, 55.1±3.9 kg and a $\dot{V}O_2$max of 59.8±8.0ml/min/kg). All subjects were informed about the details of the experimental protocol before beginning the measurements procedures, and volunteered to participate in this study.

Test protocol
The test sessions took place in a 25m indoor poll. Each subject performed an intermittent incremental test for $\dot{V}O_2$max assessment. This test had increments of 0.05m.s^{-1} each 200m stage, with 30s intervals until exhaustion [10]. Initial velocity was established according to the individual level of fitness, and was set at the swimmer's individual performance on the 400m freestyle minus seven increments of velocity (for more details see Cardoso et al [6]). VO_2 and Ve were directly measured using metabolic cart (Sensormedics 2900 oxymeter, Yorba Linda – Califórnia, USA) mounted on a special chariot running along the pool [19], and connected to the swimmer by a special respiratory valve [18]. Exhaled air was continually measured during the entire test on each 20s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. $\dot{V}O_2$max was considered to be reached according to primary and secondary traditional physiological criteria [1,11]: (i) occurrence of a plateau in oxygen uptake despite an increase in swimming velocity, and (ii) high levels of blood lactic acid concentrations ([La^-]≥ 8mmol.l^{-1}), elevated respiratory exchange ratio (R≥ 1.0), high heart rate (HR) (>90% of [220bpm-age]) and exhaustive perceived exertion (controlled visually, and case to case, by the respective coaches and scientific staff). Capillary blood samples for [La^-] analysis were collected from the earlobe at rest, in the 30s rest interval, immediately after the end of each exercise step, and at 3 and 5 min of the recovery period. These blood samples were analysed using an YSI1500LSport auto-analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). HR was monitored and registered continuously each 5s through a HR monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). Swimmers were instructed to perform an open turn, always performed to the same lateral wall side, without underwater gliding, and were verbally encouraged to swim as long as possible during the test period. The test was carried out in same conditions for each subject, i.e., temperature and humidity.

Statistical analysis
Statistical procedure includes mean and standard deviations for all variables. All data was checked for normality. VT was assessed by Ve/VO_2 curve modelling method (least square method) and was assumed as the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential) [13]. Intensity related to VT was expressed on %$\dot{V}O_2$max.

RESULTS AND DISCUSSION
The ability to sustain a high %$\dot{V}O_2$max during an endurance exercise appears to be related to %$\dot{V}O_2$max at VT [2]. Although this fact, due to the difficulties associated with the evaluation of the ventilatory parameters in swimming pool conditions, the VT assessment has been scarcely investigated [16].
The results obtained in our study show that the non linear increase of Ve seems to occur at 88.1±31.3 l.min^{-1}. This value

corresponds to 84.3±8.7% $\dot{V}O_2max$. These findings seem to be in agreement with other studies conducted in running and cycling ergometers (82.3±3% [14], and 84.6±5.1% [7]), pointing out that, despite the specificity of the aquatic environment, the VT occurs at a similar absolute intensity as in running and cycling. This seem to be so, nonetheless the different haemodinamics (because of the horizontal body position), the decreased effects of gravity, and reflex bradycardia [12], in swimming. It also seems that the variation on training patterns in swimming and other sports, such as running and cycling, does not influence the value of %$\dot{V}O_2max$ at that appends the VT. In the study conducted by Roels et al [16], there weren't found differences on the subjects' VT when performing an incremental test on water and on cycle ergometer, or between the two groups observed, swimmers and triathletes.
Although the obtained value of %$\dot{V}O_2max$ associated to VT, does not represent the maximal work rate that can be maintained for a long period of time without a continuous rise of blood [La^-] (because, like many studies demonstrate [4, 15], the VT appends to an higher intensity than the intensity associated to the non linear increase in blood [La^-]), this exercise intensity should not be ignored in the swimming training, once it is associated to a group of physiologic mechanisms (like the bicarbonate buffering of the lactic acidosis) [5, 8, 20], determinant for the impairment of muscle contractility and its capacity to generate energy.

CONCLUSION

To our knowledge, this is one of the first studies in which %$\dot{V}O_2max$ and VT are related, in swimming pool conditions. Thus, it is expected to provide additional data to better understanding of VT in swimming. The obtained results seem to indicate that the swimming training should include more intense sets on the aerobic capacity training, than the more "traditional" sets of moderate intensity, normally based or associated to the LT, which only represents one of many parameters associated to the AT. Our results indicate that to fully train the aerobic capacity, sets with intensity close to 85%$\dot{V}O_2max$ should also be included, because of the importance of the mechanisms related to VT, on the rapid adjustment of the body's acid-base status during and immediately after exercise.

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EFFECTS OF SUPINE FLOATING ON CARDIAC AUTONOMIC NERVOUS SYSTEM ACTIVITY AFTER TREADMILL EXERCISE IN WATER

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The purpose of this study was to determine the effects of supine floating on rectal temperature and cardiac autonomic nervous system activity after treadmill exercise in the water. Six healthy males volunteered for this study. Subjects were placed in a supine position for 30 minutes in both a water condition (W-condition) and control condition (C-condition) after treadmill exercise in the water. And subjects were measured for recovery while sitting for 15 minutes. During supine floating after treadmill exercise in the water, log HF was significantly increased ($p< 0.05$) under the W-condition, as compared to the C-condition, during the recovery process. These data suggest that supine floating after treadmill exercise in the water could increase cardiac parasympathetic nervous system activity. Also, the increase in cardiac parasympathetic nervous system activity continues for recovery while sitting after supine floating.

Key Words: supine floating, recovery, cardiac autonomic nervous system, rectal temperature.

INTRODUCTION

In the water, humans have different physical responses compared to land due to influences of physical characteristics of water, such as water temperature, water pressure, buoyancy and viscosity. Nishimura and Onodera (1) reported on the relaxation effects of supine floating on heart rate, blood pressure and cardiac autonomic nervous system activity, and suggested that cardiac parasympathetic nervous system activity was significantly increased by supine floating. Supine floating was useful to get into a relaxation state. Matsui et al. (2) reported on the effects of water immersion on systemic cardiovascular responses during recovery periods following steady state land exercise. After exercise, stroke volume and cardiac output were significantly increased in water, when compared to land. Increased left ventricular preload with immersion, would be an important factor in cardiovascular regulation not only at rest, but also during recovery after exercise. We (3) suggested that supine floating after high and moderate intensity exercise with a cycle ergometer on land could promote the recovery of rectal temperature and an increase in cardiac parasympathetic nervous system activity. However, it doesn't make clear the effects of supine floating after water exercise. Therefore, the purpose of this study was to determine the effects of supine floating on rectal temperature and cardiac parasympathetic nervous system activity after treadmill exercise in the water.

METHODS

Six healthy males volunteered for this study. Their mean age, height, body weight, % body fat, and maximal oxygen uptake were, respectively: 21.8±0.7years (mean±SD), 172.8±8.9cm, 63.8±6.1kg, 17.5±3.0% and 49.2±4.8ml/kg/min., respectively. All subjects signed an informed consent form prior to participation in this study. Subjects were placed in a supine position for 30 minutes in both a water condition (W-condition) and control condition (C-condition) after treadmill exercise in the water. And subjects were measured for recovery while sitting for 15 minutes. Walking velocity was 4 km/h. Water level was umbilicus. During W-condition, subjects could float using an air pillow, aqua blocks and a floating belt (fig. 1.). Heart rate, blood pressure, rectal temperature, oxygen uptake and cardiac autonomic nervous system activity were measured under these conditions. Expired gases were collected in a Douglas bag. Then O_2 and CO_2 gas concentrations were measured by mass spectrometry (Westron. WSMR-1400. Japan), and gas volume was determined using a dry gas meter (Shinagawa Dev. DC-5. Japan). Cardiac autonomic nervous system activity was calculated using Maximum Entropy Calculation (MemCalc) Methodology. The frequency domain was divided into two parts: high frequency (HF; 0.15-0.40Hz) and low frequency (LF; 0.04-0.15Hz). Cardiac autonomic nervous system activity was transformed into logarithmic values to obtain a statistically normal distribution. Log HF was an index of cardiac parasympathetic nervous system activity. Water temperature was 30 degrees Celsius. Room temperature and humidity were 27.0±1.3 degrees Celsius and 81.3±5.5%, respectively. All experiments were performed at the same hour each morning. All subjects went without food after 10 p.m. prior to the experiment day. Also, caffeine components weren't allowed for three hours before experiments. All data were expressed as mean ±SD. Two-way analysis of variance for repeated measurements was used for comparison of each measured value between the W-condition and the C-condition trials. In cases where the data showed a significant difference in the two-way analysis of variance, post hoc assessment with individual time point comparisons between two trials were carried out by Students-Newman-Keuls test. The level of significance was set up as $p< 0.05$.

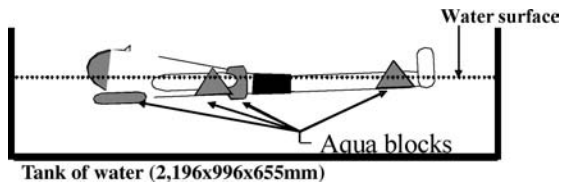

Figure 1. View showing a frame format of supine floating.

RESULTS

During treadmill exercise in the water, heart rate remained about 85 bpm and oxygen uptake remained about 1.2l/min. in both the W-condition and the C-condition. All measurement items of post exercise showed no significant differences under the W-condition, as compared to the C-condition. During supine floating after treadmill exercise in the water, delta rectal temperature (point 0-0 is end of exercise) was significantly reduced ($p< 0.05$) under the W-condition, as compared to the C-condition (fig. 2). And log HF was significantly increased ($p< 0.05$) under the W-condition, as compared to the C-condition, during the recovery process (fig. 3).

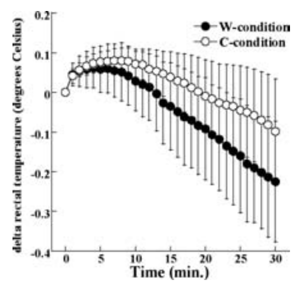

Figure 2. Changes in delta rectal temperature between the W-condition and the C-condition during recovery in supine position. Point 0-0 was end of exercise. ANOVA; $p<0.05$ W-condition VS C-condition.

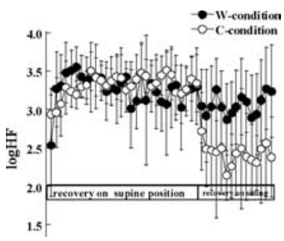

Figure 3. Changes in log HF between the W-condition and the C-condition during recovery in the supine and sitting position. ANOVA; p<0.05 W-condition VS C-condition.

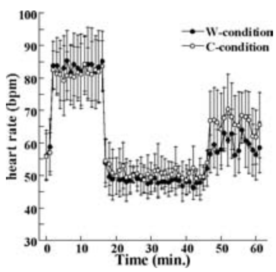

Figure 4. Changes in heart rate between the W-condition and the C-condition.

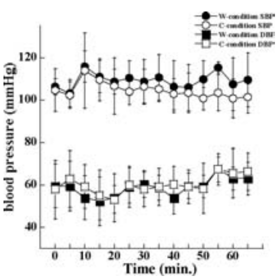

Figure 5. Changes in blood pressure between the W-condition and the C-condition.

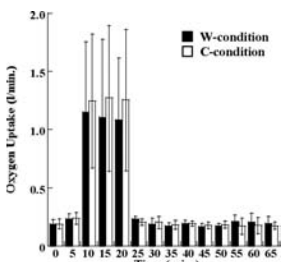

Figure 6. Changes in oxygen uptake between the W-condition and the C-condition.

Heart rate (fig. 4), blood pressure (fig. 5) and oxygen uptake (fig. 6) showed no significant differences under the W-condition, as compared to the C-condition, during recovery process.

DISCUSSION

The conductive heat transfer coefficient of water is 25 times higher than that of land. This means that venous return was cooled during water immersion. Therefore, rectal temperature was reduced by the increase of heat loss under the W-condition, as compared to the C-condition during the recovery in the supine position. The increase in log HF was caused by the bradycardia reflex, which increased central venous pressure, and the arterial baroreceptor, which increased the stroke volume. Blix et al. (4) suggested that the bradycardia reflex was caused by face immersion. In this study, the increase in log HF is the tendency that is similar to the face immersion. The increase in log HF continues for recovery while sitting after supine floating. We suggested (1) that heart rate, blood pressure and oxygen uptake showed no significant differences under the W-condition, as compared to the C-condition, during supine floating after high and moderate intensity exercise with a cycle ergometer on land. This study showed similar tendency. These data suggest that supine floating after treadmill exercise in the water could increase cardiac parasympathetic nervous system activity. Also, the increase in cardiac parasympathetic nervous system activity continues for recovery while sitting after supine floating.

CONCLUSION

Supine floating after exercise is useful for increasing cardiac parasympathetic nervous system activity not only with exercise on land, but also exercise in water.

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HOW CARDIOVASCULAR RESPONSES AFFECT TISSUE OXYGENATION AT REST AND DURING EXERCISE IN WATER?

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This study investigated how cardiovascular responses affect tissue oxygenation at rest and during exercises in water. Nine healthy men performed cycling exercises on land (LE) and in water (WE) at xiphoid levels of 40 and 60% $\dot{V}O_2$,peak. The $\dot{V}O_2$, heart rate (HR), cardiac output (CO), total peripheral resistance (TPR) and mean blood pressure (MBP) were measured. The oxy-haemogbloin (HbO_2) and total-haemoglobin (T-

Hb) were also measured using near infrared spectroscopy (NIRS). At rest, the CO and stroke volume (SV) increased ($p<0.05$) with immersion. A correlative increase in the HbO_2 level was noted. These results indicate that the oxygen supply to the muscles increased on immersion. Contrarily, the MBP during WE was higher ($p<0.05$) than that of LE at both intensities. The HbO2 level during WE was lower than that of LE at both intensities The water pressure seems to restrict the blood flow, thereby increasing MBP through activation of a muscle metaboreceptor or mechanoreceptor.

Key words: water exercise, cardiovacular response, muscle oxygenation, near infrared spectroscopy.

INTRODUCTION

The central shift in blood volume from lower limbs to the thoracic region during water immersion is caused by hydrostatic pressure, which subsequently increases the cardiac output (CO) (1, 3, 5, 8). The CO increase has been attributed to elevated stroke volume (SV), which is related to enhanced diastolic filling (1, 3, 5, 8). Although cardiovascular responses are well studied, it remains unclear how they affect skeltal muscle metaborics in water.

During the last 15 years, the physiological knowledge of human skeletal muscles substantially increase because of the utilisation of muscle biopsy complemented by non-invasive techniques such as near infrared spectroscopy (NIRS) (4, 7, 10, 11). Muscle oxygenation indicates the relationship between O_2 delivered and consumed within the tissues. Although several studies in the field of sports medicine have utilised NIRS (4, 7, 10, 11, 15), there is a lack of information on skeletal muscle oxygenation at rest and during exercise in water. It is also important to investigate how water characteristics (e.g., hydrostatic pressure) affect muscle oxygenation and associated physiological responses such as the venous return. This study was undertaken to investigate how cardiovascular responses affect tissue oxygenation at rest and during exercise in water.

METHODS

Nine healthy males participated as subjects. Their mean age, height, weight and body fat were, respectively, 24 ± 2.2 years, 175.2 ± 3.8 cm, 70.1 ± 4.7 kg and 17.0 ± 2.5%. The mean adipose tissue thickness of the vastus lateralis (VL) was 5.8 ± 1.5 mm. The subjects were informed of the experiments and their associated risks, after which they gave their consent to participate. They were then asked to perform two sets of exercises. In the first, they underwent a recumbent cycle-graded exercise on land (LE) and in water (WE). In this part of the protocol, the workload was increased every 2 min until the maximal effort was attained. The heart rate (HR) and oxygen consumption ($\dot{V}O_2$,) were continuosly mesured during the tests. The water temperature was set thermoneutrally at 32ºC (5). In the second part of the protocol, the subjects performed cycle-submaximal steady-state exercises at 40% and 60% $\dot{V}O_2$,peak both in land and in water. Each protocol was separated at least 5 days. After the subjects rested on land in sitting position, they immersed up to the set xiphoid levels in water, then rested on the ergometer for 5 min and finally pedalled for 12 min at both intensities. The $\dot{V}O_2$,, HR, CO and systolic (SBP) and diastolic (DBP) blood pressures were measured during all the experiments. The CO was measured with C_2H_2 rebreathing method (2). The mean blood pressure (MBP) was calculated as follows: DBP + (SBP-DBP)/3. The total peripheral resistance (TPR) was calculated as follows: (MBP-CVP)/CO, where CVP represents an estimate of central venous pressure (5). The CVP was assumed to be 0.4 mmHg for subjects resting in air, 3.9 mmHg for subjects exercising in air and 11.1 mmHg for subjects either resting or exercising in water (5). The oxyhaemoglobin (HbO_2) and total-haemoglobin (T-Hb) values were measured simultaneously using a NIRS system (Model HEO-200, Omron Ltd., Japan). This system has a flexible probe that consists of two light-emitting diodes set at 760 nm and 840 nm (16). Their emitted lights can penetrate soft tissues to a maximum depth of 1.5-2.0 cm. Approximately 10 min before immersion, a pneumatic cuff was inflated to over 300 mmHg to occlude arterial blood flow for 7-9 minutes until the HbO_2 bottomed out. The lowest value attained during cuff ischaemia was defined as 0%; the maximal value reached after recovery from cuff ischaemia was referred to as 100% (6) (fig. 1).

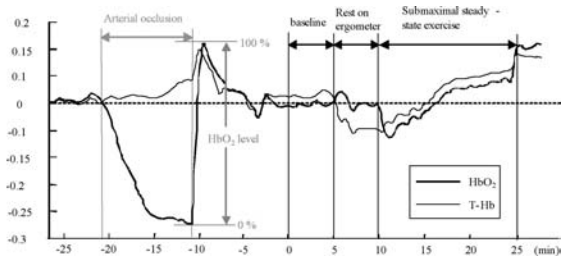

Figure 1. Submaximal steady-state exercises protocol and estimation of HbO_2 level from NIRS (6). The HbO_2 signals were measured continuously during all experiments.

RESULTS

Figures 2A and 2E show that HR and TPR, respectively, decreased significantly ($p<0.05$) upon immersion. The CO and SV, however, increased significantly ($p<0.05$). During WE and LE at both intensities, no cardiovascular responses differed, except MBP (fig. 2). The MBP was considerably higher ($p<0.05$) during WE than LE ($p<0.05$). The HbO_2 level increased during immersion (Fig. 3). The HbO_2 level for WE at 60% $\dot{V}O_2$,peak was lower than that of LE ($p<0.05$).

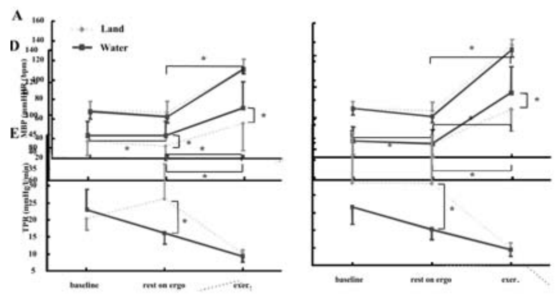

*Figure 2. Changes in HR (A), CO (B), SV (C), MBP (D) and TPR (E) ar rest and during exercise at 40% (figures on left) and 60% $\dot{V}O_2$peak (figures on right) on land and in water. Values are given as mean ± SD. egro; ergometer; exer.; exercise. * = p<0.05.*

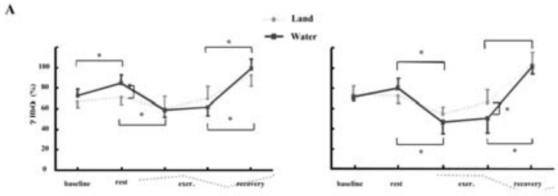

Figure 3. Changes in HbO2 levels (A) and T-Hb (B) at 40% (left panels) and 60% $\dot{V}O_2$*peak (right panels). Values of the* HbO_2 *levels and T-Hb are given respectively as mean ± SD and mean. * =* $p<0.05$

DISCUSSION

It has been suggested that both CO and SV increase with immersion or during water exercise (1, 3, 5, 7). The results of the present study reaffirmed these observation: the increase was probably caused by enhanced venous return as noted in several studies (1, 3). We could ascertain the enhanced venous return from the result of decreased T-Hb during immersion. Regarding muscle oxygenation, our data indicate that the HbO_2 level increased with immersion at both 40% $\dot{V}O_2$peak and 60% $\dot{V}O_2$peak trials. This increase might be due to the increment of CO and decrement of TPR, and suggests the increment of oxygen supply.

Some studies reported inconclusive data regarding the behaviour of BP at rest in water. In fact, the blood pressure (SBP, DBP and/or MBP) at rest in water might display slight increase (13), slight decrease (14) or no change at all (3). Our data show no changes or increase in MBP upon immersion, which is inadequately explained at present. Because some of factors stated above might be inlvoved, further research might reveal the reaons for that lack of change.

Previous studies (5, 14) reported an increase in CO and SV during ergometer exercise in an upright position in water. No signficant differences in cardiovascular responses between land and water exercise, except for that of MBP, were found in the present study. These phenomena, including the reduced venous return, might be caused by the inclined positions of the subjects in our study.

Suzuki (17) reported that hydrostatic pressures as slight as 20 mmHg can compress arterial vessels, subsequently distorting their walls; the reactivated periareterial sympathetic nerve can thereby raise blood pressure. During ergometer exercise with lower body positive pressure (LBPP), which is similar to water immersion, Nishiyasu et al. (12) reported increased MBP. They interpreted that the reduced blood flow promoted the accumulation of metabolic by-products, which activated the muscle metaboreceptor, consequently inducing reflex-rise (i.e., muscle metaboreflex). The water environment used during this study is considered to create similar conditions to that of LBPP. Therefore, we suggest that, in such an environment, the hydrostatic pressure probably raised the MBP. However, Gallagher et al. (9) argued that the MBP increase is not attributable to muscle metaboreflex, but rather to muscle mechanoreflex, a condition that is sensitive to reflex associated with increased intramuscular pressure. Thus, based on our data, it remains unclear whether the hydrostatic pressure activated the metaboreceptor or mechanoreceptor during water exercise. Hence, the MBP increase could be caused by one of these receptors.

Svedenhag and Seger (18) recognised a higher anaerobic metabolism caused by lowered perfusion pressure in the legs during running in water, resulting in maldistribution or decrease of muscle blood flow. During dynamic leg exercise with LBPP, Nishiyasu et al. (11) reported a drastic decrease of HbO_2 (and blood flow) in the thigh muscle and proposed that the decrease indicated a shift of the metabolic state to glycolysis. The water environment of this study is similar to the LBPP. Therefore, it is argued that the hydrostatic pressure restricted the blood flow and reduced the quantity of oxygen supplied to the muscles.

CONCLUSION

In conclusion, the results of this study suggest that the increments of CO and SV might increase the oxygen supply to the muscles at rest and during exercise in water at 40% $\dot{V}O_2$peak and 60% $\dot{V}O_2$peak. The hydrostatic pressure can induce the restriction of the blood flow and the oxygen supply to the muscles. That restriction probably activated the muscle metaboreceptor or mechanoreceptor, which consequently increased the MBP.

ACKNOWLEDGEMENTS

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CHANGES IN CROSS SECTIONAL AREA OF INFERIOR VENA CAVA DURING ARM CRANKING EXERCISES IN WATER

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The purpose of the present study was to investigate the cross sectional area of inferior vena cava changes during exercises in water. Six subjects voluntarily participated in this study and performed an arm cranking exercise program under the four experimental conditions (20% $\dot{V}O_2$max, 40% $\dot{V}O_2$max, 60% $\dot{V}O_2$max and control). Water temperature was 30 degrees C. Water depth was axilla. Heart rate and cross sectional area of inferior vena cava were measured by radiotelemetric electrocardiography and B-mode echocardiography, respectively. The cross sectional area of inferior vena cava decreased during the exercise program, and there was a significant relationship between the cross sectional area and intensity of the exercise program ($p< 0.05$). The findings of the study indicated that venous return had been keeping the volume during the low intensity exercise program and that had been changing the treatment from volume to velocity during the high intensity exercise program.

Key Words: venous return, the cross sectional area of inferior vena cava, exercise intensity, in water exercise, arm cranking exercise.

INTRODUCTION
It is well known that bradycadia and increases in stroke volume occur induced by hydrostatic pressure during water immersion. Onodera et al (1) clarified that the venous return increased in dependence on hydrostatic pressure. The cross sectional area of inferior vena cava significantly increased in accordance with increasing water depth. We expected that the venous return would have two factors of volume and velocity. Onodera et al (2) clarified that the response of venous return was about twenty seconds using the change of size in the cross sectional area of the inferior vena cava. However, there is still no common agreement on changes of volume in venous return during exercises in water. Therefore, the present study investigated the volume of venous return using the cross sectional area of inferior vena cava changes during exercises in water.

METHODS
Six subjects voluntarily participated in this study. All were healthy adult males with no history of cardiopulmonary disease. Descriptive data (mean + SD) are as follows: age of 23±1 years, height of 173±15 cm, body weight of 173±5, %Fat of 19±2%, maximal oxygen uptake ($\dot{V}O_2$max, STPD) of 2.44+0.55 liter/min. We used informed consent for subjects according to the HELSINKI Ethical Principle.
The exercise was performed by an arm cranking ergo meter (881, MONARK). The study was set into four experimental conditions of 20% $\dot{V}O_2$max, 40% $\dot{V}O_2$max, 60% $\dot{V}O_2$max and control. The data were compared in air and water, respectively. $\dot{V}O_2$max was measured by the steady-state conditions. Expired air for the determination of $\dot{V}O_2$ was collected in two successive bags though the respiratory valve. Collection started 2 min before the end of work. Expired O_2 and CO_2 gas concentrations were measured by mass spectrometry (Westron MGA 1200, Japan), and gas volume was determined using a dry gas meter (Shinagawa Dev.NDS-2A-T, Japan).
Subjects participated in an arm cranking exercise program for 10-min. The rest after exercise program was 10 min. To determine $\dot{V}O_2$ expired air was collected six (in water) or five (in air) times (rest in air, rest in water, 3-5 and 8-10 min during exercise, 3-5 and 8-10 min after exercise).
Heart rate was measured by radiotelemetric electrocardiography (DS-2202, FUKUDADENSHI Japan), and was monitored minute by minute. The cross sectional area of the inferior vena cava was measured using B-mode echocardiography (SSD-870 ALOKA Japan) while standing in air and water. Water and room temperature were 30.5±0.6 and 25.4±0.4 degrees C, respectively. Water depth was set on axilla height. Data were analyzed by specify ANOVA for repeated measures and the level was set at $p< 0.05$.

RESULTS
The heart rate was significantly increased according with increasing intensity of the exercise program ($p< 0.05$). At the same intensity of exercise program, heart rate in the water condition was significantly lower than in the air condition (fig. 1a, b). $\dot{V}O_2$ was significantly increased in accordance with the increasing intensity of the exercise program ($p< 0.05$), and was the same in air and water (fig. 2a, b). These results suggest that the load is the same in air and in water conditions.

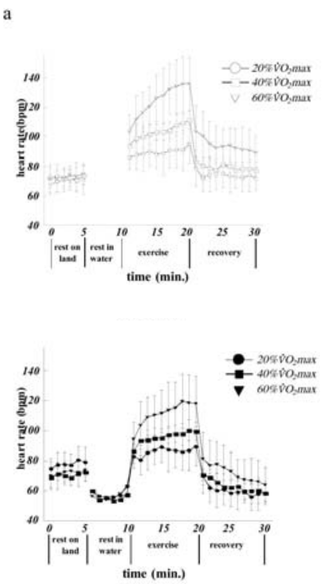

Fig.1. Comparision of heart rate during different intensity arm cranking exercise.
a: out of the water condition b: in the water condition.

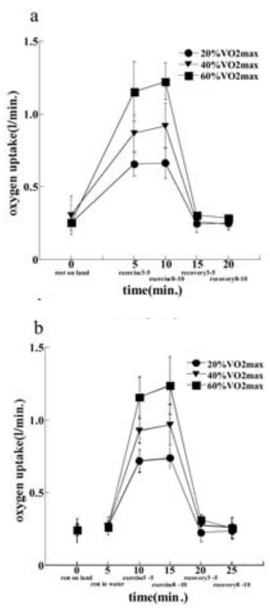

Fig. 2. Comparison of oxygen uptake during different intensity arm cranking exercise.
a: out of water condition, b: in water condition.

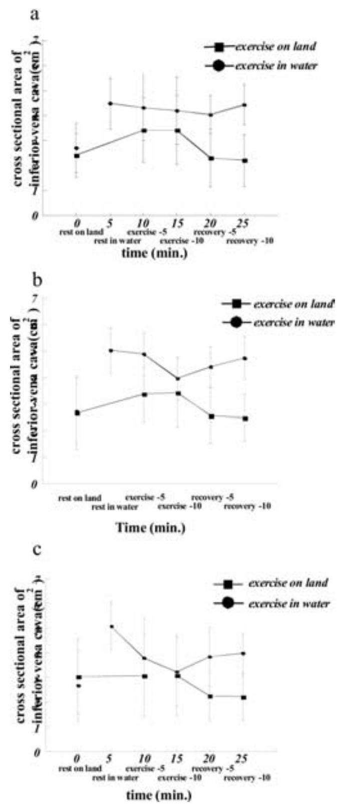

Figure 3. Comparison of cross sectional area of inferior vena cava between the exercise on land and the exercise in water. a: 60% V̇O2max. b: 40% V̇O2max. c: 20% V̇O2max.

The cross sectional area of inferior vena cava of 20% $\dot{V}O_2max$ in water was significantly higher than in air at the point of all expired air (fig. 3a, $p< 0.05$). The cross sectional area of inferior vena cava of 40% $\dot{V}O_2max$ in water was significantly higher than in air at the point of 3-5 min during exercise and of 3-5 min and 8-10 min after exercise (fig. 3b, $p< 0.05$). The cross sectional area of inferior vena cava of 60% $\dot{V}O_2max$ in water showed no significant difference during exercise, and was significantly higher than in air at the point of 3-5 min and 8-10 min after exercise (fig. 3c, $p< 0.05$). The cross sectional area of inferior vena cava after exercise was significantly lower in accordance with increasing intensity of the exercise program (fig. 3a, b, c, $p< 0.05$).

DISCUSSION

These results indicate that the cross sectional area of inferior vena cava decreased during the exercise program and that there is a significant relationship between the cross sectional area and the intensity of the exercise program ($p<0.05$). The results of recovery after the exercise program also indicate that there is a significant difference between the cross sectional area and the intensity of the exercise program ($p< 0.05$).

We suspect that the venous return has two factors controlling the velocity and volume. The findings of the study indicated that venous return had been keeping the volume during the low intensity exercise program and that had been changing the treatment from volume to velocity during the high intensity exercise program. The increase in venous return with water immersion may be associated with bradycardia during low intensity exercise in water.

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THE INFLUENCE OF COMPETITIVENESS ON MATCH EXERCISE INTENSITY IN ELITE WATER POLO PLAYERS

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This study was designed to investigate the physiological responses that elicited in different competitive level players during water polo games. Specifically, the hypothesis that the players of International calibre (IA; Greek National Team) perform with higher intensity than the National level players (NA; 1st Greek National League) was tested. Thirty players, who had equally split to IA and NA, participated in this study. No differences were found with respect to the percentage of time spent with exercise intensity above and below the threshold between IA and NA. However, regardless of relative terms (%), IA swam with significantly higher velocity than NA throughout the game. Both groups preferred to compete with an intensity fluctuating around their lactate anaerobic threshold. It is concluded that the International level players performed at higher absolute exercise intensity than National level players.

Key Words: national team, males, physiological demands.

INTRODUCTION
Successful water polo players display moderately high aerobic power (58-61 ml·kg^{-1}·min^{-1}) and high concentrations of blood lactate (13 – 16 mmol·l^{-1}) after performing an exhaustive anaerobic test (9). A comprehensive study, examining field play physiological demands in water polo, found that athletes maintained a heart rate in excess of 150 beats·min^{-1} for 91.8 % of the actual water polo game playing time. In addition, 50.8 % of the actual playing time was allotted to higher exercise intensity than the one corresponding to the subjects' ventilatory anaerobic threshold (4).
However, exercise intensity in a water polo match is known to be affected by game duration (5) and closeness of final score mach (6). It is also known that field-playing positions do not attain specific exercise intensity traits in water polo (2, 5) contrary to what happens in other ball game events (i.e. 7). The level of competitiveness has also been found to affect the metabolic demands of playing in other ball game sports (i.e. 1). In water polo, studies investigating the influence of the level of competitiveness on match play exercise intensity have not been conducted yet.
This study was designed in order to investigate the physiological responses exhibited by different competitive level players while they were playing water polo. Specifically, the hypothesis that international calibre players perform with higher absolute intensity than the national players was tested.

METHODS
Thirty water polo male players signed a informed consent sheet to participate in the study, it was previously approved by the respective ethics committee. Subjects were members of 10 different water polo clubs, out of 12 in total, participating in the First Greek National Division Championship. They were selected in such way as they could be equally split to different levels of competitiveness. The first was a group of international players (IA; n=15) who were belonging to the Greek national team continuously for the last three years and had been selected by the national coach using his own criteria without having any access to objective performance tests. The second was group of national caliber athletes (NA; n=15) who were participating regularly in the First Division Championship without affiliation with any national team. Subjects' characteristics are presented in Table 1. One week prior to the experimental games, performance testing was conducted in order to determine the physical abilities of the subjects. Then field measurements were performed during ten simulated competition games. Each one lasted 28 min of net playing time equally split into four periods.
The following measurements were performed:
1) monitoring of blood lactate during the break between each playing quarter,
2) continuous recording of the heart rate responses during competition.
Competitive exhibition games took place right after two months of regular training for securing homogeneous expression of physical abilities by all participants. During each game, the variables were recorded from 3 subjects. These subjects were arranged to play throughout the entire game without being substituted at all. All games were played following the zone defense system.

Testing Performance
Each subject completed a 400 m front crawl stroke swimming test with a constant maximum speed, in an indoor 25-m pool to determine his highest oxygen consumption (VO_{2peak}) and performance (3). Recovery metabolic rate was recorded, in a breath-by-breath mode, for 30 sec aiming to obtain the peak oxygen value. Otherwise, VO_{2peak} was calculated as it has been previously reported (8). Lactate threshold (LT) of each subject was determined by asking the participant to swim in a 50 m long pool four times the distance of 200 m at progressively incremented velocity. Heart rate (HR) was monitored (Polar Vantage NV, FI) throughout the whole test whereas blood samples from the fingertip of the subject were taken during recovery of each effort, and analysed using the reflectance photometry - enzymatic reaction method (Accusport, Boehringer, Germany).

Physiological responses during competition
The heart rate of each subject was recorded at 5 sec intervals

during the game using a radio telemetry system (Polar Vantage NV, FI). The emitter was placed and secured with a network of straps on the chest of the athletes without limiting their movement freedom. The receiver was set in each subject's swimming suit. In each game, the receivers were arranged on three athletes in remote playing positions in order to avoid telemetric signal interference. Fingertip blood samples were obtained from all three subjects within 90s of the completion of each quarter of play and analyzed. Testing details were described by Platanou et al. (5).

Table 1. Anthropometric characteristics of subjects participating in the study. Values are means ± SD.

		Age (years)	Height (m)	Body mass (kg)
National athletes	(n=15)	22.4±3.3	1.83±0.05	88.3±10.64
International athletes	(n=15)	22.6±3.6	1.82±0.05	82.1±08.14
Total	**(n=30)**	**22.5±3.4**	**1.83±0.05**	**85.2±09.82**

Statistical treatment of data
Two Way Analysis of Variance with repeated measures over time was applied to explore differences, on various dependent variables, among levels of competitiveness. Student's t-test was performed in order to detect any existing difference in all physiological characteristics between International and National athletes.

RESULTS
Table 2 summarises the physiological and performance characteristics of all subjects in total (n=30), as well as divided equally (n=15) in two subgroups according to their level of competitiveness. In addition, Table 2 shows HR and La values obtained during the water polo games. Figure 1A illustrates the mean HR response pattern per quarter of play for National and International level players. Heart rate response during the games was converted to swimming velocity (Figure 1B) based on the respective relation recorded in the preliminary performance testing. Regardless the competitiveness level, approximately 40% of total time (36.5 for NA, 46.3 for IA), excluding the breaks among quarters, was spent with a HR less or equal to 85% $HR_{peak.}$ The rest of the time was almost equally distributed among heart rate intensities within the spectrum of 85-90, 90-95, and 95-100% of its highest value. No differences were found with respect to the percentage of time spent with exercise intensity above and below the threshold between IA and NA.

Table 2. Mean values of physiological and performance characteristics as well as mach exercise intensity of elite water polo players (n=30) subdivided equally to International and National caliber athletes (n=15 in each group).

	National Mean	National ± SD	International Mean	International ± SD	P	Total Mean	Total ±SD
			400m swim				
400 m swim (min:sec)	5:07:56	0:22.42	4:48:35	0:10:94	008	4:57:80	0:22.36
VO_{2peak} (ml·kg.$^{-1}$·min^{-1})	57.14	9.26	70.23	6.97	.001	63.69	10.44
VO_{2peak} (l/min)	4.9	0.8	5.5	0.6	.02	5.2	0.8
HR_{peak} (beats·min^{-1})	186.80	7.20	179.90	6.31	.01	183.00	7.78
95% of HR_{peak}	177.50	6.80	170.20	6.20	.002	173.60	6.40
90% of HR_{peak}	168.40	6.70	161.30	5.90	.002	164.30	6.20
85% of HR_{peak}	158.80	6.12	152.30	5.50	.002	155.60	5.80
			4X200m swim				
LT (mmol·l^{-1})	4.60	0.80	3.47	0.76	.002	4.03	0.96
V_{LT} (m/sec)	1.25	0.07	1.31	0.06	.02	1.28	0.07
HR_{LT} (beats·min^{-1})	163.07	9.59	147.53	9.63	.0003	155.30	12.32
HR_{LT} as % HR_{peak}	87.33	4.01	83.79	4.36	.002	85.56	4.49
		Water-polo match					
HR (beats/min)	162.90	9.90	149.80	8.20	.001	156.4	8.90
La (mmol/l)	4.67	2.17	3.04	1.09	.002	3.9	1.89

HR_{peak}: The highest of heart rate; VO_{2peak}: Peak oxygen uptake; LT: Lactate Threshold; V_{LT} : Swimming velocity at lactate threshold, HR_{LT}: Heart Rate at lactate threshold.

HRpeak: The highest of heart rate; VO_{2peak}: Peak oxygen uptake; LT: Lactate Threshold; V_{LT}: : Swimming velocity at lactate threshold, HR_{LT}: Heart Rate at lactate threshold.

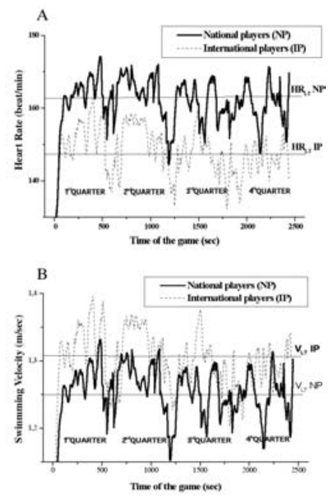

Figure 1. Mean Heart Rate response (A) and swimming velocity (B) per quarter of game for national and international players during 10 water polo games HR_{LT}: Heart Rate at lactate threshold V_{LT}: : Swimming velocity at lactate threshold.

DISCUSSION
The present study investigated the physiological responses imposed by the demands of the water polo game on two distinct groups of players, namely members of the national Olympic Greek team and players participating in the First National Division.
It was shown that the IA compared with NA possessed higher aerobic capacity and swam faster the 400 m crawl distance. Furthermore, LT in former group exhibited at higher swimming velocity than in the latter group of athletes. The lower HR_{peak} in IA compared with NA players, at the 400 m free style, is worth mentioning. Despite the high variability of the HR_{peak} values, our findings are in agreement with those recorded in other studies performed in the water, (e.g. 184±4 beats/min) (4). Due to higher values of HR_{peak} relative values of HR_{LT}, expressed as percentage of HR_{peak}, were also higher (87.3±4.01%; 163±9.6 beats/min in NA vs. 83.4±4.4; 147±9.6 beats/min in IA). As Figure 1A shows, the absolute HR recorded during the games was significantly higher (162.9±9.9 beats/min) in NA group than that measured in the members of IA (149.8±8.2 beats/min). Surprisingly, the average playing intensity in the two groups corresponded to 87 and 83% of the group's HR_{peak}, percentages that seem to be similar with respective ones at the lactate threshold. Similarly, the higher blood lactate concentration observed during the games in NA subjects compared to IA members simply reflect the different LA threshold values between the two groups. The finding that the IA exhibited significantly greater swimming velocity at lactate threshold than the NA (Table 2; Fig 1B) indicates a physiological advantage during competition for the former group of water polo players. In conclusion, these results appear to strengthen the previously expressed notion (4, 5), that water polo players

select to work overall with intensity around their anaerobic lactate threshold regardless of their skills and capabilities, and any differences observed in absolute values between the experimental groups are probably attributed to the specific physiological characteristics of the players being involved in each group.

CONCLUSIONS
The hypothesis that during water polo games International caliber players perform with higher absolute intensity than the National players was confirmed. It appears that this is mainly due to a superior aerobic capacity and an advantageous lactate threshold. Water polo games are primarily played with an intensity fluctuating around to the players' lactate thresholds.

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COMPARISON BETWEEN DIFFERENT METHODS FOR THE ASSESSMENT OF THE $\dot{V}O2$ SLOW COMPONENT OF FREESTYLE ELITE SWIMMERS

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The purpose of this study is to compare different methods for the assessment of the Oxygen uptake Slow Component (SC) in elite swimmers in a time limit test at the minimum velocity that elicits maximal oxygen consumption. Five females and two males participated in this study. $\dot{V}O_2$ was measured by a portable gas analyser connected to the swimmers by a respiratory snorkel. To describe the SC kinetics was used a mathematical model with three exponential functions. This model was compared with different methods of rigid time intervals defined as the difference between the final $\dot{V}O_2$ and that at the 2nd min ($\Delta\dot{V}O_{2[end-2]}$) or at the 3rd min of exercise ($\Delta\dot{V}O_{2[end-3]}$). This study showed that the use of the $\dot{V}O_{2[end-3]}$ underestimates the results since the SC usually begins earlier than the 3rd minute and that the use of the $\dot{V}O_{2[end-2]}$ seems to be a good solution, being less accurate but more simple to use in a day-to-day basis.

Key Words: $\dot{V}O_2$ slow component, modelling, rigid time intervals, freestyle swimmers.

INTRODUCTION
During exercise at heavy intensities, which engenders a sustained elevation in blood lactate, the $\dot{V}O_2$ kinetics becomes considerably more complex than for moderate exercise. We can observe a secondary slower component to the rise in $\dot{V}O_2$, such that attainment of a new steady-state, if attained, is delayed (1). This Slow Component (SC) usually begins 80s to 180s after the onset of the heavy exercise (1).
In the literature we can find several methods for the assessment of the $\dot{V}O_2$ SC. Many investigators have used a rigid interval to estimate the SC (2), most frequently the difference in oxygen consumption between the 3rd min and some later moment in the bout, (for example: 4, 5, 6, 7, 9, 10, 12, 18). Some authors have defined the 2nd min as the onset of the SC (8, 11, 16). Furthermore the use of a rigid interval as index of a physiologic parameter, which varies among subjects, is clearly prone to error, in addition the magnitude and significance of this error has not been investigated (2).
The purposes of this study are: (i) verify the existence of a $\dot{V}O_2$SC in Portuguese elite freestyle swimmers; (ii) compare the results of the values of the SC determined through the utilization of the mathematical model and the rigid time intervals, in a $\dot{V}O_2$ TLim test.

METHODS
Subjects
Five females (16.9±1.5 yy, 59.0±3.1 kg and 165.8±3.2 cm) and two males (18.5±0.6 yy, 74.6±8.5 kg and 176.0±11.3 cm) elite freestyle swimmers volunteered to participate in this study. All subjects were informed about the details of the experimental protocol before beginning the measurement procedures.

Test protocol
The test sessions took place in a 25m indoor pool. First, each subject performed an intermittent incremental protocol for freestyle $v\dot{V}O_{2max}$ assessment (8). $\dot{V}O_2$ was directly measured by a portable gas analyser (K4 b^2 Breath by breath Pulmonary Gas Exchange System – COSMED, Italy) connected to the swimmers by a specific respiratory snorkel for swimming (17). Expired air was continuously measured during the entire test and averaged every 5s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights in the bottom of the pool.

$\dot{V}O_{2max}$ was considered to be reached according to primary and secondary traditional physiological criteria (for more information see 8). The velocity for maximal oxygen consumption, v$\dot{V}O_{2max}$, was considered to be the swimming velocity corresponding to the first stage that elicits $\dot{V}O_{2max}$. Capillary blood samples for ([La$^-$] analysis were collected from the earlobe at rest, in the 30s rest intervals, immediately after the end of each exercise step, and at 3min (and 5 min) during the recovery period. These blood samples were analysed using an YSI1500LSport auto analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). Heart rate (HR) was monitored and registered continuously each 5s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland).
The second test session took place forty-eight hours later. All subjects swam until exhaustion at their previously determined v$\dot{V}O_{2max}$, to assess TLim. This protocol consisted in two different phases, all paced with the referred visual light-pacer: 1) a 10min warm-up at an intensity corresponding to 60% v$\dot{V}O_{2max}$, followed by a rest period of 20s for blood collection; 2) the maintenance of the swimming v$\dot{V}O_{2max}$ until exhaustion. TLim was considered to be the total swimming duration at v$\dot{V}O_{2max}$.
[La$^-$] were assessed at rest, during the 20s intervals, immediately after the exercise, and at 3min (and 5min) of the recovery period. HR was registered continuously using the same procedure previously described.
Swimmers were instructed to perform an open turn, always done to the same lateral wall without underwater gliding, and were verbally encouraged to swim as long as possible during the test period. Both tests were carried out in the same conditions for each subject, i. e., temperature, humidity and time of day.

Slow Component assessment
Mathematical model
The mathematical model consisted in three exponential terms, representing each, one phase of the response. The first exponential term started at the onset of the exercise and the other terms started after independent time delays (TDi in the equation). The following equation describes the mathematical model for the $\dot{V}O_2$ kinetics (13):

$$\begin{aligned} \dot{V}O_2(t) = {} & \dot{V}_b && \text{(basal } \dot{V}O_2\text{)} \\ & + A_0 \times (1 - e^{-(t/\tau 0)}) && \text{(phase 1: cardiodynamic component)} \\ & + A_1 \times (1 - e^{-(t-TD1)/\tau 1}) && \text{(phase 2: fast component)} \\ & + A_2 \times (1 - e^{-(t-TD2)/\tau 2}) && \text{(phase 3: slow component),} \end{aligned}$$

where t is the time, A_i represents the various components amplitudes, TD_i are the times for the onset of the different components, and τ_i stands for the transition period needed for the component to attain the steady state, during which physiological adaptations adjust to meet the increased metabolic demand (14). For the adjustment of this function to the data points it was used a nonlinear least squares method implemented in the MatLab program, using the routine LSQCURVEFIT. For each test we averaged the data values every 5s.

Methods of rigid time intervals
To assess the $\dot{V}O_2$ SC with the rigid time intervals methods we calculated: (i) the value for $\dot{V}O_2$ averaged over the 20s before the 2nd min (120s), the 3rd min (180s) and at the end of the exercise - $\Delta\dot{V}O_{2[end-2]}$20s before 2min and final; $\Delta\dot{V}O_{2[end-3]}$20s before 3min and final (3); (ii) $\dot{V}O_2$ averaged over the 30s before the 2nd min, the 3rd min and at the end of the exercise - $\Delta\dot{V}O_{2[end-2]}$30s before 2min and final; $\Delta\dot{V}O_{2[end-3]}$30s before 3min and final (iii) $\dot{V}O_2$ averaged over the 40s before the 2nd min, the 3rd min and at the end of the exercise - $\Delta\dot{V}O_{2[end-2]}$40s before 2min and final; $\Delta\dot{V}O_{2[end-3]}$40s before 3min and final (iv) $\dot{V}O_2$ averaged over the 20s before and 20s after the 2nd min, 3rd min (centred) and 20s before the end exercise – $\Delta\dot{V}O_{2[end-2]}$20s+20s around 2min and 20s before final; $\Delta\dot{V}O_{2[end-2]}$20s+20s around 3min and 20s before final; (v) $\dot{V}O_2$ averaged over the 20s before and 20s after the 2nd min, 3rd min (centred) and 30s before the end exercise $\Delta\dot{V}O_2$end - $\Delta\dot{V}O_{2[end-2]}$20s+20s around 2min and 30s before final; $\Delta\dot{V}O_{2[end-2]}$20s+20s around 3min and 30s before final; (vi) $\dot{V}O_2$ average of the 20s before and 20s after the 2nd min, 3rd min (centred) and 40s before the end exercise - $\Delta\dot{V}O_{2[end-2]}$20s+20s around 2min and 40s before final; $\Delta\dot{V}O_{2[end-2]}$20s+20s around 3min and 40" before final (8, 11).

Statistical analysis
Statistical procedures included means, standards deviations and paired Student's t-test. All data were checked for normality. The statistical procedures were conducted with SPSS 13.0. The significance level was set at 5%.

RESULTS AND DISCUSSION
In the table 1 we can see the different values of the parameters we used to describe the $\dot{V}O_2$ kinetics. The Amplitude 1 (A1), Time Delay 1 (TD1) and Time Constant (Tau1) refer to the $\dot{V}O_2$ fast component and the Amplitude 2 (A2), Time Delay 2 (TD2) and Time Constant 2 (Tau2) refer to the $\dot{V}O_2$ SC.

Table 1. Parameters of the $\dot{V}O2$ kinetics.

Swimmer	A1 (ml/ /kg/min)	TD1 (s)	Tau1 (s)	A2 (ml/ kg/min)	TD2 (s)	Tau2 (s)
1	33,11	32,39	10,88	4,21	103,87	30,00
2	42,61	21,94	20,50	3,04	105,00	59,71
3	34,24	17,70	11,09	5,05	115,00	21,32
4	34,36	24,76	14,93	8,87	108,82	46,58
5	37,87	6,67	21,20	12,00	95,00	14,13
6	39,14	5,94	20,54	2,97	105,00	59,76
7	54,63	19,34	11,98	4,78	98,92	11,57
Mean±SD	39,42±7,5	18,39±9,51	15,87±4,7	5,85±3,4	104,52±6,5	34,72±20,6

Our results indicate that all subjects present a $\dot{V}O_2$ SC. Even considering the small number of studies about this theme in swimming, there where already some indications that this activity also presented a SC in heavy exercise (7, 8, 15). Although Billat et al. (5) referred that some studies presented the drawback of studying untrained subjects or poor trained subjects and considered the SC magnitude as being almost negligible in resistance athletes (4, 5), Carter et al. (6) observed a significant SC in running and cycling athletes. The authors referred that the SC first becomes evident at about 2 min into exercise. Therefore, defining the SC as an increase in $\dot{V}O_2$ above the value at 3 min of exercise will significantly underestimate the magnitude of the SC (6).

Table 2. Mean (± SD) values for the SC amplitude (in ml.kg-1.min-1) calculated from the different methods.

Mathematical model (A_2)	$\Delta \dot{V}O_{2[end-2]}$ 20sbefore 2min and final	$\Delta \dot{V}O_{2[end-3]}$ 20sbefore 3min and final	$\Delta \dot{V}O_{2[end-2]}$ 30sbefore 2min and final	$\Delta \dot{V}O_{2[end-3]}$ 30sbefore 3min and final	$\Delta \dot{V}O_{2[end-2]}$ 40sbefore 2min and final	$\Delta \dot{V}O_{2[end-3]}$ 40sbefore 3min and final
5.8 ± 3.4	4.0 ± 1.7	0.2 ± 2.0*	4.5 ± 1.9	0.2 ± 1.8*	4.8 ± 2.1	0.3 ± 1.9*
	$\Delta \dot{V}O_{2[end-2]}$ 20s+20s around 2 min and 20s before final	$\Delta \dot{V}O_{2[end-3]}$ 20s+20s around 3 min and 20s before final	$\Delta \dot{V}O_{2[end-2]}$ 20s+20s around 2 min and 30s before final	$\Delta \dot{V}O_{2[end-3]}$ 20s+20s around 3 min and 30s before final	$\Delta \dot{V}O_{2[end-2]}$ 20s+20s around 2 min and 40s before final	$\Delta \dot{V}O_{2[end-3]}$ 20s+20s around 3 min and 40s before final
	3.0 ± 1.7	0.3 ± 1.9*	2.8 ± 1.8	0.1 ± 1.5*	2.8 ± 1.7	0.1 ± 1.6*

** $p<0.05$ for differences between A_2 and the respective method of rigid intervals.*

In fact, our results also point the fact that the amplitude of the SC using the 3rd min of exercise is, in all cases, different from that obtained from the mathematical model. Looking at Table 1, we can also see that the SC begun 104.51s±6,47s (TD2) into exercise, clearly below the 3 min (180s).

Our results also hint for the fact that using the 2nd min of exercise for the SC assessment does not present statistically significant differences with the mathematic model, meaning that the SC onset may be close to the 2nd min of heavy exercise (6).

CONCLUSIONS

(i) The present study confirms the existence of a $\dot{V}O_2$ SC in elite freestyle swimmers performing in the heavy intensity domain; (ii) there were statistically significant differences between the mathematical model for the SC amplitude and all methods of rigid time intervals using the 3rd min; (iii) there were not statistically significant differences between the mathematical model for the SC amplitude and all methods of rigid time intervals using the 2nd min; (iv) in our understanding it seems reasonable to admit that the mathematic model is the most interesting and correct method for the assessment of the $\dot{V}O_2$ SC in elite swimmers, since it allows an individual analysis of each subject and its evolution with training, as well as allowing the analysis of other important parameters for the SC definition. Nerveless, the utilization of the 2nd min of exercise for the estimation of the SC amplitude seems to be a good compromise solution for a day-to-day basis, having in mind that the mathematical model involves more complex calculations, although with modern computers it takes less than a second to perform them.

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STROKE PERFORMANCE DURING BUTTERFLY AND BREASTSTROKE SWIM AT THE LOWEST SPEED CORRESPONDING TO MAXIMAL OXYGEN CONSUMPTION

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The aim of this study was to analyse if TLim-v$\dot{V}O_2$max, tested for the first time in breaststroke and butterfly, is also influ-

enced by stroke rate (SR), stroke length (SL) and stroke index (SI). Ten elite swimmers (7 males of 19.58±2.9 yy, 176.±5.0 cm and 70.5±6.2 kg, and 3 females of 17.6±1.5 yy, 166.3±5.1 cm and 60.9±6.5 kg) performed, in their best simultaneous technique, an intermittent incremental protocol for $\dot{V}O_2max$ assessment. 48 hours late, subjects swam until exhaustion at their pre-determined velocity, to assess Tlim-$v\dot{V}O_2max$., SL=v.SR^{-1}, SR (cycles.min^{-1}) and SI=SL*v. Regarding the relationship between TLim- $v\dot{V}O_2max$ and the different stroke parameters, it was not found any relationship for each technique. However, when both techniques were considered, it was observed an inverse relationship between TLim- $v\dot{V}O_2max$ and SR and between TLim- $v\dot{V}O_2max$ and $v\dot{V}O_2max$.

Key Words: time limit, $\dot{V}O_2max$, simultaneous swimming strokes, stroke parameters.

INTRODUCTION

One of the most recent topics of interest in swimming training and performance diagnosis is the concept of Time Limit, i.e., the time duration during which a certain intensity of exercise can be sustained until exhaustion (1). This concept was been studied mainly at intensities corresponding to maximal oxygen uptake (TLim-$v\dot{V}O_2max$). Time Limit was previously studied in cycling and in running. In swimming it was firstly conducted in swimming-flume (2, 3, 4). However swimming in these conditions can impose particular mechanical constraints when compared to free swimming in a conventional poll. So, there been only a few studies that were care down in a conventional poll (e.g. 5, 10). The main findings of the above-mentioned studies were: (i) TLim-$v\dot{V}O_2max$ seems to be direct and positively influenced by accumulated oxygen deficit, the $\dot{V}O_2max$ slow component and the swimming economy; (ii) TLim-$v\dot{V}O_2max$ seems to be inversely influenced by $v\dot{V}O_2max$ and 3,5mmmol l^{-1} blood lactate anaerobic threshold; (iii) TLim-$v\dot{V}O_2max$ seems to be a kind of effort very well related to the 400 m freestyle performance.

All of the above-mentioned studies and consequent results were conducted only for front crawl swimming. Therefore, to our knowledge, there is no study that considered other swimming techniques. Arguing that the aerobic energy supply contributes relevantly in all maximal efforts of durations higher than 75sec (7), including the 200m event in all techniques, we think that it is quite important to study this topic in all swimming techniques.

So, the aim of present study was to identify some of the factors that determined the TLim-vVO_2 in simultaneous swimming techniques, specifically some stroke parameters related with swimming economy (SR, SL and SI).

METHODS

Subjects

Ten elite swimmers of the Portuguese National Team participate in this study, 7 male and 3 female. They were divided into two groups, according with their best swim technique: (i) a group of 4 butterfly swimmers (3 males and 1 female) and (ii) a group of 6 breaststroke swimmers (4 males and 2 females). Mean and standard deviation (mean ± sd) values for their physical characteristics and swimming frequency of training are described in Table 1.

Table 1. Mean and standard deviation values of physical characteristics and weekly training frequencies.

	Butterfly		Breaststroke	
Parameters	Male (n=3)	Female (n=1)	Male (n=4)	Female (n=2)
Age	20,70±3,37	17,42	19,09±2,69	17,63±2,11
Weight	70,13±8,50	54,2	70,45±5,41	64,2±4,24
Height	179,3±5,03	165	173±3,70	167±7,07
Weekly training frequency	9	9	9	9

Test Protocol

All the test sessions took place in a 25 m indoor swimming pool. Each swimmer performed, in their best simultaneous technique, an individualized intermittent incremental protocol for $v\dot{V}O_2max$ assessment; with increments of 0.05 m s^{-1} each 200 m stage, and 30 s intervals until exhaustion (5). VO_2 was directly measured using a telemetric portable gas analyzer (K4b^2, Cosmed, Italy) connected to the swimmer by a respiratory snorkel and valve system (9, 11). Expired gas concentrations were measured breath-by-breath (BxB). Swimming velocity was controlled using a visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. All equipment was calibrated prior to each experiment.

$\dot{V}O_2max$ was considered to be reached according to primary and secondary traditional physiological criteria (8), $v\dot{V}O_2max$ was considered to be the swimming velocity correspondent to the first stage that elicits $\dot{V}O_2max$.

The second test session occurred 48 hours later. All subjects swam at their previously determined $v\dot{V}O_2max$ to assess TLim-$v\dot{V}O_2max$. This protocol consisted in two different phases, all paced: (i) a 10 min warm-up at an intensity correspondent to 60% $v\dot{V}O_2max$, followed by a short rest (20 s) for earlobe blood collection, and (ii) the maintenance of that swimming $v\dot{V}O_2max$ until volitional exhaustion or until the moment that the swimmers were unable to swim at the selected pace. TLim-$v\dot{V}O_2max$ was considered to be the total swimming duration at the pre-determined velocity.

In the second test the general biomechanical parameters were assessed by the counting of strokes and the time that the swimmer needed to perform 25m. To calculate the general biomechanical parameters were used the traditional formulas: SR= cycles.min^{-1}, SL=v.SR^{-1}, and SI=SL*v.

Swimmers were instructed to use a surface open turn, always performed to the same lateral wall side, without underwater gliding. In-water starts were also used. Swimmers were verbally encouraged to perform as long as possible during the tests. Both tests were carried out in the same conditions for each subject (i.e. water and air temperature, and time of the day) and all were instructed not to exercise hard before and between the evaluations.

RESULTS AND DISCUSSION

The main value that we obtain for the TLim-vVO_2, $v\dot{V}O_2max$ and the stroke parameters for each technique are described in Table 2.

Table 2. Main Values of Tlim- v$\dot{V}$O2max, v$\dot{V}$O2max and stroke Parameters.

Parameters	Butterfly N=4	Breaststroke N=6
Tlim-v$\dot{V}O_2$max (sec)	277,6±85,6	331,4±82,7
v$\dot{V}O_2$max, (m/sec)	1,29±0,0	1,10±0,1
SR (cycle/min)	36,48±1,2	29,96±2,7
SL (m/cycle)	2,14±0,1	2,23±0,2
SI [(m^2/(cycle*sec)]	2,76±0,1	2,48±0,4

To our knowledge, this is the first study in which Tlim-v$\dot{V}O_2$max was determined in simultaneous swimming techniques. Thus, we have to compare this results with the ones previously obtained for front crawl swimming. The main value of Tlim-v$\dot{V}O_2$max obtained in butterfly seems to the similar to the majority of values previously published for front crawl swimmers (2, 4, 5, 6). For breaststroke swimming, we find out that the main value of Tlim-v$\dot{V}O_2$max was higher than the one previously described for front crawl, perhaps due to the inverse relationship between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max, already reported by previously mentioned studies. This inverse relationship suggested that the swimmers with lower v$\dot{V}O_2$max can sustain that exercise intensity for a longer period of time. The relationships between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max, and between Tlim-v$\dot{V}O_2$max and the stroke parameters (SR, SL and SI) are described in table 3.

*Table 3. Relationships between Tlim- v$\dot{V}O_2$max and v$\dot{V}O_2$max, and between Tlim- v$\dot{V}O_2$max and the stroke parameters (SR, SL and SI). Significant differences are shown: * ($p \leq 0.10$) and ** ($p \leq 0.05$).*

	v$\dot{V}O_2$max	SR	SL	SI
	Butterfly (n=4)			
Tlim-v$\dot{V}O_2$max	-0,427	-0,628	0,515	0,069
	Breaststroke (n=6)			
Tlim-v$\dot{V}O_2$max	-0,497	-0,625	0,229	-0,07
	Simultaneous Techniques (n=10)			
Tlim-v$\dot{V}O_2$max	-0,482*	-0,580**	0,335	-0,158

Analysing the relationship between TLim-v$\dot{V}O_2$max and v$\dot{V}O_2$max, and between TLim-v$\dot{V}O_2$max and the different stroke parameters, it was not found any significant relationship for each technique. However, an inverse non-significant tendency was found between TLim-v$\dot{V}O_2$max and v$\dot{V}O_2$max and between TLim-v$\dot{V}O_2$max and SR in both techniques (table 3).
This fact can be explained by the low number or swimmers studied for each technique. Though, when both simultaneous techniques were pooled together, n raised, and we could observe an inverse relationship between TLim-v$\dot{V}O_2$max and v$\dot{V}O_2$max (r=-0,482, p≤ 0.10) - Figure 1 - and TLim-v$\dot{V}O_2$max and SR (r=-0,580, p≤ 0.05) - Figure 2. These relationships are similar to the ones previously obtained for front crawl.

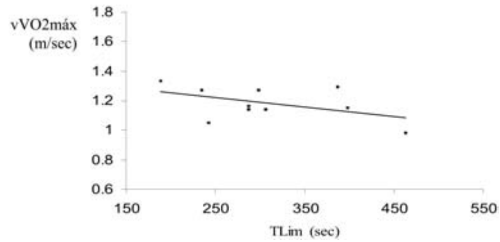

Figure 1. Inverse relationship between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max for both simultaneous techniques.

This inverse relationship has already been reported by some studies conducted in front crawl (2, 4, 5), and suggests that swimmers' with lower level of maximal aerobic metabolic rate present a larger capacity to sustain that exercise intensity.

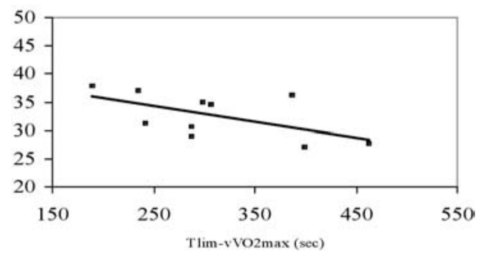

Figure 2. Inverse relationship between Tlim-v O_2max and v O_2max for both simultaneous techniques.

This inverse relationship suggests that the swimmers with lower SR are able to achieve higher TLim-v$\dot{V}O_2$max. This finding is in agreement with previous studies (6), and suggests that the most economic swimmers are the ones that can sustain for more time the exercise intensity corresponding to $\dot{V}O_2$max.

CONCLUSION
We can conclude that Tlim-$\dot{V}O_2$max value obtain for butterfly is similar to the previously reported for front crawl. For breaststroke we find a higher value for Tlim-$\dot{V}O_2$max compared to those already reported for front crawl. When we consider both simultaneous techniques pooled results, inverse relationships between Tlim-$\dot{V}O_2$max and $\dot{V}O_2$max, and between Tlim$\dot{V}O_2$max and SR were observed. These findings seem to bring new insite related to one relevant performance determinant factors in middle distance swimming.

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DIAGNOSING OF PERFORMANCE BY THE APPLICATION OF SWIMMING TESTS

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Determining the level of preparedness, as a significant factor in training, represents the feedback information about the current condition of an athlete. It plays an important role since it provides the information about the changes of the athlete's conditions caused by the training load and other factors with the objective to regulate the impact the training process on the athlete. To monitor the level of both endurance and pace, a set of swimming tests has been compiled. Some of the tests used by the Slovak Swimming Federation have been taken into consideration. The paper deals with the 3000 meters crawl results, which have been carried out on sample of 105 swimmers aged 13-16 years, and the 4 x 50 meters freestyle test realized on the sample of 53 swimmers aged 13 – 16 respectively. The average blood lactate level, when using the 3000m test, was 5,67 mmol/l for boys aged 13-14 and 4,67 mmol/l for boys aged 15-16. The blood lactate level was lower when measured for girls; 4,50 mmol/l for 13-14 years old and 3,20mmol/l for 15-16 years old, respectively. When using the 4x50m test, the values were following: boys aged 13-14 were at 0,02 mmol/l, 15-16 years old at 11,22 mmol/l, girls aged 13-14 at 10,20 mmol/l and finally, girls aged 15-16 at 10,58 mmol/l.

Key Words: swimming, diagnostics of performance, blood lactate.

INTRODUCTION

Diagnosing in sport is the process which is focused on the evaluation of the preparedness of the athletes in relation to the training load as much as other various factors, in order to control the training process (6). This process is continuous and intentional so that it the effectiveness of the training process can be improved.

Functional tests with the appropriate load are being carried out in the natural environment of the athlete. These tests are an important means of the complex diagnosis of the special preparedness and also the prerequisite of the effective management of the training process. The response of the organism to the training load thus provides the information about the athlete's preparedness. In case of the functional test the elements that are most important for the performance in a particular discipline are selected. These elements are being practiced on regular basis during the training and they are easily measurable and can be easily repeated if needed for further evaluation. The choice of the working load relatively simple when considering the cyclical sports, such as swimming, cross-country skiing, cycling, etc.

Despite the fact that at present there is no adequate structure of the swimming performance being set, it is possible to state, based on the up-to-date information, that the limiting factors are endurance and force capabilities, functional predispositions, somatic predispositions, technique factors and personal disposition (1, 2, 9).

One of the basic functional parameters for evaluation of the general aerobic endurance is the maximum oxygen consumption ($\dot{V}O_2$max). Its value reflects to a great extent the genetic predisposition and its dynamics of development is time-restricted. In recent years the monitoring of the development of the aerobic abilities by the determination of the anaerobic threshold has been becoming widely spread. Anaerobic threshold can be measured by the determination of the blood lactate level, however, it can also be monitored by the respiratory indicators' values. The indicator of the anaerobic threshold is considered to be a more sensitive indicator of the preparedness level than the $\dot{V}O_2$max (5). Most of the authors relate the anaerobic threshold to the lactate level 4mmol/l which represents so called conventional anaerobic threshold. The others relate it to the beginning of the sudden, exponential increase of lactate when it comes to the disturbance of the lactate curve – individual anaerobic threshold (10). The anaerobic threshold is an important functional indicator that reflects the changes in a particular performance better than the maximum oxygen consumption. This can be visible especially in endurance sports (3). The advantage of this indicator is the possibility of direct implementation into the control of the training process. The anaerobic threshold, as the intensity of the working load at which the dynamic balance between the production and removal of the lactate from blood is kept, appears to be a suitable criterion when selecting the intensity of the working loads aimed at the development of the aerobic endurance. It is actually the working load at the anaerobic level is considered (3) to be a suitable training means for development of the endurance abilities.

Anaerobic endurance activates the lactate system, involving mostly the fast glycolytic muscle fibers and to a lesser extent fast oxidative muscle fibers. The intensity above the $\dot{V}O_2max$ level puts higher demands on the anaerobic processes, where they reach the threshold values of the acidosis at the lactate level 20-25 mmol/l. The athletes with highly developed anaerobic abilities have usually only average, even below-average aerobic abilities, and vice versa. The development of the anaerobic abilities has a blunting effect on the development of the aerobic ones and vice versa. The objective of the study is the verification of the performance diagnosis through the means of selected swimming tests used by the Slovak Swimming Federation.

METHODS

In co-operation with the National sport center, Slovak swimming federation and selected swimming clubs in Trnava, Trencín and Bratislava the testing of 61 swimmers aged 13-14 years (34 boys and 28 girls) and 44 swimmers aged 15-16 years (27 boys and 16 girls) took place during March and April, using the 3000m test. This test has been adopted by Olbrecht et al. (8) from the Institute of the Sport Medicine in Cologne, Germany. The date of the testing had been deliberately introduced at the end of the special training period in the summer macro-cycle of the training cycle of 2004/05 (January – July 2005). The capillary artery blood samples took place after the 3rd and 10th working load.
The testing of 33 swimmers aged 13-14 years (17 boys and 16 girls) and 20 swimmers aged 15-16 years (13 boys and 7 girls) took place in June 2005, using the 4x50 meters freestyle test. The date of the testing had been deliberately introduced during the main period of the summer macro-cycle 2005. The capillary artery blood samples took place after the 3rd and 5th working load. The following are the parameters observed and monitored during the research: blood lactate level, quiet-mode PF between input and output training load. The blood lactate level has been monitored and determined with the aid of Biosen 5130 apparatus. This device enables to take blood samples with constant capacity of 20 μl of capillary blood and allows for divergence of < 3% at 12mmol/l. The capillary blood sampling has been conducted with the assistance of the Accusport blood sampling set, using entirely standard procedure. PF has been measured with the Polar S 610i sport testers with the 5s interval of records.

RESULTS AND DISCUSSION

The lactate values provide the information about the activation and proportional distribution of both anaerobic and aerobic mode, and the information about their performance in combination with the swimming speed. Measuring of the blood lactate then enables the high-probability determination of the real working load. The lactate is one of the best reflection of the training intensity. In order that the lactate test is reliable it is important to take the capillary artery blood sample from an ear-lobe or a finger and find the highest concentration of the lactate, i.e. to record the highest after-working-load values, for instance of 1st, 3rd and 5th minute after the load has been carried out. The values gathered in this manner provide the information about the lactate production in muscles. Chart 1 provides the information gained from the 3000m freestyle test. The results have been categorized according to the age groups, which had been observed.

Table 1. Basic statistic characteristics of the 3000m test results.

	Men		Women	
T3000	13-14y. (n=34)	15-16y. (n=28)	13-14y. (n=27)	15-16y. (n=16)
Test results (min.)	38:25-58:30	38:40-51:15	41:40-56:21	38:25-49:33
Swimming speed ($m.s^{-1}$)	0.855-1,284	0.976-1.402	0.890-1.200	1.010-1.302
Blood lactate level (mmol/l)	1.87-8.42	2.06-6.96	2.00-6.21	2.14-5.08
Average blood lactate level (mmol/l)	5.67	4.67	4.50	3.20
Standard deviation (s)	5.24	3.83	2.66	1.75

The results signify that some boys aged 13/14 years are capable of achieving the values high above the conventional anaerobic threshold, which is being set at 4 mmol/l. The findings of the Olbrecht research (8) are being confirmed, where the anaerobic threshold had oscillated at 1-6 mmol/l.
The relatively high blood lactate values can be explained in a number of ways. Stemming from the fact that it is very difficult to measure the heart beat frequency by means of the sport testers, especially with boys, it is therefore a problematic task to maintain the similar tempo throughout the 3000m. The findings of the raised lactate levels in this test can thus be greatly determined by the disturbance of the tempo and possible speeding up, especially in the final phase. Another interpretation of these values could be the anaerobic threshold's determination not only by the preparedness and nature of the working load, but also by age and sex (5). Children's anaerobic threshold is higher that that of the adults. The reason for this is the shorter time of the oxygen's 'reception' and consumption. The low blood lactate levels after the swim can be results of the low motivation in case of the low average swimming speed, or by the higher aerobic capacity level at higher speeds, when the shift of the anaerobic threshold towards the lower blood lactate values takes place. Hamar et al. (4) determined the level of anaerobic threshold when constantly swimming at the threshold speed 1.364 $m.s^{-1}$.
The blood lactate values, observed in the group of swimmers in the midst of specialized phase of the training process, were taken after the 3000m freestyle test and are extensively variable. Due to the high values of the directive deviation the statistical processing of the date will be much more complicated in the further phase of the research.
The input measuring of the blood lactate level suggests that 4x50m test freestyle is the real reflection of the mixed anaerobic-aerobic working load series, and which ability to tolerate the lactate is probably reflected in the anaerobic capacity of the swimmer.

Table 2: Basic statistic characteristics of the 4x50m test results.

	Men		Women	
T 4x50 meters	13-14y. (n=17)	15-16y. (n=16)	13-14y. (n=13)	15-16y. (n=7)
Test result (min.)	2:03 - 2:27	1:55 - 2:17	2:09 - 2:48	2:19 - 2:33
Swimming speed ($m.s_{-1}$)	1.625-1.353	1.739-1.450	1.546-1.186	1.435-1.300
Blood lactate level (mmol/l)	6.58 – 13.38	7.91 – 14.60	5.00 – 15.84	7.40 – 12.47
Average blood lactate level (mmol/l)	10.02	11.22	10.20	10.58
Standard deviation (s)	2.02	1.90	2.77	1.72

The findings suggest that in order to further process data gathered by the test these have to be differentiated in the following pattern. Either they have to be divided into 2 groups, one being crawl, back-stroke and butterfly, and the other one being breast-stroke, or maybe it will be even necessary to divide the results into 4 different groups, where every group will represent a single swimming stroke. Even divide the results 4 groups. Therefore we do not list the breaststroke results in the table 2, since they significantly misinterpreted the overall results. From the relative homogeneity point of view the 4x50m test results came out much better than the 3000m test.

CONCLUSION

Based on the results of the applied 3000m test with men and women for particular age groups during the specialized phase of the training process it is possible to assume that these provide a relatively precise estimate of the swimmer's tempo at the anaerobic threshold level. These results have been achieved on the basis of the appropriate proportion between the length and intensity of the working load. The swimmers are with great probability not able to swim, at this volume of the working load, at the intensity which would disturb the balance between the lactic acid production and its disposal from muscles. This test proves to be the appropriate method for the evaluation of aerobic capacity of both senior and junior swimmers. The succeeding research will need to implement the pulse frequency in order to control and sustain the steady tempo throughout the test, even though it is much more complicated in swimming at present.

Based on the findings from the 4x50m freestyle test it is possible to maintain that it likely reflects the anaerobic lactate system level. However, the values of the blood lactate recorded by us were not getting close to the threshold values of 20-25 mmol/l. The findings point out the necessary differentiation of the recorded values according to a particular swimming style.

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DOES THE LONG-TERM ORAL CREATINE SUPPLEMENTATION IMPROVE REPEATED SPRINT PERFORMANCE IN ELITE SWIMMERS?

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This study investigated the effects of high-dose/long-term oral creatine supplementation on repeated sprint swimming performance in elite male swimmers. Twelve subjects, all swimmers, were separated randomly into creatine group (n = 6) and placebo group (n = 6). Swimmers of the creatine group were supplemented creatine (12 g/day) during 8 weeks. Supplementation was performed using double-blind method. Before and at the end of supplementation, ^{31}P-NMR spectroscopy of the triceps muscle of the arm, blood analysis, and intermittent repeated sprint swimming tests were conducted. Eight-week creatine supplementation tended to increase the muscle PCr content ($p = 0.055$). However, no significant improvement was shown for repeated sprint swimming performance. These results suggest that high-dose/long-term creatine supplementation increased muscle PCr content with no disadvantage to physiological functions in elite male swimmers. However, it was difficult to prove an ergogenic effect on repeated sprint performance in elite male swimmers.

Key Words: creatine, long-term, sprint performance.

INTRODUCTION

It has been reported that the intramuscular phosphocreatine (PCr) and serum creatine contents were increased through creatine supplementation (6). It is generally acknowledged that these increments engender delayed PCr depletion and enhance dependence upon the ATP-PCr energy system during exercise. In addition, creatine supplementation might improve the ability of buffering lactate because the ATP-PCr energy system uses the generated proton (H^+) (7). Consequently, performance during high-intensity intermittent exercise and short duration single performance might be improved through creatine supplementation (1, 2, 3, 5, 6, 8, 12).

Numerous studies have demonstrated the ergogenic effect of creatine. Most of those studies adopted high-intensity intermittent exercise method (1, 2, 3, 5, 6, 8, 12). They have reported that creatine supplementation can inhibit the reduction of power and performance at the latter set/event of prescribed trial. In contrast, studies that have not reported the ergogenic effect of creatine evaluated single-exercise performance (4, 9, 13).

A few studies have investigated the effect of creatine supplementation in swimmers. Mujika et al. (9) and Burke et al. (4) reported that short-term creatine supplementation (20 g/day, 5 days) did not improve single swimming performance (25 m, 50 m, 100 m). Thompson et al. (13) also reported that long term creatine supplementation (2 g/day, 6 weeks) did not improve single swimming performance (100 m, 400 m). In contrast, Grindstaff et al. (5) reported that intermittent performances (swimming and cycling) were improved after creatine supplementation (21 g/day, 9 days). Although many studies have described the ergogenic effect of creatine supplementation on intermittent swimming performance, Nagasawa et al. (10) reported that short-term creatine supplementation (24 g/day, 6

days) did not improve intermittent swimming performance in females. In light of all of those disparate findings, the ergogenic effects of creatine supplementation are controversial irrespective of exercise method in swimming.
This study investigated the effects of long-term oral creatine supplementation on repeated sprint performance using a swimming flume that can be used to control the intensity and duration of trial.

METHODS

Subjects

Twelve highly trained male swimmers participated in this study. They were separated randomly into a creatine group (Cre: n = 6, age = 20.0 ± 0.9 years, height = 177.8 ± 1.7 cm, weight = 71.6 ± 3.9 kg) and a placebo group (Pla: n = 6, age = 20.5 ± 1.1 years, height = 177.8 ± 2.0 cm, weight = 71.4 ± 4.9 kg). They were informed of the purpose and potential risks of participating. No swimmers had ingested creatine during the month preceding supplementation.

Supplementation

A double-blind study was performed. The creatine group ingested four doses of 3 g of creatine (total 12 g) per day for 8 weeks, whereas the placebo group ingested the same dosage of a glucose placebo.

Determination of muscle PCr

Measurements taken using ^{31}P-nuclear magnetic resonance (NMR) from the triceps muscle of the arm at rest were conducted using MR apparatus (Gyroscan ACS-NT; Philips Co.). The arm was positioned with a magnet over a 10 cm diameter surface coil. The coil was turned to either the proton or the phosphorus frequency: ^{31}P-NMR signals were acquired at 1500 Hz with a repetition period of 3000 ms. Acquired spectrum data were analysed using spectral-analysis software "NHI image version 1.62" (National Institutes of Health, USA), which integrated the PCr, Pi and ATP spectral peaks. The muscle PCr contents were represented as a ratio to the integration value of ATP spectrum because muscle ATP content is putatively constant.

Performance test

Repeated swimming trials using the swimming flume were conducted before and after the supplementation period. Performance tests consisted of 30 s sprint swimming and a 30 s rest. The swimming velocity was set at 85% of each subject's 100-m-best record. Subjects continued repeated swimming trials to exhaustion: the point at which subjects became unable to maintain the velocity. Executed sets were evaluated as repeated swimming performance. Blood from the fingertip was taken 1 min and 3 min after the trial and the blood lactate was determined. The heart rate and RPE were also measured immediately after the trials.

Blood analysis

Blood samples were drawn from the antecubital vein at rest on the mornings before and after the supplementation period. Subjects were instructed to ingest nothing except water for 8 h. Collected samples were centrifuged and analyzed in the laboratory.

Statistical analysis

Results are represented as means (± SD). Data before and after the supplementation period were compared using Student's t-test for dependent samples. Statistical significance was accepted at the 0.05 level ($p<0.05$).

RESULTS

Exercise Performance

Repeated swimming performance did not improve in either group (executed sets of Cre: pre 2.95 ± 1.21, post 2.89 ± 1.02, Pla: pre 4.59 ± 3.71, post 4.33 ± 1.60, Fig. 1). Blood lactate, heart rate and RPE after the post-trial did not change from pre-trial levels in either group (Blood lactate after 1 min Cre: pre 13.2 ± 1.2 mmol/l, post 12.5 ± 0.6 mmol/l, Pla: 13.2 ± 2.3 mmol/l, post 13.8 ± 1.6 mmol/l, 5 min Cre: pre 14.0 ± 1.3, post 14.0 ± 1.9 mmol/l, Pla: pre 13.3 ± 2.5 mmol/l, post 14.0 ± 1.9 mmol/l, Heart rate Cre: pre 174.5 ± 2.5 bpm, post 174.3 ± 4.1 bpm, Pla: pre 174.2 ± 6.9 bpm, post 174.0 ± 6.0 bpm, RPE Cre: pre 18.00 ± 1.55, 17.67 ± 1.21, Pla: pre 16.50 ± 1.38, 16.67 ± 1.03, Table 1).

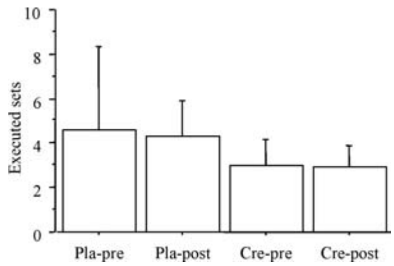

Figure 1. Repeated swimming performance using the swimming flume before and after the supplementation period.

Table 1. Heart Rate, Bla and RPE after repeated swimming trials before and after the supplementation period

		Pla-pre		Pla-post		Cre-pre		Cre-post	
		mean	±SD	mean	±SD	mean	±SD	mean	±SD
HR	bpm	174.2	6.9	174.0	6.0	174.5	2.5	174.3	4.1
Bla(1min)	mmol/l	13.1	2.2	13.8	1.6	13.2	1.2	12.5	0.6
Bla(5min)	mmol/l	13.3	2.7	14.0	1.9	14.0	1.3	13.4	0.5
RPE		16.5	1.4	16.7	1.0	18.0	1.6	17.7	1.2

Physiological index

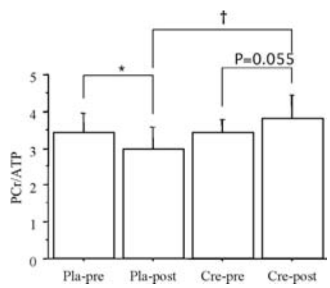

*Figure 2. The PCr/ATP ratio-determined spectra before and after the supplementation period. Significant differences between before and after supplementation period (*p<0.05). Significant differences between Cre and Pla (†p<0.05).*

PCr content in triceps muscle tended to be increased by high-dose (12 g/day) and long-term (8 weeks) creatine supplementation (pre 3.42 ± 0.37, post 3.38 ± 0.61, $p = 0.055$, Fig. 2). Contrarily, PCr content of Pla decreased significantly (pre 3.44 ± 0.53, post 3.00 ± 0.57, $p < 0.05$). The serum creatine concentration, GPT and LDH in Cre increased significantly after the supplementation period (Serum creatine: pre 1.00 ± 0.11 mg/dl, post 1.55 ± 0.44 mg/dl, GPT: pre 11.00 ± 3.03 IU/L, post 22.50 ± 4.81 IU/L, LDH: pre 327.2 ± 46.8 IU/L, post 430.2 ± 65.1 IU/L, $p < 0.05$, Table 2). The serum creatine concentration was greater than the normal range, but the GPT and LDH concentrations were in the normal range. The serum creatine concentration in Pla decreased after the supplementation period but the concentration did not change significantly (pre 1.02 ± 0.13 mg/dl, post 0.70 ± 0.35 mg/dl, $p > 0.05$). The groups showed no significant difference of the change of body composition during the supplementation period.

Table 2. Blood analysis data before and after the supplementation period.

			Pla-pre		Pla-post		Cre-pre		Cre-post	
		normal range	mean	±SD	mean	±SD	mean	±SD	mean	±SD
GOT	IU/L	11-35	19.8	5.7	22.2	1.2	20.2	4.3	25.8 †	1.6
GPT	IU/L	6-39	12.3	5.2	15.0	7.7	11.0	3.0	22.5 *	4.8
LDH	IU/L	180-460	285.8	56.8	337.2	23.7	327.2	46.8	430.2 *†	65.1
CPK	IU/L	48-259	173.3	119.3	154.8	58.3	162.5	90.6	201.2	40.6
creatine	mg/dl	0.1-1.2	1.02	0.13	0.70	0.35	1.00	0.11	1.55 *†	0.43
creatinine	mg/dl	0.8-1.3	0.98	0.18	1.03	0.16	1.05	0.14	1.12	0.12

*Significant difference between before and after supplementation ($P<0.05$)

Significant difference between Cre and Pla ($P<0.05$)

DISCUSSION

Many studies have investigated the ergogenic effect of creatine supplementation for athletes (1, 2, 3, 5, 6, 8, 13). It has been established clearly that high-dose oral creatine supplementation might elevate muscle creatine and PCr content (8). Furthermore, creatine supplementation might improve performance during high-intensity intermittent exercise (1, 2, 3, 5, 6, 8, 12), but not single events (4, 9, 13). The present study showed that high-dose (12 g/day) and long-term (8 weeks) creatine supplementation tended to elevate the muscle PCr contents ($p = 0.055$). This result is supported according to the increment of serum creatine concentrations in Cre. Nevertheless, performance during high-intensity repeated swimming using swimming flume was not improved in elite male swimmers. Exercise intensities were comparable in all trials because the heart rate and RPE after the post-test were not changed in comparison to pre-tests in both groups. The blood lactate after the repeated swimming test in Cre tended to be reduced by creatine supplementation ($p > 0.05$, not significant). Balsom et al. (1, 2) reported that high-dose (20–25 g/day) creatine supplementation can reduce the blood lactate concentration after high-intensity intermittent cycling tests. They suggested that creatine supplementation elevates the contribution of ATP-PCr energy system during high-intensity exercise. The present study showed that the contribution of the ATP-PCr energy system during repeated swimming test was likely to have been elevated by the increment of muscle PCr content. Blood lactate levels at post-testing in Pla tended to be higher than those of pre-testing ($p > 0.05$, not significant). Grindstaff et al. (5) and Theodorou et al. (12) reported that creatine supplementation improves intermittent swimming performance. They set the exercise intensity as the maximal effort. The present study adopted 85% velocity of subjects' respective best records in 100 m events as the exercise intensity. This intensity was determined so as to execute at least two sets in trials. Consequently, subjects might not need a maximal effort to swim at velocity, especially early sets of trials. Reportedly, urinary creatine and serum creatinine concentration (11), GOT, GPT and LDH activity (8) were elevated by high-dose creatine supplementation. In the present study, the serum creatine concentration, GPT and LDH activity were elevated through high-dose (12 g/day) creatine supplementation. However, it seems unlikely that creatine supplementation would be harmful to renal and hepatic functions in male swimmers because those values after the supplementation period were in the normal range.

CONCLUSION

Long-term creatine supplementation increased muscle PCr content without harm to health in elite male swimmers, but it did not improve their repeated swimming performance. The contribution of the ATP-PCr energy system during repeated swimming in this study might have been elevated by creatine supplementation as it was in previous studies. However, it is difficult to prove that creatine supplementation affected high-intensity swimming performance.

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EVIDENCE OF INSUFFICIENT PULMONARY VENTILATION DURING CRAWL SWIMMING WITH MAXIMAL AND SUPRAMAXIMAL INTENSITIES

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The aim of the study was to establish whether limited pulmonary ventilation due to biomechanical characteristics of front crawl swimming causes insufficient elimination of CO_2 from the lungs during breathing, which induce hypercapnia. Twelve male swimmers performed 4 swims on 200 m crawl at intensities from 80%, 90%, 100% to 110% on separate days with a swimming snorkel. Respiratory parameters (V_E, Vco_2, Vo_2) and some parameters in the blood ([LA^-], Pco_2, Po_2) were measured. From results we were able to demonstrate that limited V_E during exercise in swimming occur and that is a possible influence on increased acidosis during maximal and supramaximal swimming. We found notable excess Vco_2 after exercise at these intensities. We can also not conclude that hypercapnia was caused because values of Pco_2 were similar to those during rest; however, it has to be considered that these values were obtained with significantly increased V_E.

Key Words: swimming, front crawl, ventilation, pH, hypercapnia.

INTRODUCTION
Respiration during front crawl swimming is limited with swimming technique and the duration of the inspiratory phase is reduced. A previous study (2) found no indication of hypoventilation during swimming, however only saturation of blood with oxygen was measured. In the same study maximal pulmonary ventilation during swimming was significantly lower than during running by elite swimmers. A study with controlled frequency breathing from 2 to 8 strokes during swimming (5) found increased $PaCO_2$ in swimming with progressively reduced breathing frequency. In the same study it was also found that stroke rate increases proportionately with breathing restriction. A similar study (1) found that carbon dioxide production, respiratory exchange ratio, and heart frequency did not change significantly in response to controlled frequency breathing (CFB) swimming. Estimated alveolar partial pressure of O_2 (PaO_2) decreased and $PaCO_2$ increased significantly during CFB. However, estimated saturation of arterial blood with O_2 (SaO_2) was essentially undiminished during CFB. These responses do not indicate hypoxia, but rather hypercapnia during CFB. The aim of the research was to establish whether limited pulmonary ventilation due to biomechanical characteristics of front crawl swimming with different intensities causes insufficient elimination of CO_2 from the lungs during breathing, which induce hypercapnia.

METHODS
Twelve male swimmers aged 24 ± 3 yrs, of a height of 181 ± 9 cm and mass of 77 ± 13 kg volunteered to participate in this study. All subjects had a minimum of eight years competition swimming experience and considered front crawl their best stroke. The subjects were informed of the risks involved in the experiment before they agreed to participate.
All swims were performed using the front crawl stroke in a 25 m indoor swimming pool. The temperature of the water was 27∞ C. Each swimmer performed 4 swims on 200 m crawl at intensities from 80%, 90%, 100% to 110% on separate days with a swimming snorkel (4). First, swimmers performed maximal 200 m front crawl swim. Thereafter, swimmers performed submaximal swims with 80% and 90% of maximal 200 m front crawl swim velocity. Finally, swimmers performed a supramaximal swim with 110 % velocity until exhaustion. A light leader was used to keep even pace during swimming with submaximal and supramaximal intensities.
Arterialised blood samples (20 μl) were collected from the earlobe after a warm up and in 1, 3 and 5 minute of recovery after swimming and analysed for blood lactate concentration ([LA^-]) using a Kodak Ektachrome analyser. At the same time, arterialised blood samples (60 - 80 μl) were collected and analysed for PCO_2 and PO_2 with an ABL5 analyser (Radiometer Copenhagen). Calibration of the equipment was performed before each measurement.
Ventilation (V_E), O_2 uptake (VO_2) and CO_2 output (VCO_2) were measured using a portable respiratory gas analyzer METAMAX 2 (Cortex, Germany). Average data for 10-s period were recorded with a swimming snorkel (4) after warm up, during swimming and 5 minute after the end of each swim. The flow meter was calibrated with a syringe of known volume (3.0 l). The gas analyzer was calibrated by known standard gases. Excess CO_2 output per unit time (Vco_2 excess) was calculated by subtracting the VO_2 values from the Vco_2 values. The Vco_2 excess was integrated from the start of exercise to the end of exercise, and from the end of exercise to 5 min postexercise. The sum of Vco_2 excess from the start of the exercise to the 5 min of postexercise was defined as the total excess CO_2 output (CO_2 excess).
Means and standard deviations were computed for all variables. Individual one-way repeated measures ANOVAs were employed to test for any significant differences between the measured parameters. Significance was accepted when $p<0.05$. Bonfferonies post-hoc tests were performed if significant differences were apparent.

RESULTS
The average velocity of maximal swimming was 156.2 ± 13.1 s. Swimmers were able to swimm with 110 % intensity 113.8±17 meters or on average for 81.3 ± 12.7 seconds.

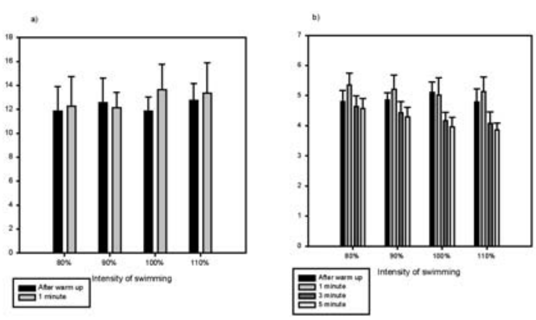

Figure 1a,b. Po_2 (a) and Pco2 values after warm up and in the 1st minute after swimming with different intesities (for Pco_2 also values in the 3rd and 5th minute are shown (b). Values are means±SD.

There were no differences between the values of Po_2 and Pco_2 measured when resting after warm up and those measured during the 1st minute after exercise.
In the 3. minute after exercise there were no differences between the values at 80 % (4.6 kPa ± 0.4) and 90 % intensity of swimming (4.5 kPa ± 0.4) for Pco_2. At 100 % intensity of swimming there was signifficant decrease of Pco_2 (3.9 kPa ± 0.7) ($p<0.05$). Similar tendencies were found also at 5th minute after exercise (fig. 1b).

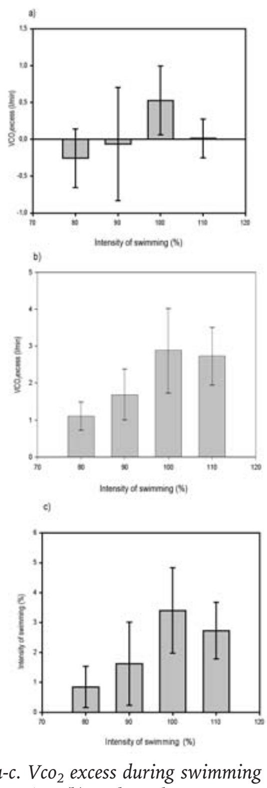

Figure 2a-c. Vco_2 excess during swimming (a), after swimming (b) and total Vco_2 excess (c).

There was a tendency to increase of excess Vco_2 during swimming from 90% (-0.09±0.7 l) to 100% (0.53±0.47 l) and then again decrease during swimming at 110 % intensity (Fig. 2 a). Excess Vco_2 after exercise increased most notably from 90% (1.69±0.7 l) to 100% (2.72±0.7 l) ($p<0.01$) intensity; at 110% intensity it was similar to 100% intensity (Fig. 2 b). Total excess Vco_2 showed tendency to increase from 90% (1.62±1.39 l/min) to 100% (3.41±1.42 l/min) intensity ($p<0.05$); at 110 % intensity it was similar to 100 % intensity (Fig. 2 c).

Table 1. Comparision of average maximal measured values of V_E, VCO_2 and VO_2 during swimming with different intensities (± SD).

	80 % intensity	90 % intensity	100 % intensity	110 % intensity
V_E	78.2±13.5 lxmin^{-1}	91.4±13.6 lxmin^{-1}	117.4±18.0 lxmin^{-1}	108.7±17.2 lxmin^{-1}
Vo_2	3.09±0.51 lxmin^{-1}	3.44±0.49 lxmin^{-1}	3.81±0.51 lxmin^{-1}	3.70±0.51 lxmin^{-1}
Vco_2	3.17±0.43 lxmin^{-1}	3.59±0.64 lxmin^{-1}	4.44±0.59 lxmin^{-1}	4.21±0.62 lxmin^{-1}

Maximal V_E increased at intensities ranging from 80% (78.2±13.5 l/min) to 100% (117.4±18 l/min) ($p<0.05$), but at 110% intensity it was similar to the values at 100% intensity. Something similar happened with Vo_2 (80% = 2.65±0.5 l/min, 100% = 2.76±0.6 l/min) ($p<0.05$) and Vco_2 (80% = 3.17±0.4 l/min, 100% = 4.44±0.6 l/min) ($p<0.05$).

Table 2. Comparision of average maximal obtained values of $[LA^-]$ during swimming with different intensities (± SD).

	80 % intensity		90 % intensity		100 % intensity		110 % intensity	
	1. min	Max	1. min	Max	1. min	Max	1. min	Max
$[LA^-]$	5.7±1.1	6.1±1.5	7.4±1.0	7.8±1.4	12.7±2.4	14.2±2.5	9.9±1.5	12.0±1.9

The most notable change of $[LA^-]$ in the 1st minute after exercise and also for the maximal measured values was from 90 % to 100 % intensity ($p<0.001$) (Table 2.). Between 100% and 110% intensity there were no changes.

DISCUSSION

In our research we were not able to demonstrate that limited V_E during exercise in swimming is a limiting factor to performance; however, we were able to demonstrate that it does occur and that limited V_E is a possible influence to increased acidosis during maximal and supramaximal swimming because of insufficient elimination of CO_2 from the body. Metabolic CO_2 dissolved in the body fluids forms carbonic acid, which than dissociates H^+ ($CO_2 \Leftrightarrow H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3$). Because V_E affects H^+ concentration (or pH), V_E affects acid-base balance. We found notable excess Vco_2 after exercise at these intensities (100% and 110%), which was much more pronounced than during swimming (Figure 2. b). In heavy exercise, it is known that the concentration of HCO_3 changes in reciprocal fashion to that of $[LA^-]$ in arterial blood, and that $PaCO_2$ first increases and then decreases to below the resting level (6). In supramaximum exercise, it has been observed that CO_2 is not completely excessively expired during exercise but after the end of exercise, although lactic acid begins to be produced from the start of exercise (6). Results of our study suggests that Vco_2 excess after the exercise was much more increased after maximal and supramaximal swimming in comparison to the Vco_2 excess during swimming and was not only $[LA^-]$ dependent (Fig. 2 a, b and Table 2.), but probably occurred also because of limited V_E. We can neither conclude that during swimming hypercapnia was caused because values of Pco_2 were similar to those during rest; however it has to be considered that these values were obtained with significantly increased V_E. Our results seem to be in accordance with the results of previous studies (2, 5). However, in this interpretation it should be considered that because of the protocol of collecting samples from the earlobe, approximately 30 seconds were needed and in that time according to measured V_E during maximal and supramaximal swimming on average about 60 l of the air was exchanged in the lungs. This could influence obtained results of Pco_2 and Po_2. It should also be considered that in the study where swimmers performed 200 m freestyle at maximum effort and haemoglobin saturation was measured using a finger pulse oximeter swimmers developed exercise induced arterial hypoxemia (3). Controlled respiratory parameters during exercise when swimming with swimming snorkel (V_E, Vco_2, Vo_2) increased with the swimming intensity from 80 % to 100 % intensity; however, during 110 % intensity, the swimmers were no longer able to sustain the previously defined swimming velocity at the moment the mentioned respiratory parameters reached almost similar values to the ones at 100 % intensity (table 1.). It is thus evident that limited pulmonary ventilation due to biomechanical characteristics of front crawl is probably the factor which mostly limits the observed parameters (V_E, Vco_2, Vo_2), and therefore the limits of values are probably not absolute but specific for each individual swimmer.

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KINETIC RESPONSE OF SALIVARY IGA TO SEVERAL EXERCISE PROTOCOLS PERFORMED BY WELL TRAINED SWIMMERS

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The relationship between training load and the mucosal immune responses has been a recent focus of research. Intense training and the psychological stress associated with competition seems to lower the salivary IgA (sIgA) levels in athletes. Salivary IgA antibodies provide protection against infections and play a significant anti viral role at the mucosal surface. Salivary IgA deficient persons are susceptible to recurrent infections, mostly of the upper respiratory and gastrointestinal tracts. The purpose of this study was to monitor the salivary IgA response to different aerobic and anaerobic land tasks and two aerobic swimming protocols, using several time points in order to study the time effects of the exercise loads in the mucosal immunity of the athletes.

Key Words: mucosal immunity, salivary IgA, training load, swimmers.

INTRODUCTION

The influence of training load on the immunity status has been the subject of extensive research in different environments of sporting participation (2, 3, 4, 5). Due to less invasive methodology, one of the most commonly immunity marker used in this kind of research is the salivary IgA (sIgA). Several studies reported immune suppression with low values of sIgA associated with intense training, contrasting with the reinforcement of sIgA levels associated with moderate exercise (3, 4, 5). Different loads induce specific physiological adaptations. It was hypothesized that the immune response behaves differently adjusting to specific training loads. The purpose of this study was to monitor the salivary IgA response as an immunological marker, using several time points after different tasks and at rest to follow the influence of the training load on this parameter. Two swimming aerobic protocols of identical intensity and volume but with different procedures, namely continuous and intermittent loads, one running test aiming to estimate the $\dot{V}O_2max$ and the Wingate anaerobic test were selected.

METHODS

Twelve male swimmers of Portuguese national level (17 ± 0.9 years old, height 177 ± 7 cm, weight 66.5 ± 7.2 kg, 7.3 ± 0.9 years of training), participated in this study. The subjects were informed about the implications of the study and gave their consent. During 10 days they accomplished four different protocols : two swim aerobic tasks – a 20min continuous swim and an intermittent 5 x 400 m with 45 s rest swim and two land protocols - the Luc Léger running test aiming to estimate the VO_2 max, and the Wingate Anaerobic Test (WanT) used to determine the maximal anaerobic power. Swimming, Wingate and Luc-Léger exercices were preceded by a normalized warm-up. The schedule used on this study alternated land and water protocols, with at least 48 hours between testing sessions. All sessions took place at the same hour of the day (7.00 pm). During the study, athletes underwent a normal training schedule corresponding to a stabilizing workload period. Each testing session was preceded by at least 12 hours of rest.

1ª protocol	→	2ª protocol	→	3ª protocol	→	4ª protocol
5 x 400L	48 h	Wingate aanaerobic test	48h	T20	48h	Luc-Léger aerobic test

Figure 1. Study schedule.

Capillary blood samples were taken after exercise to evaluate the lactate (La) concentration. Heart Rate (HR) and perception of effort (Cr10) (2) were also controlled at each protocol. Saliva samples were colleted for determination of IgA concentration, flow rate and IgA secretion rate. The collecting time points were: immediately before de exercise; 15 min, 1.5 hours and 2.5 hours after; in the next morning at wakeup and 24 hours after the test. Obeying to the same timetable on the nearest weekend free from either training workouts or competitions, saliva samples were collected, aiming to get the sIgA response on a recovery day with the purpose to control for possible circadian effects. Saliva collection was done using salivette tubes (Sarstedt, Portugal). Salivary IgA levels were determined by nephlometry (BN2 Analyzer, Dade Behring, USA). To determine the IgA secretion rate (srIgA), the subjects were told to chew on the cotton swab for 2 min. The volume of saliva collected was measured and the secretion rate calculated according to the following equation: *IgA sr=([IgA]*Vsal)/ t*, were Vsal (μl) is the volume de saliva collected, and *t* is the time of collection (s) (1). To compare the behaviour of sIgA and srIgA between moments and protocols, the non-parametric Wilcoxon test was used, with a confidence level of 95%. This statistical option avoids the errors associated with the small dimension of the sample and prevents the absence of a normal distribution of some of the variables.

1º time point	2º time point	3º time point	4º time point	5º time point	6º time point
Before test	15 min after	1.5 h after	2.5 h after after	Next morning Wake up	24 h after

Figure 2. Time points of saliva sample collection.

RESULTS AND DISCUSSION

As expected, significant higher values of HR, [La] and perception of effort (Cr10) were found on the Luc Léger test when compared to all the other protocols. The same parameters were higher in the Wingate Anaerobic Test compared to the swimming tasks. Between these last two situations, there were no significant differences, however, the intermittent protocol showed slightly higher levels of these markers (Table1). The intensity used at the two swimming situations was respectively 71.0 % ± 2.3 for T20, and 74.2 % ± 3.1 for the5x400m, of the maximal velocity obtained on a maximal test of 15 m (v15).

Table 1. Mean and Standard Deviation (SD) for the perception of effort (Cr.10 Borg), Lactate (La) heart rate (HR), predicted $\dot{V}O_2$max from the Luc Léger test, peak power of the Wingate Anaerobic test, intermittent aerobic task (Int Aer. Task), percentage of maximal swimming velocity used on swimming protocols, and T20".

	Luc Léger		Wingate		Int Aer. task		T 20	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cr10	8	1.3	6.6	1.1	4.4	1.8	3.5	0.7
La	13.6	4.0	10.0	2.0	3.6	1.5	2.9	0.6
HR	197	7	165	10	161	9	157	11
$\dot{V}O_2$max (ml.kg.m^{-1})	52.3	2.8						
Peak Power (W)			656	97				
% max. Velocity (m.s^{-1})					75.0	2.3	74.2	3.1

The sIgA concentration values (table 2) show identical patterns at different experimental conditions. With the Wingate Anaerobic test and the two swimming aerobic protocols the sIgA concentration showed a significant increase ($p<0.05$) (6) after testing followed by a decrease 1.5h and 2.5h after the test. This decrease was significant ($p<0.05$) in the response to the intermittent aerobic swim protocol. In the land tasks this decrease was significant 2.5h after ($p<0.05$). Next morning fasting saliva showed significantly ($p<0.01$) higher values of sIgA. 24h after testing, sIgA levels had recovered to the initial values in all situations ($p<0.01$).

With the Luc Léger test, sIgA, showed an initial decrease after test which was significant ($p<0.05$) for the srIgA values, followed by an elevation 1.5h after and again a significant ($p<0.05$) decrease 2.5h after. The morning and the 24h after values followed the same pattern of the other situations (1, 7). At rest situation, an identical behavior for the sIgA values was found but with less diurnal variation. The only significant alteration of sIgA and srIgA values on the resting day was found in the morning with a slight elevation. These results agree with the idea of exercise influencing the sIgA behavior.

Table 2. Mean and Standard Deviation (SD) of salivary IgA concentration (mg.dl^{-1}) for all the time points (TP) selected of the different protocols and at rest situation.

	TP 1		TP 2		TP 3		TP 4		TP5		TP 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T20 Swim	5.45	2.92	7.55	4.12	3.63	2.25	4.03	1.77	23.7	25.4	3.94	1.30
Aer Int Swim	6.41	4.84	8.37	6.03	4.73	3.58	5.85	4.65	27.5	24.2	8.13	6.72
L.Leger	8.15	5.76	5.60	3.31	7.19	4.39	3.53	1.59	18.1	10.7	7.59	4.04
WanT	5.40	4.11	8.60	6.19	3.90	2.44	2.35	0.81	32.2	46.1	5.30	5.16
Rest	7.10	7.37	7.23	5.80	5.27	4.45	10.1	8.6	12.2	14.2	6.2	3.1

When the salivary IgA response between protocols was compared, a statistical significant difference was found between time points 1 and 4, respectively before and 2.5h after in all the tasks. In the Luc Léger test, the sIgA concentration 1.5h after (3º time point) showed higher values when compared to the swimming protocols and the Wingate test. After the Wingate test, the sIgA concentration 2.5h after (4º time point) was significantly lower when compared to the same time point in the intermittent swimming protocol. For the 24h recovery time point, the continuous swim protocol (T20), showed significant lower values of sIgA when compared to the same time point for the intermittent swim and the Luc Léger tests.

In spite of significant differences in lactate levels, heart rate, and perception of effort (Cr10) between the land and water tasks, 24 hours after testing the sIgA concentration and secretion rate values were similar to the ones found before testing (1st time point).

When the sIgA values were compared at rest situation (nearest rested weekend), with the different protocols tested, significant differences were only found for the 4th time point with Wingate test. Both sIgA concentration and secretion rate were lower at this time point for the other three protocols but they failed to reach statistical significance. Rest values show minor variations related to the diurnal cycle when compared to the ones obtained after the tests.

Table 3. Mean and Standard Deviation of Salivary IgA secretion rate (μg.mn-1), for all time points (TP) selected for the different protocols and rest situation.

	TP 1		TP 2		TP 3		TP 4		TP 5		TP 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T20	50.27	33.97	61.65	37.26	34.83	22.80	39.29	18.60	181	154	41.78	18.97
Aer Int												
Swim	51.44	49.56	59.85	53.31	35.26	29.20	41.21	33.62	153	88	60.13	41.33
L.Léger	57.6	40.81	39.77	29.52	62.16	43.15	28.53	16.58	129	75	57.91	40.34
WanT	35.46	24.73	55.78	44.89	39.18	36.32	29.42	21.21	226	238	43.3	46.3
Rest	55.93	63.11	55.71	44.41	48.78	50.91	70.27	55.9	102	116	49.88	23.64

The IgA secretion rate generally followed an identical pattern to the sIgA concentration reinforcing the importance of the variation of this immune parameter (1).
When percentual variation of sIgA values were analysed, in all the protocols studied, the negative impact of the load was located 2.5hours after the test, with values that were 50 to 85% of the initial ones. Only for the continuous swimming protocol, the sIgA recovery values were under the initial ones. This may be related with the longer time spent on the task which probably conduced to a greater utilization of glycogen. In spite of the similar duration of the intermittent aerobic swimming protocol. the managment of the load does not have an identical impact on the glycogen stores.
Identical results are found on studies aiming to understand the acute response of salivary IgA to exercise. The protocols selected for this study aim to reproduce some of usual training loads done by athletes namely swimmers at their preparation (2). Most studies with swimmers only use swim tasks but land work is also an important tool in swim training. With these specific loads our results show that 24 hours are sufficient for the recovery of the sIgA values.
The relevance of this study resides on the recognition of an immune alteration regarding salivary IgA in response to exercise, mostly 1.5 hour to 2.5 hours after the training session. Coaches and swimmers must be aware of this variation, as it seems that because of the kind of the exercise done (with some intensity), they may be more prone to infection during this period. Keep way from crowded places and wrap up when you leave, is good advice to avoid infections of the upper respiratory tract.

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INSULATION AND BODY TEMPERATURE CHANGES BY WEARING A THERMAL SWIMSUIT DURING LOW TO MODERATE INTENSITY WATER EXERCISE

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This study investigated thermal swimsuit (TSS) effects on body temperature and thermal insulation during low-intensity and moderate-intensity water exercise. Nine male subjects were immersed in water (23°C) and pedalled on an underwater ergometer for 30 min with a TSS or a normal swimsuit (NSS) at two exercise intensities. Oesophageal temperatures (T_{es}) were maintained higher in TSS than in NSS at both intensities. Moderate exercise decreased the tissue insulation (I_{tissue}) compared to low-intensity exercise. However, the increased metabolic heat production at moderate intensity and added suit insulation (I_{suit}) were sufficient to offset the decrement of I_{tissue} and T_{es}. The proportion of I_{suit} to total insulation and skin-fold thickness showed a negative correlation, indicating that subjects with lower body fat can benefit more from wearing TSS. Results suggest that TSS in cool water was especially useful for subjects with low body fat.

Key Words: thermal insulation, body temperature, thermal swimsuit, water exercise.

INTRODUCTION

Several investigators have shown that moderate exercise facilitates overall heat loss during cold water immersion (5, 10) because the increased blood circulation to muscle tissues raises the conductive heat transfer from the body core to the skin, thereby reducing tissue insulation (12). Furthermore, in this moderate exercise conditions, body movements through the water accelerate convective heat loss from the skin surface to the water. However, vigorous physical activity seems to maintain the core body temperature (5, 11) because the increased metabolic heat production is sometimes sufficient to offset the heat loss. The intensity of water exercise for improving physical fitness or learning swimming techniques is lower than that for competitive swimming training. Therefore, we must develop some means to maintain the core body temperature without increasing the exercise intensity. An additional layer of insulation on the skin surface is a convenient strategy to reduce convective heat loss without an increment of exercise intensity. Many investigators have reported that wetsuits' additional insulation layers mitigate the decrease of core body temperature and facilitate longer immersion periods (1, 3, 13). However, the wetsuits investigated in those reports were produced for use in severe cold water environments for occupational divers or military specialists. In contrast, thermal swimsuits (TSS), which are a partial-coverage wetsuits, were developed to use in cool water environment for improving physical fitness or learning swimming techniques, and no data has been published so far regarding its insulation features. In this sense, the main purpose of this study was to investigate the effects of a thermal swimsuit on body temperatures and thermal insulation during low-intensity and moderate-intensity water exercise.

METHODS

Nine healthy male subjects volunteered for this study. Table 1 shows their physical characteristics. Body-fat percentages were measured using bioelectrical impedance analysis (BC-118; Tanita, Japan). The mean skin-fold thickness (MSFT) was averaged from six body regions measured using a skin-fold calliper. The body surface area (*SA*) was estimated using the DuBois equation ($SA = 0.007184 \cdot BW^{0.425} \cdot H^{0.725}$), where *BW* is the body weight and *H* represents height.

Table 1. Physical characteristics of subjects.

	Age (year)	Height (cm)	Weight (kg)	% Fat (%)	MSFT (mm)	SA (m^2)
mean	25.4	175.7	70.6	19.1	9.5	1.86
SD	2.1	4.2	4.5	2.3	2.8	0.08

After subjects sat in room air (22–24°C) for 5 min, they were immersed in water (23°C) up to their chest on an underwater cycle-ergometer for 8 min. Then, they pedalled at 50 rpm for 30 min. Each subject carried out the protocol four times: with normal swimsuit (NSS) and with a TSS (206776-09; Footmark Co. Ltd., Japan) and at two submaximal exercise intensities (low: $\dot{V}O_2$= 11–12 ml·min^{-1}·kg^{-1}, moderate: $\dot{V}O_2$= 20–22 ml·min^{-1}·kg^{-1}). The TSS used in this study was made of nylon-faced neoprene (2 mm thick), covering the thighs, trunk, upper arms, and neck. During experiments, oesophageal temperature (T_{es}) and 10 skin temperature regions were measured using thermistor sensors. The mean skin temperature (T_{es}) and mean body temperature (T_b) were calculated using the following equations: $\overline{T}_{sk} = 0.07T_{head} + 0.35(T_{chest} + T_{abdomen} + T_{back}) / 3 + 0.14(T_{upperarm} + T_{forearm}) / 2 + 0.05T_{hand} + 0.19T_{thigh} + 0.13T_{calf} + 0.07T_{foot}$, $\overline{T}_b = 0.67\ T_{es} + 0.33\ \overline{T}_{sk}$.

Expired gases were continuously assessed using a mass spectrometer (WEMS2000; Westron Corp., Japan). Values of the oxygen uptake ($\dot{V}O_2$), carbon dioxide elimination ($\dot{V}O_2$), and respiratory exchange ratio (*RER*) were averaged every 1 min. Total metabolic heat production (*M*) was calculated from $\dot{V}O_2$ and *RER*. Metabolic heat production from the unit skin surface (M_s) was calculated as 0.92·*M / SA*, where the respiratory heat loss was assumed to be 8% of *M*. Body heat storage (S_s) was calculated from $\Delta\overline{T}_b$, *BW* and the human body specific heat capacity (C_b) ($S_s = C_b \cdot \Delta\overline{T}_b \cdot BW / SA$). Heat loss from the skin to the water (H_s) was calculated by subtracting S_s from M_s ($H_s = M_s - S_s$). Total insulation (I_{total}) and tissue insulation (I_{tissue}) were estimated respectively by dividing the temperature difference between the oesophagus and water or the oesophagus and skin with H_s ($I_{total} = (T_{es} - T_w) / H_s$, $I_{tissue} = (T_{es} - \overline{T}_{sk}) / H_s$). Suit insulation ($I_{suit}$) was calculated by subtracting I_{tissue} from I_{total} ($I_{suit} = I_{total} - I_{tissue}$).

Cardiac output ($\dot{Q}_c$) was measured using a mass spectrometer with acetylene rebreathing technique (2) every 10 min. Systolic (SAP) and diastolic (DAP) arterial blood pressures were recorded every 5 min. Mean arterial blood pressure (MAP) was calculated as DAP + (SAP – DAP) / 3. Total peripheral resistance (TPR) was calculated as MAP /$\dot{Q}_c$ to estimate the extent of peripheral vasoconstriction.

Statistical significances (p<0.05) between TSS and NSS at the same intensity were shown with an asterisk (*); and significances between low and moderate intensity with the same suit were shown with a dagger (†) in Figures and Tables.

RESULTS

Changes in T_{es} and $\overline{T}_{sk}$ are shown in Fig. 1. At the beginning of water immersion, $\overline{T}_{sk}$ dropped rapidly with NSS at both intensities; however, a slower decrease was found with the TSS. After the onset of water exercise, $\overline{T}_{sk}$ decreased gradually for approximately 10 min, then stabilised until the end of immersion in all conditions. At each intensity, $\overline{T}_{sk}$ was significantly higher with TSS than with NSS throughout the exercise (p<0.05). During low-intensity exercise, T_{es} with both swimsuits decreased; T_{es} was significantly higher with TSS than with NSS from 25 min to 30 min (p<0.05). During moderate intensity exercise, T_{es} with both swimsuits increased from pre-immersion baseline, and no difference were observed between suit conditions.

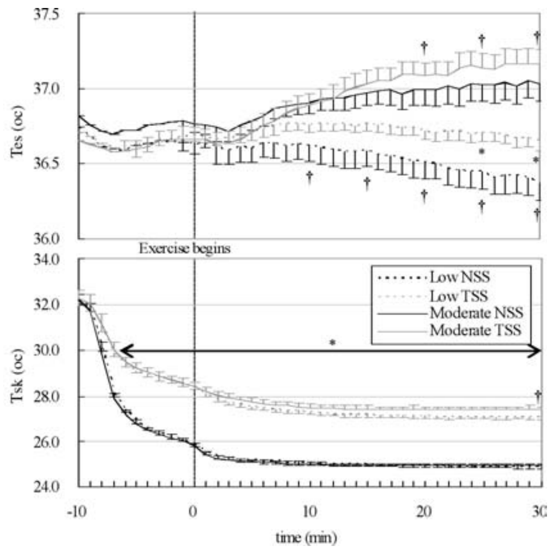

Figure 1. Body temperature change during immersion and exercise in water (mean ± SE).

Average values of $\dot{V}O_2$, $\dot{Q}_c$, MAP cnd TPR during water exercise are shown in Table 2.

The $\dot{V}O_2$, $\dot{Q}_c$, and MAP at moderate intensity were significantly higher than those at low intensity (p<0.05). The TPR were significantly lower at moderate intensity than at low intensity (p<0.05). Values of $\dot{V}O_2$, $\dot{Q}_c$, MAP and TPR showed no differences between TSS and NSS conditions at both intensities.

The M_s, S_s and H_s during 30 min water exercise are shown in fig. 2. The M_s were significantly higher at moderate intensity than at low intensity with both swimsuits (p<0.05). The M_s

showed no differences between TSS and NSS conditions at both intensities. The S_s were significantly lower in TSS than in NSS at both intensities ($p<0.05$). At both intensities, TSS showed significantly lower H_s than in the NSS condition ($p<0.05$).
Results of I_{total}, I_{tissue} and I_{suit} during water exercise are shown in fig. 3. The I_{total} was significantly higher in the TSS than in the NSS condition at both intensities ($p<0.05$). The I_{tissue} at moderate intensity was significantly lower than that at low intensity with both suits ($p<0.05$). The I_{tissue} showed no differences between TSS and NSS conditions at both intensities.

Table 2. Cardiovascular responses during water exercise (mean ± SE).

	Low intensity		Moderate intensity	
	NSS	TSS	NSS	TSS
$\dot{V}_{O2}$ (ml·min^{-1}·kg^{-1})	11.78 ± 0.67	10.71 ± 0.35	21.74 ± 1.42†	20.61 ± 1.51†
$\dot{Q}_c$ (l·min^{-1})	6.45 ± 0.27	6.20 ± 0.51	9.45 ± 0.38†	9.47 ± 0.61†
MAP (mmHg)	94.7 ± 3.0	95.7 ± 3.9	101.7 ± 3.6 †	103.2 ± 3.5 †
TPR (mmHg·min·l^{-1})	15.0 ± 0.7	16.4 ± 1.5	10.8 ± 0.3 †	11.2 ± 0.6 †

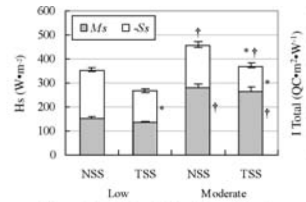

Figure 2 M_s, S_s and H_s during 30 min water exercise (meanÅ}SE)

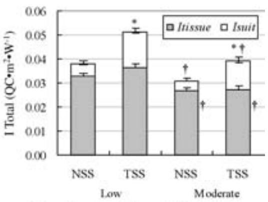

Figure 3 I_{tissue}, I_{suit} and I_{total} during 30 min water exercise (meanÅ}SE)

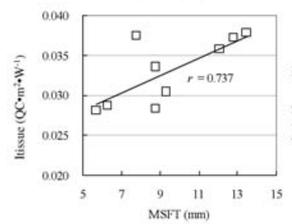

Figure 4 The relationship between MSFT and the I_{tissue} at low-intensity exercise with the NSS

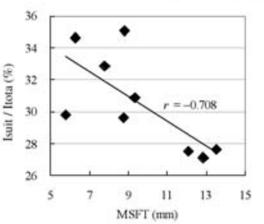

Figure 5 The relationship between MSFT and I_{suit}/I_{total} at moderate - intensity exercise with the TSS

Fig. 4 shows the relationship between MSFT and the I_{tissue} at low intensity with NSS. The I_{tissue} were correlated significantly with the MSFT ($p<0.05$, $r = 0.737$). Fig. 5 shows the relationship between the MSFT and the proportion of I_{suit} to I_{total} (I_{suit}/I_{total}) at moderate intensity with the TSS. The I_{suit}/I_{total} showed significantly negative correlation with the MSFT ($p<0.05$, $r = -0.708$).

DISCUSSION

In the present study, the I_{tissue} at moderate intensity with both suits was significantly lower than that at low intensity ($p<0.05$). The decrease in I_{tissue} agrees with the results of previous studies (7, 8). Sagawa et al. (8) reported that I_{tissue} was inversely proportional to the increase in water exercise intensity at T_w of 28.8 – 36°C. Similarly, Park et al. (7) reported that I_{tissue} declined as an exponential function of the exercise intensity in water of 28 – 32°C. They (7, 8) indicated that exercise increased blood circulation to the working muscles and thereby reduces I_{tissue}. In accordance with other studies, we found a higher $\dot{Q}_c$ and lower TPR during moderate intensity exercise, which indicated the increase in the blood circulation to the working muscles. However, the exercise-induced heat production was greater than the heat loss attributable to the decreased I_{tissue}; therefore, moderate intensity exercise was able to maintain T_{es}.
Kang et al. (4) observed that, in divers working at T_w of 22.5°C and wearing wetsuits, I_{tissue} were slightly lower than those of suitless divers. In addition, Shiraki et al. (9) observed a similar tendency of decline of I_{tissue} in wetsuit-protected divers during diving work at T_w of 27°C. They suggest that these I_{tissue} levels reflected the higher peripheral blood flow attributable to less cold-induced vasoconstriction in divers with wetsuits. On the other hand, in our study, the I_{tissue} showed no differences between TSS and NSS conditions at both intensities, which suggests that the TSS has no effects on peripheral blood flow unlike in the case of wetsuits. Our data of $\dot{Q}_c$, MAP and TPR showed no cardiovascular differences between suit conditions as like as I_{tissue}, which could ascertain that the TSS has no effect on the peripheral blood flow. We postulated that the partial-coverage form and thinner layer of the TSS was one reason for the different effect on I_{tissue} between the TSS and wetsuits. Thermal input from the exposed distal extremities might attenuate the predicted peripheral vasodilatation with TSS. From these results, we could reveal the difference between the TSS and wetsuits.
The significant correlation between MSFT and I_{tissue} in NSS condition indicated that subjects with low body fat had a thinner insulation layer than that of obese subjects (3). This result suggests that wearing a TSS is advantageous for subjects with low body fat to compensate for the smaller I_{tissue}. Because of the relationship between MSFT and I_{tissue}, a negative correlation was observed between MSFT and I_{suit}/I_{total} at moderate intensity exercise. The I_{suit}/I_{total} for each subject reflects the TSS contribution to the subject's total insulation. The negative correlation suggests that the lower fat subjects could have more benefit of TSS to I_{total}. No previous wetsuit studies have assessed suit-attributable differences among subjects' physical characteristics using the I_{suit}/I_{total} parameter. The greater I_{suit} of wetsuits compared to TSS might obscure the individual suit contribution differences. We can suggest greater usefulness of wearing TSS for subjects with low body fat by indicating the negative correlation between MSFT and I_{suit}/I_{total}.

CONCLUSION

During immersion in 23°C water, moderate intensity exercise reduced I_{tissue} compared to low-intensity exercise resulting from higher blood circulation to working muscles. Wearing a TSS served to increase I_{total} by adding I_{suit}, thereby reducing heat loss from subjects' skin to the water. Consequently, subjects with TSS were able to maintain higher body temperatures than those same subjects with NSS. Results showing negative correlation between I_{suit}/I_{total} and MSFT suggest that subjects with lower body fat might receive more benefit from TSS to I_{total} during water exercise in cool water.

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SWIMMING BIOENERGETICS

INVITED CONTRIBUTION

BIOPHYSICS IN SWIMMING

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Performance is the time (t) to cover a given distance (d), i. e. speed of swimming (v = d / t). In turn, v is the product of stroke rate (SR), and distance per stroke (d/S). Maximal v is set by maximal metabolic power (E'_{max}) and energy cost of swimming (C_s). Drag (D), efficiency (η) and v set the metabolic requirements. D can be partitioned in friction (22%), pressure (55%) and wave (23%) drag. D reduction can be achieved by training and swim suit design. _ and C_s are influenced by D, by the energy wasted to water and by the internal work. E'_{tot} is a combination of aerobic and anaerobic power: it increases monotonically with the speed, is highly variable and, it decreases with training. Aerobic, anaerobic lactic and alactic energy supply 38, 43, and 19% in 200 yd and 19, 54, and 26% in 50 yds. At competitive v, C_s is lowest in front crawl and higher in backstroke, butterfly and breaststroke (in that order). The above mentioned factors are highly variable, but even among elite swimmers each is highly trainable.

Key Words: biomechanics, swimming, aerobic, anaerobic, drag, efficiency, training.

INTRODUCTION

Swimming is characterized by the intermittent application of a propulsive force (thrust) to overcome a velocity- dependent water resistance (drag, D). The thrust is generated by a combination of arm cycling and leg kicking which result in fluctuations of thrust and velocity. As the four competitive strokes use differing combinations of arm cycling and leg kicking their inherent fluctuations in velocity are different (3). Fluctuations in thrust, drag and velocity contribute to the highly variable performance in swimming. In all swimming strokes the average velocity (v) is the product of the stroke rate (SF) and the distance the body moves through the water with each stroke cycle (d/S) (3):

$$v = SF \cdot d/S \quad (1)$$

The generation of a given velocity requires a given metabolic power output (E'_{tot}) that is velocity-dependent. It is determined by the mechanical power output (W'_{tot}, of which D is a major component) and by the overall efficiency (η) of the swimmer:

$$E'_{tot} = W'_{tot} / \eta \quad (2)$$

Since the ratio of E'_{tot} to swimming velocity (v) is the energy cost of swimming per unit distance:

$$Cs = E'_{tot} / v = W'_{tot} / \eta \cdot v^{-1} = W_{tot} / \eta \quad (3)$$

where W_{tot} is the mechanical work per unit distance. Equation 3 can also be expressed as:

$$v = E'_{tot} / Cs = E'_{tot} / (W_{tot} / \eta) \quad (4)$$

Equation 4 shows that the maximal velocity is set by the maximal metabolic power of the subject ($E'_{tot\ max}$), divided by Cs at that speed:

$$v_{max} = E'_{tot\ max} / Cs = E'_{tot\ max} / (W_{tot\ max} / \eta) \quad (5)$$

where W_{tot} is the maximal mechanical work per unit distance.In turn, $E'_{tot\ max}$ is given by:

$$E'_{tot\ max} = AnS / t_p + MAP - MAP\tau\ (1 - e^{-tp/\tau}) / t_p \quad (6)$$

where AnS is the energy derived from the anaerobic stores; t_p is the performance time, MAP is the maximal aerobic power and τ is time constant with which $V'O_{2max}$ is attained at the onset of exercise (1). Combining equations 5 and 6, one obtains:

$$v_{max} = (SF \cdot d/S)_{max} = E'_{tot\ max} / Cs$$

$$v_{max} = (SF \cdot d/S)_{max} = (AnS / t_p + MAP - MAP\ \tau\ (1 - e^{-tp/\tau}) / t_p) / (W_{tot\ max} / \eta) \quad (7)$$

This shows that maximal swimming performance depends on the interplay between biomechanical (SF, d/S, $W_{tot\ max}$, η) and bioenergetic aspects (AnS, MAP, τ).Thus if we can understand the biomechanical and physiology aspects of swimming as a function of velocity we can better understand the biophysics of swimming.

VELOCITY, STROKE RATE AND DISTANCE PER STROKE

The pioneering work of Craig (3) described the relationship between SF, d/S and velocity for all four competitive strokes in elite swimmers. A subsequent study (4) demonstrated the application of the SF-v relationship in competitive events. The basic observation of Craig (3) was that for low velocities, the increase in v was due mostly to the increase in SF. However, with increasing v, the increase of v was due to the combination of an additional increase of SF and a decrease of d/S. These stroke rate-velocity (SF-v) curves are unique to each competitive stroke but similar among swimmers within each stroke. These observations were confirmed by Termin (2001) (Figure 4). The front crawl (FC) had the greatest d/S and SF. The back crawl (BC) was similar to the FC except that at a given SF the d/S and v were less than for the FC.

Increases of v of the butterfly (BF) were related almost entirely to increases in SF, except at the highest v. In the breaststroke (BS) increasing v was also associated with increasing in SF, but the d/S decreased more than in the other strokes. Craig (3) also showed that better swimmers had a greater maximal d/S and could maintain a higher d/S as the SF and v increased. The distance of swimming races was also shown to have a major effect on the SF-v relationship. In U.S. Olympic swimming trials faster velocities were achieved in 1984 (4) than 1976 (3) by increased d/S of the swimmers in many events. However, in selected events, faster v was achieved by using a higher SF, while in many events the higher d/S resulted in lower stroke frequencies. These data suggest that swimmers can choose their SF and d/S based on their technique and physiology, to obtain and sustain a specific velocity. Whether a swimmer can change his/her SF-v relationship and if so, what are the best training techniques.

The intermittent application of thrust and the changes in drag, result in fluctuations in v. As shown by Craig (3) the fluctuation of v in the front and back crawl were (± 15-20%) while in the breast and butterfly strokes this variability was much greater (± 45-50%). In the breast stroke Termin (23) demonstrated very large fluctuations in velocity, including a deceleration to zero velocity for a short period during the cycle. It has also been shown that swimmers with less variation in their inter-cycle v have faster v (23).

ENERGY COST OF SWIMMING

The velocity of swimming is determined by the energy cost of swimming and the swimmer's metabolic power (aerobic + anaerobic, eq. 4). In the aerobic range, the energy cost of swimming can be determined by measuring the rate of oxygen consumption $V'O_2$ using standard open circuit techniques. At competitive swimming speeds the anaerobic contribution from anaerobic glycolysis can be estimated from venous blood lactate (La), as validated (8, 7) and used (1, 25). In practice (25) swimmers swam 50, 100, 200, and 400 yards. Each swim was on different days, under meet conditions in a competitive pool, and serial venous blood lactates were taken 6-10 min post-swim on the pool deck under a pool heater. The peak value of net La was determined. Assuming net blood lactate accumulation starts at 10 s of exercise, the rate of La accumulation as a function of the speed. This was converted to oxygen equivalents assuming a La equivalent of 3 $mlO_2 \cdot kg^{-1} \cdot mM^{-1}$ (6, 7, 8). The total metabolic power (E'_{tot}) was estimated from adding the O_2 equivalent for lactate to the maximal aerobic power (8, 1, 25). These data are shown in Figure 1.

The E'_{tot} (indicated as $V'O_2$ in the figure) was similar for the FS and BC below 1.5 $m \cdot s^{-1}$. At greater speeds the energy expenditure of the BC increased at a faster rate than in the FC but the maximal E'_{tot}'s were similar. The maximal speed was less in BC than in FC (1.75 vs. 2.0 $m \cdot s^{-1}$). The energy expenditure of BS and BF were greater than FC and BC at all speeds with BS having the greatest cost and the lower maximal velocity.

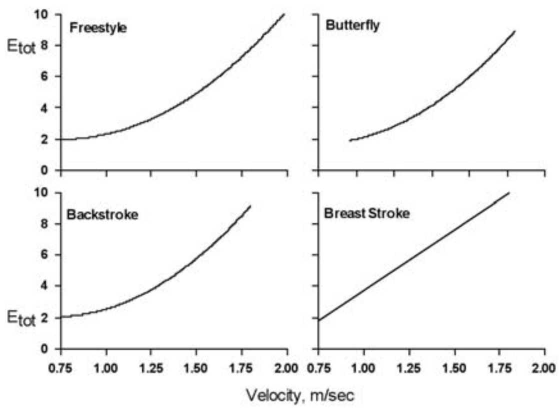

Figure 1. The total energy expenditure (E'_{tot}, aerobic + anaerobic) of swimming as a function of velocity for upper division swimmers in the four competitive strokes.

The energy cost per unit distance (Cs) within a stroke was constant for the FC, BC, BS and BF up to speeds of 1.7, 1.4, 1.35 and 1.3 $m \cdot s^{-1}$, respectively. At velocities greater than these values the Cs increased exponentially in all strokes.

Drag

Water resistance or drag is a major determinant of the energy cost of swimming. Determination of drag in actual swimming (active drag, D_a), to date, has not been measured directly. Drag determined by towing a non-swimming subject through the water, called passive drag (D_p), has been reported for more than a century. Drag measured in this latter manner ignores the drag that the swimmer creates when he/she develops thrust to overcome the drag. However, measures of D_p can be utilized to investigate the components of total water resistance, namely friction ($D_p = kv$), pressure ($D_p = kv^2$) and wave drag ($D_p = kv^4$). In the study of Mollendorf (10) it was found that total D_p increased monotonically up to 86.2 ± 4.3 N at a v of 2.2 $m \cdot s^{-1}$ when swimmers wore the traditional brief swim suit. Partitioning D_p revealed that pressure drag dominated D_p at all speeds accounting for 76 %, 63 %, 58 % and 54 % at 1.0, 1.5, 2.0 and 2.2 $m \cdot s^{-1}$, respectively; whereas friction (5%, 10%, 15%, 18%) and wave (0%, 12%, 21%, 24%) drag shared similar percentages of D_p at the corresponding speeds. The conclusion from these data is that water pressure causes the greatest D_p and thus this form of drag is critical and reducing it could improve performance.

The drag created by the swimmer is such that D_p significantly underestimates the D_a, a fact that has been confirmed by several studies (e.g. 5, 13, 14, 27); thus measuring D_a is an essential prerequisite to understand swimming performance. Several methods have been proposed to measure D_a including di Prampero et al. (5): Clarys, Clarys and Jiskoot, Hollander et al. and Toussaint (26, 27, 28, 29): Zamparo et al. (33) and Payton (12). The two most reported techniques are the indirect extrapolation system of di Prampero et al (5) and Toussaint's MAD-system (26, 27, 28, 29). We are presenting here D_a data as obtained using the di Prampero (5) and Pendergast (14) approach. Data for active D_a are shown in Figure 2 for novice and Upper Division swimmers swimming the front crawl. D_a increased monotonically in both groups up to 100 N at 1.15 $m \cdot s^{-1}$ in novice and 160 N at 1.8 $m \cdot s^{-1}$ in Upper Division swimmers. The values of drag measured by this method are higher than D_p and of the values reported by others using different techniques (9, 26, 27). This may be due to the added drag caused by movements of the arms and the legs when swimming, which are not considered in other methods. It is only fair to say that this method is indirect, and may have its own limitations.

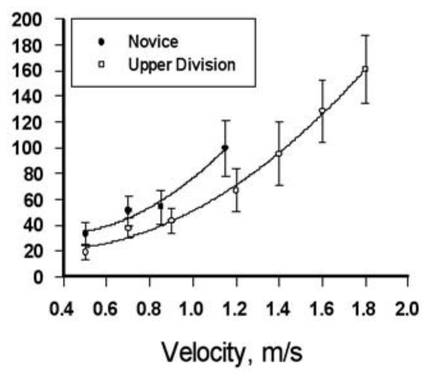

Figure 2. Active drag (D_a) is plotted as a function of swimming velocity for male novice (n = 18, ○) and Upper Division (n = 42, ●) swimmers, swimming the front crawl.

The data for partitioned D_a, as described above for D_p, are shown in Figure 3 for novice and Upper Division swimmers. For the novice swimmers pressure D_a is the major contributor to total D_a over their entire range of speeds, which is consistent with the greater frontal surface area that they present when swimming due to their poor technique. For the Upper Division swimmers pressure D_a also plays an important role, however at speeds greater than 1.5 m · s^{-1}, where competitive events are swum, wave drag becomes as important as pressure drag and is consistent with their higher speeds and their position "on the water".

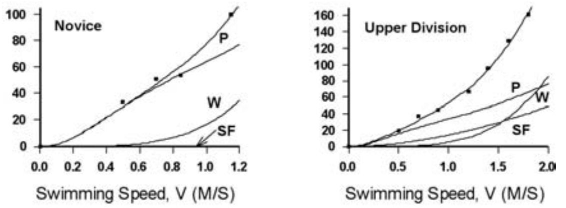

Figure 3. Active drag (D_a) is plotted as a function of swimming velocity for Upper Division (n = 43, left panel) and novice (n = 12, right panel) swimmers for total (●) and skin friction (SF), pressure (P), and wave (W) drag.

Effect of frontal surface area on drag
A major determinant of pressure drag is the area projected in the frontal plane. One determinant of which is the body composition of the swimmer, specifically the underwater torque (T), that is tendency of the legs to rotate around the center of mass. Cs has been shown to be directly proportional to T (13). Increasing or decreasing torque by adding weights resulted in proportional changes in Cs (32). Male swimmers have greater torque than females with ratios of 1.69 at 13 years and 2.04 for adults (32). The T is offset by the hydrodynamic lift on the legs. This lift during swimming is due to the velocity generated by the arms, as the legs contribute relatively little to thrust (33); thus, the leg kick should be minimized.

Thrust
At constant speed, the thrust must equal the D_a. The maximal v is set by the maximal thrust, which is determined by the muscular force of the swimmer (11, 12). Hence, maximal swimming v should be related to muscular force and power. However, studies of elite swimmers have failed to support this relationship: the distance per stroke (d/S, an index of force application) at 1.25 m · s^{-1} were 2.62 and 2.52 m while at 1.8 m · s^{-1} were 1.82 and 1.7 m for the strongest vs. weakest swimmers on the team (17). Further evidence of the minor importance of strength was the absence of differences in swimming and physiological variables between elite swimmers that added resistance training to swim training (18). The maximal force of arm pulling is over 1000 N while the thrust in tethered swimming is less than 200 N (only 20% of maximal). Furthermore an increase of muscle mass, particularly in the legs, would increase torque and density and in turn Cs (33). This leads to the conclusion that muscular strength is not the key issue in swimming fast or with minimal Cs, which depends on efficiency (η).

Efficiency
The overall mechanical efficiency can be expressed by the ratio of total mechanical work per unit distance to the energy cost of swimming (eq.3). In swimming W_{tot} is the sum of the work to accelerate/decelerate the limbs around the center of mass (W_{int}, internal work) and the work to overcome the external forces (W_{ext}), the latter including the work to overcome D_a (thrust, W_{Da}), and the work to accelerate water away from the body not useful for propulsion (W_k). Propelling efficiency (η_p) is defined as the proportion of total mechanical power which is transformed in useful thrust:

$$\eta_p = W'_{Da} / W'_{tot} = W'_{Da} / (W'_{ext} + W'_{int} + W'_k) \quad (8)$$

Hence W'_{tot} can be calculated if D_a, v ($W'_{Da} = Da \cdot v$) and propelling efficiency (η_p) are known. η_p can be modeled for arm movements (as a paddle wheel) and leg kick (slender fish) (33). η_p measured with only arms (26, 27, 28, 29) ranges from 0.45- 0.75 (FC). η_p in FC was 0.40 with arms plus legs (33), the lower values reflecting the negative effect of the legs on Σ_p. In addition the values of η_p reported (33) were associated with the d/S of the swimmers, confirming previous speculation (3, 4, 27). The internal power during front crawl swimming (W'_{int}) was shown to range from 13 to 36.2 W and to be proportional to the arm (SF) and leg kick (KF) frequencies ($W_{int} = 38.2\ SF^3$ and $W_{int} = 6.9\ KF^3$) (33); while W'_{int} of the arms is minimal, that of the legs can not be ignored. These data suggest that leg kicking should be minimized in swimming FC. For speeds from 1.0 to1.4 m · s^{-1}, W'_k increased from 56.8 to112.3 W, W'_{Da} from 52.5 to 96.9 W and W'_{tot} from 122 to245 W. Overall efficiency (η, see eq. 1) was 21%, a quite reasonable value compared to other types of locomotion (8).

Drag reducing swimming suits
It is commonly believed that drag-reducing suits (microscopic vortex generators and ribblets) reduce skin friction, as does shaving (21); however, this effect would be relatively small due to low skin friction. However testing these suits revealed that total D_p was reduced at competitive swimming speeds by 3% to 10%, due mostly to reduced pressure drag (10). These data suggest that the water flow was tripped by frictional drag, remained attached to the body, thus reducing pressure drag. This concept has been supported by data from suits that used ribblets (30) or a trip wire technology (10). Studies of the effects of a drag reducing suit on active drag at low to moderate speeds failed to show a benefit (20, 29), however at the fastest speed the suit reduced the D_a of some of the swimmers (29). One study based on physiological data demonstrated and advantage (22), while another study did not (19). It is our opinion that drag reducing suits do reduce drag, particularly if they cover both the torso and legs at velocities above 1.5 m/s.

METABOLIC POWER
The approach described above under **Energy Cost of Swimming** provides an estimate of Cs as well as of the total metabolic power of swimming (E'_{tot}) (1, 5, 6, 7, 13, 14, 15, 16, 25). According to Equation 6, E'_{tot} can be subdivided into the aerobic (E'_{aer}) and anaerobic (AnS) components, and the latter can be further partitioned into the lactic (E'_{AnL}) and alactic (E'_{AnAL}) components. The relative contribution of the energy systems are affected by v; the higher the speed the lower the aerobic (19%) and the higher from the anaerobic sources (54 and 26%). At a given speed these contributions nor E'_{tot} are similar among the four competitive strokes.

Training based on biomechanical and metabolic principles
Stroke mechanics
The studies described above formed the basis for the swimming training program at University at Buffalo (Termin 1998; 1999;

2000). The first step was improving d/S and SF. To improve d/S the swimmer has to take less SF at a given v which can only be done at slow speeds, however, as the biomechanics improved, the swimmer could swim faster, maintaining the same d/S at higher speeds. To train the swimmers three aids had to be provided; first an individualized SF-v curve that was "shifted" to the greater d/S and SF (3), second a velocity pacing system that set the v, splits and rest intervals (a computerized underwater light pacing system), and finally a stroke pacing system (goggles or beeper metronome) (24, 25). Over the weeks of training, the swimmer's workouts were moved to higher v, and SF, attempting to maintain the greatest d/S, until they reached the peak v. Once peak v was reached they returned to slow speeds and the d/S was increased, and the cycle repeated. Studies have shown that weight training was not an advantage to d/S and therefore this training was not done. Data showing the results of this training over a 4 year Upper Division collegiate career are show in Figure 5 for all four strokes. The conclusion of this study was that swimmers' could shift their SF-v relationship for all strokes (25) and this implied that they also improved their $\eta_{p,}$ and reduced their W_{tot} (33).

Metabolism

The relative contribution of aerobic and anaerobic power in the four strokes is similar and, even if this contribution is velocity dependent, at all speeds all factors play an important role and therefore should be trained. During the first phases of training, focused on the increase in d/S, the metabolism was primarily aerobic, however, at the upper end of this phase, anaerobic lactic and alactic metabolism becomes important. To maximize the improvement in $V'O_{2max}$ and facilitate oxidative reduction of lactate, 8 weeks of training were performed at a v that required 110% of $V'O_{2max}$, which could be sustained for 8-10 minutes prior to reaching maximal tolerable lactate. This period was followed by 10 min of active recovery, and then was followed by two more of these cycles (one hour total time, paced by the light system). This phase of training reduced Cs at aerobic speeds (Figure 6). This training system also improved $V'O_{2max}$ 3.38 to 4.86 $l \cdot m^{-1}$ (48%) and maximal lactate from 8.71 to 11.59 mM (33%) in swimmers with over 10 ears of previous long-slow training, most of which occurred in the first two years of training (25).

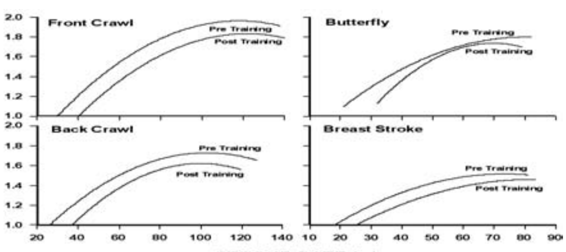

Figure 4. Velocity is plotted as a function of stroke frequency for Upper Division swimmers over their collegiate careers for their individual prime stroke. The "shift" in the relationship ("curve") to greater d/S and higher speeds progressed each year.

The second phase of the training involved moving the swimmers "up their curve" progressively, to faster v and higher SF, while maintaining d/S, up to the maximal v. To accomplish this goal swimmers' swam primarily 25 yard splits with rest intervals decreasing from 30s to 15s for a one hour practice (25 for more detail). These practices relied more and more on the lactic and alactic energy systems and the effects of it can be seen in Figure 6. There was a decrease in the energy requirements for a given speed (of 48% at higher speeds), an increased total metabolic power (21%) and an increase in the maximal v (22%).

Performance

Improved biomechanics and metabolism improved performance. The times of competitive events improved 5-10% over the swimmer's career, as compared to the 1-3% improvements seen in swimmers who train traditionally (2). In addition, the swim meter (3) was used to determine instantaneous velocity during starts (23, 10) and during free swimming (23). An example of this is during breaststroke swimming, the v accelerates during the arm stroke. After that the v decreases rapidly to zero or slightly greater than zero the legs are flexed in preparation for the leg kick. During this deceleration between time of the arm and the leg actions the frontal area of the swimmer increases, and this change of position increases Da and decreases v (23). During the dive or turn, the velocity rapidly decreases to levels below the average steady-state swimming speed (Mollendorf 2004). When this happens, the swimmer has to use one or two stroke to get back to the desired speed. The overall time for the lap is compromised by the period when the v is less than the swimmers surface speed. In addition, accelerations and decelerations are part of each stroke (more in breaststroke and butterfly), with greater fluctuations resulting in increased Cs. Thus the most uniform v throughout a stroke or race would result in the lowest Cs.

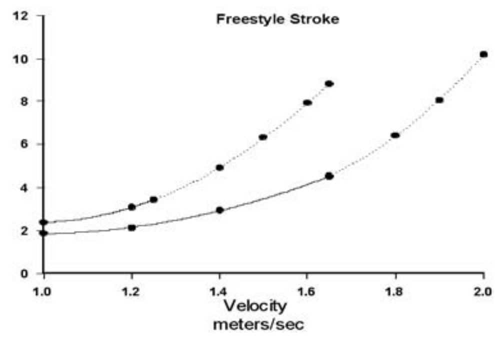

Figure 5. The total energy output is plotted for front crawl swimming at the beginning of training and after four years of training in Upper Division swimmers (data from 25).

SUMMARY

Swimming is a unique sport as both its energy cost and metabolic power requirement are more variable. Active drag is a crucial determinant of the energy cost of swimming; its reduction allows the swimmers to make the biggest gains in performance. The general principles of exercise metabolism should be applied to swimming, and training paradigms should be shifted to higher intensity training.

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TIME LIMIT AT THE MINIMUM VELOCITY OF $\dot{V}O_{2MAX}$ AND INTRA-CYCLIC VARIATION OF THE VELOCITY OF THE CENTRE OF MASS

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The purpose of this study was to analyse the relationship between time limit at the minimum velocity that elicits maximal oxygen consumption (TLim-v$\dot{V}O_{2max}$) and intra-cyclic variations of the velocity of the centre of mass (dv) in the four competitive swimming techniques. Twelve elite male swimmers

swam their own best technique until exhaustion at their previously determined $v\dot{V}O_{2max}$ to assess TLim-$v\dot{V}O_{2max}$. The test was videotaped in the sagittal plan and the APAS software was used to evaluate the horizontal velocity of the centre of mass (Vcm) and its intra-cyclic variation (dv) per swimming technique. Results pointed out that the strokes that presented higher intra-cyclic variations also presented larger values of TLim. Intra-cyclic speed fluctuations (dv) decreased during the TLim test in the four strokes studied, probably due to fatigue.
Key words: VO_2, intra-cyclic velocity variations, time limit, centre of mass.

INTRODUCTION

Time to exhaustion at minimum intensities corresponding to maximal oxygen uptake ($v\dot{V}O_2$máx) is a relatively new topic of interest in swimming training and performance diagnosis (2). It is commonly new as Time Limit at $v\dot{V}O_2$máx (Tlim-$v\dot{V}O_2$máx).

Previous studies of Time Limit in swimming were mainly conducted in swimming flume (3, 5, 6). However, the swimming flume can impose mechanical constrains that may compromise generalisation of results to free swimming conditions. So, a new protocol to assess Time Limit to the minimum speed corresponding to $\dot{V}O_2$máx (Tlim-$v\dot{V}O_2$máx) in normal swimming-pools was recently proposed (7).

Despite Tlim-$v\dot{V}O_2$máx in swimming remains a recent research topic, different influencing factors were already checked (3, 5, 6, 7) in literature. Among these, energy cost (8, 9) and stroke parameters (12) were the first biomechanical related parameters already exploited. Meanwhile, intra-cyclic fluctuations of the swimmer's velocity are among the most relevant performance determining biomechanical factors (1,11,15). Nevertheless, this parameter was never related to Tlim-$v\dot{V}O_2$máx in the literature at our disposal. The aim of the present study was to explore the relationship between TLim-vVO_2máx and intra-cyclic variations of the centre of mass velocity (dv) in the four competitive swimming techniques.

METHODS

Subjects

Twelve elite male swimmers (19.8 ± 3.5 y, 70.1 ± 8.0 kg and 178.3 ± 6.5 cm) were volunteered to serve as subjects. All the swimmers were informed about the characteristics and the purposes of the study.

Test protocol

Tests were conducted in a 25m indoor swimming pool. First, all subjects performed an intermittent incremental protocol for freestyle $v\dot{V}O_{2max}$ assessment. The test used increments of 0.05 m/s each 200m stage, with 30s intervals until exhaustion. $\dot{V}O_2$ was directly measured by a portable gas analyser (K4 b^2 Breath by breath Pulmonary Gas Exchange System – COSMED, Italy) connected to the swimmers by a specific respiratory snorkel for swimming (10, 14). Expired air was continuously measured during the entire test and averaged every 5s. $v\dot{V}O_{2max}$ was considered to be the swimming velocity corresponding to the first stage that elicits $\dot{V}O_{2max}$.

Forty-eight hours late, the subjects swam their own best technique until exhaustion, at their previously determined $v\dot{V}O_{2max}$ to assess TLim-$v\dot{V}O_{2max}$. This protocol considered in three different phases, all paced through a visual light pacer (TAR.1.1, GBK – electronics, Aveiro, Portugal) used to control swimming velocity: (i) a 10 minutes warm-up at an intensity corresponding to 60% $v\dot{V}O_{2max}$, followed by a short rest period (20s) for blood collection; (ii) a 50 m distance performed at progressive velocity, allowing the swimmers to reach their individual $v\dot{V}O_{2max}$, and (iii) the maintenance of that swimming $v\dot{V}O_{2max}$ until exhaustion. TLim was considered to be the total swimming duration at $v\dot{V}O_{2max}$ (7).

The test was videotaped in a sagittal plan, with two cameras (JVC SVHS), that provided, after mixing and editing, a dual-media image of the swimmer (17). The APAS software (Ariel Dynamics Inc, USA) was used to evaluate the horizontal velocity of the centre of mass (Vcm) and its intra-cyclic variation (dv) per swimming technique. A complete cycle of all techniques was analyzed, in the first and last laps of the TLim test, as well as in all the intermediate 100m laps.

Statistical analysis

Means and standard deviations of all variables were calculated. The variation coefficient (VC) of the intra-cyclic time distribution of instantaneous horizontal swimming velocity of the centre of mass was also calculated within a stroke cycle. Linear regressions were computed between variables, as well, its coefficients of determination and correlation. The level of statistical significance was set at $p \leq 0.05$.

RESULTS AND DISCUSSION

Figure 1 presents the regression line computed between the intra-cyclic fluctuations of the velocity of the centre of mass and the time duration of the TLim test, irrespectively of the swimming technique used.

Through the observation of the regression line of the Figure 1 it is recognizable that the swimmers with higher dv values perform longer at $v\dot{V}O_{2max}$. However, previous results available in literature support the hypothesis that dv should be taken as an indicator of energy cost of locomotion, inversely related to swimming economy and to the maximal velocity attainable by a given swimming technique (4, 13, 16).

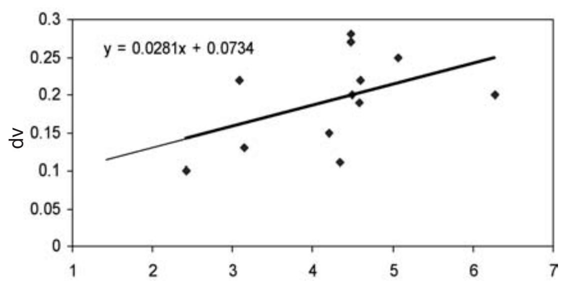

Figure 1. Relationship between TLim and dv for pooled data (r = 0.528, p = 0.078).

The apparent incongruence of the late finding with literature lead us to admit the hypothesis of a swimming technique specific effect on the relationship searched, suggesting the need of a stroke by stroke analysis. The results of such approach are presented in Figure 2. The Table 1 summarises the values of the correlation coefficients computed between TLim and dv.

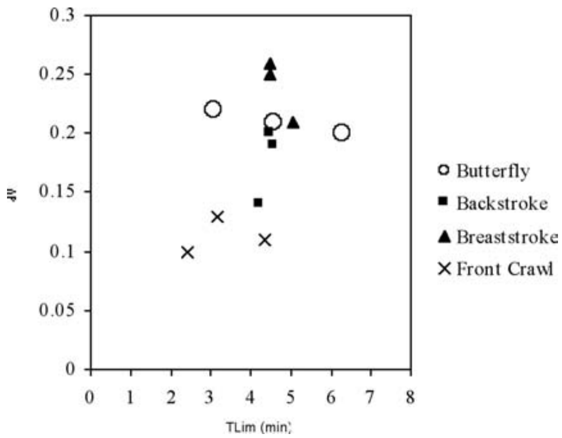

Figure 2. Relationship between TLim and dv for each swimming technique.

Table 1. Coeficients of correlation between TLim and dv.

Stroke	r	p
Buterfly	-0.296	0.809
Backstroke	0.911	0.271
Breaststroke	- 0.945	0.212
ront Crawl	0.195	0.875

No statistical significant correlations were obtained between TLim-v$\dot{V}O_{2max}$ and dv values for the different techniques, probably due to the reduced number of subjects of the particular samples. Nevertheless, the r values obtained for backstroke and breaststroke were quite high (0.911 and -0.945, respectively).
It is possible to observe that the technique that presented smaller values of dv - the front crawl - is also characterised by low TLim results. The technique that showed larger intra-cyclic fluctuations of the CM velocity was the breaststroke, also the one that delivers the higher values of TLim. Very interesting to note was that the simultaneous swimming techniques were characterized by inverse relationships between both variables, while the alternated ones showed a direct one. So, both backstroke and butterfly assume intermediate dv / TLim relationships in the interval between the boundaries defined by front crawl and breaststroke.
In our opinion, the reason for such controversial results should be searched in relevant co-variants not controlled in this study, namely the relative anaerobic energy contribution at v$\dot{V}O_{2max}$ for each technique. It maybe the case that different muscular activity and particular biomechanics of different swimming techniques imposed different energy partitions, for instance a more anaerobic v$\dot{V}O_{2max}$ for the front crawl and the backstroke, imposing less TLim durations despite a more economic mechanics (lower dv) in comparison with butterfly and breaststroke. Further investigation is needed to clarify this particular issue.
Figure 3 show the behaviour of dv and Vcm values in different moments of TLim test for each technique.

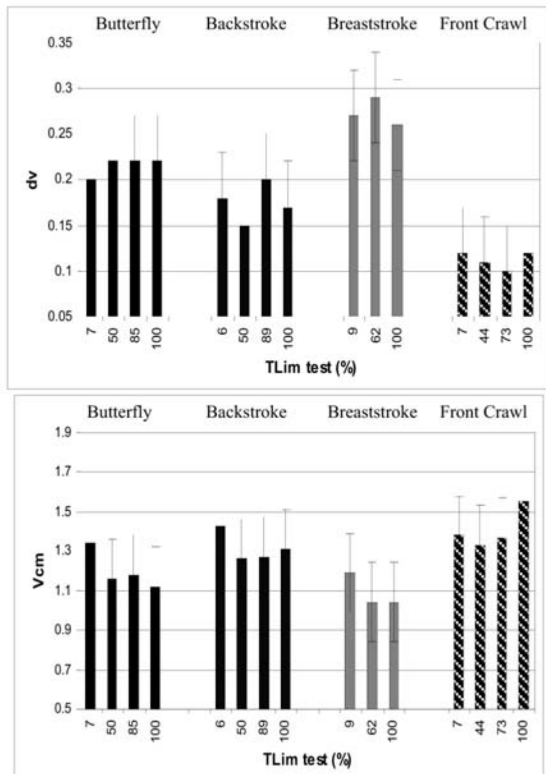

Figure 3. dv and Vcm values during TLim test in the four competitive techniques.

The techniques that present smaller dv values, Backstroke and Front Crawl, have larger values of Vcm, probably because dv allows for higher swimming economy and this one favours higher Vcm.

CONCLUSION
The results of the present research pointed out that the relationship between intra-cyclic speed fluctuations and TLim-v$\dot{V}O_{2max}$ may be strongly influenced by other co-variables, and that it should be searched, preferably, considering each swimming stroke independently. Butterfly, and breaststroke, the swimming techniques with higher speed fluctuations per stroke cycle are characterized by a tendency to an inverse relationship between speed fluctuations and TLim-v$\dot{V}O_{2max}$. The inverse tendency was perceived to the alternated techniques, and for the pooled data.

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RELATIONSHIPS BETWEEN ENERGY COST, SWIMMING VELOCITY AND SPEED FLUCTUATION IN COMPETITIVE SWIMMING STROKES

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The purpose of the study was to analyse relationships between total energy expenditure ($\dot{E}_{tot}$), energy cost (EC), intra-cycle variation of the horizontal velocity of displacement of centre of mass (dv) and mean swimming velocity (v). 17 Portuguese elite swimmers (4 at Freestyle, 5 at Backstroke, 4 at Breaststroke and 4 at Butterfly) were submitted to an incremental set of nx200-m swims. Bioenergetical and biomechanical parameters presented significant interrelationships. For pooled data, the relationship between $\dot{E}_{tot}$ and v was $r=0.59$ ($p<0.01$), between EC and dv was $r=0.38$ ($p<0.01$) and the polynomial relationship, between dv and v was $r=0.17$ ($p=0.28$). Individual evaluation and identification of biomechanical critical points may help the swimmers to become more efficient at a certain swimming velocity.

Key Words: competitive strokes, energy expenditure, energy cost, speed fluctuation, velocity.

INTRODUCTION
In swimming science, economy of movement is an interesting field of research. Several investigations have been conducted to understand the role of bioenergetics and its repercussions in performance. Most of those studies focused exclusively on the contribution of aerobic system to produce energy for movement even though all competitive swimming events also require significant contribution from anaerobic energetic system to cover total energy expenditure. Particularly in swimming, environmental factors have hindered the measurement of cardiorespiratory variables within the actual field setting. However, machinery to explore human aerobic energetics during field conditions has become available with the improvement of miniaturized metabolic measurement systems.
Intra-cycle variation of horizontal velocity of centre of body mass (dv) is a widely accepted criterion for biomechanical description of swimming techniques. There is a positive relationship between high dv and increased energy cost, especially in Breaststroke (12) and Butterfly stroke (2). In Backstroke and Freestyle the relationship was not so evident (1). In this perspective, it is important to obtain a better understanding of the relationship between the energy cost and dv in the competitive strokes.
Some investigators suggested the possibility of high dv being related with lower swimming velocities (e.g., 2, 12). It was

observed a significant and negative relationship between the mean horizontal velocity and the speed fluctuation in Butterfly stroke (10) and Breaststroke (9). Nevertheless, there is no study in the literature about the relationship between swimming velocity and dv, in Freestyle and Backstroke.
The purpose of this study was to analyse the relationships between total energy expenditure, energy cost, intra-cycle variation of horizontal velocity of displacement of centre of body mass and mean velocity of swimming.

METHODS

Subjects

17 elite swimmers (5 females and 12 males) of the Portuguese national team, volunteered to serve as subjects. 4 swimmers were evaluated performing Breaststroke (including 2 female swimmers), 4 swimmers performing Butterfly (including 1 female swimmer), 5 swimmers performing Backstroke and 4 swimmers performing Freestyle (including 2 female swimmers).

Design

The subjects were submitted to an incremental set of nx200-m swims. The starting velocity was set at a speed, which represented a low training pace, approximately 0.3 $m.s^{-1}$ less than a swimmer's best performance. The last trial should represent the swimmers all out pace. After each successive 200-m swim, the velocity was increased by 0.05 $m.s^{-1}$ until exhaustion and/or until the swimmer could not swim at the predetermined pace. The resting period between swims was 30s to collect blood samples. Under-water pace-maker lights (GBK-Pacer, GBK Electronics, Aveiro, Portugal), on the bottom of the 25-m pool, were used to control the swimming velocity and to help the swimmers keep an even pace along each step. In addition, elapsed time for each swim was measured with a chronometer to control the swimmer's velocity.

Data Collection

The swimmers breathed through a respiratory snorkel and valve system (7, 11), connected to a telemetric portable gas analyzer (K4 b^2, Cosmed, Rome, Italy). The oxygen consumption (VO_2) was measured for each swim breath-by-breath. Blood samples (25 μl) from the hyperemisized ear lobe were collected to analyze blood lactate concentration (YSI 1500 L, Yellow Springs, Ohio, USA) before and after each swim, as well as, 1, 3, 5 and 7 minutes after the last swim. Total energy expenditure (E_{tot}) was calculated using the VO_2 net and the blood lactate net (difference between the highest value measured in the end of the stage and the rest value), transformed into VO_2 equivalents using a 2.7 $mlO_2.kg^{-1}.l^{-1}$ constant (5). The energy cost (EC) was calculated dividing the E_{tot} by the swimming velocity (v).
The swims were videotaped (50 Hz) in sagital plane with a pair of cameras (JVC GR-SX1 SVHS and JVC GR-SXM 25 SVHS, Yokoama, Japan), providing a dual-media images from both underwater and above the water perspectives as described elsewhere (2). The images of the two cameras were real time synchronized and edited on a mixing table (Panasonic Digital Mixer WJ-AVE55 VHS, Japan) to create one single image. Ariel Performance Analysis System (Ariel Dynamics Inc, California, USA) and a VCR (Panasonic AG 7355, Japan) at a frequency of 50 Hz were used to perform a kinematical analysis of the stroke cycles, including the dv of the centre of mass. Zatsiorsky's model with an adaptation by de Leva (3) was used with the division of the trunk in 3 articulated parts. A filter with a cut-off frequency of 5Hz was used for the analysis of the horizontal velocity curve of the centre of mass.

Statistical procedures

Means and standard deviations of all variables were calculated. Coefficients of variation for the horizontal velocity of the centre of mass along with the stroke cycle were calculated. Linear regressions between the E_{tot} and v, between EC and dv and polynomial regressions of 2^{nd} order between dv and v were computed. Partial correlations between EC and dv controlling v and between EC and v controlling dv were also calculated. The level of statistical significance was set at $p \leq 0.05$.

RESULTS AND DISCUSSION

Figure 1 presents the relationships between the bioenergetical and biomechanical variables studied. The relationship between E_{tot} and v was r=0.70 ($p<0.01$) at Butterfly stroke, r=0.88 ($p<0.01$) at Breaststroke, r=0.67 ($p<0.01$) at Backstroke and r=0.85 ($p<0.01$) at Freestyle. The relationship between EC and dv was r=0.55 (p=0.01) at Butterfly stroke, r=-0.20 (p=0.43) at Breaststroke, r=0.38 (p=0.05) at Backstroke and r=0.79 ($p<0.01$) at Freestyle. Polynomial model presented a better adjustment than the linear approach, for the relationship between dv and v. The polynomial relationship between dv and v was r=0.47 (p=0.05) at Butterfly stroke, r=0.65 (p=0.02) at Breaststroke, r=0.45 (p=0.06) at Backstroke and r=0.65 ($p<0.01$) at Freestyle. For pooled data the relationship between E_{tot} and v was r=0.59 ($p<0.01$), between EC and dv was r=0.38 ($p<0.01$), and the polynomial relationship between dv and v was r=0.17 (p=0.28).

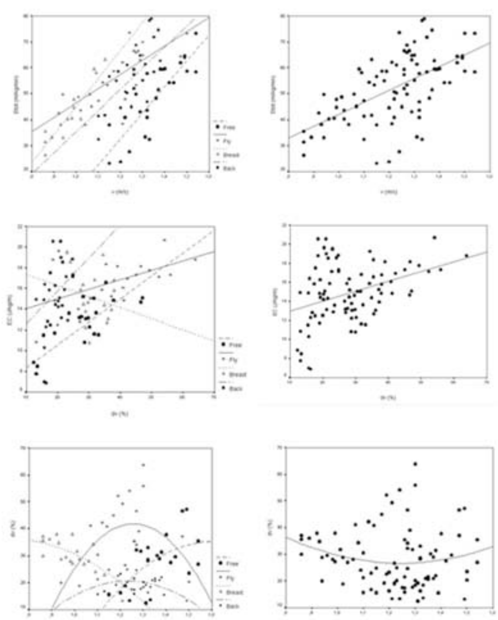

Figure 1. Relationships analysed between the bioenergetical and biomechanical variables, for each competitive stroke and for pooled sample.

In all situations, increases of E_{tot} were significantly related to increases in swimming velocity. The increase of E_{tot} is due to the necessity to overcome drag force, which is related to v. The higher adjustment of the linear relationship compared to the cubic one is due to the decrease of internal mechanical work to compensate the hydrostatic torque at higher velocities (4). Increases of the dv promoted significant increases of the EC, except for Breaststroke. Speed fluctuation while swimming as compared to swimming with constant velocity leads to an increase in the amount of total energy expenditure done by the swimmer (2). This increase is related to the need of overcoming the inertia and the drag force. Polynomial relationship between dv and v presented a better adjustment than the linear one. This phenomenon is described on regular bases for terrestrial locomotion (8). The parabolic function is explained by the curve between force and velocity for neuromuscular activity (6, 8). So, the data suggests that the neuromuscular activation of several muscles in a multi-segment and multi-joint movement follows the force-velocity relationship pattern for a single joint system (6).
Table 1 presents the partial correlations between EC and dv controlling the effect of v and the partial correlation between EC and v controlling the effect of dv. It seems that the increases of EC are strongly related to dv. Moreover, increases of EC are also strongly related to v, when controlling the effect of dv in the four competitive strokes. However, when a large number of observations from several competitive strokes are pooled together, the dependence of EC from v it is not so evident.

Table 1. Partial correlations between energy cost (EC), speed fluctuation (dv) and swimming velocity (v).

	Correlation between EC and dv controlling v	Correlation between EC and v controlling dv
Freestyle	r= 0.62 (p<0.01)	r=0.43 (p=0.05)
Backstroke	r= 0.55 (p<0.01)	r=0.56 (p<0.01)
Breaststroke	r= 0.60 (p=0.01)	r=0.86 (p<0.01)
Butterfly stroke	r= 0.55 (p=0.01)	r=0.51 (p=0.02)
Pooled sample	r= 0.39 (p<0.01)	r=0.16 (p=0.14)

CONCLUSION
The bioenergetical and biomechanical parameters analyzed presented significant relationships in each of the competitive strokes, so that changes in dv enhanced EC and E_{tot} considerably. Biomechanical evaluation of swimming technique, and identification of execution critical points, may, consequently, be critical for performance enhancement in a biologically restricted supply of energy.

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METABOLIC AND MECHANICAL CHARACTERISTICS OF OLYMPIC FEMALE GOLD MEDALIST

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To clarify metabolic and mechanical characteristics of a superior swimmer, an Olympic gold medalist was compared to 16 elite Japanese college swimmers who belonged to an inter-college champion team. Maximal oxygen uptake ($\dot{V}O_2max$), maximal blood lactate concentration (LA_{max}), a drag coefficient, a drag exponent, drag-swimming speed relationship and maximal propulsive power (MPP) were determined. In the comparison of $\dot{V}O_2max$, LA_{max}, and MPP, no marked differences were observed between the gold medalist and the other swimmers. On the other hand, the drag-swimming speed relationship revealed lower drag for the gold medalist, especially at higher swimming speed (near race pace). Taken all, it is suggested that mechanical (technical) factors, such as propelling efficiency and the stroke technique to reduce drag, should be considered as more significant determinants of superior swimming performance.

Key Words: metabolic capacity, active drag, stroke technique, performance, gold medallist.

INTRODUCTION

Swimming performance is determined by several factors like metabolic capacity, drag and stroke technique, and thus many investigations have examined the relative importance of these factors for swimming performance. However, since data related to top swimmers are very limited, it would be interesting to investigate metabolic and mechanical characteristics of an Olympic gold medalist. Therefore, to enhance the understanding of the relative importance of various swimming performance for superior swimming performance, we performed a physiological and biomechanical analysis of an Athens Olympic gold medalist, and compared her profile to those of Japanese college top swimmers.

METHODS

Subjects

The subjects were 16 elite Japanese college swimmers who belonged to an inter-college champion team in 2005, and the 800m free style an Olympic gold medalist. Their mean (±SD) age, height, and body mass were 20(±1) yrs, 1.65(±0.05) m, and 57.3(±3.1) kg, respectively. The physical characteristics and best records are indicated in Table 1. Each subject was fully informed of the purposes, protocol, and procedures of this experiment, and any risks, and voluntarily participated in this study.

Experimental procedures

Maximal oxygen uptake ($\dot{V}O_2max$), maximal blood lactate concentration (LA_{max}), and swimming speed at onset of blood lactate accumulation (V_{OBLA}) were measured as indices of metabolic capacity. Also a drag coefficient, a drag exponent, drag-swimming speed relationship and maximal propulsive power (MPP) were determined as indices of mechanical characteristics. Metabolic and mechanical measurements were done on a separate day following procedures described below, and it took almost one week to complete all measurements.

Table 1 Physical characteristics and personal best records for each particular stroke of subjects

subject	height m	body mass kg	Age yrs	Best record	min.s.		min.s.
A	1.76	62.3	23	400m FR	4.06.74	800m FR	8.24.54
B	1.62	54.8	22	200m BU	2.13.63	200m BR	2.34.64
C	1.59	54.5	22	200m FR	2.05.26	400m FR	4.21.75
D	1.67	59.2	22	100m BA	1.04.36	200m BA	2.16.68
E	1.60	52.7	21	100m BA	1.02.62	200m BA	2.12.04
F	1.63	52.1	21	100m FR	58.31	200m FR	2.04.01
G	1.63	54.9	21	50m FR	27.19	100m FR	58.45
H	1.66	60.6	21	200m BA	2.16.62	100m BA	1.04.51
I	1.60	53.6	20	200m IM	2.18.47	400m IM	4.51.32
J	1.66	57.2	20	200m FR	2.02.27	400m FR	4.17.10
K	1.71	56.4	20	400m FR	4.24.71	800m FR	9.01.27
L	1.60	59.0	19	200m IM	2.24.00	400m IM	4.57.10
M	1.70	58.7	19	400m FR	4.19.08	800m FR	8.57.00
N	1.60	60.2	19	400m FR	4.14.19	800m FR	8.41.80
O	1.62	60.4	19	100m BU	59.69	200m BU	2.11.67
P	1.67	58.4	19	50m FR	26.7	100m FR	58.2
Q	1.66	59.8	19	50m FR	26.6	100m FR	58.1

FR : free, BR: breast, BA : back, BU : butterfly, IM : individual medley

$\dot{V}O_2max$

The measurement of $\dot{V}O_2max$ was carried out during front crawl swimming in a swimming flume (length 17.2 m, width 5.0 m, height 8.0 m). Water was circulated in a 2.1 m wide and 1.4 m deep channel (Ogita and Tabata 1993). An incremental swimming speed test was used to determine $\dot{V}O_2max$ and the water flow rate was increased by 0.03-0.05 $m \cdot s^{-1}$ every minute. The protocol was set individually to cause exhaustion in 8-12 min. VO_2 was measured every 30 s during the last few minutes of exercise, and the highest value was taken as $\dot{V}O_2max$.

V_{OBLA} and LA_{max}

To determine the relationship between swimming speed and blood lactate concentration, each subject was asked to swim five times 200m at the swimming speed of 80%, 84%, 88%, 92% and 100% (maximal effort) of her best record. From 1st to 4th trial, each trial was separated by 5 minutes, and blood lactate concentration was measured at 1 minute after the end of 200m swimming. Before the 5th trial, the subject was allowed to rest for at least 20 min, and blood lactate concentration was measured at 3 and 5 min after the end of swimming. V_{OBLA} was estimated by intrapolating to a swimming speed at which 4 $mmol \cdot l^{-1}$ would occur using the relationship between swimming speed and blood lactate concentration. The highest $[La^+]$ value was accepted as LA_{max}.

Active drag and MPP

All mechanical analyses were completed with a modified MAD system similar to that described by Toussaint et al. (1988) (Fig. 1). The essential aspects of the apparatus and the accuracy of the collected data have been previously described in detail (Ogita 2004, Toussaint 1988). The important points are summarized here.

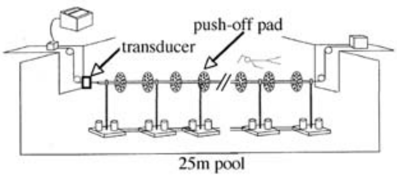

Fig.1 Schematic side view of system to measure active drag (MAD system) used in this study

The MAD system allowed the swimmer to push off from fixed pads at each stroke. The 15 push-off pads were fixed 1.30 m apart on a 23 m horizontal rod 0.75m below the water surface. At one end of the swimming pool, the rod was connected to a force transducer. Force signal was low-pass filtered (30-Hz cut-off frequency), on-line digitized at 100-Hz sampling rate, and stored on a computer hard disk. For the drag measurement, the subject performed only arm stroke (without leg kicking), while the legs were supported and fixed together by the same pull buoy (buoyant force 15.7N). Therefore, the average propulsive force applied by the arms equaled the average drag force (F_d). For the calculation of average F_d, the first and last push-off force were neglected to eliminate influence of the push-off from the wall (first-pad) and the deceleration of the swimmer at the end of the lane (last pad). The remaining force signal is time integrated, yielding the average F_d. The mean swimming speed was computed from the time needed to swim the distance between second and last pad (i.e. 16.9m).

To determine the drag-swimming speed relationship, the subject was asked to swim 25 m 8 to 12 times at different but constant swimming speed. On each trial, mean F_d and mean swimming speed (v) were measured. These v and F_d data were least-squares fitted to the function

$F_d = A \cdot v^n$

Where A and n are constants of proportionality, and were respectively adopted as drag coefficient and drag exponent in this study. Propulsive power was calculated by the product of F_d and v, and the highest value was accepted as MPP.

Measurements

VO_2 was determined by the Douglas bag method. The face mask used for collecting expired gas allowed unhindered movement of the arms during swimming. Expired gases passed through a low resistance valve and tubing (length; inspiration side: 1.0-m, expiration side 2.0-m, inner diameter 36 mm). The O_2 and CO_2 fraction in the expired gas were determined by an automatic gas analyzer (Vmax 29, Sensormedics Corporation, California, USA). Expired gas volume was measured by a dry gas meter. Blood lactate concentration was determined by an automatic analyzer (Lactate Pro, Arkray, Kyoto, Japan).

Statistics

The values were expressed as mean and SD or individual value. Standard correlation statistics were done to test the relationship between swimming speed and several variables, and the 0.05 level of significance was used.

RESULTS

Relationship between swimming performance and measured variables

When swimming speed calculated from the swim time of the 200m exhaustive trial was related to measured variables, significant correlations were only observed for V_{OBLA} ($r=0.753$, $P<0.01$) and for the drag coefficient ($r=-0.583$, $P<0.05$) (Table 2).

Table 2 Correlation between 200m swimming performance and measured valuables

	VO_2max		Lamax	V@OBLA	A	n	MPP
	$l \cdot min^{-1}$	$ml \cdot kg^{-1} \cdot min^{-1}$	$mmol \cdot l^{-1}$	$m \cdot s^{-1}$			W
200m speed	0.227	0.296	0.053	0.753**	-0.583*	0.182	0.101

**$P \leq 0.01$ *$P \leq 0.05$

Gold medalist vs other elite swimmers

The gold medalist was the tallest of our subjects, and had a better physique compared to the others (Table 1). In the comparison of $\dot{V}O_2max$, the absolute value of the gold medalist was relatively high, but this value expressed as per unit of body mass was close to the average (Fig. 2). LA_{max} of the gold medalist was considerably low. On the other hand, her V_{OBLA} was the highest of all swimmers.

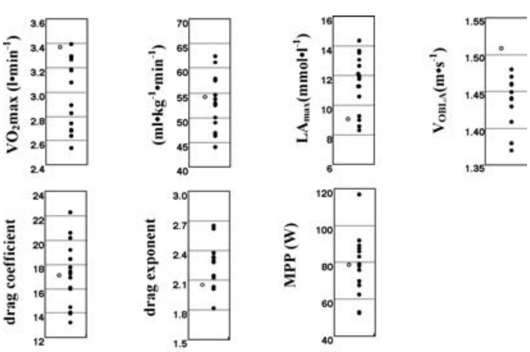

Fig 2 Comparison of metabolic and mechanical data between gold medalist and top swimmers Open circle indicates the value of the gold medalist.

In the comparison of mechanical factors, drag coefficient, drag exponent, and MPP of the gold medalist were almost equal to, or smaller than the average of the others. However, the drag-swimming speed relationship for the gold medalist showed a tendency for below average drag values, especially at higher swimming speeds (near race pace) (Fig. 3).

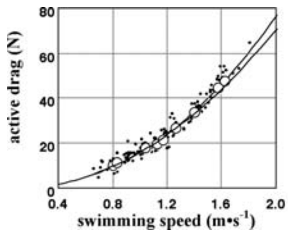

Fig 3 Comparison of drag-swimming speed relationship between gold medalist (open circles) and top swimmers (closed circles).

DISCUSSION

It has been considered that higher metabolic capacity is a very important factor determining swimming performance. Indeed, if swimming efficiency is the same, it should be true that a higher metabolic capacity will enable faster swimming. However, the metabolic capacity for this gold medalist as measured with the, i.e. $\dot{V}O_2max \cdot kg^{-1}$ and LA_{max} for the gold medalist was not exceptional in this study. This suggests that her superior swimming performance would not be caused by higher metabolic capacity, but by swimming efficiency. Swimming efficiency is determined by the product of mechanical (gross) efficiency and propelling efficiency (Toussaint 1994). According to Toussaint (Toussaint 1990a, b, 1994), the mechanical efficiency in swimming does not differ between elite swimmer and less skilled swimmer. On the other hand, propelling efficiency reveals greater difference between competitive swimmer (61%) and triathletes (44%), which would largely depend on the swimming technique. Therefore, higher propelling efficiency could be one of important determinants of superior swimming performance.

Also, it is a common observation that proficient swimmers are much more economical in VO_2 than that in the less skilled swimmers (Holmér 1972, Toussaint 1990a). The lower VO_2 would be attained not only by higher propelling efficiency but also by lower power to overcome drag (i.e. lower drag). Actually, in the gold medalist, the drag at higher swimming speed became lower in comparison to the other swimmers even though her physique is the biggest of the subjects. Therefore, drag which can be reduced by a better swimming technique would be considered as a significant determinant of superior swimming performance.

CONCLUSION

Finally, it is concluded that metabolic capacity might not be necessarily a dominant determinant in top swimmers but that mechanical (technical) factors, such as propelling efficiency and the stroke technique to reduce drag should be considered more significant determinants of superior swimming performance.

ACKNOWLEDGEMENTS

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SWIMMING EVALUATION, ADVICE AND BIOFEEDBACK

INVITED CONTRIBUTION

THE USE OF CRITICAL VELOCITY IN SWIMMING? A PLACE FOR CRITICAL STROKE RATE?

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For any swimmer, a hyperbolic relationship links velocity (*v*) and stroke rate (SR) to time to exhaustion (*t*). The asymptotes of these relationships are called Critical Velocity (CV) and Critical Stroke Rate (CSR). Both could be maintained, at least in theory, indefinitely. This review presents the origins of these two concepts, their physiological / biomechanical underpinnings to emphasis their usefulness for training. Coaches should appreciate the ease in using the CV model to set training loads, monitor training effects, and predict performance. The CSR concept is very recent and should be further investigated. However, current available knowledge suggests there is merit in using the two parameters for training.

Key Words: Critical velocity, critical stroke rate, swimming training, swimming evaluation.

INTRODUCTION

Understanding that physiological assessment of athletes is inherent to a good training process, laboratory testing in Sports and Exercise Science are becoming more and more accessible to athletes and a wide range of testing procedures are today recommended in the literature for cyclists (15) and runners (26). Physiological assessment should be sport-specific (3), but routine measurements are technically limited in swimming (41), assessing the physiological potential of a swimmer remains challenging. A number of 'field' tests have been developed. Smith et al. (41) acknowledge, in a review on the physiological and psychological tools used in the evaluation of swimmers, that the first-level of evaluation should be the competitive performance itself. The use of the individualised swimming speed versus time performance 'curve' based on a series of criterion effort has appeared attractive and appealing for physiological assessment in swimming (41). The 'critical swimming velocity' concept could provide the basis to analyse the effects and trends brought about through training, predict future competitive performance, and provide recommendations for continued directional training. Alongside the critical velocity concept (CV), a critical stroke rate (CSR) concept has been proposed in swimming (11). The purpose of this review is to address the usefulness of CV and CSR for swimming training. Because of a lack of evidence concerning the validity and reliability of the second parameter that can be derived from the CV concept (the Anaerobic Distance Capacity, ADC), its usefulness for training is not presented in the present review.

ORIGINS OF THE CONCEPTS: THE CRITICAL POWER CONCEPT

The CV and CSR concepts are extensions of the critical power concept originally introduced by Monod and Scherrer fifty years ago (35). Attempting to improve the understanding of the local work capacity of one muscle or one synergistic muscle group, these authors highlighted that local work (*W*) and time to exhaustion (*t*) were linearly related (Equation 1). The slope of the relationship, called Critical Power (CP), was defined as a 'threshold of local fatigue' while the y-intercept (a) was corresponding to a reserve of energy.

$$W = a + CP.t \qquad \text{(Eq. 1)}$$

CP can also be derived from the *P-t* relationship. The higher the power, the lower the time to exhaustion, so that the *P-t* relationship is hyperbolic, with CP being its asymptote. Indeed, when time tends to the infinity, power tends to CP. CP is therefore mathematically defined as the power that can be maintained indefinitely.

The 2-parameter model has been one of the first physiological models applied to human endurance (1). Indeed, it was used few years later to model world records dating from 1965 in swimming, running, speed skating, and cycling (14). The aims were to predict performances and to explain the limits of human endurance. A *d-t* relationship (Equation 2) equivalent to equation 1 of Monod and Scherrer (35) was proposed. The y-intercept of the relationship (Anaerobic Distance Capacity, ADC (23)) was therefore a distance in meters which could be run on oxygen reserves and the energy supplied by anaerobic metabolism, while the slope (CV (23)) was interpreted as a maximal rate of synthesis of these reserves by aerobic metabolism. This application of the CP concept to cyclic activities is not without assumptions that are better detailed in Dekerle et al. (8).

$$d = ADC + CV.t \qquad \text{(Eq. 2)}$$

In the latter stage of the 20th century, most of the works on the models of Monod and Scherrer (35) and Ettema (14) were conducted to affine the methodology used to plot the *W-t* and *d-t* relationship, and better define the physiological meanings of the different constants. The numerous *post hoc* interpretations of the slope and the y-intercept of the *d-t* and *W-t* relationships these last 50 years have permitted a better understanding of the physiological meanings of the above-mentioned parameters.

CRITICAL VELOCITY IN SWIMMING

Methodology and reliability.

Three equivalent models can be used to calculate Critical Velocity in swimming (CV). Indeed, CV is represented by the slope of the *d-t* relationship (Equation 2; Panel A, Figure 1), the asymptote of the *v-t* relationship (Panel B, Figure 1), and the y-intercept of the *v*-1/*t* relationship. The relationship the most used in swimming to derive CV is the linear *d-t* one (Panel A, Figure 1). This is certainly due to its easy application from the plot of two or more swimming performances over time. Performances recorded on several events allow critical velocity to be determined (Figure 1, Panel A). It is however important to remember that the value of this slope is dependent on the exhaustion times used to plot the relationship (8, 13) (influence of the energetic cost in swimming). It is therefore recommended to include in the model tests or races that enable VO_2max to be reached (between 2 and 15 min). Competitive distances ranging from 200 to 1500m can be advised in swimming (33, 49). According to these requirements, and in a wish to make the determination of critical speed easy and rapid for coaches, the suggestion of Wakayoshi et al. (47) and Dekerle et al. (11) to base this determination on only two performances (200m and 400m) seems today pertinent.

However, using only two performances to derive CV would decrease its level of reliability. This has to be considered when using the *d-t* relationship to predict performance or monitoring effects of periods of training. It can be noticed that CV determination has been shown to be reliable even if exhaustion times are variable (21, 44) and physiological responses at CV have also been shown in swimming, to be reproducible (4).

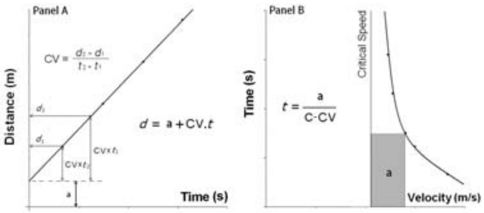

Figure 1. Illustration of two different but equivalent representations of the 2-parameter CV model.

Definition and validity.

According to its mathematical definition, CV has firstly been thought to correspond to a sustainable intensity and has been compared to parameters such as the maximal lactate steady state (MLSS; highest intensity that can be maintained without any drift in the blood lactate concentration ($[La^-]$)) or the onset of blood lactate accumulation (OBLA; intensity corresponding to a 4-mmol.l^{-1} of $[La^-]$ during an incremental test). Wakayoshi et al. (47) and Brickley et al. (4) obtained steady $[La^-]$ values during several 400-m blocks performed at CSV (around 3-4 mmol.l^{-1}). But the 30-45 sec of rest enabling blood samples to be taken between the blocks could have helped the swimmer keeping his motivation, limiting the drift of $[La^-]$ and maintaining a 'relatively' good efficiency. Stroking parameters have indeed been shown to change, with progressive stroke rate increases and stroke length decreases within and between the 400-m blocks (4). Most authors today agree that CV does not correspond to a sustainable intensity. In fact, swimmers can hardly maintain their CSV for longer than 30-40 min (unpublished data from our laboratories) and CV has been shown to be close to the velocity of a 30-min test (11) and higher than MLSS (10) and OBLA (12, 40, 47, 48). Similar responses and exhaustion times have been recorded on treadmill and ergocycle (5, 7, 17, 22, 34, 36, 39).

CV is today defined as the upper limit of the heavy intensity domain, i.e. the highest intensity that does not allow VO_2max to be attained during a constant load exercise (19). Below CV, progressive drifts of blood $[La^-]$, heart rate and VO_2 ('slow component') are observed but maximal values are not reached. The slow component of VO_2 is not great enough for VO_2max to be attained. Capillary blood $[La^-]$ can attain 8-10 mmol.l^{-1}. These speeds can be maintained from an hour (exhaustion times usually recorded at MLSS) to 30-40 min. High inter-individual variations were also reported (Brickley et al., 2002). In swimming, CV would refer to a 2000-m performance.

Above CV, because of the slow component phenomena, VO_2max should be elicited. The work of Hill and collaborators (19, 20) corroborates this definition in running and cycling but this has not yet been directly verified in swimming. However, it is in line with several findings reported in the literature. CV has been shown in swimming to be a good indicator of the capacity of the aerobic energy system (43). Several studies confirmed this finding in young swimmers (6, 42). CV is lower than the end velocity of an incremental test, traditionally identified as the maximal aerobic velocity (around 92-96% of the 400-m velocity in trained swimmers (4'15 up to 4'45)). It is highly correlated to OBLA (45, 47, 48), the average 400-m velocity (45, 47, 48), and MLSS (10). The first belief that CV was sustainable for a very long period of time was a misinterpretation of the mathematical (and not physiological) definition of CV, i.e. the intensity that can be maintained "in theory" indefinitely.

THE USE OF CRITICAL VELOCITY IN SWIMMING?

Setting training intensities

CV allows demarcating two different intensity domains and should be used as a reference to set training intensities. The 400-m pace is usually used by coaches for this purpose. However, two swimmers with similar performances on 400 m can have different aerobic potentials (Figure 2). One can swim a 1500 m quicker than the other one (and so on, for short races). The physiological stress to exercise of long duration will be different for the two swimmers. It is important to properly individualise training loads to optimise the physiological adaptations while avoiding overtraining especially when accuracy in the definition of the training loads is required as higher levels of performance.

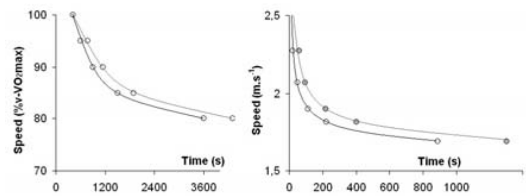

Figure 2. Schematic of the speed-time relationship of two different swimmers having different aerobic potentials.

Using CV for aerobic training programs offers great potential. It allows better setting of continuous, long and short interval training for each. Continuous training (2000-3000m) and long interval training at and below CV would induce great lactic acid production leading to accumulation of H^+ that would be buffered and La^- that would be oxidised in different body cells. An example of long interval training could be 6 to 10 x 400m swum at CV with 15-sec rest. Indeed, several 400-m blocks performed at CV can be swam with steady $[La^-]$ values (around 3-4mmol.l^{-1}) when separated by 30-40s of rest (4). Among all acute adaptations, we could expect a great improvement of the buffering capacity and oxidative potential of several body cells on top of the muscular ones (18). This increase in the buffering capacity has been shown to well explain the improvement of performance of trained athletes (30).

The other interest in swimming above CV relies on the hypothesis that to improve the VO_2max of trained athletes, VO_2max has to be solicited, and thus for a long time (2). Short interval training could then appear as one of the most interesting forms of training since it enables the time spent at VO_2max to be up to threefold those recorded during a continuous training. Short interval training presents other interests: 1) since the fifties, it is used by long and middle distance runners to train at speeds close to competitive ones (2). In swimming, it therefore enables to swim at stroke length and stroke rate ratio close to the competitive ones. 2) It induces a greater lipid solicitation for a given work done compared to continuous training (for example, 15 sec at 100% of VO_2max, 15 sec rest, compared to an hour at 50% of VO_2max). Consequently, greater physiological adaptations (especially a greater oxidative capacity of the type 2 muscle fibres;

lower muscular glucose and glycogen, and greater lipid reliance for a given intensity after training). It has even been evocated that in highly trained population, performances can 'only' be envisaged using short interval training (2, 30). On top of the improvements of the aerobic capacity and power, increase in anaerobic capacities has also been observed after a period of short interval training in trained athletes (2, 30). Adequate long and short interval training above CV (20-30 x 100m at 110% CV, 30-s rest; 1min at 120% CV, 1min rest for 20 min) would therefore enable VO_2max (very high heart rate and stroke volume) to be solicited and maintained for a very long time.

Central and peripheral adaptations occur with training performed around CV but it can be expected that the peripheral adaptations induced by swimming at and below CV would be less predominant with the increase in the intensity, the central adaptations becoming even more important.

Interval training swum around CV has been mentioned to be of great interest for improving aerobic and anaerobic potentials of swimmers. On top of these physiological adaptations, this kind of training allows swimming at high race paces while challenging the aerobic potential (200- up to 1500-m pace in this case). Training at race pace is important, especially in swimming where swimming coordination (42), energetic cost (6), and technical efficiency are changing depending on the velocity. Short interval training would enable to focus on the swimming techniques whose swimmers should attempt to maintain efficient while fatigue progressively develops during such long aerobic work performed around CV.

Monitoring training effects and predicting performance

A few studies conducted in laboratories have shown the 2-parameter model to be affected by training (24, 25). Aerobic training has a positive effect on CV (32). In swimming, MacLaren and Coulson (31) reported an increase and steady state in CV determined from the performances over a 50, 100, 200, and 400-m race, after a 8-week aerobic training period and a 3-week anaerobic training period, respectively. The results concerning the intercept of the *d-t* relationship were not reported as consistent.

Recently, Dekerle and Carter (in press) analysed the changes in CV during the last century of swimming Olympic performances. The greater improvements of long distance performance compared to shorter ones between two Olympic Games induced an explainable increase of CV. Plotting the *d-t* relationship would enable to monitor the effects of training on CV over a season (Figure 3) but further investigations are required to clarify the methodology that has to be used (number of performances required to plot the *d-t* relationship). Regarding the findings concerning the intercept of the *d-t* relationship, we would suggest being prudent when interpreting its value and change over time.

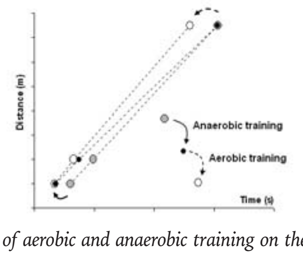

Figure 3. Effects of aerobic and anaerobic training on the d-t relationship.

As shown in rowing (27) and running (16), when knowing the equation of the *d-t* relationship, it is possible to predict performance. Again, this should be confirmed or infirmed in swimming by further research. However, because of the good linearity of the relationship, coaches can try to predict performance as long as they are ranging between around 2 and 30 min (8).

A PLACE FOR CRITICAL STROKE RATE?

Alongside the endurance-time relationship, the CP concept has recently been extended in swimming to characterise the stroke rate (SR) – *t* relationship (11). Several studies have illustrated the hyperbolic SR – velocity curve (9, 28, 29, 37, 46). Indeed, when attempting to swim faster, a swimmer will increase his SR. This increase in SR will be detrimental to the stroke length (SL) above a given sub-maximal intensity (MLSS or OBLA (9, 28, 29, 37)). Consequently, the longest the race is, the lowest the speed is, and the lowest the SR is. Dekerle et al. (11) suggested that the SR-*t* relationship could be modelled using a hyperbolic model, the asymptote being called Critical Stroke Rate (CSR). CSR is mathematically defined as the highest SR that can be maintained indefinitely, i.e. for a very long period of time.

The determination of CSR does not required extra-tests to be performed compared to the CV determination. It relies on the record of the SR of each performance. The hyperbolic SR-*t* relationship can then be modelled (Figure 4, Panel B). To simplify the modelling, Dekerle et al. (11) proposed another model equivalent to the hyperbolic SR-*t* one. This procedure enables a quick and easy determination of CSR by using a simple linear regression method. Indeed, CSR is also represented by the slope of the "number of stroke cycles" (N=SR x *t*) – *t* relationship (Figure 4, Panel A).

No study has yet tested the reliability of the CSR concept and further investigations should also focus on its validity. However, Dekerle et al. (11) reported regression line coefficient of 0.99-1 when modelling the N-*t* relationship (performances over a 50, 100, 200, and 400m swim). CSR was not significantly different and was highly correlated to the average SR of a 30-min test. Moreover, when swimming at CV, the nine participants spontaneously adopted SR values similar to CSR. Similarly, when having to swim at the imposed CSR, participants swum at CV.

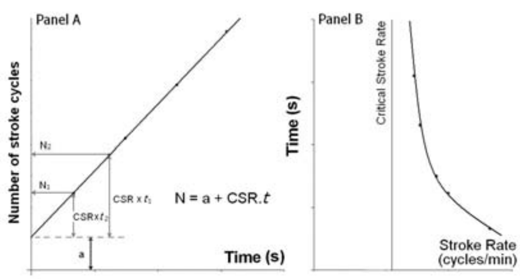

Figure 4. Illustration of two different but equivalent representations of the 2-parameter CSR model.

It is today acknowledge that SR/SL ratio should be monitored during training in order to control and even improve stroke efficiency. When preparing a repetition, alongside the set of distance/duration, intensity, number of repetitions, and duration and form of the recoveries, coaches should control the

SR/SL ratio in order to preserve a good technical gesture. When considering the results of Dekerle et al. (11), it could even be suggested that a given SR could be imposed during training repetitions rather than the usual time "allowed" to cover a given distance. Because training is just about "pushing the limits of the swimmer", the aim in aerobic swimming training performed at CV could consist in maintaining CV with a lower SR than CSR, or maintaining CSR while swimming faster than CV. This would require higher SL to be adopted and maintained.
As explained above, it is known that training at race pace is of importance for technical aspects of the strokes. Therefore, this training strategy relying on the multiple combinations linking the stroke parameters ("task constraint" strategy) should be performed at any velocity of the race spectrum. The SR-*t* relationship that supports the CSR concept could then represent a very useful tool for coaches.

CONCLUSION
The actual knowledge on the application of the CV concept seems sufficient to underlie its interests for training. The *d-t* relationship is a useful tool for setting training intensities, monitoring training effects, and predicting performances. However, "luckily" for researchers, further research is required to confirm its meaningfulness in swimming (responses at and above CV) and usefulness for training (among all, effects of training at intensities around CV, effects of training on the *d-t* relationship, kicking *vs* full stroke CV, prediction of performance). Almost all the studies conducted on the CV have been conducted on trained swimmers whose 400-m performance ranged from 72-84% of the world record. Published data on elite international swimmers will help to create strong performance indicators. More work on the Critical Stroke Rate concept is needed that incorporates an input from coaching, biomechanics, motor control, and physiology.

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INVITED CONTRIBUTION

TECHNOLOGY APPLIED TO OPTIMISE TREINING FOR IMPROVEMENT OF FRONT-CRAWL SWIMMING PERFORMANCE

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Peak performances in swimming require the full deployment of all powers a swimmer possesses. The development of those powers require years of hard training. Developments of measurement technology (e.g. MAD-system (16)) have aided the sport scientist in identifying several factors as determinants of performance. These include drag, propulsion technique, and mechanical power (20). The development of this knowledge provides the modern swimming coach with some guide-lines how to design training programmes. However, it may be argued that training-time will be especially efficient when devoted to the enhancement of those performance factors that are weak links in the individual performance chain. This implies that on an individual level it is necessary to identify in what phase of the process the performance system first becomes insufficient. In the training process it is rather challenging for coaches to determine which training load is sufficient to induce the required adaptation without risk of overtraining. More insight in the individual relation between training dose and adaptation response is necessary to optimise this training process. Training dose and changes in swim performance capacity can be modelled (2). In this model performance is a systems output varying over time according to the systems input; the training dose or training impulse (TRIMP), quantified from exercise intensity and volume. Thus the swimmer is represented by a system with a daily amount of training as input and performance capacity as output. It is possible to use heart rate recordings as training dose indicator while simple time trials monitor performance capacity development. A sketch will be given how technological developments leading to instrumented swimming wear could be put to use to optimise the training process.

Key Words: drag, mechanical power output, propelling efficiency, training, competitive swimming.

INTRODUCTION

Science has long since entered the sporting arena, with computer aided analysis forming an integral part of the athlete's daily training regime. In doing so the athletes overall performance is dismantled into segments. So the question is how in the field of swimming a mosaic of individual analyses is formed that can be combined to create the top swimmer. However, swimming presents a special challenge for the sport scientist. Unlike on-land activities, the propelling forces are generated by pushing off from water that gives way. If forces are to be measured, where can you put a force transducer?

The MAD-system, the system to Measure Active Drag, solves this problem. Fixed push-off pads are provided to the swimmer and push-off forces can be measured (Figure 1). It is employed by the Swimming Research Center Amsterdam, and provides a degree of measurability into an element in which capturing any other data than time is very difficult. It is an example of how technology is applied to measure key parts of the mosaic which enables for example to study propelling forces separately as a part of the overall performance. Other factors like drag forces, mechanical power output and propelling efficiency can be measured as well. When conducted at regular intervals, tests assist the trainer in identifying and filtering out flaws. In this paper a brief sketch is given of these tests and of how technology is applied to support the analysis of the training process.

The long-term goal of the collaboration between the Amsterdam Swimming Research Center and Top Swimming Amsterdam (TZA) is to develop tools that will enable prediction of individual performance given a training program. This requires development of mathematical models describing the relationship between training doses and the response in terms of adaptation of the swimmer leading to a better performance capacity (3). A sketch will be given how technology can be applied to develop such a training aid.

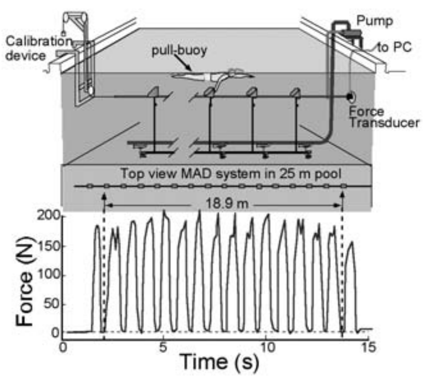

Figure 1. Schematic drawing of the MAD-system mounted in a 25 meter pool. The MAD-system allows the swimmer to push off from fixed pads with each stroke. These push-off pads are attached to a 22 meter long rod. The distance between the push-off pads can be adjusted (normally 1.35 m). The rod is mounted ± 0.8 m below the water surface. The rod is connected to a force transducer enabling direct measurement of push-off forces for each stroke (see lower panel). (note: the cord leading to the calibration device is detached during drag-measurement).

PERFORMANCE FACTORS

Human swimming performance can be studied by looking at the interaction of propelling and resistive forces. Given this 'force-balance-approach', a swimmer will only improve performance by reducing resistive forces, or drag, that act on the swimming body at a given velocity or by increasing the propelling forces. However, this point of view is limited and ignores the peculiar propulsion mechanism in water. On land propulsion is made from a fixed point. In water the push off is made against water that will undergo a velocity change. Therefore, part of the mechanical energy generated by a swimmer is necessarily expended in giving water a kinetic energy change (16). This implies that part of the mechanical work the swimmer delivers during the push-off is spent on moving water. Hence, only a proportion of the total mechanical energy the swimmer delivers is used to move forward, while the other part is expended for moving water. Since in competition swimming velocity is to be optimized, it is more relevant to look at the time derivative of the work produced by the swimmer, i.e. the mechanical power production. Thus in competitive swimming two important mechanical power terms of the total power (P_o) can be discerned: power used beneficially to overcome drag (P_d) and power lost in giving water a kinetic energy change (P_k). The ratio between the useful mechanical power spent to overcome drag (P_d) and the total mechanical power output (P_o) is defined as the propelling efficiency e_p

$$e_p = \frac{P_d}{P_o} = \frac{P_d}{P_d + P_k} \qquad \text{(Eq. 1)}$$

Swimming fast will therefore depend on 1. the ability to produce a high mechanical power output enabling the generation of high propelling forces, 2. the ability to reduce drag, while 3. keeping power losses to pushed away water (P_k) low, i.e. swimming with a high propelling efficiency. Of course, knowledge of the backgrounds of propulsion, drag and propelling efficiency is relevant if swim performance is to be optimized. An overview of the different theories regarding propulsion is outlined elsewhere (20, 21).

Drag

Throughout the history of swimming research, attempts have been made to apply technology to determine this resistance. As early as 1905, Dubois-Reymond (6) towed people behind a rowing boat, measuring resistance with a dynamometer. Amar (1) was the first to assume that the resistance is related to the square of the swimming speed

$$D = K \bullet v^2 \qquad \text{(Eq. 2)}$$

in which *D* denotes drag, *K* is a constant, and *v* the swimming speed. Both Amar (1) and Karpovich (11) used measurement techniques determining the resistance of swimmers gliding passively through the water. The relation between resistance (N) and speed ($m \bullet s^{-1}$) based on their experiments was approximately $D = 29\ v^2$. It was conjectured that the movements necessary to create propulsion could induce additional resistance. This resulted in attempts to determine the drag of a person who is actively swimming. Techniques to determine this *active* drag were developed by several groups in the 1970's (4, 5, 10, 14). A common feature of the methods developed was their adoption of extrapolation techniques. These methods yielded comparable results and, as expected, higher values (150-300%) than the previously reported values for *passive* drag.

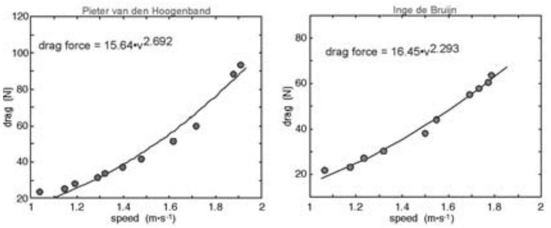

Figure 2. Active drag dependent on speed for a male (left) and female (right) elite swimmer.

In the mid-1980's, Hollander *et al.* (9) developed an approach to measure active drag (MAD-system). The technique relies on the *direct* measurement of the push-off forces while swimming the front crawl. Later on, Kolmogorov and Duplisheva designed yet another method to determine the active drag (12). When these more recent techniques were used to estimate *active* drag (12, 17) considerably lower values were found than active drag values reported in the 70's. Kolmogorov's approach yielded even lower values: $D = 16 \bullet v^2$. A comparison of this method to drag determinations employing the MAD-system for the same group of swimmers suggests that similar drag results are found provided that the equal power output assumption in the velocity perturbation test is not violated (18). An example of recordings of the active drag-speed relationship is given in Figure 2 for a male and a female elite swimmer.

Components of drag

The total drag (F_d) swimming at a constant speed consists of frictional (F_f), pressure (F_p), and wave drag (F_w) components, namely (8):

$$F_d = F_f + F_p + F_w \quad \text{(Eq. 3)}$$

Frictional or viscous drag originates from fluid viscosity, and produces shear stresses in the boundary layer. The magnitude of frictional drag will depend on the wetted surface area of the body and flow conditions within the boundary layer.

Pressure or form drag arises as a result of distortion of flow outside of the boundary layer. The orderly flow over the swimmers' body may separate at a certain point, depending on the shape, size and velocity of the swimmer. Behind the separation point, the flow reverses and may roll up into distinct eddies (vortices). As a result, a pressure differential arises between the front and the rear of the swimmer, resulting in 'pressure drag', which is proportional to the pressure differential times the cross sectional area of the swimmer.

For swimming near the water surface, a third component of the total resistance is due to the so-called 'wave-making resistance'. Kinetic energy from the swimmer is lost as it is changed into potential energy in the formations of waves.

It is interesting to note that friction drag is a small component of total drag. Especially at higher swimming speeds friction drag is estimated to be below 5% of total drag (25). Several suits were introduced to reduce drag. Technology is applied to fabrics that have biomimetic knitted constructions forming ridges, where small vortices are formed. The ridges are scientifically calculated for height and width to the exact proportion as that of the Shark's dermal denticles, which is the most efficient configuration for SPEED! (from Speedo: FAST-SKIN – THE FACTS, 2000). However, the assumption underlying the proposal that riblets are performance-enhancing is itself controversial. Vogel (24) questioned that tenet:

'Drag reduction has been claimed for just about every feature of the surface of every large and rapidly swimming animal. The present chief candidate is the ridging characteristic of the dermal scales of sharks. These are claimed to be lined up with the local flow direction. It should be emphasized that in sharks these are tiny ridges, closely spaced-less than 100 micro-meters apart and still less in height - and that what is involved is a reduction of skin friction. Two matters, though, get omitted from popular accounts. First, no one seems to have any direct evidence that the ridges actually reduce the drag of sharks or that they work on sharks by the proposed mechanism. And second, the drag reduction achieved with the artificial coatings are less than 10%, enough to create excitement in the hypercompetitive world of boat racing, enough perhaps to make a difference to fitness in the competitive world of pelagic predation, but nothing approaching the difference in skin friction between laminar and turbulent flows.

Writers of popular material in science are biased toward believing what scientists claim or even suggest. I think what's needed at this point is a bio-fluid version of Koch's famous postulates in bacterial epidemiology. A claim of drag reduction should be viewed with scepticism until it: (1) has been tied to a plausible physical mechanism, (2) has been shown to work on physical models under biologically relevant conditions, and (3) has been shown to work by some direct test on real organisms under controlled and reproducible conditions. Much less desirable alternatives to the third are interspecific comparisons of morphology and correlation's of morphological differences with differences in habit and habitat.'

Tests of the effect of the Speedo Fast-skin™ on drag using the MAD-system did not reveal any effect and certainly not the 7.5% drag reduction claimed by Speedo (15, 19).

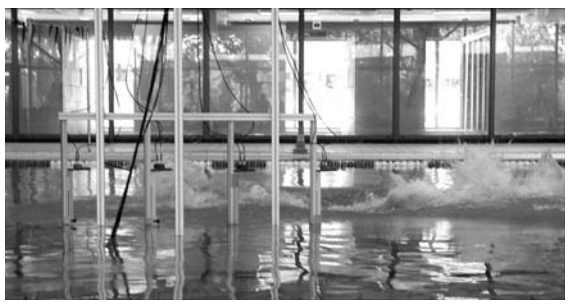

Figure 3. Left panel: The four wave probes, registering wave amplitude, were located at a fixed distance from the MAD-system. The distance between the wave probes was 0.5 meter; the probes covered half a stroke-cycle of the swimmer. For each probe the wave resistance was calculated. It seemed that the wave resistance varies during the stroke.

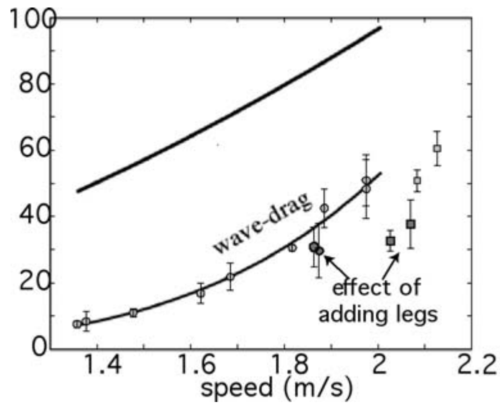

Figure 4. Individual estimates for wave drag dependent on speed. Error bars indicate the uncertainty interval of each estimate. The wave drag swimming free arms only is not different from that swimming on the MAD-system (filled dots). The addition of leg activity (swimming whole stroke; filled squares) seems to induce lower wave drag for this swimmer.

Wave drag
Similar to what occurs for ships, wave amplitude increases with increasing swimming speed. Is it possible to make an estimate of wave making resistance and assess its relative importance? A first approximation is to determine the wave drag using the longitudinal wave cut method (7), a technology borrowed from ship-building research (see Figure 3) and now applied to human swimming. Wave drag was estimated while drag was measured swimming arms only on the M.A.D.-system enabling a comparison of the magnitude of wave drag to that of total drag. Results indicate that wave drag amounts up to 50% of total drag swimming (arms only) at maximal speed (Figure 4). The results show that wave drag cannot be neglected when contemplating improvement of competitive swimming speed. For some swimmers leg activity actually seems to induce lower wave drag (Figure 4), probably by reducing the stern wave by disrupting the pressure field at the rear of the swimmer. The magnitude of this drag reducing effect for this swimmer is about 10% of total drag. This suggests that the mechanism of how leg kick could reduce wave drag deserves thorough investigation. This is a promising area where technology will aid in discovering relationships between metabolic, morphological, mechanical and coordinative aspects of swimming.

Propelling efficiency
The generation of propulsion in a fluid *always* leads to the loss of mechanical energy of the swimmer that will be transferred in the form of kinetic energy to the fluid. Two aspects of this analysis are important for human swimming: (i) the power losses are considerable ($e_p << 100\%$), and (ii) the power losses to the water are highly dependent on technique.

Measurement of propelling efficiency
The total mechanical power a swimmer produces is apportioned to power to overcome the total resistance and power to generate the propulsion. If for simplicity it is assumed that average drag relates to speed squared, the average mechanical power required to overcome drag will thus equal

$$P_d = F_d \cdot v = K \cdot v^2 \cdot v = K \cdot v^3 \qquad \text{(Eq. 4)}$$

The calculation of the mechanical power lost in the generation of propulsion (P_k) and therewith the determination of e_p, is less obvious. One approach is to compare the speed swimming of all out sprints 'free' to the speed swimming sprints on the M.A.D.-system (see for a more in depth description of this approach 22). The fixed push of pads below the water enabling propulsion generation without loss of energy to the water. Therefore, all-out sprints performed on the M.A.D.-system enable faster swimming than all-out sprints swimming 'free'. Considering that power to overcome drag relates to swimming speed cubed and assuming equal power output in two 25 m sprints (free and M.A.D.), the ratio of speed cubed sprinting all-out 'free' relative to the speed cubed sprinting all-out on the M.A.D.-system reflects e_p, recasting equation 1:

$$e_p = \frac{P_d}{P_o} = \frac{K \cdot v_{free}^3}{K \cdot v_{M.A.D.}^3} = \frac{v_{free}^3}{v_{M.A.D.}^3} \qquad \text{(Eq. 5)}$$

Using the latter approach propelling efficiency values of on average 73% (range 65.5 – 81.2%) for an average speed of 1.64 m•s^{-1} were found. The e_p value of 81% observed in one of the subjects is remarkable, albeit that this subject is a world record holder and an Olympic Champion during the time of testing. Repeated testing over a season reveals that propelling efficiency is more or less constant in elite swimmers.

Measurement of power output
In a group of eleven elite swimmers the effect of training was evaluated approximately every 6 weeks (June-June) by evaluating maximal power output (W) of the arms (MAD-system). The maximal power output showed significant ($p<0.05$) changes during the season, which seemed to be related to the training volume. The overall increase in power output was 18% ($p < 0.01$).

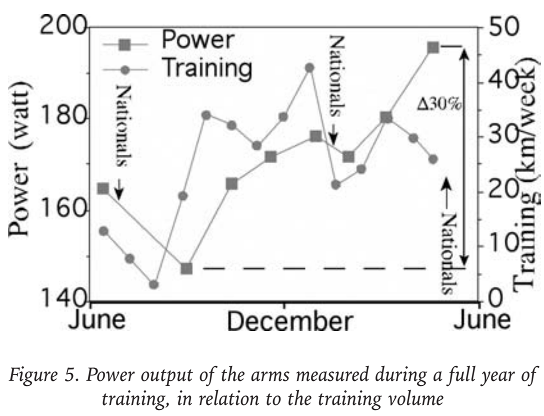

Figure 5. Power output of the arms measured during a full year of training, in relation to the training volume

Expressed in percentage of change, the power output showed the greatest response to training: 18% increase in 1 year. In this group of highly trained swimmers (among them 3 Olympic medal winners) this was a surprising result.

MAD-Training

The observation that training led to considerable changes in mechanical power output measured on the MAD-system raised the question whether training on the MAD-system would be helpful to increase power output with consequent performance improvement. The reasoning is that the push off is made against fixed points and consequently higher forces can be achieved. This suggested that such an arrangement could provide a useful water based training device which would be very specific to the normal movement pattern. During ten weeks the training group followed the same program but 3 times per week sprints performed on the MAD were substituted for normal free swimming sprints. Despite the fact that training time and volume were equal, the training group showed a significantly greater improvement in power (from 160 to 172 W, 7%) as measured on the MAD system, and an increase in distance per stroke in free swimming. The training group showed a significant improvement in race times for 50 m (from 27.2 to 26.6 s), 100 m (from 59.3 to 57.4 s), and 200 m (from 129.6 to 127.3 s). It was concluded that the MAD-system is a specific training device especially suitable for increasing maximal power output during swimming (23).

FUTURE TECHNOLOGY APPLIED TO TRAINING

In the training process it is rather challenging for coaches to determine which training load is sufficient to induce the required adaptation without risk of overtraining. More insight in the individual relation between training dose prescription, actual individual training dose and individual adaptation response is necessary to optimise this training process. In a preliminary study training prescription of a group of 6 elite swimmers was compared to the actual training executed by the swimmer. Differences of up to 30% between distance and speed were observed. Hence, training prescription provides only a rough indication of the actual training carried out by the swimmer. Furthermore, the same physical load (e.g. in terms of for example speed) can have different physiological effects when swimmers are compared, given individual differences in drag factor, propelling efficiency and mechanical efficiency. Nowadays swim coaches are used to express the exercise intensity in swimming speed. Target times for specific distances are set. However a small difference in velocity leads to a great difference in exercise intensity. This is because the power needed to overcome drag (P_d) is dependent on speed cubed (see Eq. 4). When swimming speed is 3% higher the swimmer has to produce 9% more power. It is difficult for the swimmer to swim exactly the speed prescribed by the coach. Therefore target times seem not to be the best method to quantify the exercise intensity and to determine the training dose of swimmers. Consequently, the optimization of the training seems insurmountable complex when all these factors have to be taken into account. However, it is possible to by-pass these complexities by conceiving the training swimmer as a ‘black box’, linking the adaptations to physical training without detailed analysis of the underlying physiological processes (2). In this model performance is a systems output varying over time according to the systems input; the training dose or *training impulse* (TRIMP), quantified from exercise intensity and volume. The subject is represented by a system with a daily amount of training as input and performance capacity as output. The working of the system is described by a transfer function, which is the sum of two first order transfer functions (3). One function represents the adaptation to training leading to enhanced fitness (fitness factor). The second function represents the fatiguing effects of exercise (fatigue factor). For quantifying the training dose, exercise volume and intensity during training has to be monitored. Exercise intensity could be determined as the rate at which ATP is hydrolysed and converted into mechanical power. Unfortunately, it is difficult to measure the metabolic power precisely during training in the swimming pool. Therefore, exercise intensity has to be determined from a variable that is closely related to energy expenditure rate and is easily monitored. Heart rate reflects the amount of work the heart must do to meet the increased energy expenditure rate when engaged in activity. Measuring exercise intensity by monitoring the heart rate is based on the linear relationship that exists between heart rate and metabolic exercise intensity during dynamic exercise. Is it possible to use heart rate as indicator of training dose rather than blood lactate values as previously used by Mujika (13)?

For three swimmers heart rate was monitored each training during an intensive 18 day training period. Every third training swimmers performed a time trial at the end of the training to monitor changes in performance capacity. The fit between modelled and actual performance was significant for all subjects; r^2 ranged from 0.680 to 0.728 ($P < 0.05$; see Figure 7). It is thus possible to use heart rate recordings as indicator for the training dose. This opens up the possibility to apply technology to monitor training intensity and link this in a structured way to training prescription, such that optimisation of training prescription on an individual level can be achieved.

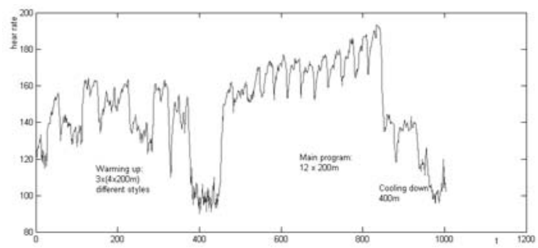

Figure 6. Hear rate recorded during training is used to quantify TRIMP.

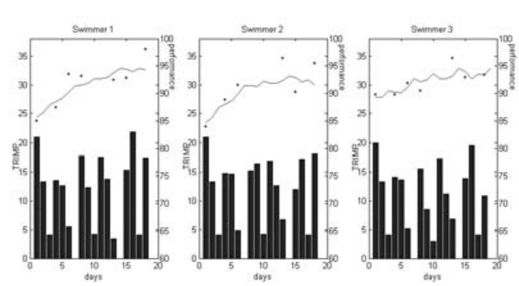

Figure 7. Bars represent TRIMPs; line represents predicted performance; dots represent criterion performance.

CONCLUSION

Performance in swimming can be decomposed in several performance factors. Factors like power output, propelling efficiency and drag can be measured using the MAD-system. Technology can be applied to quantify training load in relation to changes in performance capacity. This opens up the possibility of optimization of training prescription on an individual level.

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SPEED AND PHYSIOLOGIC REPLY IN SWIMMING, CYCLING AND RUNNING

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The triatlon is characterized for being a test of effort of long duration of pace of aerobic and anaerobic intensity. To determine the variations before maximum and submaximum intensities in relation to the speed, it has been studied the behavior of the heart rate and of the lactate accumulation as physiological variables, the effort perceived as psychological variable and the frequency of movements as cinematic variable. The results have showed that the metabolic exigency before maximum intensities of mixed character aerobic/anaerobic in swimming is less than in cycling and in running. The intensity of 90% of the maximum speed, comes closer to the values of the Anaerobic Threshold in the tests of swimming and cycling, being higher in the test of running. In conclusion, the percentage of Speed does not seem to be an equivalent indicator for three disciplines to discriminate the intensity of the effort.

Key Words: lactate, heart rate, rating of perceived exertion, speed, frequency of cycle y triathlon.

INTRODUCTION

The sport of triathlon is characterized for being a test of effort of long duration of very varied nature with changes of pace of aerobic and anaerobic intensity. Three disciplines compose it: swimming, cycling and running. The anaerobic threshold (UA) changes in three disciplines of the triatlón (1, 2). With relation to the heart rate (HR) as a variable determining the intensity different responses have been studied in each of the disciplines (3). Other authors (4) propose the "Borg scale adapted" to determine "rating of perceived exertion" (RPE) in triathletes. The basic aims of this study has been to analyze and determine the physiological response in triathletes before maximum and submaximum efforts depending on the speed of movement.

METHODS

Sample

Eleven of national level amateur triathletes took part in this study with ages included between 18 and 32 years of age. They belong to four representative teams of the Valencian Community and they were in competitive period. As it is possible to observe in this distribution, there are 6 triathletes that come from the speciality of athletics, 4 from cycling and only one from swimming. The average of age was of 25,6 ± 4,7 years, the level of training was high for most of them, the average of height was 175,7 ± 5,8 cm and the average weight was 70,4 ± 4,7 kg.

Equipment

The materials used for the measurements in the different tests of evaluation were: the lactate tester "LACTATE-PRO" Blood lactate test meter (LT-1710) with test strip only (mark: ARCRAY, lot: L4K05B) to obtain the quantity of lactate in every level of effort and discipline; the POLAR pulsimeter S720i for the determination of the HR in every level of effort and discipline; chronometers KONUS with laps of 1/100 seg. (Konustart-3) to measure the times in the tests, the frequency of cycle and control of the laps in the application of the 90% the maximum speed tests; and finally the equipment of lights mark Swim Master (2) for the same control of laps in the test of swimming. For the capture of information a few schedules of record were in use.

Method

It consisted of the application of three field tests, one for every discipline, bearing in mind for its election the similar times of duration of effort, in order that it does not influence the results. Concretly they have been: 300 meters in swimming, freestyle, in swimming pool of 25 m; 3000 meters in cycling, in bicycle of personal route of similar characteristics with plate of 53 teeth and crown from 23 to 13 teeth, in velodrome of 250m; and 1500 meters in athletic career, in track of athletics of 400m. The above mentioned tests have been applied in two different forms: 1st at maximum intensity (100 %), that is to say, in the minor time or maximum speed (better personal mark); and 2nd at submaximum intensity (90 %) of the maximum obtained and applied speed controlled during the whole test with lap times.

Protocol

Has been taken into account the period of the competition in which the triathletes were, formalizing a short schedule of two weeks in which they did not foresee their participation in sports competitions, so that the study was not affecting in the competitive participation of the triathletes, nor that their competitive participation was affecting in the results of the study. In the first week there three tests of maximum intensity (100 %) have been applied in the alternate days and from 18 to 22h, always after a warming up from 15 to 20 minutes. In the second week and also in the alternate days and in the same conditions the test was applied to submaximum intensity (90 %).

Variables

They were obtained from the parameters measured in every test, discipline and the form of application has been: on, the one hand, the independent one or speed in m/s (S) in every tests and discipline to 100 % of intensity, and on the other hand the dependents, both to maxim (100 %) and submaximum intensity (90 %), the frequency of cycle in cycles/minute (CF), the maximum lactate in mM/l (LA), the pulsations per minute on having finished the test (HR) and the subjective value of the physical effort done according to Borg's Scale on having finished every test (RPE). All the variables were registered at the conclusion of each of the test. Extractions performed in case of LA from the minute 1 until the value was getting down were done every 2' to obtain the maximum value.

Analysis of results

First it was done in a description of the statistical values of all the dependent and independent variables as well as the percentage value of the independent variables in the test of 90% in relation to the values obtained in the test of 100% to maximum speed. Later, the statistical differences were calculated according to the test "t" of student for related samples of dependent and independent variables among three disciplines of the triathlon: the swimming, the cycling and the running with the statistical package SPSS v.11,5 for Windows.

RESULTS

In swimming at 100% 12,8 LA, 173,1 HR, 18,1 EPE, in cycling 14,4 LA, 179,4 HR, 18,2 EPE and in race 14,2 LA, 186,3 HR, 18,3 RPE show statistically significant differences between three disciplines ($p < 0{,}01$) to 100 % except in RPE in swimming, running and cycling. In cycling and running significant differences do not show in LA. In swimming 5,1 LA, 152,6 HR, 13,4 RPE, in cycling 5,9 LA, 158,3 HR, 13,5 RPE and in career 7,2 LA, 176,5 HR, 14,7 RPE show statistically significant differences between three disciplines to 90% ($p < 0{,}01$), except in swimming and cycling. In running and cycling it does not show significant differences (table 1). The percentage values of all the variables in V to 90% in relation to the values obtained in V to 100% (table 4) only find significant differences ($p < 0{,}01$) in swimming (39,9 % LA), 87,5 % HR, 74,1 % RPE) and in running (51,3, % of LA), 95,4 % HR, 80,8 % REP).

DISCUSSION

In the table 2 we can observe the times of effort done in three tests applied by disciplines, which show a few maximum differences of 23 seg. equivalently to a low percentage (8,6 %), understanding that the right election of the tests applied by their similarity in the duration of physical effort to maximum intensity (100%). This allows comparing the results of the dependent variables among the disciplines.
As for the use of the REP proposed by other authors (4) to determine the intensity of the effort done, the results show the efficiency of this tool since the information that contributes to discriminate with the differences obtained between disciplines both to 100% and to 90%. Thus, the athletic running is the discipline that needs a physiological higher response, followed by cycling and by swimming.

Table 1. Statistics of related samples and mean of differences between swimming variables and R, SW and C, R and C, SW in triathletes.

SW and R	N	mean	sd	p	SW and C	N	mean	sd	p	R and C	N	mean	sd	p
CF-100% SW	8	38,127	4,762	,000	CF-100% SW	7	38,161	5,143	,000	CF-100% R	10	94,153	5,847	,308
CF-100% R	8	95,536	5,470		CF-100% C	7	97,738	7,259		CF-100% C	10	97,317	6,123	
CF-90% SW	11	31,7888	3,963	,000	CF-90% SW	9	31,904	4,345	,000	CF-90% R	9	87,891	3,624	,312
CF-90% R	11	88,111	3,692		CF-90% C	9	91,055	9,373		CF-90% C	9	91,055	9,373	
RPE -100% SW	11	18,090	1,300	,676	RPE -100% SW	11	18,090	1,300	,810	RPE -100% R	11	18,272	1,348	,821
RPE -100% R	11	18,272	1,348		RPE -100% C	11	18,181	,873		RPE -100% C	11	18,181	,873	
RPE -90% SW	11	13,363	1,206	,000	RPE -90% SW	11	13,363	1,206	,846	RPE -90% R	11	14,727	1,190	,014
RPE -90% R	11	14,727	1,190		RPE -90% C	11	13,454	1,293		RPE -90% C	11	13,454	1,293	
LA-100% SW	11	12,790	1,788	,031	LA-100% SW	11	12,790	1,788	,018	LA-100% R	11	14,190	2,236	,783
LA-100% R	11	14,190	2,236		LA-100% C	11	14,418	2,459		LA-100% C	11	14,418	2,459	
LA-90% SW	11	5,109	1,167	,000	LA-90% SW	11	5,109	1,167	,326	LA-90% R	11	7,200	1,140	,230
LA-90% R	11	7,200	1,140		LA-90% C	11	5,936	3,067		LA-90% C	11	5,936	3,067	
HR-100% SW	7	175,571	8,734	,000	HR-100% SW	7	175,571	8,734	,004	HR-100% R	10	186,300	10,122	,001
HR-100% R	7	189,285	8,616		HR-100% C	7	181,714	7,587		HR-100% C	10	179,400	9,617	
HR-90% SW	10	152,600	10,123	,000	HR-90% SW	8	155,625	7,327	,210	HR-90% R	9	177,111	8,447	,002
HR-90% R	10	178,000	7,257		HR-90% C	8	162,250	15,663		HR-90% C	9	158,333	18,781	

The lactate concentrations (LA) obtained in the three specialities to 90% is over the anaerobic threshold of, theoretically, 4 mMl/l. The values obtained in the athletic running indicate that the intensity of the effort to speeds of 90% is over the UA. Contrary to this, in swimming and cycling 90% of the maximum speed comes closer to the values that represent an accumulation of LA related one to the UA. These results coincide with the contributed ones with other studies (1, 2). Moreover, it is important that at maximum intensities of mixed character aerobic/anaerobic like these in the present study swimming has a metabolic lower response that in cycling and running.

Table 2. Mean and descriptive estatistics of independent variable (v) of swimming (SW), running (R) and cycling (C) in triathletes, obtained directly from the time (t) in test of maximum intensity.

	SW					R					C				
V	N	M	sd.	Min.	Max	N	M	sd	Min	Max.	N	M	sd	Min.	Max.
T-100%	11	253,5	18,3	201,2	271,5	11	276,3	11,7	261,6	297,9	11	267,2	13,1	242,9	287,0
S-100%	11	1,2	0,1	1,1	1,5	11	5,4	0,2	5,0	5,7	11	11,3	0,6	10,5	12,4
T-90%	11	281,6	20,4	223,2	301,2	11	307,5	13,4	291,0	331,5	11	296,3	13,6	270,0	310,8
S-90%	11	1,1	0,1	1,0	1,3	11	4,9	0,2	4,5	5,2	11	10,1	0,5	9,7	11,1
S-90% of S-100%	11	90,0	0,1	89,8	90,1	11	89,9	0,7	87,8	90,4	11	90,2	0,7	89,9	92,4

As for the heart rate (HR) our observations coincide with other authors (3) in that swimming is the one that supposes an average lower HR, possibly due to a minor muscular implied mass, to the horizontal position or to the minor effect of the gravity, followed by cycling with higher results, being the highest those of running.
The order observed of lower to higher physiological exigency can justify the sequential order in which the triathlon develops: swimming, cycling and athletics.
Another outstanding aspect is the analysis on the differences between the percentage values of the independent variables LA, CF, REP and HR. From the results one distinguishes that to submaximum efforts (90% of the speed) the CF and the HR have similar percentage values in relation to their maximum responses (table 3).
The intensity of 90% of the maximum speed aproaches to UA's values in the tests of swimming and cycling (5,1 and 5,9 LA), being superior to the UA in the test of running (7,2 LA). These results seem to indicate a major muscular effort in the discipline of running.

Table 3. Mean and descriptive statistics of % of the dependent variables of swimming, running and cycling in triathletes, depending on the results of tests to 90% of intensity.

	SW					R					C				
v	N	M	sd	Min.	Max.	N	M	sd.	Min.	Max.	N	M	sd.	Min.	Max.
CF-90%	8	85,3	4,6	80,6	94,1	11	93,3	3,1	89,1	99,1	9	93,7	10,0	82,7	113,4
REP-90%	11	74,1	6,8	61,1	82,4	11	80,8	6,6	72,2	93,8	11	74,0	6,5	61,1	83,3
LA-90%	11	39,9	7,9	30,1	50,9	11	51,3	8,3	38,5	68,6	11	41,3	21,9	21,0	98,5
HR-90%	8	87,5	3,2	84,0	94,3	10	95,4	3,6	90,2	101,6	9	88,1	6,4	79,9	102,1

CONCLUSION
All the variables show a behavior different at 100% and at 90% of the speed in three disciplines, for what the percentage of speed does not seem to be an equivalent indicator for three disciplines discriminating the intensity of the effort.
The discipline of major physical effort is the athletic running; secondly, cycling and finally, swimming. We consider very suitably, according to the exigency of the physical effort, the established order in the triathlon (swimming-cycling-running).
The percentage responses of the CF and HR are those which come closer to the submaximum intensities (90%) depending on the maximum speed.

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VIDEOGRAMETRICALLY AND VELOCIMETRICALLY ASSESSED INTRA-CYCLIC VARIATIONS OF THE VELOCITY IN BREASTSTROKE

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The purpose of this study was to analyse the intra-cyclic variations of velocity in breaststroke through the analysis of its variation in the Centre of Gravity and in an anatomically fixed point – the hip. The aim was to verify whether the intra-cyclic variations of velocity of the hip (videogrametrically assessed – ViV_{hip1} – and velocimetrically measured – ViV_{hip2}) present similar patterns among them, and with the intra-cyclic variations of velocity of the CG (ViV_{CG}) in trained male and female performing 25 m breaststroke at maximum speed. The velocity was registered and analysed via videogrametric kinematic processor

using two cameras with dual-media assembling as described by Vilas-Boas et al. [9]. A speedometer with optic reader developed by Lima et al. [3] was used for mechanical velocimetery. Results pointed out that the speedometer can be used as a tool for diagnosing problems within stroke cycle due to the similar velocities patterns of the hip and CG.

Key Words: breaststroke swimming, intra-cyclic velocity variations, velocimetry.

INTRODUCTION

Performance is though associated to the need of overcoming the inertia, as well as, the hydrodynamic drag. The increase of mean velocity without increasing velocity variations is crucial to prevent greater energy expenditure. In competitive swimming, these intra-cyclic variations of velocity are considered to have a limiting effect on swimming performance. In breaststroke these variations have a more critical role than in other competitive strokes. McElroy e Blanksby [5] stated that intracycle velocity variations impose a higher energetic cost, statement that was afterward experimentally confirmed by Vilas-Boas [9]. Considering the skill level of swimmers, D'Acquisto et al. [2] characterized the better breaststroke sprinters as able to obtain a higher peak linear body velocity during propulsive phases, and by the ability of minimizing the drop in linear velocity before the propulsive phase of the arm pull.
Ungereschts [7] suggested that, aiming optimization of swimming mechanics should be given priority to a reduction of intra-cycle variations of linear velocity of swimmers. Thereby, intra-cycle profile of the velocity of a swimmer should be considered as a useful instrument to skill evaluation [4]. In fact, these variations during the stroke cycle allow very relevant information about the coordination of partial movements, so that improvements in technical training could be achieved by using them regularly [8].
A relevant issue in the study of intra-cyclic velocity variations is the controversy related to the usefulness and similarity of the kinematic profiles of the hip and the body centre of gravity (CG). From a dynamic point of view, the CG is more accurate then the hip, however, a less time-consuming evaluation and advice method is obtained with a fixed anatomical spot.
The aim of this study was to compare the kinematics of the hip obtained by biomechanical videogrametry (viV_{hip1}), and by cable (mechanical) velocimetry (ViV_{hip2}), with the velocity variation of the CG (ViV_{CG}) within a stroke cycle.

METHODS

Ten (7 female and 3 male) trained swimmers were studied. Mean age of the sample was 18.3 ± 2.9 yy. Each subject performed a 25 m Breaststroke at maximum speed. The swimmer's movement was videotaped in the sagittal plane with dual-media image technology [9] using two cameras (JVC GR-SX1 SVHS and JVC GR-SXM 25 SVHS). Both, cameras were real-time synchronized and images assembling conducted through an AV mixer (Panasonic Digital AV Mixer WJ-AVE5). A speedometer with optic reader, developed by Lima et al. [3], was used for cable (mechanical) velocimetery assessment. Video images were videogrametrically analysed using the Ariel Performance Analysis System, from Ariel Dynamic Inc. (APAS). The data collected by the speedometer were filtered to 50 Hz through MatLab (version 6.1) software. The obtained data were time normalised T (0-1). In order to obtain an intra-cycle variation profile, and evaluation parameters, six common points of analyse were defined, with T (0-1) / V (m/sec) coordinates (Table1). The stroke cycle begin was considered when the swimmer obtains the minimum velocity values before the start of the legs action (end of the recovery phase). Mean (±SD) computations for descriptive analysis were obtained for all variables, and Pearson correlation coefficients were computed. Differences between mean values were tested using t-test de Student for a=0.05.

Table 1. Analised coordinates in each stroke cycle.

vVt=0	T (0-1) V (m/sec)	Time value at the beginning of the cycle Velocity value at the beginning of the cycle
vVmax La	T (0-1) V (m/sec)	Time value at maximum velocity obtained by legs action Velocity value at maximum velocity obtained with legs action
vVminIC	T (0-1) V (m/sec)	Time value at the intermediate minimum obtained between legs and arms actions Velocity value at the intermediate minimum obtained between legs and arms actions
Time dif.	T (0-1)	Time difference value between peak values associated with legs and arms actions
vVmax Aa	T (0-1) V (m/sec)	Time value at the maximum velocity (2nd peak) obtained through the arms actions Velocity value at maximum peak obtained through arms actions
vVt=1	T (0-1) V (m/sec)	Time value at the end of cycle Velocity value at the end of cycle

RESULTS AND DISCUSSION

In general, the ViV_{CG} profile of the breaststroke swimmers was characterized by two velocity peaks, with higher values associated with the legs action (La). Consequently, the stroke cycle was characterized by two phases of positive acceleration and two other phases of negative acceleration, as described by Craig et al. [1]. For the total group, near zero velocity values (0.6 ± 0.1m/sec) were obtained in association with the legs recovery phase, as it was already described [10]. The maximum peak velocity within the stroke cycle was noticed as a consequence of the La (1.6 ± 0.1m/sec). Similar results were also previously described [1, 2, 10]. The average velocity values obtained were 1.0 ± 0.4m/sec, also similar to other previously obtained and used for research purposes [1, 6], inclusively higher than some others [2]. The mean time difference between the two peak velocities was 0.5 ± 0.1sec witch is in accordance with previous reports [1, 2, 10]. In terms of gender, the velocity values were not invariably superior for males. They were, for instance, similar for both genders in vVminIC (0.9 ± 0.1 m/sec to females and 0.9 ± 0.4 m/sec to males) and vVmax La (1.4 ± 0.1m/sec to both genders). In accordance with previous results [10], female swimmers weren't able to overlap the arm action with the leg action showing a minor transition phase, with a reduced velocity lost when compared to their male counterparts. A continuous time synchronization of the breaststroke technique seems to be advantageous because it allows the overlapping of the end of the propulsive phase of the leg kick and the beginning of the propulsive phase of the arm stroke. The mean value of the variation coefficient of the velocity distribution for females was of 0.44 ± 0.04, and for the males 0.45 ± 0.14.
Considering technical speciality, the values of velocity associated with the La were superior for the specialists (1.7 ± 0.3m/sec) in comparison with the non-specialists (1.6 ± 0.1m/sec), who obtained similar values of velocity of the

vVmax Aa (1.4 ± 0.1m/sec) as the specialists. The mean variation coefficient of the velocity of the specialists was of 0.44 ± 0.04 while for the non-specialists was 0.41 ± 0.06. For both independent variables (gender and speciality), no significant differences were obtained on analysed parameters previously discussed ($p \leq 0.01$).

The hip velocity shows the same patterns as the CG. Nevertheless it shows higher variations, probably associated to the fact of being a static body landmark; the peaks and valleys of CG velocity variation profile are, instead, minimized by the movement of the limbs throughout the stroke. As an example, we can take the upper limbs movement effect on the CG kinematics during the arm stroke phase; during this action the hip velocity increases more than the CG velocity, once the arms are creating propulsion by pulling back relatively to the body (accelerating the body, and the hip), but this backward movement of the arms toward the feet serves also to bring the CG slightly toward the feet, reducing the forward velocity increase. This phenomenon leads us to more extreme velocity values expected, and obtained to the hip in comparison to the CG.

The Pearson correlation coefficients obtained between the velocity distributions obtained for the hip (videogrametrically - ViV_{hip1} -and velocimetrically - ViV_{hip2}) and the CG are presented in Table 2, as well as the mean values calculated for the sample results.

Table 2. Pearson Correlation Coefficients obtained for each subject, and respective mean and standard deviation values for ViV_{hip1} vs. ViV_{CG}, for ViV_{hip2} vs. ViV_{CG} and for ViV_{hip1} vs. ViV_{hip2}.

Subject	viV_{hip1} vs. viV_{CG}	viV_{hip2} vs. viV_{CG}	viV_{hip1} vs. viV_{hip2}
1	0.92**	0.89**	0.94**
2	0.96**	0.86**	0.91**
3	0.93**	0.95**	0.97**
4	0.90**	0.89**	0.99**
5	0.91**	0.90**	0.96**
6	0.95**	0.95**	0.99**
7	0.94**	0.89**	0.98**
8	0.91**	0.91**	0.97**
9	0.86**	0.88**	0.95**
10	0.94**	0.93**	0.97**
Mean ± sd	0.92 ± 0.03	0.90 ± 0.03	0.96 ± 0.02

** $p \leq 0.01$

The correlations were positive and significant for ViV_{hip1} with ViV_{CG} (r=0.92 ± 0.03), for ViV_{hip2} with ViV^{CG} (r=0.90 ± 0.03) and for ViV_{hip1} with ViV_{hip2} (r=0.96 ± 0.02). Data obtained seems to be in accordance with those previously published by Maglischo et al. [4] despite correlations were not so expressive. All correlations were statistically significant for $p \leq 0.01$.

CONCLUSION

The speedometer can be used as a tool for diagnosing problems within stroke cycle due to the similar velocities patterns of the hip and CG. The hip and CG tended to accelerate and decelerate at nearly the same time. The hip velocity peaks tended to reach more extreme values as compared to the CG.

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EXPERIMENTING WITH VARIOUS STYLES TO OPTIMIZE THE PERFORMANCE PER CRAWL EVENT

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In this study, one disabled world record holder in crawl sprint is taken as a test case. In trying out various styles to optimize his performance, a rotating arm action style appeared to be the fastest on 50m sprint and a glide stroke with high elbow on longer distances. Movement analyses of the swimmer and observation of coloured water, displaced by the arm pull, were combined. During the downward movement of the hand in the stroke with high elbow, propulsion could be generated. In the two fastest styles, water appeared to be better displaced backward than in the other styles.

Key Words: crawl, style experimentation, optimizing.

INTRODUCTION

In this study, a disabled world record holder on 50m crawl participated in analysing his own technique. Due to an osteo sarcoma, his right leg was amputated above the knee in 1989, at

the age of six. Since 1995, he visited the Leuven Evaluation Centre frequently for technical and physical analyses. Since 1999, he competed in major championships in the S9 class (S10 is the least disabled).
In the Evaluation Centre, the first technical analyses of leg-amputated competitors were made at the Paralympics in Heidelberg, 1972 (5). They succeed in avoiding lateral body displacements by alternating a usual downward two-beat kick with a horizontal cross over leg kick. Nevertheless, at one side the body did not roll much, which was combined with a relatively lateral arm action. To keep the body horizontal, notwithstanding only one downward kick, submersing the head and entering the fore arm steeply downward were advised.
At the Paralympics in Athens, 2004, for the subject in this study a so-called rotating arm action style was the fastest on the 50m but too exhausting on the 100m. After the Games, his sprint styles were further investigated as well as a glide stroke with high elbow for longer distances. Because his upper limbs were very strong, he used a long arm lever, which was predominantly vertical (fig. 1). He experimented also with other levers. To simplify the problem of the body roll, he did not breathe. From video recordings, a quick routine movement analysis was made of the timing and the velocity variation. In addition, the direction of water displaced by the arm action could be estimated from side view by using coloured powder. In this study, a didactical approach, following Maglischo (3), was chosen to explain propulsion, namely that *"the law of action-reaction offers the most likely explanation for human swimming propulsion"*. Some authors, including those of this article, adhere the vortices theory (1, 8), while others treat this theory with caution (4). In this article, only visualised water, displaced behind the arm is discussed.

Figure 1. Front view of a leg-amputated crawl swimmer. Three instants delimiting phases (from side view, angles hand-shoulder-horizontal of 45°, 90° and 135°).

METHODS
The trials were recorded with two video cameras below the water surface (Sony-DV), from side and front view. A side view video-sequence was transferred to a PC using Adobe Premiere software. To study the timing, the instants delimiting phases of the arms were determined most at precise angles hand-shoulder-horizontal (fig. 2 and 3: C) (6). During one cycle, these phases were specified for both arms as well as the downward and horizontal cross over left leg kicks. To make interpretations about propulsion, a curve of the corresponding swimming velocity variation was calculated by digitising a point close to the hip joint every 0.04 sec (using TPS-DIG software) (fig.2 and 3: E). Because the two arms remain approximately opposed to each other with a rotating arm action, the hip velocity can be considered as almost equal to the velocity of the body centre of mass. Further, the paths of the midpoint of the hand or of the flat part of the forearm (wrist) with a high elbow style were drawn, as well as the positions of the hand or forearm at the instants delimiting the phases (fig. 2 and 3: A).
To visualise water displaced from the hand or wrist, a tape (containing sodium fluorescelnate powder) was attached on one of the midpoints (2). During the downward press phase, the displaced water could be observed apart (fig. 2 and 3: A 1). During the whole arm cycle, with small lateral deviations and a predominantly vertical hand path (fig. 1), three separate parts of displaced water (corresponding to three sweeps, from entry to ± 90°, to ±135° and to 180°) could be distinguished and were coloured differently on the still pictures (grey, black and white) (using Adobe Photoshop). The direction and the distance of these three displaced water parts could be estimated (from vertical white lines) (fig. 2 and 3: A and fig. 4).

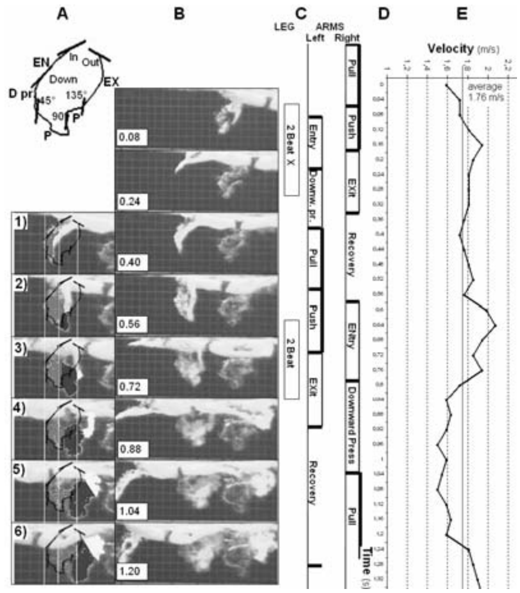

Figure 2: One cycle of a rotating arm action crawl of a leg-amputated competitor.
B: From a side view video recording, every 0.16 s a picture was taken.
D and C: Time line (s) and timing of the phases of:
- both arm actions: Entry, Downward press (to 45° in the angle hand-shoulder-horizontal), Pull (45° to 90°), Push (90° to 135°), Exit and Recovery,
- left leg actions: a usual downward 2 beat and a cross over (X) 2 beat.
E: Velocity variation of the hip and the average velocity (m/s).
A: The path of the midpoint of the left hand and its positions at the phase delimiting instants. Coloured water (by dye dissolved at the midpoint) divided in 4 parts:
- in A1: part kept close to the hand and forearm during the downward press phase (grey)
- in A2-A6: 3 separable parts, displaced during the whole cycle in sweeps: a) down-backward, ± 0° to 90° (grey); b) slightly in-up-backward, while flexing the arm, ± 90° to ± 135° (black), c) slightly out-upward, ± 135° to out (white). The distance and the direction of 3 water parts displacements can be estimated from 3 vertical lines (each starting when becoming visible).

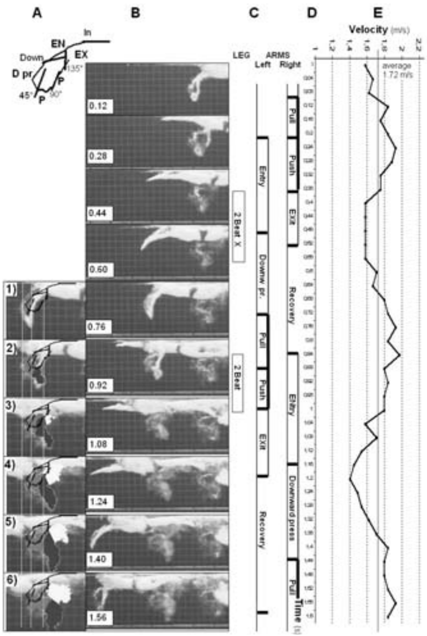

Figure 3. Glide stroke with high elbow: on each picture in A, the path of the midpoint of the flat part of the forearm (wrist) and the positions of the forearm at the phase delimiting instants. For explanation, see fig. 2.

RESULTS AND DISCUSSION

In the glide stroke with high elbow, the velocity increases already during the two downward press phases (fig. 3: E). Because meanwhile no propulsion is generated by the kick, while the other arm is recovering, the visualised water kept close to the hand and forearm, indicates that there is suction, resulting in propulsion (fig. 3: A1).

The success of the rotating arm action and of the glide stroke with high elbow could partly be explained because during each of the three sweeps the direction of the additional displaced water parts (including the water kept close to the arm during the downward press apart) is predominantly backward (fig. 4: A and B). Amazingly, the direction of the water displaced from the hand and from the wrist (with the high elbow style) is similar.

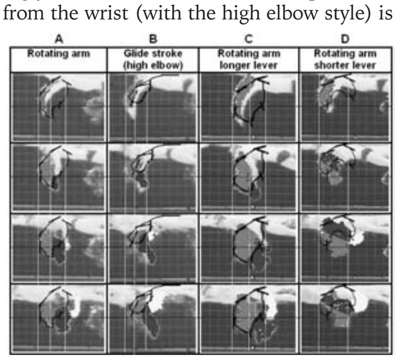

Figure 4. Movement path of the middle of the hand in three sprint styles (A, C, D) and of the forearm in a glide stroke with high elbow (B). For explanation, see fig. 2.

Because lateral left hand movements were small, there could be an analogy with the propulsion mechanism of the old paddle wheel with movable blades (7). Using a longer arm lever in the rotating arm action, more water mass was displaced but more vertically (fig. 4: C). Using a shorter arm lever, the parts of water displaced from the two first sweeps remain above each other and the part of water from the second sweep (black) is to close to the body (fig. 4: D). These observations could partly explain lower swimming velocities. For competitors with more body roll and more out and in sweeps of the arm, a bottom-view video recording could provide additional information about a sideward component of the water displaced backward.

CONCLUSION

Already during this study, his performances were improving although the training quantity was very limited, suggesting the value of experimenting with and reasoning about ones own technique. The recent performance improvements could partly be explained by minor technique changes after observing the water being displaced.

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ANTHROPOMETRIC PROFILE OF ELITE MASTER SWIMMERS

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In order to define a functional model of Master Swimmer, anthropometric data and upper and lower limb strength were assessed in 54 men and 61 women participants to the 10th Fina World Master Championships. ANOVA showed age-related significant differences ($p<0.05$), just in male subjects, concerning Fat Mass (FM%) percentage-increasing and thigh (TV) and forearm (FV) muscle-bone volume decreasing, which may be explained by decreasing of whole muscle mass. Different statistic tendencies among men and women might be due to i) lower muscle mass in females, whereupon the loss is reduced with aging and ii) different loss rate in muscular mass which is gender associated. Significant ($p<0.05$) strength progressive decrease came up to evidence, for both sexes.

Key Words: master swimmers, anthropometry, strength, gender differences.

INTRODUCTION

Researching on age-related physiological decline of functional capacity, and possibilities on limiting it, constitutes one of the most important study-branches in sport sciences, also for social effects in contexts of progressive increasing of average-aging in specific populations (1). Physical and sport activity is one of the most studied topics and it is widely recalled to be a good way on limiting aging-process of biological structures, on increasing age-related physiological functional capacity, on making elderly subjects more independent, on ensuring a better quality of life, and, finally, to avoid and/or prevent specific pathological conditions (9). The analysis on working and functional capacity in subjects practising sports in elderly age represents one of the best information sources in this field. Especially, the study and evaluation of the master athlete is extremely useful, giving possibilities to test capacity and functionality in subjects who train regularly and often intensively. Study on elderly subjects' performance and on specific adaptations induced by regular training (according to type and intensity) may bring useful information on human performance limits and on possibilities to maintain functional capacity or to limit physical decline, at least (3). We can consider swimming favouring to reliable and complete researches, since it has less trauma risks and high percentage of participants with higher sex-related homogeneity in later age-ranges compared to other sports (8). In addition to previously described main-features, or, even better, dealing with them research studies would supposed to give a contribute about a defining on "performance model", concerning not only a specific sport-discipline, but even measured on sex and age-ranges: this is not to waste because master activity has lost its main representative feature as a more "being together and socialize" practise than a competitive one since a long time ago, emphasizing agonistic aspects and willing to perform. It is obvious the need to set up different performance-models, each one referred to comparable age range.

Concerning a wide range of sport disciplines, studies having the same aims and bases are quite numerous now (4), most of their results are an important contribute to define features of master athletes and to understand performance-abilities according to sport and age-ranges. Researches on master swimmers studied performances and athletes characteristics, clarifying differences with younger athletes and giving information on anthropometric features and performing capacity (7, 10, 11). The purpose of this study is to provide a contribute on elderly athletes assessment and on definition of a profile in high level master swimmers, particularly about anthropometric characteristics and muscle strength values.

Table 1. Characteristics of 54 men and 61 women Elite Master Swimmers (mean ± DS).

	Gr./Age	N	Age yrs	H cm	W kg
	1 (40-49)	11	44.5±2.4	179.1±6.1	79.9±9.1
M	2 (50-59)	12	54.7±3.2	178.8±6.5	82.4±11.3
E	3 (60-69)	14	64.0±2.8	174.4±8.3	80.2±8.0
N	4 (70-79)	12	73.7±2.1	170.9±7.5	78.7±8.7
	5 (≥ 80)	5	85.6±7.4	170.7±8.7	71.1±11.1
W	1 (40-49)	15	44.4±2.8	165.5±7.3	60.5±8.2
O	2 (50-59)	21	53.8±3.2	163.1±5.1	61.3±6.5
M	3 (60-69)	12	64.5±3.3	161.1±5.5	59.2±6.2
E	4 (70-79)	11	73.9±2.7	161.0±6.6	64.3±10.9
N	5 (≥ 80)	2	89.5±3.5	151.5±3.5	53.5±6.4

METHODS

Among all the athletes participating in the 10th Fina World Master Championships, held in Riccione (Italy) in June 2004, 115 subjects (54 men and 61 women), aged 40 to 96, were recruited through paper advertisement. Age groups, height and weight of the subjects are shown in Table 1. The race performances of the subjects ranged between 10 and 30% less than the world record for the age group. Subjects gave their written informed consent to participate in the study which was previously approved by the Human Ethics Committee of the University of Urbino (Italy). Stature (H) and body mass (W) were measured with a telescopic rod and medical scale (Seca, Italy) and the body mass index (BMI) calculated. With subjects standing relaxed with legs slightly apart bicipital, tricipital, suprailiac and subscapular skinfolds at the dominant side were measured with a Harpenden skinfold calliper (British Indicators LTD, West Sussex, UK) and sum of skinfolds (SSK) was calculated. Fat mass % (FM%) was later calculated according to Durnin and Womersley (2). Furthermore, thigh (TV) and forearm (FAV) muscle-bone volume were estimated adopting a modified version of the anthropometric method proposed by Jones and Pearson (6). Maximal voluntary isometric knee extensors strength (keMVC) was measured on the dominant leg with a leg-extension machine (Panattasport, Apiro, Italy) equipped with a strain gauge, sampled at 100 Hz and linked to a data collection unit (Muscle Lab Bosco System, Ergotest Technology a.s., Langesund, Norway). The knee joint angle was 90° and the hip angle was 120°. The lever arm length was adjusted according to the leg length. Subjects were instructed to push against the lever as quickly and strongly as possible, trying to maintain the maximal force for about 3-4 seconds, while a vigorous verbal encouragement was given. The keMVC was calculated by averaging the values of force registered during 600 ms which included the maximal peak force point. Maximal voluntary isometric handgrip strength (hgMVC) was measured, on the dominant side, with a Jamar hydraulic hand dynamometer (Lafayette Instrument Co., Lafayette, IN, USA). Before the measurement, the size of the grip was adjusted to the subject's hand dimension. Subjects, standing upright with their arms at the side squeezed the grip as fast and as strong as possible, maintaining the effort for 3-4 s. Two trials were measured, with at least 1 minute rest in between. The best measure was selected as representative of the hgMVC. Data, separately for gender, were analysed by one way

ANOVA, followed by a Tukey HSD post-hoc test. Group 5 (subjects ≥ 80 years) was not included in the statistics, because of the reduced number, for both men and women.

RESULTS AND DISCUSSION

The result of measures according to the age groups (group 1 to 5), are shown in Table 2 and Table 3, for men and women respectively. The ANOVA showed, for anthropometric data, significant differences, only for men, in FM%: group 1 vs group 4, + 6.5%, p=0.00; TV: group 1 vs group 3, -16.4% and 4, -23.0%, p=0.02 and 0.00 respectively; group 2 vs group 4, -16.7%, p=0.03 and FAV: group 2 vs group 4, -14.5%, p=0.02.

Table 2. Anthropometric and strength data of 54 Men Elite Master Swimmers (mean ± DS).

Gr./Age	N	BMI	FM%	SSKFmm	TV ml	FAV ml	keMVC N	hgMVC N
1 (40-49)	11	24.8±1.8	20.1±4.6%	37.8±13.1	4607.0±585.7	1361.6±167.4	696.4±177.7	571.4±69.4
2 (50-59)	12	25.7±3.0	24.5±4.9%	46.3±14.2	4257.3±540.7	1405.6±218.7	677.7±196.1	553.2±79.5
3 (60-69)	14	26.4±2.6	24.7±4.1%	46.4±12.2	3852.6±646.0	1308.7±135.9	523.4±102.0	479.0±68.5
4 (70-79)	12	26.9±2.4	26.6±5.1%	53.2±17.0	3546.8±718.6	1201.5±161.1	410.3±63.8	398.8±57.8
5 (≥80)	5	24.3±1.9	23.5±3.6%	42.3±9.8	3214.3±461.8	1177.9±131.4	360.1±97.5	364.8±45.1

Table 3. Anthropometric and strength data of 61 Women Elite Master Swimmers (mean ± DS).

Gr./Age	N	BMI	FM%	SSKFmm	TV ml	FAV ml	keMVC N	hgMVC N
1 (40-49)	15	22.1±2.6	30.7±3.8%	51.5±17.8	3207.9±744.9	858.4±104.0	326.8±65.9	352.4±48.0
2 (50-59)	21	23.0±2.5	32.7±3.9%	49.8±14.3	2988.0±616.6	892.4±133.8	311.2±71.7	347.9±45.7
3 (60-69)	12	22.8±2.0	33.3±3.9%	51.9±14.5	3032.9±489.5	888.2±103.4	294.2±51.5	298.3±50.9
4 (70-79)	11	24.9±4.1	33.9±5.8%	56.6±21.8	2849.8±626.4	955.3±106.5	258.2±51.9	317.4±32.0
5 (≥80)	2	23.3±1.7	33.7±2.9%	52.5±11.5	2453.4±268.6	750.1±125.1	200.2±17.9	235.3±55.4

KeMVC shows significant differences for men in group 1 vs group 3, -24.8%, p=0.02, and vs group 4, -41.1%, p=0.00, and group 2 vs group 3, -22.8%, and vs group 4, -39.5%, p=0.04 and 0.00, respectively. For women keMVC differences are significant between group 1 and 4, -21%, p=0.04.

In men hgMVC's values are significantly different for group 1 vs 3, -16.2%, p=0.01, and vs group 4, -30.2%, p=0.00, for group 2 vs group 3, -13.4%, and group 4, -27.9%, p=0.04 and 0.00, and for group 3 vs 4, -16.7%, p=0.02, whilst in women hgMVC shows differences between groups 1 vs 3, -15.4%, p=0.01, and 2 vs 3, -14.3, p=0.01.

The results show that: i) there is, in men, a progressive increase in FM% and a decrease of thigh and forearm volumes, ii) there are no remarkable changes in female subjects concerning anthropometric parameters. This could be a direct consequence of muscle-mass and fat mass physiological values that in young adult subjects are different in men compared to women; men have higher muscle mass levels, so they could be sensible to remarkable changes related to physiological muscle mass decline (5).

Strength values show statistically meaningful reduction of isometric strength of knee-extensors both in men and women, even though the difference in men is progressive-depending on age ranks, as there is a significant difference just between range 1 and 4 in women. The values of hgMVC have a progressive, significant, reduction between groups both in men and women. Difference in age-related strength decrease, among men and women, could be due to different muscle mass in the two sexes.

CONCLUSION

The presented data in show the changes in anthropometric parameters and in strength values in various age-groups of high level master swimmers, by highlighting the differences among men and women they could be intended as a contribute to define a profile of Master Swimmer's performance. In fact, the increasing participation to Master Events, in addition to the increase of performances related to various age-ranges (e.g. world records) suggests the necessity of a specific approach to these athletes introducing an appropriate performance model focused on sport activity, gender and age and then new training methods and specific evaluation process. Moreover these data could be useful to other studies, even related to different sport and physical activity, giving information to understand the decline of some physiological capacities in elderly subjects.

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MAGNITUDE OF THE EFFECT OF AN INSTRUCTIONAL INTERVENTION ON SWIMMING TECHNIQUE AND PERFORMANCE

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The purpose of this study was to determine the magnitude of the effect of an instructional intervention on technique (as measured by the active drag coefficient, C_d) and performance (swimming velocity, SV). The subjects (12 male and 6 female competitive swimmers) were pretested with Aquanex+Video. A one-week intervention included three classroom and five poolside instructional sessions with technique feedback and

specific visual and kinesthetic cues designed to improve the C_d and SV. The subjects were then posttested. There was an overall significant improvement in both C_d and SV. The C_d decreased by .31σ (p<.05) and the SV increased by .26σ (p<.05). The results demonstrate that even a relatively short duration of carefully targeted instruction can make a meaningful improvement in technique and performance and will hopefully encourage coaches to reconsider training time allocation.

Key Words: biomechanics, technique, instruction, measurement, drag coefficient.

INTRODUCTION

In competitive swim programs, training distance is often given priority at the expense of technique instruction. There are countless stories of the training distance accomplishments of individuals and teams, but examples of programs that place similar importance on technique are rare. The lack of emphasis on technique may be related to a misperception about the potential impact on performance. The purpose of this study was to determine the magnitude of the effect of an instructional intervention on technique (as measured by the active drag coefficient, C_d) and performance (swimming velocity, SV).

METHODS

The subjects were 18 competitive swimmers (12 males and 6 females) between the ages of 12 and 15. The descriptive statistics for the males were: age (M = 13.1 yrs, SD = 1.16), height (M = 166 cm, SD = 10.2), and mass (M = 56.6 kg, SD = 10.1). The female data were: age (M = 13.2 yrs, SD = .75), height (M = 160 cm, SD = 4.1), and mass (M = 49.8 kg, SD = 5.6). Informed consent was obtained.

Subjects were pretested with Aquanex+Video sprinting over a 20 m swim to the wall with hand force and swimming velocity data collected over the last 10 m (Figure 1). The instrumentation and testing protocol were previously described and validated (1). Each subject was tested for all four strokes with about 1 min rest between trials. A MANOVA with repeated measures was used to analyze the data.

After the pretest, a one-week intervention included three classroom and five poolside instructional sessions. The classroom treatment included technique feedback based on the analysis of the synchronized underwater video and hand force data from the pretest. A frame by frame playback showed the variation of hand force with changes in arm position. The feedback included information about positive elements of technique, as well as limiting factors.

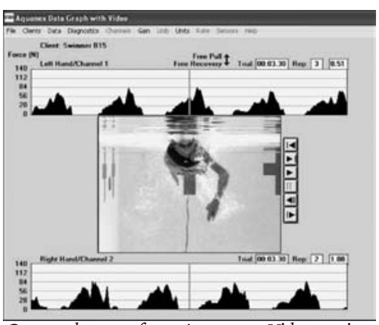

Figure 1. Captured screen from Aquanex+Video testing procedure shows synchronized underwater video image and hand force curves.

Also during the classroom sessions, specific visual and kinesthetic cues were related to positions within the stroke cycle based on a computer-generated model (Figure 2). The cues were associated with body segment and environmental references (e.g. the surface of the water) so that the swimmers could monitor control of their movements and thereby, improve the C_d and SV. The poolside instructional sessions reinforced the use of cues with additional explanation, drills that isolated certain cues, and immediate feedback regarding compliance with the cues. During numerous repeats of 25 m swims, the subjects were encouraged to swim at a slow enough velocity that they could control their movements to comply with the cues. Daily training distance during the intervention was similar to the typical distance for the subjects (5 km). The subjects were then posttested.

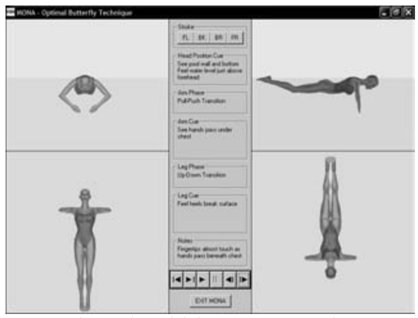

Figure 2. Biomechanical model for instructing subjects in the use of specific cues to monitor technique in butterfly.

RESULTS

There were no gender interactions so the data were collapsed across genders. There was an overall significant improvement (trial effect) in both C_d and SV. The C_d decreased by .31σ (p<.05) and the SV increased by .26σ (p<.05). There was a significant increase in stroke length (p<.01), but no significant increase in stroke rate. The pre- and posttest data are listed in Table 1 and graphed in Figure 3. Follow-up tests found a significant improvement in the C_d and SV for both backstroke and butterfly (p<.05).

Table 1. Swimming velocity, active drag coefficient, stroke length, and effect size (ES) data for pretest and posttest.

	Pretest		Posttest			
	M	SD	M	SD	ES (σ)	p
Swimming Velocity (m/sec)						
Backstroke	1.08	.09	1.13	.12	.47	<.05
Breaststroke	.93	.10	.96	.09	.27	
Butterfly	1.23	.14	1.30	.15	.46	<.05
Freestyle	1.30	.15	1.36	.13	.45	
Active Drag Coefficient						
Backstroke	1.23	.17	1.10	.13	.92	<.05
Breaststroke	1.55	.28	1.50	.38	.16	
Butterfly	1.06	.29	.91	.16	.67	<.05
Freestyle	.98	.20	.91	.14	.43	
Stroke Length (m/cycle)						
Backstroke	1.75	.22	1.87	.23	.53	<.01
Breaststroke	1.42	.20	1.53	.21	.58	
Butterfly	1.56	.17	1.62	.20	.32	
Freestyle	1.74	.20	1.80	.17	.31	<.05

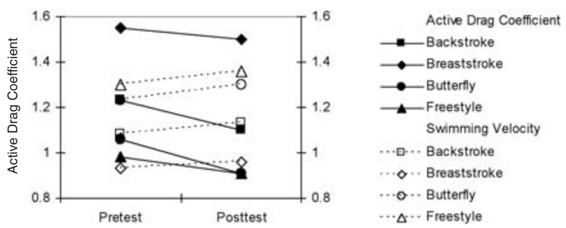

Figure 3. Changes in active drag coefficient and swimming velocity with instructional intervention.

DISCUSSION

In previous research (1), differences were found between faster and slower performance levels in active C_d (.46σ) and SV (.65σ). In the present experiment, the magnitude of the improvement in both C_d and SV was about one-half the size of the effect between those faster and slower swimmers. Even with a more modest rate of improvement after this initial treatment, it is conceivable that repeated instructional interventions would change "slower" swimmers into "faster" ones.

Previous research also found no significant difference in C_d across age groups of teenage swimmers who were not exposed to an instructional treatment (1). Swim teams often shift the emphasis for teenagers away from technique instruction and toward an increased training distance. The results of the present experiment show that substantial technique improvements for teenagers are entirely possible. In addition, the value of greater training distance on performance has previously been questioned (3). Quite possibly, the combination of reduced training distance with increased technique instruction will offer optimal conditions for improving performance.

The improvement that was found in SV is attributed to the increase in stroke length (SL), as there was no significant increase in stroke rate (SR). The SL and SR results are consistent with a decrease in C_d, as an overall improvement in hydrodynamics would increase SL, but not necessarily SR. If the increase in SV was not due to the treatment (i.e. the subjects simply swam faster on the posttest), then an increase in SR and possibly even a decrease in SL would have been expected.

The magnitude of the improvement is attributed to several key factors of the intervention. First, the swimmers had the advantage of a playback of their pretest that showed hand force variations with changes in arm positions. Second, visual and kinesthetic cues were associated with body segment positions so that the subjects had references for controlling and monitoring their technique adjustments. Third, poolside instruction with drills that targeted specific cues gave the swimmers many opportunities to swim short distances (25 m) without fatigue and at a velocity that they could control their movements to comply with the cues. Fourth, the subjects received immediate individual feedback regarding compliance with the cues. Although any one of these four components can help a swimmer improve, the combination of factors provides a more complete treatment for making changes.

CONCLUSIONS

A one-week instructional intervention significantly improved both C_d and SV. The results demonstrate that even a relatively short duration of carefully targeted instruction can make a meaningful improvement in technique and performance. Consequently, it is recommended that coaches include the following instructional components in their programs: underwater video and hand force analysis; specific visual and kinesthetic cues for controlling and monitoring technique changes; adequate repetitions at a slow enough velocity to allow control and develop mastery; and individual feedback immediately following performance. The magnitude of the effect of this instructional intervention will hopefully encourage coaches to reconsider training time allocation.

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SUPPORT SCULL TECHNIQUES OF ELITE SYNCHRONIZED SWIMMERS

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The purpose of this study was to investigate support scull techniques in synchronized swimming based on three-dimensional motion analysis. The support scull movements of ten elite synchronized swimmers were analyzed using a three-dimensional DLT method. It was found that support scull is a lever movement made from the elbow that produces propulsive force by generating drag force during the outside transition phase and lift force during both out-scull and in-scull of the horizontal stroke phases. To scull in a smoother and more stable performance, swimmers should hold their elbows and upper arms stationary and keep their forearms horizontal during sculling. Palms should face downwards throughout sculling and hands should be held at the proper attack angle to produce an efficient lift force.

Key Words: support scull, synchronized swimming, three-dimensional motion analysis.

INTRODUCTION

In synchronized swimming, the support scull is a fundamental skill that is used in the vertical position and vertical variation positions as a propulsive and support technique. It is important for swimmers to hold their body more steadily and higher above the water surface. A few studies have clarified the theoretical background for the efficient generation of propulsive force (2, 5), and the characteristics of the support scull have been clarified (1, 3, 8). Although sculling is a three-dimensional movement, past studies on sculling have been two-dimensional analyses. Since coaches require practical data and information on the relative effectiveness of different techniques, the present study investigated support scull techniques in synchronized swimming based on three-dimensional motion analysis.

METHODS

The subjects comprised 10 female skilled synchronized swimmers. Four swimmers had been silver medalists at the 2004 Athens Olympics (Olympic swimmers: mean age, 22.8 years; height, 1.64 m; weight, 55.4 kg). The remaining 6 subjects were skilled swimmers from the Japanese National B and Junior teams (Elite swimmers: mean age, 17.2 years; height, 1.58 m; weight, 49.7 kg). Written informed consent was received from each swimmer prior to their inclusion in the study.

Figure 1: Support scull in vertical position (Side view).

Swimmers maintained a stationary vertical position (Fig. 1) under two load conditions: no load; and a 1.5-kg load attached to the waist. A 1.5-kg load is commonly used for sculling drills during training. Two underwater video cameras were synchronized by means of a frame counter and an external signal generated by the synchronizing device. One was placed on the bottom of the pool, and one was set up to film through the pool's underwater observation window. Videotapes were manually digitized using our own software, "Movie digitizer" (6, 7), which linked the movie file to Mathematica v. 5.1 (Wolfram Research, USA). Three-dimensional coordinates were obtained using a three-dimensional direct linear transformation method. The axes of the inertial reference frame were defined relative to the pool. A rectangular parallelepiped (1.0 m x 1.0 m x 0.7 m) with 16 control object points was used as a three-dimensional DLT control object. Errors in the reconstructed coordinates of that object were 5.22 mm (X-axis), 4.6 mm (Y-axis) and 3.9 mm (Z-axis). All three-dimensional coordinate data were interpolated to 60 Hz using the Mathematica interpolation function, and then smoothed using a Butterworth low pass digital filter with a 7.5-Hz cutoff (9).

Since the sculling movement is a repeated motion, only one stable cycle was analyzed. In this experiment, the right arm of one cycle of the support scull starting from outside was analyzed. The stroke phase from outside to inside was termed the "in-scull," and the stroke phase from inside to outside was termed the "out-scull." The point where motion changed between outside and inside was termed the "transition phase." Upper arm angles, the three-dimensional angle between the upper arm and a vertical line through the shoulder and trochanter majors; elbow angles, the three-dimensional angle between the forearm and upper arm; wrist angles of flexion, extension, radial and ulnar deviation; forearm pronation and supination; attack angle, changes in attack angle of the hand relative to the direction of motion; scull range, range of hand motion (which gives insight into shoulder external and internal rotation); sculling time during one cycle scull; hand velocity; and sculling pattern, the paths of the fingertips and wrists were analyzed.

RESULTS

The ranges of upper arm angles were smaller in the Olympic swimmers ($p < 0.05$) than those in the Elite swimmers, as shown in Figure 2. A comparison of 1.5-kg load and no load revealed the minimum upper arm angles to be smaller with the 1.5-kg load ($p < 0.01$) than those with no load. The ranges (max-min) of upper arm angles with the 1.5-kg load were larger than those with no load ($p = 0.0532$). Mean elbow angles for 10 swimmers under no-load and 1.5-kg load conditions were 145° outside and 100° inside. With a 1.5-kg load, the elbow angles were decreased at the outside transition phase.

In the present study, the mean scull ranges for 10 swimmers were 105° with no load and 110° with a 1.5 kg load, in which the hands moved from 8° outside to 113° inside with no load (Fig. 3) as the hands traced almost a quarter circle. Moreover, scull ranges with the 1.5-kg load were slightly shifted to the back.

Table 1. Wrist angles of flexion (+), extension (–), radial (+) and ulnar (–) deviations, and forearm angles of pronation (–) and supination (+) depend on no load and 1.5-kg load conditions for Olympic swimmers (n = 4) and Elite swimmers (n = 6).

		Wrist flexion & extension (°)			Wrist radial & ulnar deviation (°)			Forearm pronation & supination (°)		
		Right			Right			Right		
		max	min	max-min	max	min	max-min	max	min	max-min
Olympic swimmers(n=4)	no load	22.3	-3.8	26.1	7.3	-32.8	40.1	125.1	1.9	33.2
	1.5 kg	30.0	0.2	29.8	9.1	-34.8	44.0	125.7	5.2	30.5
Elite swimmers (n=6)	no load	28.0	-12.3	40.4	13.9	-36.3	50.2	126.4	4.0	32.4
	1.5 kg	26.5	-4.0	30.5	12.2	-31.1	43.3	124.8	10.0	24.8
Total (n=10)	no load	25.8	-8.9	34.7	11.2	-34.9	46.1	125.9	3.2	32.7
	1.5 kg	27.9	-2.3	30.3	11.0	-32.6	43.6	125.2	8.1	27.1

Wrist angles of radial and ulnar deviation varied individually. During in-scull, small ulnar deviations of the wrists (–34.9° no load, –32.6° 1.5-kg load) were observed for most swimmers, but no clear radial deviations were observed (Table 1). For wrist angles of flexion and extension, under the 1.5-kg load, large wrist flexions were clearly observed at the outside transition phase (Table 1). The forearm showed large supination throughout sculling. Angles of forearm supination with no load were a clearly visible maximum of 125° at the outside and a minimum of 3° at the inside (Table 1). Under both load conditions, maximum attack angles were approximately 60–70° on in-scull and 80° on out-scull. Mean sculling time during one cycle for 10 swimmers was 0.69s for no load and 0.68s under 1.5-kg load. Sculling time during in-scull was 0.31s (44.9%) for no load and 0.30s (44.1%) for the 1.5-kg load; and during out-scull were 0.39s (55.1%) for no load and 0.38 (55.9%) for the 1.5-kg load. Out-scull times were longer than in-scull times. There were no differences between Olympic swimmers and Elite swimmers, or between loads. Hand velocity reduced during both the outside and inside transition phases and increased during the stroke phases.

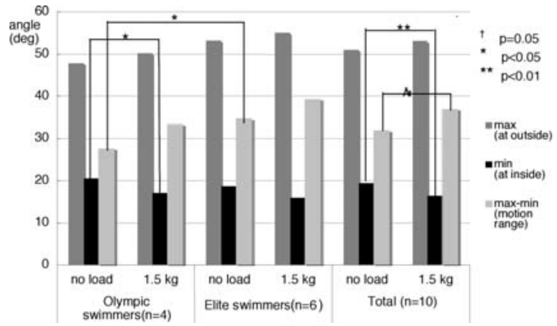

Figure 2: Maximum, minimum and motion range (max-min) of upper arm angles during one support scull for Olympic swimmers and Elite swimmers under no load and 1.5-kg load conditions.

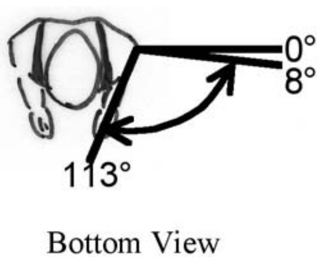

Figure 3: Scull range during support scull. The mean range for 10 swimmers with no load was approximately 105°, from 8° outside to 113° inside.

As shown in Figure 4, with no load, sculling patterns of the fingertips and wrists for most swimmers drew a sideways figure-of-eight. With the 1.5-kg load, fingertips and wrists drew a sideways figure-of-eight with the outside circle larger, but some swimmers traced a slanting sharp-pointed ellipse.

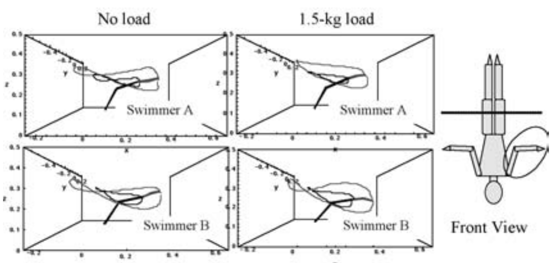

Figure 4: Front view sculling patterns of right middle fingertip and right wrist for Olympic swimmers under no load and 1.5-kg load conditions. Sculling pattern with no load is a slanting sideways figure-of-eight. Sculling pattern with a 1.5-kg weight is a slanting sharp-pointed ellipse for Swimmer A, and larger out circle for Swimmer B.

DISCUSSION
Upper arms were stationary for more advanced swimmers, showing the same characteristics as the flat scull in the back layout position (4). It can therefore be said that holding the upper arms and elbows stationary is a tip for both support scull and flat scull techniques. This finding additionally indicates that the support scull is a lever movement that is made from the elbow.
Elbow flexion angles were 145° outside and 100° inside in the present study. This result was different from the instructions given in some manuals, which prescribe 90° (5, 11). During one scull, elbows are flexed during in-scull and extended during out-scull. Rybuyakova *et al.* (8) have reported that the range of elbow angles in highly skilled swimmers was 150° to 112°. We observed similar elbow angles. Moreover, it appears that increased elbow angles are linked to increased upper arm angles so as to keep the forearms in a horizontal line; and this movement produces efficient lift force by the forearms and hands.
The scull ranges of the present study were 105–110°, much greater than the angles described by Zielinski (10), in which the scull range is from straight out to the sides and at approximately 60° toward the front. To maintain the body higher in the water, it is necessary to produce a great deal of propulsive force by using long sculling phases.
The wrist angle results show that the hands lead during in-scull and the hands and forearms move as a unit during out-scull.
The forearm showed large supination during scull, as indicated by the palms facing the bottom throughout sculling. This forearm supination movement produces the optimal attack angle of the hand and causes the fingertips and wrists to draw a sideways figure-of-eight. Comparing the out-scull and in-scull movements shows scull time on the out-scull to be longer and maximum attack angles on out-scull to be larger. It can thus be said that the hands exerted more pressure on the out-scull. The sideways-slanting figure-of-eight sculling pattern of the hands under no load indicates that support scull produces its propulsive force by generating drag force at the outside transition phase and lift force during the horizontal sculling phases. This finding supports Francis and Smiths' conclusions (1).
Comparing the no-load and 1.5-kg load conditions, the chief characteristics of scull movements under load were that the range of upper arm angles was larger, that greater elbow and wrist flexion were observed during the outside transition phase, that scull ranges were slightly shifted to the back, and that sculling patterns of hands were a sideways figure-of-eight with a large circle on the outside or a slanting, sharp-pointed ellipse. As load increased, swimmers needed to scull harder toward the bottom at the outside transition phase to support their body weight at maximum height. It appears that drag force contributed more to producing a propulsive force under loaded conditions.

CONCLUSION
Support scull is a lever movement made from the elbow that produces propulsive force by generating drag force during the outside transition phase and lift force during both out-scull and in-scull of the horizontal stroke phases. To scull in a smoother and more stable fashion, swimmers should keep their elbows and upper arms stationary and their forearms horizontal, with 110–145° elbow flexion. Palms should be facing downwards throughout sculling and the attack angle of the hands should be such as to produce an efficient lift force. Forearms and hands are moved as one unit, but the hands

lead with slight ulnar deviations during in-scull. Scull range is from straight out to the sides to in front of the trunk as the hands trace a quarter circle. Sculling is harder and should exert more pressure during out-scull. Under no load, the hands trace a sideways figure-of-eight.
As load increases, the hands push the water downwards harder at the outside transition phase and trace a sideways figure-of-eight with the outside circle larger, or a slanting, sharp-pointed ellipse. The drag force contributed more to production of propulsive force under loaded conditions.

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ESTIMATION OF ARM JOINT ANGULAR DISPLACEMENTS IN FRONT CRAWL SWIMMING USING ACCELEROMETER

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The purpose of this study was to estimate arm joint angular displacements, such as shoulder extension and elbow flexion angle during front crawl swimming using an accelerometer that was attached to the swimmer's wrist. The arm joint angles were formulated and wrist acceleration was identified mathematically. A well-trained swimmer, as the subject, performed front crawl swimming with a wrist-mounted accelerometer. Shoulder extension and elbow flexion angle were estimated from the measured acceleration corresponding to the calculated acceleration. The estimated angles corresponded well with the angles obtained by videography. The desirable results demonstrated the possibilities of its practical use as a methodology to measure swimming motion.

Key Words: estimation of joint angle, arm motion, accelerometer, front crawl swimming.

INTRODUCTION

It is important to feed back the information of the swimmers' motion in the training to improve their performance. The feedback procedure should be simple and more immediate._Measurements using sensor, which is readily available and can automate the procedure, are suitable for the feedback system of human motion in sports field (1, 2, 3, 8, 9, 10) and in medical field (4, 5, 6, 7, 11, 12). Especially, inertial sensor, such as accelerometer, would be better suited for swimming since it was not only sufficiently small, relatively inexpensive and lower energy consumption through development of the technology (5, 6) and but also the output was not affected by environment optically.
Previous studies have reported that the stroke frequency and the duration of the arm stroke were estimated from the experimental acceleration of the wrist in front crawl swimming (2). And acceleration of the front crawl swimmer's wrist was affected mainly by shoulder extension and elbow flexion (1).
The purpose of this study was to estimate arm joint angular displacements, such as shoulder extension and elbow flexion angle, during underwater phase in front crawl swimming using an accelerometer attached on the swimmer's wrist.

METHODS

Experimental design

The subject was a well-trained male swimmer. The length of the swimmer's forearm and upper arm were measured. The trials were 50-m front crawl swimming with three different velocities subjectively (Slow, Middle and Fast speeds). The swimmer had an attached an accelerometer on the left wrist for acceleration measurement, and visual markers on the left shoulder, elbow and wrist joints for videography.
The accelerometer included an acceleration sensor (ADXL210; Analog Devices Inc.) and a data-logging system. It recorded at a sampling frequency of 120 Hz. The measurement axis of the accelerometer was along the longitudinal axis of the forearm. After trials, the stored data were downloaded into a personal computer.
Two waterproof cameras (EVI-D30; Sony Corp.) were set up under water to measure the displacement of the left arm. Images from the cameras were superimposed using the field counter, which was synchronised for the accelerometer, and recorded on digital video recorders. The visual markers of the swimmer's joints on images were digitized at 30 Hz. The digitized data were transformed into the corresponding three-dimensional coordinates using 3-D DLT method.

Estimation of angular displacement of the arm

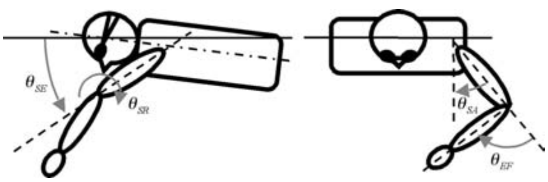

Figure 1. Definitions of the arm joint angles, the shoulder extension (SE), abduction (SA), rotation (SR), and the elbow flexion (EF) in frontcrawl swimming.

It was necessary to identify the acceleration of the wrist mathematically to estimate the shoulder extension and the elbow flexion angles during the underwater phase.
Shoulder extension and elbow flexion angles during the underwater phase were formulated as

$$\theta_{SE}(t) = 180^\circ/(1+e^{-kSE(t-tSE)}) \quad \text{(Eq. 1)}$$

$$\theta_{EF}(t) = \theta_{EF\,\max}\, e^{-kEF(t-tEF)^2} \quad \text{(Eq. 2)},$$

where the suffixes "SE" and "EF" respectively denote "Shoulder Extension angle" and "Elbow Flexion angle". The parameters k_{SE} and the k_{EF} were related to each angular velocity. The t_{SE} was the time to reach 90 deg, and the t_{EF} was the time when the elbow flexed up to $\theta_{EF\,\max}$, which was the maximal flexion angle of the elbow (1).
Additionally, it was assumed that the shoulder abduction and rotation angles were formulated as the following.

$$\theta_{SA}(t) = 0^\circ \quad \text{(Eq. 3)}$$

$$\theta_{SR}(t) = 90^\circ - 80^\circ e^{-20(t-t_{SR})^2} \quad \text{(Eq. 4)}.$$

In those equations, "SA" and "SR" respectively denote the "Shoulder Abduction angle" and "Shoulder Rotation angle". The value of θ_{SR} was positive when the shoulder rotated externally. The t_{SR} was substituted the time when the θ_{SR} reached 45 deg. Assuming that the swimming velocity was constant and that the shoulder displacement was substantially less than that of the elbow and the wrist, the acceleration of the wrist on the global coordinate system can be calculated from Eqs. 1–4.

$$\boldsymbol{A}_{wrist} = \frac{d^2 \mathbf{P}_{wrist}(\theta_{SE}, \theta_{EF}, \theta_{SA}, \theta_{SR})}{dt^2} \quad \text{(Eq. 5)}$$

In that equation, $\boldsymbol{A}_{wrist}$ and $\mathbf{P}_{wrist}$ were the acceleration and displacement vector of the wrist on the global coordinate system. The measured acceleration in the experiments was the component along the longitudinal forearm of the wrist. It was expressed as

$$a = (\boldsymbol{A}_{wrist} + \mathbf{g}).\mathbf{j} \quad \text{(Eq. 6)}$$

where $\mathbf{g}$ was the gravitational acceleration, and $\mathbf{j}$ was the unit vector along the longitudinal axis of the forearm.
The difference between the measured and the calculated acceleration was expressed as the performance function I for the estimation.

$$I = \sum_{i=0}^{n} \{a(i) - a_{\text{measured}}(i)\}^2 \quad \text{(Eq. 7)}$$

Minimising function I, the parameters in Eq. 1 and Eq. 2 were calculated using Levenberg-Marquardt method to estimate the shoulder extension and elbow flexion angles.
Estimated angles of shoulder extension and elbow flexion were compared with angles measured using videography. All data processing for analysis and estimation were performed using a computer program (Mathematica 5.1; Wolfram Research, Inc.).

RESULTS
The time during 50-m front crawl swimming as trials were 35.5 sec in Slow speed, 31.6 sec in Middle and 27.4 sec in Fast. Estimated angles from the accelerometer and those measured using videography are shown at Fig. 2. The estimated shoulder extension angles corresponded well to measured values in all trials. Estimations of the elbow flexion angles were acceptable, although it was observed that there were differences of the value and timing at maximal elbow flexion.
When we tried to calculate all parameters in Eq. 1 and Eq. 2 at once, some estimated angles differed from the measured angles. Therefore, the results in Fig. 2 were obtained by dividing the procedure of the calculation into two steps. First, the parameters in Eq. 2 were fixed and the parameters in Eq. 1 were calculated for estimation of the shoulder extension angle. Second, only the parameters for elbow flexion were calculated with the parameters in Eq. 1 obtained at first step.

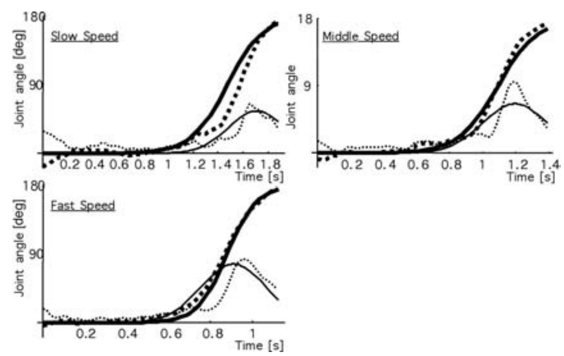

Figure 2. Comparison of the angular displacement between that estimated from the acceleration (solid) and that measured using videography (dotted) of the shoulder extension (thick) and the elbow flexion (thin).

DISCUSSION
The promising results shown in Fig. 2 demonstrate that measurements using the accelerometer would be useful as a means to measure swimming motion quantitatively.
Measurement for the swimmers field should affect motion to the least degree possible (5, 11), yet provide helpful information quickly to improve swimmers' performance. In this study, one acceleration sensor was used for estimation of the swimming motion, so that the measurement might not encumber the swimming motion and minimise the swimming performance. Estimations corresponded to the actual motion of the arm well, even though the experimental data were only acceleration of the wrist and the arm length. The shoulder extension and the elbow flexion angles were the fundamental factors of

the arm motion in front crawl swimming. Feedback of such angular displacements of swimming motion would be more effective for swimmers and their coaches than that of the other kinematic parameters because it was easier to comprehend intuitively and it would be expected to provide visual feedback such as stick pictures and computer graphics.
The estimation in this study was based on previous findings that the acceleration of the wrist in front crawl swimming depended mainly on the shoulder extension and elbow flexion (1). Primitive estimation was tried under simple condition that wrist's acceleration was identified mathematically using only Eq. 1 and Eq. 2 without consideration of Eq. 3 and Eq. 4. However, the estimation from the calculated acceleration simply did not provide adequate results of elbow flexion. It was necessary to consider shoulder rotation, as shown in Eq. 4, and divide the procedure of the calculation into two steps in order to obtain the Fig. 2. The fixed parameters, such as t_{SR} , 90, 80 and 20 in Eq. 4 were not based on experimental data accurately, and formulas Eq. 3 and Eq. 4 might not exactly represent the actual motions of swimmers. Therefore, it could improve the accuracy of the estimation by the proper selections of formulas and parameters for shoulder abduction and rotation. It is impossible to calculate displacement of body segment from output signal of accelerometer directly, because the output involves components of acceleration that derived from rotation of the sensor and gravity (7). In the estimation with simple condition, the separation of the components would not be adequate. The procedure which was divided calculation steps provided the better results. It was suggested that the procedure would be available to separate each component of acceleration to the purpose in order to measure motion. Technological advancements produce wireless, miniaturized and integrated sensor devices that can provide measurements more easily and practically. Further studies will examine estimation of other joint angles, not only the shoulder abduction and rotation, but also the rolling angle of the body and the rotation angle of the forearm, through improvements of the type, position and number of sensor devices and the selection of an appropriate computational algorithm.

CONCLUSION

In this study, joint angular displacements, such as the shoulder extension and the elbow flexion angles, during underwater phase in front crawl swimming were estimated using only acceleration data of the swimmer's wrist. The estimated angles corresponded with angles that were measured using videography. It provided good estimation results, suggesting that motion measurements using the accelerometer can be of practical use in swimming training. In the future, sensor-based measurement system for swimming motion would provide real-time feedback, long-term monitoring and remote coaching, etc. as practical system to contribute the improvement of swimming performance in the training.

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PERFECTING OF THE CRAWL IN NON-SKILLED SWIMMERS: COMPARISON BETWEEN THE DRAG REDUCTION AND IMPROVEMENT OF THE PROPULSION

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Swimming results as a compromise between propulsive actions and gliding through water. This research observed the improvements in non-skilled swimmers taught by two specific training programs. The first aimed to have a drag reduction and a better glide (improving the balance, the position in the water and the breath control). The second program aimed to improve the efficiency of the propulsive actions (with respect to continuity and length of the armstroke, rhythm of the actions). The two perfection methods were proposed to 97 non skilled subjects. In the pre-post analysis within each group an improvement of the efficiency index in all male subjects and in the females working on propulsion were found. Moreover and an improvement of long distance swim was recorded in all subjects.

Key Words: swimming, drag reduction, propulsive action.

INTRODUCTION

Swimming results a combination between a propulsive action and the gliding through water (4). There are relationships among best performance, stroke length and stroke rate in elite swimmers (3). Skilled swimmers were characterized by a higher stroke frequency and superposition of both arm actions (1). The same speed could be obtained as result of different combination of frequency and stroke length (3). According to Chollet (2) skilled swimmers maintain velocity, frequency and length of stroke during the entire race. The improvement of the technique of the front crawl stroke is also related to fitting in the breathing action in the stroke cycle (7). In non-skilled swimmers each progress in balance, breathing and propulsion leads to an improvement of stroke length. In non-skilled swimmers a training program based on the improvement of velocity by increasing stroke frequency leads to a prompt rise of the velocity. On the other hand, a specific program focussing on improving stroke length allows more stable and durable results (8). Specific data such as weight, height, gender and age should be considered important factors of swimming performance (5, 6). Willie and Pelayo proposed, as evaluation tools for non-skilled swimmers, reference tables, based on the efficiency index and size (8).
The aim of this research was to compare the improvements in non-skilled swimmers prepared with two training programs: (i) mainly addressed to actions allowing a drag reduction and a better glide (such as balance, position in the water, breath control); (ii) to improve the efficacy of propulsion (continuity and length of the armstroke and rhythm).

METHODS

This study involved 97 subjects, non skilled, divided into four groups: 2 male (age 20.5±1.3, 20.9±1.6, weight kg 75.8±5.4, 73.6±8.6, height cm 180.6±5.4, 178.3±5.6) and 2 female (age 21±2, 21.1±1.5, weight kg 60.4±7.2, 57.8±5.2, height cm 165.2±3.8, 166.9±3.3).
Two different learning methods for the perfecting of the crawl technique have been proposed in a 10-lesson of 30 minutes program.
One male and one female group ("drag reduction" groups) were instructed with a method focussing on improving the position in the water, with regard to breathing technique and rhythm, to armstroke synchronism, to arm recovery actions that could influence the balance and the trim. The other male and female groups ("propulsion" groups) practised a specific program to improve the propulsion. For example, it was employed a "contrast method", such as to execute both a flutter kick by either an over-bending or an under-bending action, respectively; this in order to perceive the actions that produces a better propulsion).
Both instruction methods involved the same amount of time per lesson, in which the same didactical approach was used.
Before and after the research period, the effect of instruction was evaluated by: (i) a filmed 50m speed test, where the time from 5 to 50m, stroke rate and stroke length were taken and the Efficiency index (Ei = Distance^2 · time^{-1} · number of stroke cycles) was calculated; (ii) a freestyle 6min test, where the swimming distance was recorded.
Pre and post test results within each group were compared by paired Student's t test ($p<0.05$). Additionally, we wanted to test the Post-test results among the four study groups by One-way ANOVA.

RESULTS

For each group significant differences ($p<0.05$) were found as an effect of instruction: improvement of 50m speed in the female "drag reduction" group; improvement of the efficiency index in both male groups and in the female "propulsion" group; improvement of swim distance in the 6min test in all groups (Table 1a – 1b).

Table 1a. Paired t-test between Pre and Post experimentation tests in Male groups. Significant differences are shown: (*) when p<0.05.

	Male "Propulsion" group			Male "Drag Reduction" group		
	Mean	*Std. Deviation*		*Mean*	*Std. Deviation*	
Time 50m (sec.) – Pre	35.13	3.76		38.20	6.06	
Time 50m (sec) – Post	35.14	3.92		37.62	8.73	
Min 6 (mt) – Pre	273.18	68.53	*	232.50	60.88	*
Min 6 (mt) – Post	291.82	64.00		273.75	43.33	
Cycles (nr.) – Pre	25.91	2.65		28.67	2.10	
Cycles (nr.) -Post	24.45	3.04		27.33	3.49	
Efficiency Index – Pre	2.27	0.28	*	1.91	0.35	*
Efficiency Index – Post	2.39	0.25		2.05	0.35	
Stroke Length (mt/cycle) – Pre	1.75	0.17		1.59	0.13	
Stroke Length (mt/cycle) – Post	1.86	0.22		1.66	0.25	
Stroke Rate (Cycles/min) –Pre	44.81	7.32		45.85	6.86	
Stroke Rate (Cycles/min) –Post	42.51	9.08		45.87	11.33	

Table 1b. Paired t-test between Pre and Post experimentation tests in Female groups. Significant differences are shown: (*) when p<0.05.

	Female "Propulsion" group			Female "Drag Reduction" group		
	Mean	*Std. Deviation*		*Mean*	*Std. Deviation*	
Time 50m (sec.) – Pre	40.08	5.35		40.28	5.17	*
Time 50m (sec) – Post	39.40	5.22		41.75	5.76	
Min 6 (mt) – Pre	261.57	62.95	*	252.00	89.01	*
Min 6 (mt) – Post	281.64	48.02		274.50	64.44	
Cycles (nr.) – Pre	26.75	3.087		28.40	3.39	
Cycles (nr.) –Post	26.25	3.10		27.90	3.25	
Efficiency Index – Pre	1.95	0.40	*	1.85	0.40	
Efficiency Index – Post	2.02	0.35		1.80	0.39	
Stroke Length (mt/cycle) – Pre	1.71	0.19		1.59	0.18	
Stroke Length (mt/cycle) – Post	1.85	0.21		1.64	0.14	
Stroke Rate (Cycles/min) –Pre	40.43	5.23		42.55	4.72	
Stroke Rate (Cycles/min) –Post	40.11	7.38		40.08	4.90	

In the post experimentation comparison among groups, differences were found only between the male "propulsion" group and each female group in the efficiency index (Table 2).

Table 2. Comparison of efficiency index post-experimentation among groups: Tukey Post Hoc One-way ANOVA results. Significant differences are shown: (*) when p<0.05.

(I) GROUP	(J) GROUP	Mean Difference (I-J)	Std. Error	Sig.
1. Male "Propulsion"	2.	.34091	.14124	.090
	3.	.36948(*)	.13632	.046
	4.	.59091(*)	.14784	.001
2 . Male "Drag Reduction)	1.	-.34091	.14124	.090
	3.	.02857	.13311	.996
	4.	.25000	.14487	.323
3. Female "Propulsion"	1.	-.36948(*)	.13632	.046
	2.	-.02857	.13311	.996
	4.	.22143	.14009	.400
4. Female "Drag Reduction"	1.	-.59091(*)	.14784	.001
	2.	-.25000	.14487	.323
	3.	-.22143	.14009	.400

DISCUSSION

No significant differences were found either in the speed, in the stroke rate, and in the stroke length. However, both learning methods employed have been found significantly effective in three out of four groups on the stroke technique (efficiency index). Additionally, in all groups improvements in the long distance stroke were recorded.

Base on these data, we can not assume that one method could be superior to the other, in term of efficacy in the 6 minute swim. However, both methods were effective on the final results on the long distance test. We can not exclude that this finding could be due also to the effect of conditioning, achieved with the training.

The observation of post experimentation test results among groups did not show significant differences, except in the comparison of efficiency index between the male "propulsion" group and each female group. This difference found could simply depend to the different gender of subjects.

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SWIMMING AND TRAINING: COMPARISON BETWEEN HEURISTIC AND PRESCRIPTIVE LEARNING

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Different opinions are given about the approaches of learning methods in swimming. Some supporting the prescriptive-cognitive theory, others the ecological-dynamic method, also called heuristic learning. Two groups of children attending a swimming school were taught by a prescriptive (subdivided) and by a heuristic methods. It seems that, in the swimming teaching, an ecological dynamic approach in the learning of the technique results to be more effective than a more rigid and defined prescribed method.

Key Words: swimming, heuristic, prescriptive, learning.

INTRODUCTION

The prescriptive-cognitive theory and the ecological-dynamic method, also called heuristic learning, represent two different approaches of learning.

The prescriptive-cognitive theory considers the motor skills such as mixed processes (central and peripheral) that include three different steps. The motor skills are first selected (general motor level); secondly, the parameters to adjust the movement to the task are identified and then the correction of the errors is made by a revision from afferent sensory informations (7).

An implication of this theory is to indicate to the student some practice procedures in order to stabilize and to perfect the motor planning and to minimize the variability of the execution. This approach is possible by a subdivided method, which can bear many complex skills into some easier. It is possible to simplify the complex movements by dividing, subdividing or reducing their velocity or their requests of executive precision (10).

Chollet's studies (2, 3) pointed out the formulation of these learning contents in the aquatic environment. These studies were based on finding motor skills adjustment in swimming and then on performance improvement, thanks to feed-back information or to extra affected information (hydrodynamic pressures, instant changes of speed). Giving immediately bio-feedback information to the swimmers would help the improvement of technique.

On the theoretical plan, Bernstein's studies (1) are contrasting to cognitive theories indicating how a motor program can not supervise the variability of the range of motion of the human body joints. Under the ecological-dynamic theory, the movement is the result of self-adaptation of neuromotor system to the external variables (5). A readjustment of motor skill will occur from the new state coming, combining intrinsic movement coordination with the coordination requested by the new task (6, 8).

According to Verejken et coll. (9), the dynamic model would be advisable in cyclic skills, such as in swimming. Educational consequences of ecological-dynamic approach consist on "repeat without to repeat" (1). To practice does not mean to achieve the same result several times in the same way, but to present different solutions to obtain the same final result.

The aim of this research was to observe the results of the didactic proposal made according to two different methods in two groups of children attending a swimming school.

METHODS

The study involved 20 children, average age 7-8, that passed the first level of aquatic development (settling in).

The children were randomly divided into two groups tested for homogeneity. The first group (weight kg. 26.67±2.18, height cm 129±0.05) has been taught by the prescriptive method, the other group (weight kg. 24.83±2.24, height cm 126±0.05) by the heuristic method.

Before and after the experimentation all subjects were tested by earth and aquatic neuromotor tests, in order to evaluate: the balance (T1), the spatial differentiation abilities (T2), the coordination abilities (T3), the independence in the water (T4), the self-control in the water (T5), the body awareness in the aquatic environment (T6), the controlled submersion (T7).

At the end of the teaching program, further summative tests (such as submersion, orienteering, backstroke, front crawl stroke) were made, with the aim to verify whether some specific abilities of the second level of aquatic development (raw swimming technique) were reached.
The results were compared by the Student's t test ($p<0.05$).

RESULTS
A significant difference of the mean scores of tests submitted at the end of the teaching period has been found (fig. 1).

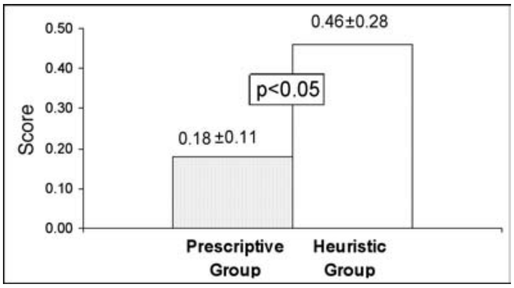

Figure 1. Results after the teaching period (Mean and SD).

No differences were found in the summative tests (fig. 2).

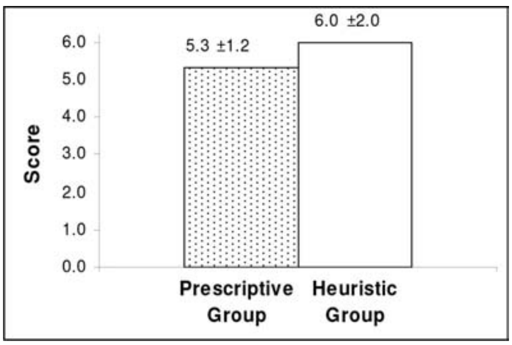

Figure 2. Results of the summative tests after the teaching period (Mean and SD).

In the group learned by the prescriptive method no differences were found between pre-post results in any test performed (fig. 3).

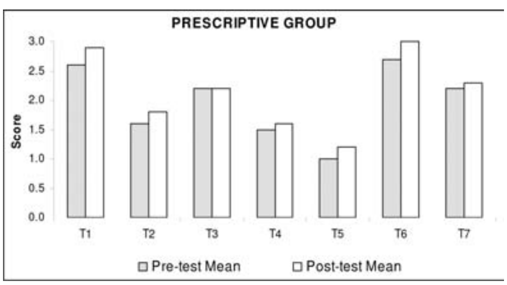

Figure 3. Comparison between pre-tests and post-tests scores obtained by subjects of group learned by the prescriptive method.

In the group learned by the heuristic method (fig. 4) significant differences ($p<0.05$) were found in the tests about the balance (T1), the independence in the water (T4) the self-control in the water (T5) and the body awareness in the aquatic environment (T6). The differences in the test about the controlled submersion (T7) were very significant ($p<0.01$).

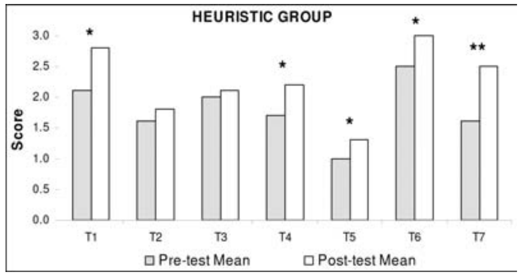

Figure 4. Comparison between pre-tests and post-tests scores obtained by subjects of group learned by the heuristic method. Significant differences are shown: (*) when $p<0.05$, (**) when $p<0.01$.

DISCUSSION
Based on the data from the present study, it seems that, in the swimming teaching, an ecological dynamic approach in the learning of the technique results to be more effective than a prescribed more rigid and defined method.
According to Schoner (8), the best results obtained by subjects taught by heuristic method in the post-test and in the summative tests could suggest a better stimulation to the central neural system produces a better reorganization of the motor activities. New experiences seem to have a direct influence on the learning process. In the heuristic method the whole neuromotor system would better adapt to the didactic proposal, as globality of stimulations would strongly interact on the reorganization capacity of the motor skills, gaining a better result.
Based on these data, a learning process based on repeating and perfecting an assigned task, would not achieve the same results obtained with the heuristic method. Prescriptive method, divided into three different steps (the selection of the motor skills, the selection of the parameters to adjust the movement and the correction of the errors), may not be able to cause a sufficient capacity of global reorganization of motor responses.

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THE BREATHING FREQUENCY CHANGES DURING SWIMMING BY USING RESPIRATORY VALVES AND TUBES

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The purpose of the present study was to ascertain the influence of a respiratory valve and tubes (RV) during three different swimming tests (submaximal and maximal 200-m front crawl swim and front crawl swimming to exhaustion) on a breathing frequency and selected biomechanical parameters. Twelve former competitive male swimmers performed each swimming test twice: first, with RV, and second, without RV. Swimming with RV induced slower maximal 200-m front crawl swim and shorter front crawl swimming to exhaustion in comparison with swimming without RV. Furthermore strategies of the breathing frequency during submaximal and maximal swimming tests were also differed between swimming with RV and swimming without RV. Therefore, it may be concluded that when RV is used for measuring respiratory parameters during swimming, a different pattern of breathing (comparing to swimming without RV) may occur.

Key Words: swimming, breathing, respiratory valve.

INTRODUCTION
Measurements of oxygen uptake and respiratory parameters play an important role in swimming studies. However, use of measuring equipment (especially a respiratory valve and tubes - RV) may influence dramatically on swimming performance and/or physiological response during swimming. To overcome this problem measuring should be performed with minimal influence on swimming performance and physiological response. Toussaint et al. (1987) have developed RV specifically designed for measurements of oxygen uptake and respiratory parameters during swimming. This RV did not increase body drag during swimming (8), and have a little influence on swimming technique in comparison with swimming without it (3). Later, RV was modified for breath-by-breath gas analysis using portable metabolic cart. Modified RV was validated in laboratory (2) and used for obtaining oxygen uptake kinetics during swimming (5, 6). However, the unanswered problem still remains. Is it possible that respiration during swimming with RV remains similar as it is during swimming without RV? Respiration during front crawl, breaststroke and butterfly swimming is synchronised with swimming strokes. Furthermore, the breathing frequency (Bf) has to be in accordance with the stroke rate. On the contrary, RV enables optional Bf during swimming. Considering that it could be questioned whether swimmers during swimming with RV maintain similar Bf as they have during swimming without RV. Therefore the purpose of the present study was to ascertain the influence of RV during three different swimming tests (submaximal and maximal 200-m front crawl swim and front crawl swimming to exhaustion at fixed, pre-determined velocity) on Bf and selected biomechanical parameters.

METHODS
Twelve former competitive male swimmers (age: 24 ± 3 years, height: 181.3 ± 9 cm, weight: 77.4 ± 13 kg) volunteered to participate in this study. They had more than eight years of competitive swimming experience and they finished their swimming careers at least two years ago. They were mostly middle-distance specialists (200 – 400 m) at national level. First, swimmers performed maximal 200-m front crawl swim twice: with RV first, and second, without RV. Thereafter, swimmers performed submaximal 200-m front crawl swim with and without RV. The velocities were determined 90% of velocity, reached at 200-m front crawl with and without RV, respectively. Finally, swimmers performed (even paced) front crawl swimming to exhaustion with and without RV. They swam as long as possible at fixed, pre-determined velocity. That was 110% of velocity, reached at 200-m front crawl with and without RV, respectively. Under-water pace-make lights were used to help the swimmers to keep even pace during swimming to exhaustion. Swimmers made turns with head out of the water (like butterfly and breaststroke turns) during all swimming tests. Each swimming test was performed at different days in 25-m indoor pool in which the water temperature was 27 °C. The swimming test was filmed from the side.
Time was measured for each of the swims with digital CASIO stopwatch. Split times for each 25-m were also obtained to calculate velocity (v) for each of the pool lengths. At the swimming tests with RV, Bf was measured B_B continuously during the swimming tests using a portable gas exchange system (Metamax 2, Cortex, Germany). The swimmers breathed through RV (8). At the swimming tests without RV, the measures of number of breaths were taken from videotapes. In addition, Bf was calculated by dividing the number of breaths with the time, which were both measured during the swimming tests. The measures of stroke rate (SR) were taken from videotapes. SR was recorded by mentioned stopwatch, which included a frequency meter (base 3). It was measured for each 25-m and expressed as the number of complete arm cycles per minute. In order to describe the changes of Bf and SR during the swimming tests, the data of these parameters were fitted by linear function for each subject. Concerning that SR significantly changed after first 50-m during 200-m front crawl event (7), the linear regression model was used without the data measured at first 25-m. A change (mean ± standard deviation) of each parameter per 100-m distance was calculated from the slope of the linear regression line for swimming with and without RV.
The values are presented as means ± standard deviations (SD). The paired *t* test was used to compare the data between front crawl swimming with and without RV. A 95% level of confidence was accepted for all comparisons. All statistical parameters were calculated using the statistics package SPSS and the graphical statistics package Sigma Plot (Jandel, Germany).

RESULTS

Swimmers swam without RV significantly faster (maximal 200-m front crawl swim) and longer (front crawl swimming to exhaustion) as they did with RV (table 1).

Table 1. Comparisons of v at maximal 200-m front crawl swim (MS) and swimming distance at front crawl swimming to exhaustion (SE) between the swimming with RV and the swimming without RV.

	with RV	without RV
v at MS (m/s)	1.28 ± 0.1	1.38 ± 0.1 **
Swimming distance at SE (m)	114 ± 17	129 ± 18 *

*** - significant difference between swimming with and without RV ($p \leq 0.01$);*
** - significant difference between swimming with and without RV ($p \leq 0.05$).*

Table 2. Comparisons of the change of SR per 100-m distance during the swimming tests (submaximal 200-m front crawl swim – SS, maximal 200-m front crawl swim – MS, front crawl swimming to exhaustion - SE) between the swimming with RV and the swimming without RV.

	with RV	without RV
change of SR per 100-distance (min^{1-}) during SS	1.81 ± 1.44	1.76 ± 1.58
change of SR per 100-distance (min^{1-}) during MS	0.68 ± 2.96	-0.97 ± 2.99
change of SR per 100-distance (min^{1-}) during SE	6.85 ± 6.67	4.88 ± 6.37

There were no significant differences in the slopes of the linear regression line of SR during swimming tests comparing swimming with RV and swimming without RV (table 2). However, the slopes of the linear regression line of Bf during swimming tests were different between swimming with RV and swimming without RV ($p \leq 0.01$). According to that the results of Bf during swimming test are presented in figures in the following text (figure 1, 2, and 3). In these figures, solid and dashed lines are linear regression lines fitting data points after first 50-m for swimming with RV and swimming without RV, respectively.

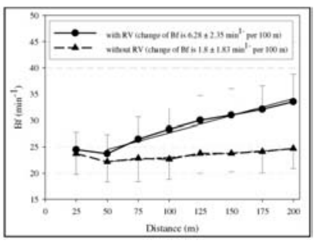

Figure 1. Comparisons of Bf during submaximal 200-m front crawl swim between swimming with RV and swimming without RV.

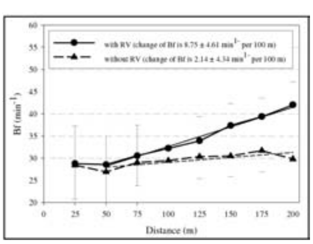

Figure 2. Comparisons of Bf during maximal 200-m front crawl swim between swimming with RV and swimming without RV.

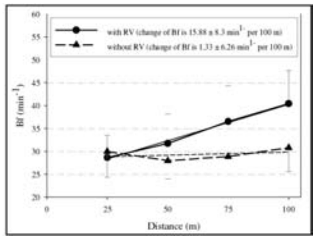

Figure 3. Comparisons of Bf during front crawl swimming to exhaustion between swimming with RV and swimming without RV.

When swimmers swam without RV, Bf was almost unvaried or slightly increased during all three swimming tests. On the contrary increases of Bf during swimming tests were much steeper, when swimmers swam with RV.

DISCUSSION

The main finding of present study was that swimming with RV induced slower maximal 200-m front crawl swim and shorter front crawl swimming to exhaustion in comparison with swimming without RV (table 1). Furthermore strategies of Bf during submaximal and maximal swimming tests were also different between swimming with RV and swimming without RV (figure 1, 2 and 3).

Rodriguez et al. (2001) reported that during incremental test with increasing speed every 50-meters, swimming with the respiratory snorkel and valve system did not prevent swimmers from reaching their maximal speed. In the line of theirs results were also result of Kjendlie et al. (2003). They assessed the implications of RV during interval front crawl set (6 x 25-meters). However, the swimming test used in present study was differed from testing protocol of mentioned studies. Two different varieties of maximal test were used in the present study: test which "simulates" competition event like maximal 200-m front crawl swim and "open-ended" constant load test like (even paced) front crawl swimming to exhaustion. Therefore durations of maximal swimming (200-meters and 114-meters as it was average swimming distance at front crawl swimming to exhaustion with RV) were longer in the present study as they were at mentioned studies (it could be assumed that swimmers swam only last 50-meters with maximal speed in study of Rodriguez et al. (2001)). However, the question why swimmers swam faster and longer without RV in present study, still need to be answered. Since it is known that RV did not increase active drag during swimming (8), it seemed that there were no biomechanical limitations for swimming with RV. In addition, RV enables swimming without turning the head for inhalation. These could lead to better swimming efficiency by reducing energy cost (1) and the hydrodynamic resistance (4) in comparison with swimming without RV.

The pulmonary ventilation during front crawl swimming is synchronised with strokes. Therefore the breathing phases (exhalation, inhalation, apnea associated with Bf) should be in accordance with the stroke parameters (stroke rate and stroke length). In the present study there were no significant differences in stroke rate during swimming tests between swimming with RV and swimming without RV (table 2). However, differences in strategies of Bf between swimming with RV and swimming without RV show that swimmers when swam with the RV did not maintain similar Bf as they had during swimming without RV (figure 1, 2 and 3). When swimming with RV, swimmers increased their Bf according the increased metabolic demands for more frequent breaths imposed by high intensity (maximal or near maximal) swimming. On the contrary, swimming without BV induced almost unvaried Bf during the swimming tests.

CONCLUSION
Based on results of the present study, it may be concluded that when RV is used for measuring respiratory parameters during swimming, a different pattern of breathing (comparing to swimming without RV) may occur.

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A TETHERED SWIMMING POWER TEST IS HIGHLY RELIABLE

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The aim of this study was to investigate test-retest reliability, diurnal variations and effects of performance level and familiarization of a tethered maximal swimming force (F_{max}) test. Test and retests were conducted on separate days, either at the same time of day, or as a morning and afternoon pair, and repeated on two more occasions. 22 competitive swimmers and 10 university sport students performed 3 tethered trials where F_{max} was registered by a load cell connected to the subject by a rubber tube. The reliabilities were found to be high, both from day to day, from morning to afternoon and within the test protocol (Cronbach's $\alpha = 0.99$). Mean coefficient of variation for the familiarised swimmers was as low as 1.6 ($\pm$1.4)%. Effects of familiarization were significant for swimmers but not for students, and the test-retest variation was lower for the swimmers. Diurnal variations were not higher than for test-retest on the same time of day.

Key Words: tethered swimming, reliability, familiarization, diurnal variation.

INTRODUCTION
Several methods have been applied to measure the propulsive forces in swimming, including 3D quasi steady analysis from video recordings (e.g. 8), using pressure measuring gloves (10), direct measurements of forces during swimming with fixed push-off pads (e.g. 5), semi-tethered (e.g. 9) or fully tethered (e.g. 6,11) swimming. Depending on the purpose of the measurements, these different methods have its advantages and disadvantages, and it may be questioned whether the results from tethered swimming force measurements are transferable to normal swimming. Nevertheless Bollens et al. (2) found that fully tethered swimming is similar to free swimming when regarding the activated muscles in use. Evaluation of specific muscular strength of swimming movements may thus be done using tethered swimming. However, the reliability and diurnal variations of a tethered swimming measurement system is not often reported. Dopsaj et al (3) found that a 60s tethered swimming test was valid and reliable for competitive swimmers, using a test-retest procedure on the same day. Diurnal variations of swimming performance lasting 60 seconds have been found (1), however morning vs afternoon variation of shorter sprints in swimming, like a 10s tethered swimming maximal force test (F_{max}), is to our knowledge not known.
Experiences using maximal force measurements with tethered swimming indicate that subjects achieve higher values of force after familiarization, and during successive trials in the test protocol. Furthermore, it is hypothesized that non-experienced swimmers may have a larger variation of swimming technique and thereby may have a different factor of variability for tethered swimming force testing than competitive swimmers. The biological, or within subject variation during tethered swimming is not known for non-experienced swimmers. The aim of this study was fourfold: 1- to investigate the test-retest reliability of a tethered swimming force test for competitive swimmers and non-competitive students, 2- to study the effect of familiarization, 3- to examine the repeated measure test protocol reliability and 4- to study the diurnal variations of tethered force testing.

METHODS
A test-retest design was conducted, where each subject was his own control. Test and retest was conducted on separate days within one week, at the same time of day, and then repeated on two more test sessions, i.e. with (comparing test 2 and 3) and without familiarization (comparing test 1 and 2). Furthermore a series of test-retest were conducted, where morning tests were administered before 9 am and afternoon tests were done after 4 pm. The 32 subjects who volunteered for the study were 22 competitive swimmers (16 males and 6 females) and

10 college sport students (9 males, 1 female). Mean (±SD) age was 17±2 years for the competitive swimmers, and approximately 22 years for the university students. Only the competitive swimmers participated in the morning-afternoon test pairs, and they were all well accustomed to morning exercises.
The test protocol consisted of 3 tethered 10s trials where the maximal force was registered, and the highest value of the 3 tests was used as the test score (F_{max}). The subjects were connected to a load cell with peak-hold display (AEP, Italy) using a rubber tube to smoothen the measured force during the stroke. Comparisons were done using paired t-tests for the comparison of familiarization and for comparisons between the 3 trials of the protocol. Unpaired t-tests were used to compare swimmers and students, and a χ^2 -test was used to test the frequency distribution of maximal force appearance during the protocol trials. Cronbach's α was used to evaluate reliabilities.

RESULTS
Table 1 shows the results of the same time of day test and retest, and figure1 show the test –retest plot of the competitive swimmers in the familiarised state. Cronbach's α for the reliability between test and retest F_{max} was 0.992 (n=67). The effect of performance level on the coefficient of variation for this kind of testing was significant – the swimmers showing lower test retest difference compared to students ($p<0.02$). The effect of familiarization was significant for the swimmers ($p<0.03$) but not for students.

Table 1. Mean (SD) for the test and retest of maximal tethered swimming force (F_{max}) and the absolute fractional difference between test and retest.

	Competitive Swimmers		Students	
	Not Familiar	Familiar	Not Familiar	Familiar
F_{max} test (N)	141 (33)	150 (33)	130 (35)	137 (30)
F_{max} retest (N)	144 (36)	150 (34)	131 (34)	143 (28)
abs diff. (%)	3.0 (2.8)	1.6 (1.4)	3.7 (3.0)	5.3 (4.4)
Correlation, r=	0.989	0.995	0.978	0.978

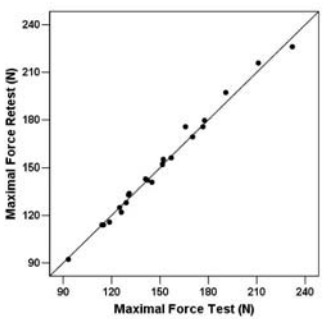

Figure 1. Maximal tethered force test and retest for familiarised swimmers (r=0.995).

Results from the repeated measures within a test session show that F_{max} appeared 24% of the times on trial 1, 39% on trial 2 and 37% on trial 3, with no statistical difference on these frequencies (χ^2=3.8, df=2 and p=0.15). Cronbach's α for reliability within the 3 trials was 0.995 (n=101). The mean (SD) force was 139.9 (31.9)N, 140.9 (31.2)N and 141.1 (32.1)N for trials 1, 2 and 3 respectively. Even though the mean differences between the tree trials seems small, trial 1 force was significantly different from trials 2 and 3 ($p<0.05$), no statistically difference was found between trial 2 and 3.
Reliability of morning and afternoon test retest was found to be 0.990 (Cronbach's α, n=34). The mean (SD) morning and afternoon tethered swimming force was 141.4 (28.5) and 143.5 (28.8) N respectively, with mean paired differences of 2.2 (5.6) N ($p<0.05$, t=2.3 and df=33). The correlation coefficient between morning and afternoon testing was r=0.981 ($p<0.001$). Average absolute coefficient of variation of morning and afternoon testing was 3.4 (2.4)%, and was not statistically different from the total set of 67 test-retests on F_{max} done on the same time of day (mean = 3.0 (2.9)% and p=0.5).

DISCUSSION
The results from the present study show that within subject variations for the tethered swimming power test are very small. This is manifested both by a large Cronbach's α value (0.992), high correlations coefficients between test-retest, and the small coefficients of variation. The coefficients of variation of the swimmers are lower than those reported from dry land maximal isokinetic leg strength testing (<5%) (7), and the students also have lower values for the unfamiliarised and slightly higher values for the familiarised test. Testing swimmers on maximal isometric voluntary force in a dry land setting has previously produced a test-retest correlation of r=0.93 (r^2=0.87) (4). The within subject variation may be due to variations in technique, the normal biological variation in performance or the level of muscle recruitment at the maximal level.
Swimmers were found to have lower coefficient of variation for the test-retest when compared to students. This may probably be due to improved swimming technique. Our experience with university students shows that their technique is relatively unstable. The students tested in the present study were midway in a swimming curriculum of 34 teaching lessons of basic swimming technique. Their unfinished state of swimming technique is considered also as the main reason also for their larger coefficient of variation when familiarised with the test. On the contrary to the swimmers, the students did not have any statistically significant effect on the familiarization. This may imply that the familiarization they underwent was of insufficient magnitude, and that this kind of subjects may need more familiarization than a single test session (3 trials). For the swimmers this dose of familiarization significantly reduced the coefficient of variation to a mean of 1.6% and increased the correlation coefficient to r=0.995 (r^2=0.99). The unfamiliarised state for the swimmers also had a very low coefficient of variation; therefore for training studies where only small changes in maximal force may be the effect, we recommend familiarization with 3 trials of tethered swimming.
Within-test session reliability was found to be very high (α=0.995). Mean force of trial 1 was significantly lower than for trials 2 and 3, and the same for F_{max}. Based on this it is suggested that the test protocol must consist of more than one trial to find a true F_{max}. In our data F_{max} appeared 24% of the times in trial 1, 39% in trial 2 and 37% in trial 3, however, no significant differences between these frequencies was encountered. In light of these results it seems that a 3 trial protocol is unnecessary, and two trials are sufficient.
Reliability for morning and afternoon measurements of F_{max} was found to be high, as manifested by a Cronbach's α of

0.990. A significantly higher F_{max} was found in the afternoon test, this correlates well with previous findings on efforts of longer duration than the 10s F_{max} test, where afternoon 100m swimming performance was significantly higher (1). However the average absolute difference of afternoon and morning F_{max} was not statistically different from the test-retest difference done on the same time of day as reported above. The results thus indicate that for a maximal tethered swimming force test the time of day for testing may be of less importance. However some variations may occur for different individuals and the largest difference between morning and afternoon test for the included subjects was 5.7%. It must be considered that all the subjects were accustomed to morning practice, and that the morning exercise habit has been found to reduce the difference between morning and afternoon swimming performance (1).

CONCLUSION

It is concluded that a tethered swimming power test is highly reliable and shows low values of variations. Competitive swimmers have lower coefficients of variation compared to college students, for whom familiarization did not reduce the variation. The data supports the idea that the test protocol should include more than one trial to achieve a true maximal tethered force (F_{max}). Tethered swimming F_{max} testing may be done with only small diurnal effects affecting performance. The diurnal variations were not different from the variations expected for the same time of day test-retest.

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THE APPLICATION OF COMPUTATIONAL FLUID DYNAMICS FOR TECHNIQUE PRESCRIPTION IN UNDERWATER KICKING

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Computational Fluid Dynamics (CFD) was developed to provide answers into problems which have been unobtainable using physical testing techniques. This study sought to discriminate between the active drag and propulsion generated in underwater dolphin kicking. A 3D image of an elite swimmer was animated using results from a kinematic analysis of the swimmer performing large/slow and small/fast dolphin kicks underwater. The CFD model was developed around this input data. Changes were also made to the input kinematics (ankle plantar flexion angle) to demonstrate the practical applicability of the CFD model. The results demonstrated an advantage in using the large, slow kick over the small, fast kick over the velocity range that underwater dolphin kicks are used. This highlights the potential benefits of using CFD models in technique prescription.

Key Words: computational fluid dynamics, swimming, underwater kicking.

INTRODUCTION

The underwater phases of swimming form a large and important component of the total event time in modern swimming. Currently, in elite competition, there exists a range of underwater technique strategies utilized by the swimmers with very little scientific rationale applied in their selection. Previous empirical testing (1) has examined the net force produced during underwater kicking due to the complexities in separating the propulsive force and active drag. Results were compared to prone streamlined gliding in order to prescribe an approximate velocity at which to initiate underwater kicking. The study assumed steady state (constant velocity) conditions, which limited the applicability to real swimming, where the body is continually accelerated and decelerated.

It has long been accepted that understanding fluid flow patterns in swimming should lead to performance enhancements. CFD was developed by engineers to numerically solve complex problems of fluid flow using an iterative optimization approach. The net effect is to allow the user to computationally model any flow field provided the geometry of the object is

known, and some initial flow conditions are prescribed. This can provide answers into problems which have been unobtainable using physical testing methods, thereby bridging the gap between theoretical and experimental fluid dynamics.
The current study sought to discriminate between the active drag and propulsion (net thrust) generated in underwater dolphin kicking with the goal of optimizing the underwater kicking component in swim starts and turns. The objective information gained from this type of CFD analysis can equip sports scientists with tools to more accurately provide advice on technique modifications in order to gain the extra edge at the elite level.

METHODS

Kinematic Measurements

An elite national level swimmer was videoed underwater from a sagittal view, while performing underwater dolphin kicks at maximal effort. The swimmer performed both high amplitude, low frequency dolphin kicks and low amplitude, high frequency dolphin kicks. The kick frequencies of these underwater kicks was of similar magnitudes to that found in current elite competition based on analysis of underwater kicking from the Sydney Olympic Games. One of each kicking pattern was selected based on similar average velocity and depth over the kick cycle between the 2 trials. A full 2D analysis was performed for the 2 selected trials with 10 landmarks on the left hand side being digitized. Symmetry was assumed between the left and right sides of the body. Summary results of the kinematic analysis demonstrate a clear difference in amplitude and frequency between the 2 selected underwater kicks (see Table 1).

Table 1. Descriptive kinematic variables.

Derived Kinematic Variables	Large/Slow Kick	Small/Fast Kick
Kick Amplitude (vertical toe displacement) (m)	0.54	0.42
Maximum Knee Angle (º)	121.7	139.9
Kick Frequency (Hz)	2.27	2.63

3D Laser Imaging

The 3D mapping of the swimmer was performed using a Cyberware WBX whole body laser scanner with a density of one point every 4mm. Higher resolution scans were also conducted of the hands and feet using casts of these limbs (density of one point every 2/3mm). This was performed given the importance of these areas in setting the initial flow conditions (in the case of the hands) and in developing thrust (in the case of the feet). The higher resolution scans were then aligned and merged seamlessly into the full body scan to provide more accuracy at these locations. All scans were performed with the swimmer assuming a streamlined glide position with hands overlapping and feet plantar-flexed (see fig. 1). This 3D model is used as input for the CFD model to describe the swimmer's geometry.

Figure 1. 3D laser scanned image of the subject.

CFD Model Methodology

The computer simulation was performed using the CFD software package, FLUENT (version 6.1.22). In brief, the CFD finite volume technique involved creating a domain inside which the flow simulation occurred, bounding the domain with appropriate external conditions, and breaking the domain up into a finite number of volumes or cells. The governing equations of fluid flow were then integrated over the control volumes of the solution domain. Finite difference approximations were substituted for the terms in the integrated equations representing the flow processes. This converted the integral equations into a system of algebraic equations that were solved using iterative methods. The model utilized the addition of user defined functions and re-meshing to provide limb movement. This analysis was completed by breaking the limb movements down into discrete time steps and having the package solve the flow field for that position before moving on to the next position. The volume mesh was also updated at each time step with the previous flow field being the starting point at the next time step.

Validating the CFD model

Although the basis of this case study was to compare two different dynamic kicking techniques, the model needed to be validated to show the compatibility with actual test results. Due to the unavailability of empirical testing to accurately measure active drag throughout an underwater kick cycle, the model was validated using steady-state tests. Repeated streamlined glide towing trials showed that the CFD model results were within two SD of the average empirical passive drag for the subject, indicating that CFD predicted results were of sufficient accuracy.

CFD User defined functions

Using the solid-body kinematics function, user defined functions (UDF) and dynamic meshing, the body was broken into four rigid (feet, shanks, thighs, complete upper body) and three flexible sections (hips, knees, ankles). Based on the measured kinematic data of the swimmer, a mathematical curve was fitted to the rotational movements of the three main joints with global horizontal and vertical movements also modeled. Due to the accuracy of both the fluent software and the kinematic data, the position of the swimmer at any point in time was estimated to be within 5mm of the actual position.

RESULTS AND DISCUSSION

One of the major benefits of the CFD modeling procedure is that it allows the user to modify the inputs into the model to determine how variance in the inputs affect the resultant flow conditions. Hence, the CFD model was rerun over a range of velocities to ascertain any differences in drag and propulsion at various kicking velocities.
An output of combined pressure and viscous drag was calculated at each time step through the analysis runs. The best measurement of effectiveness of a technique is the momentum created, or removed, from the swimmer per cycle. This momentum can then be converted to a per-second measurement to compare different techniques. Table 2 details the momentum removed from the swimmer for the analysis runs completed.

Table 2. Momentum (Ns) reduction in a full cycle and an average second of kicking.

	Large Kick			Small Kick		
	2.40 ms^{-1}	2.18 ms^{-1}	1.50 ms^{-1}	2.40 ms^{-1}	2.18 ms^{-1}	1.50 ms^{-1}
Total per cycle	44.40	35.04	9.59	38.03	31.24	9.74
Total per second	103.46	81.65	22.34	103.45	84.98	26.48

From the analysis results it can be seen that both kick techniques have a similar effect at 2.40 ms^{-1}. Although not quantified, it appears that for speeds of greater than 2.40 ms^{-1} there is a trend for the small kick to become more efficient. For speeds less than 2.40 ms^{-1} the large kick appears to be more effective, with approximately 4% better efficiency at 2.18 ms^{-1}, increasing to 18% more efficiency at 1.50 ms^{-1}.

When comparing the dynamic underwater kicking data to the steady-state results of previous studies (1), it can be seen that velocities around 2.40 ms^{-1} represent a cross-over point, whereby at higher velocities it is more efficient for the swimmer to maintain a streamlined position than to initiate underwater kicking. This is due to the swimmer creating more active drag than propulsion while kicking compared to remaining in a streamlined position, leading to wasted energy and/or a deceleration of the swimmer. Hence, although it is possible that the swimmer would benefit from a smaller kick at higher velocities, it may be even more beneficial to maintain a streamline position.

The main benefit of the large kick is the acceleration that is created on both the upswing and the down-sweep. The larger kick can create up to 50N more propulsion in these acceleration phases, whilst only creating 25N more drag in the non-acceleration phase. The main benefit of the propulsion is not coming from the feet where the propulsive forces are only marginally greater for the large kick but rather from the thighs and calves, where much greater propulsion is generated in the large kick compared to the small kick. A major point of drag on the large kick is when the knees drop prior to the main down-sweep due to the increased frontal surface area and flow changes, and creates substantially more drag for the large kick model. Movement of the upper body on the large kick also generates significantly more drag in phases of the kick cycle than that of the small kick. However, in the upswing of the feet, the body maintains sufficient momentum to offset some of the loss imposed by the high amplitude kick.

To illustrate the capabilities of the CFD modeling technologies, various scenarios were modeled by varying ankle movement in order to examine the effects on the swimmer's net thrust. In this case example three scenarios were examined with results in Figure 2:

1. The full range of ankle plantar flexion/dorsi-flexion of the test subject (pink curve).
2. A 10° shift in the ankle flexibility – referring to 10° less maximum plantar flexion and 10° greater maximum dorsi-flexion angle (green curve).
3. A 10° decrease only in maximum plantar flexion angle (blue curve).

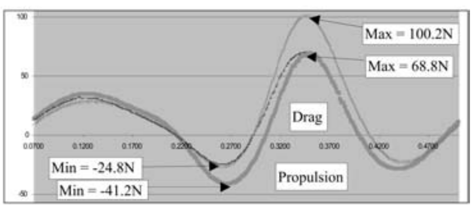

Figure 2. Net thrust graph highlighting the effects of ankle flexibility on propulsion.

The results in Figure 2 demonstrated that while the swimmer is traveling at 2.18 ms^{-1}, a 10° increase in ankle plantar flexion will create 16.4N greater peak propulsive force during the kick cycle. However, with 10° degrees more dorsi-flexion, the peak drag will increase by 31.4N. These results indicate that increasing ankle flexibility will increase the efficiency of stroke by approximately 1Ns per degree of increased flexion for this subject. Although this cannot be generalized, it highlights important information to coaches on the effects of flexibility on the generation of propulsion while kicking.

CONCLUSIONS

Although it shows the large kick has produced the better results of the two styles, this is based solely on the two kicking patterns analyzed and cannot be generalized to the large number of possible kicking patterns used by swimmers. However, this case study does highlight the powerful tool that CFD can be in optimizing swimming technique. The results have demonstrated the CFD can effectively be used as a tool, both to improve the foundational knowledge of swimming hydrodynamics as well as provide useful practical feedback to coaches in the short term on technique prescription. The benefits of using a modeling approach lies also in the area of technique modification strategies. Alterations in technique can be examined experimentally using the model, rather than 'trial and error' approach that typically is used.

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ANALYSIS AND COMPARISON OF SOME AQUATIC MOTOR BEHAVIORS IN YOUNG CHILDREN

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Several studies considered aquatic motor sequences in young children and their relations with some aspects of aquatic psychomotor development. The aim of this study was to understand if spontaneous swim movements of the child can evolve into an effective action, after a "keep doing" and a "free exploration" based methodological approach. Three groups of ten children, different in age (4-12 months, 12-24 months, 24-36 months), were studied. The presence of some motor skills pre and post a period of 10 events of free experience in a swimming pool were detected. No differences were found in the pre-post comparison within each group. Differences resulted in the comparison of the children aged 4-12 versus 24-36 months and in the children aged 12-24 versus 24-36 months.

Key Words: swimming, young children, motor behaviours.

INTRODUCTION

In literature there are many studies pointing out the presence of an ordered sequences in the aquatic motor conducts of young children (1, 3). This evolution comes from neuronal development of children, which keeps pace with evolution

related to development of the terrestrial basis motor patterns (3, 4). Some assessments were performed with electromyography and video analysis about lower limbs movements of young children (5) and some others about description of leg movements of children aged 3-20 months (6). Other authors assert that water experiences could improve specific skills (2).
The aim of this study was to understand if spontaneous swim movements of the child can evolve into an effective action, after a "keep doing" and a "free exploration" based methodological approach.

METHODS
This study involved 30 children divided into 3 groups (5 males and 5 females each), aged respectively 4-12 months (group A: age 10.8±1.8 months, weight 9.6±1.4 kg, height 74.7±4.44 cm), 12-24 months (group B: age 17.0±2.3 months, weight 11.8±1.7 kg, height 82.8±6.1 cm) and 24-36 months (group C: age 31.9±3.0 months, weight 13.7±1.6 kg, height 96.8±7.3 cm).
The study was performed with the same teacher, who proposed 10 lessons of 30 minutes each. The swimming pool had irregular edge, depth of 90 cm, Cl^- 0.6 p.p.m., pH 7-7.4, water temperature 33°-34° C, room temperature 29°-30° C.
The children experienced the water environment, freely playing. Several tools to increase their creativity and their imagination were placed in the water, such as mats, floating toys, slides, balls. No aids to floating, movement or programs to induce learning to swim were used.
The spontaneous behaviours of the children pre and post the period of free experience in the water were analyzed. The presence of the following six specific characteristic responses to the aquatic environment stimulation was observed and recorded by pictures and underwater videos: (I) a spontaneous submersion; (II) a balanced body inclination from 20 to 45 degrees; (III) a simultaneous action of the arms, (IV) an alternated action of the arms; (V) a simultaneous actions of the legs; (VI) an alternated action of the legs.
The criterion of scoring employed was: "0" when the characteristic was absent, "1" when it was present.
A comparison of the pre-post status within group and a comparison among the three groups for each characteristic observed, were conducted with a Mann-Whitney non-parametric Test, for $p<0.05$.

RESULTS
No significant differences ($p>0.05$) were found in the comparison between the pre and post experience analysis within group. On the contrary, in the comparison 4-12 versus 24-36 months, a significant differences ($p<0.05$) were found in all the characteristics evaluated, except in the spontaneous submersion action. In the comparison 12-24 versus 24-36 months, differences were found in the body position and in the arm movements (table 1).

Table 1. Comparison among groups with Mann-Whitney Test (= p<0.05; ** = p<0.01).*

Characteristics	4-12 Vs. 12-24 (months)	12-24 Vs. 24-36 (months)	4-12 Vs. 24-36 (months)
Submersion			
Inclined Body Position 20°-45°		*	*
Simultaneous arm movements		**	**
Alternated arm movements		**	**
Simultaneous leg movements			*
Alternated leg movements			**

DISCUSSION
From the results, it appears that no differences within group were noticed in the spontaneous motor actions observed. We can suppose that in young children aged 4 to 36 months, a free experience in the water environment does not produce effects in the aquatic motor behaviours considered.
On the contrary, variations appear in the comparison among groups. In the comparison of the children aged 12-24 versus 24-36 months differences were found in the body inclination and in the arm movements. The children aged 4-12 versus 24-36 months present differences in every aquatic motor behaviour observed, except in the spontaneous submersion action. Based on the data from the present study, we can suppose that, according to the literature (3), the aquatic motor development of the young children should depend mainly on age.

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VALIDATION OF A CABLE SPEEDOMETER FOR BUTTERFLY EVALUATION

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Getting fast results from the evaluation of swimmers is one of the most important goals to achieve with technological development in the field. The purpose of this study was to validate a real-time velocimetric device (speedometer) through the comparison of their results with computer assisted videogrametry. The sample included 7 international level swimmers (3 females and 4 males). Each swimmer performed four 25m trials, two at 200m race pace and two at 50m race pace. For each trial, two stroke cycles were studied, resulting on a total of 28 cycles

analysed. Hip v(t) curves obtained from speedometer and videogrametry were compared, as well as the speedometer hip curve with the one of the centre of mass (CM). The higher mean correlation obtained was between v_{hip1} and v_{hip2} (0.955±0.028), followed by v_{hip1} with v_{CM} (0.920±0.049). The lower correlation was v_{hip2} vs. v_{CM} (0.878±0.053). It was concluded that the speedometer is a reliable, fast and interactive tool for training advice.

Key Words: swimming, biomechanics, velocity, speedometer, images processing.

INTRODUCTION
Swimming coaches intend to get better competitive results by improving swimmer's technique. There are several ways of doing so, and biomechanical analysis is, certainly, one of the most accurate and profitable solutions. Nevertheless, biomechanical analysis normally requires options rather expensive and time consuming for data analysis. Moreover, in Swimming, the biomechanical evaluation of the stroke technique is limited by original constraints related with the environment – air and water -, that do not exist in other sports: (i) the distortions of the swimmer's image produced by the water refraction, undulation and turbulence; (ii) the need of obtaining synchronized images in two elements of distinct density and (iii) the underwater visibility problems arising due to water aerisation [1]. Consequently, in this sport, biomechanical / technical evaluation is specially difficult, mainly if we intend to deliver results in a fast and useful time for swimmers and coaches. So, getting fast results from the biomechanical evaluation of swimmers is one of the most important goals to fulfil with technological developments related to swimming science.
In this domain, one of the most popular and rather informative evaluation procedures is the assessment of the intra-cycle speed fluctuation profile of the swimmer. The mean velocity of a given swimmer depends on the balance between propulsive and drag forces. During a swimming cycle, the intensities of both forces change constantly, once the motor actions are more or less discontinuous (reaching to his fullness in the simultaneous techniques), and the relative positions of the body segments are constantly changing [2]. So, in each stroke cycle, the speed of the swimmer's forward displacement suffers more or less pronounced modifications due to the positive and negative accelerations induced by the continuous variations of the resultant impulses.
There are two different ways of measuring the intra-cycle speed profile of the swimmer: (i) by getting the velocity variations of an anatomical point (usually the hip) or (ii) analysing the swimmers Centre of Mass (CM) speed profile [3]. A fixed anatomical landmark can be monitored directly using the so cold cable Speedometers or Swim-meters, or the propeller based Swim speed recorders. Radar solutions can also be attempted. Nevertheless, for the CM velocimetry, only image processing solutions can be used, with automatic digitizing routines seriously compromised due to the dual-media condition. Consequently, this procedures are to much time consuming and are characterized by a reduced interaction capacity with the training process.
The purpose of this study was to validate a real-time velocimetric device (speedometer) through the comparison of their results with those provided for the hip and the CM from computer assisted videogrametry.

METHODS
The sample included 7 swimmers (63.4±9.3kg; 171.9±12.7cm) from the Portuguese national team, being 3 females and 4 males. As a solution to facilitate images processing, the swimmers were marked with adhesive tape or ink black colour in the main anatomical landmarks to be digitalized. Starting in the water, each swimmer performed, two repetitions of 25 meters Butterfly: one at the corresponding velocity of a 200m race (V200m) and other at 50m race pace (V50m). The study included two cycles in each repetition, resulting on a total of 28 cycles studied.

Speedometer
A low cost, house made speedometer was built (fig. 1). This instrument is based over a bobbin set in a tripod using a nylon line with almost no elasticity. This cable is fixed to the swimmer at the swimming suite, t a middle distance between the two hip joints.

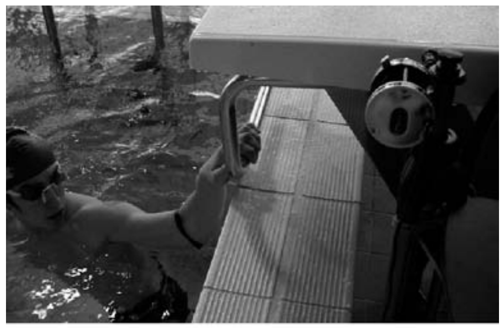

Figure 1. The speedometer

Fixed to the bobbin, a switch sends a signal to the computer, obtained at a 1000Hz frequency. This data is analysed by the computer that gives a graphic v/t in real time (fig. 2). These data can be exported from the software as ASCII and then be used in different analyses with basic software such as *Microsoft Excel*.

Figure 2. The graph v(t) obtained in real time

Images processing
Two video cameras were used (*JVC GR-SX1 SVHS* and a *JVC GR-SXM 25 SVHS*) in a special support with two shelves (fig. 3). A camera was 20cm below the water surface, inside a waterproof box (*Ikelite Underwater Systems*). The other one was

20cm above the water surface. The images obtained in the sagittal plan by the two cameras were synchronized in real time and mixed in a video mixing table (*Panasonic Digital AV Mixer WJ-AVE5*), originating a dual-media single image with corrected refraction, that was sent to a video recorder (*Panasonic AG-7350 SVHS*). The *Ariel Performance Analysis System*, from *Ariel Dynamic Inc.*, was used with Zatsiorsky model for centre of mass kinematical analysis.

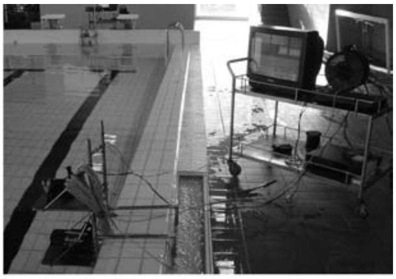

Figure 3. The dual-media image capture and mixing mechanism

Into the images obtained were digitized 24 anatomical points to get an accurate location of the centre of mass. Lately, results were filtered in x and y to eliminate possible errors from digitalization (*Digital Filter Algorithm* with a 5Hz frequency). After these procedures all the data were visualized, as shown in picture 4, both with the swimmer video image, the tick figure and the CM velocity graph.

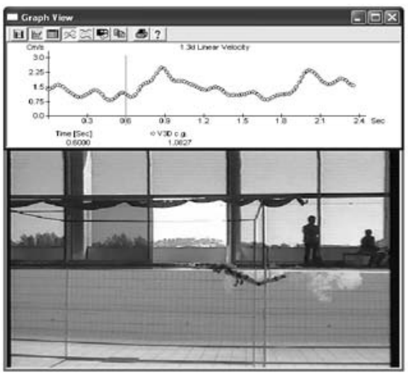

Figure 4. Data analysis

RESULTS AND DISCUSSION
The variables analysed were v_{hip1}, v_{hip2} and v_{CM}. The v_{hip1} stands for the velocity of the hip obtained by the images processing, v_{hip2} stands for the velocity of the hip assessed using the speedometer, and the v_{CM} stands for the velocity of the centre of mass of the swimmer. The kinematics of this last spot was taken as reference. An example of the v(t) curve for butterfly swimming, taken from one of the subjects of the sample is presented in Figure 5. To obtain this data was necessary to digitize, frame by frame, all the anatomical points. This took us a lot of time and it is, in fact, a procedure hardly available for the average swimming coach.

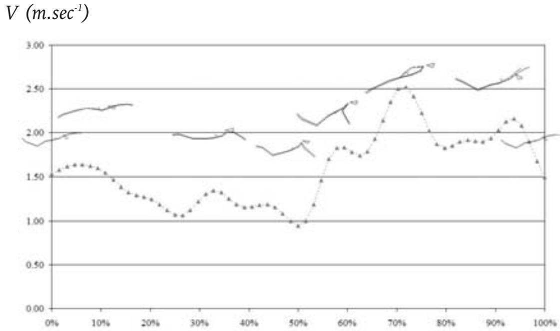

Figure 5. Butterfly intra-cycle velocity variation profiles of v_{CM} from a swimmer during a stroke cycle.

Using our home made speedometer we were able to obtain, in real time, the results presented in Figure 6. There it can be seen the successive cycles performed along the 25m distance, their intra-individual variability, the effect of fatigue associated with de decline of the mean velocity, and the intra-cycle variation of velocity (and their kinetics along the test duration). So, immediately after the test, the swimmer and the coach can have a set of very relevant biomechanical parameters associated with the butterfly technique performed just before. In the figure, between the vertical lines, a stroke cycle is defined.

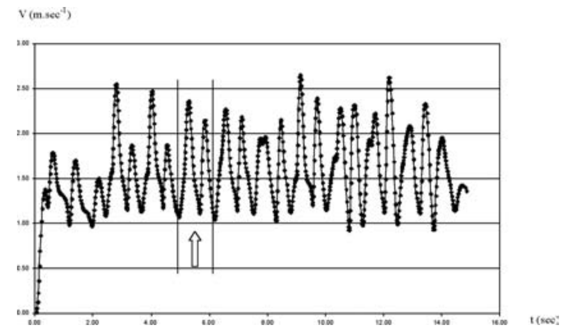

Figure 6. Speed profiles of v_{hip2} from a swimmer during a 25 meter Butterfly set.

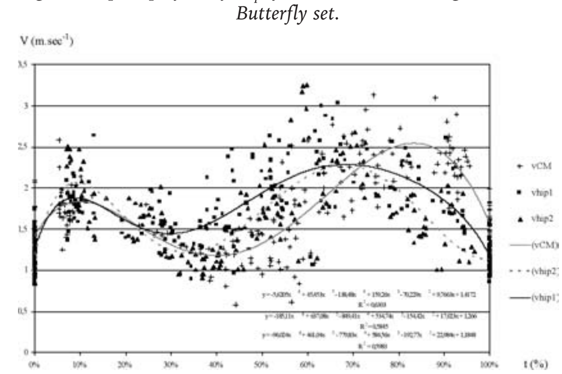

Figure 7. Velocity profiles obtained for the pooled data for v_{hip1}, v_{hip2} and v_{CM} during a stroke cycle.

The Pearson correlation coefficient computed for each swimmer between the variables analysed (v_{hip1}, v_{hip2}, and v_{CM}) was statistical significant in all cases (p≤ 0,01). The higher mean value of the obtained individual r values was found between v_{hip1} and v_{hip2} (0.955±0.028), followed by v_{hip1} with v_{CM} (0.920±0.049). The lower mean value for r was obtained between v_{hip2} vs. v_{CM} (0.878±0.053). After normalizing to the time duration for the period of a cycle we were able to create the Figure 6 scattergram and v(t) polynomial fluctuations best fitted to each distribution (v_{hip1}, v_{hip2}, and v_{CM}).

CONCLUSIONS

From these results we can assume that the study of a swimmer intra-cycle velocity profile assessed through the speedometer is reliable with the profile described for the same anatomical point but obtained through image processing biomechanical videogrametry. It is also very strongly correlated with the CM kinematical profile, despite some function discrepancies associated, mainly, to the effect over the CM of the simultaneous forward recovery of the arms. So we are strongly convinced that this artefact may be of extreme relevance for training evaluation and advice, allowing a number of practical applications to the performance enhancement of swimmers without major equipments, and time 8and money) costly analysis.

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ESTIMATION THE LAP-TIME OF 200M FREESTYLE FROM AGE AND THE EVENT TIME

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This investigation aimed at the estimation of the lap time of 200m freestyle races from age and event time on national level swimmers. Subjects were 1759 swimmers that selected by D'Agostino-Pearson test of each age from 1857 swimmers that participated in 200m freestyle of the Japanese national level competitions in 2002. The lap time in every 50m and the event time were used for analysis. Exponential function approximation of the event time by aging was carried out. Furthermore, the linear regression between a lap time and event time for every age was calculated respectively. It seems that the competitive time of 200m freestyle reach the maturity about 20 years old for men and/or 18 years old for women. The estimation formula applied to international level swimmer has high validity (0.904 to 0.987, n=118 and 86) on condition that the age factor should fix at 22 for over 22 years old male swimmer and/or at 21 for over 21 years old female swimmer.

Key words: lap-time, age, event time.

INTRODUCTION

The performance of 200m freestyle improves with aging in the period of growth. The contents of race change with grades of development of many physical fitness factors. The competitive record shows synthetic performance. On the other hand, the lap times are the composition elements of the swimming performance. It is not discussed by details about these development tendencies until now. This investigation aimed at the estimation of the lap time of 200m freestyle races from age and event time on national level swimmers. This investigation aimed at the estimation of the lap time of 200m freestyle races from age and event time on national level swimmers.

METHODS

Subjects were 1857 swimmers (men: 935, women: 922) that participated in 200m freestyle of the Japanese national level competitions in 2002. These subjects included from 10 to 22 years old.

The normal distribution of subjects is required for the parametric presumption. Therefore, the data arranged in order of the event time for every age respectively. The D'Agostino-Pearson test (ZAR 1999) which authorizes the normal distribution from coefficient of skewness and kuytosis was used. The swimmer which the normal distribution was not held as probability < 0.1 excepted. The lap time in every 50m and the event time were used for analysis. It was obtained permission of these data use from the Japan Amateur Swimming Federation Information System Committee. Exponential function approximation of the event time (TIME) by aging (AGE) was carried out. The time constant (TC) was decided as a correlation of TIME and a presumed value became the highest. The estimation formula of TIME from AGE was as follow:

$$TIME = a\left((TIME_{max} - TIME_{min})\cdot \exp\left(-\frac{(AGE\text{-}10)}{TC}\right)\right) + b \quad \text{(Eq. 1)}$$

Furthermore, the linear regression between a lap time (LAP) and TIME for every age was calculated respectively. The linear regression coefficients were smoothed with 3rd order polynomial regression. The estimation formula that calculated the LAP from AGE and TIME was as follow:

$$LAP = (a_1AGE^3 + a_2AGE^2 + a_3AGE^3 + c_1)TIME + (b_1AGE^3 + b_2AGE^2 + b_3AGE + c_2) \quad \text{(Eq. 2)}$$

RESULTS AND DISCUSSION

The 908 men's and 851 women's swimmers were selected by D'Agostino-Pearson test applied to the event time. Figure1 showed the case of 15 years old boys, 15 slower swimmers were cut from 137 swimmers. The critical point was at 132.75sec.

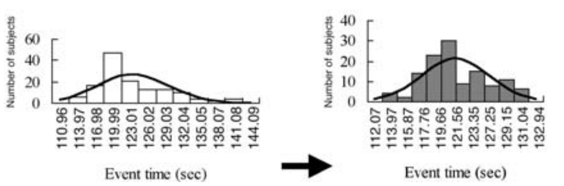

Figure1. Sample selected for the normal distribution by D'Agostino-Pearson test.

Ninety eight swimmers were excluded in all subjects (5.28%) because they swam too slowly as the national level swimmers. It seemed that the normal distribution of subjects was confirmed.

Base on the estimation formula (1), the development tendency of TIME by aging could be approximated by the following function: for men,

$$TIME=46.19 \cdot \exp\left(-\frac{(AGE\text{-}10)}{3,35}\right)+115.88$$

for women,

$$TIME=31.76 \cdot \exp\left(-\frac{(AGE\text{-}10)}{2.76}\right)+128.01$$

The development amplitude for men was 46.19sec, and for women was 31.76sec. As sex differences were not obvious in 10 years old swimmers, it was considered that the saturation of event time appeared in women earlier than in men. Since three times of TC showed 95% saturation of an exponential function, it seemed that TIME and LAP of 200m freestyle reached the maturity at an age of about 20 years old for men and/or 18 years old for women (see Figure 2).

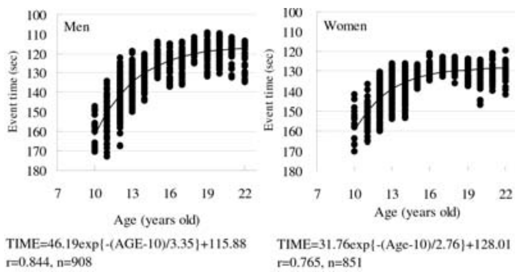

Figure 2. Development tendency of 200m freestyle event time.

The development tendency of LAP by aging could be approximated as follows:

for men,

$$LAP_{50}=9.57 \cdot \exp\left(-\frac{(AGE\text{-}10)}{3.32}\right)+27.04 \qquad (r=0.852)$$

$$LAP_{100}=12.46 \cdot \exp\left(-\frac{(AGE\text{-}10)}{3.40}\right)+29.13 \qquad (r=0.847)$$

$$LAP_{150}=13.04 \cdot \exp\left(-\frac{(AGE\text{-}10)}{3.35}\right)+29.91 \qquad (r=0.835)$$

$$LAP_{200}=11.115 \cdot \exp\left(-\frac{(AGE\text{-}10)}{3.33}\right)+29.79 \qquad (r=0.779)$$

for women,

$$LAP_{50}=6.15 \cdot \exp\left(-\frac{(AGE\text{-}10)}{2.56}\right)+30.06 \qquad (r=0.737)$$

$$LAP_{100}=8.86 \cdot \exp\left(-\frac{(AGE\text{-}10)}{2.67}\right)+32.28 \qquad (r=0.782)$$

$$LAP_{150}=9.09 \cdot \exp\left(-\frac{(AGE\text{-}10)}{2.94}\right)+32.90 \qquad (r=0.762)$$

$$LAP_{200}=7.68 \cdot \exp\left(-\frac{(AGE\text{-}10)}{2.84}\right)+32.75 \qquad (r=0.684)$$

The correlations with TIME and LAP of each age were significant from 0.475 to 0.988 ($p<0.001$). It appears that a linear regression was appropriated to the estimation of LAP from TIME for every age. The slope and intercept of the linear regression between LAP and TIME were calculated. These linear regression coefficients were smoothed with a cubic regression between the coefficient and AGE. These coefficients of the estimation formula (2) that calculated the LAP from AGE and TIME are shown in Table 1.

Table 1. Coefficients of the formula that calculated the LAP from AGE and TIME.

women	LAP100	$0.241*10^{-3}$	$-1.097*10^{-2}$	$1.578*10^{-1}$	-0.473
	LAP150	$-0.123*10^{-3}$	$0.519*10^{-2}$	$-0.662*10^{-1}$	0.531
	LAP200	$-0.549*10^{-3}$	$2.479*10^{-2}$	$-3.579*10^{-1}$	1.959
Intercept		b1	b2	b3	c2
men	LAP50	$9.058*10^{-3}$	$-47.494*10^{-2}$	$81.322*10^{-1}$	-38.361
	LAP100	$-2.276*10^{-3}$	$18.997*10^{-2}$	$-39.661*10^{-1}$	23.953
	LAP150	$-8.924*10^{-3}$	$49.062*10^{-2}$	$-85.390*10^{-1}$	43.742
	LAP200	$2.141*10^{-3}$	$-20.565*10^{-2}$	$43.729*10^{-1}$	-29.334
women	LAP50	$-58.721*10^{-3}$	$261.466*10^{-2}$	$370.670*10^{-1}$	176.249
	LAP100	$-34.229*10^{-3}$	$158.006*10^{-2}$	$232.008*10^{-1}$	109.721
	LAP150	$17.237*10^{-3}$	$-73.163*10^{-2}$	$93.948*10^{-1}$	-38.665
	LAP200	$75.713*10^{-3}$	$346.309*10^{-2}$	$508.730*10^{-1}$	-247.304

Estimatinon formula:

$$LAP = \left(a_1 AGE^3 + a_2 AGE^2 + a_3 AGE + c_1\right) TIME + \left(b_1 AGE^3 + b_2 AGE^2 + b_3 AGE + c_2\right)$$

The high correlations between the actual lap time and the estimated lap time from AGE and TIME ranged from 0.944 to 0.990. Relation among LAP, TIME and AGE were drawn in Figure 3 for men and in Figure 4 for women. Open circle denotes actual data and a mesh shows LAP values estimated from TIME and AGE.

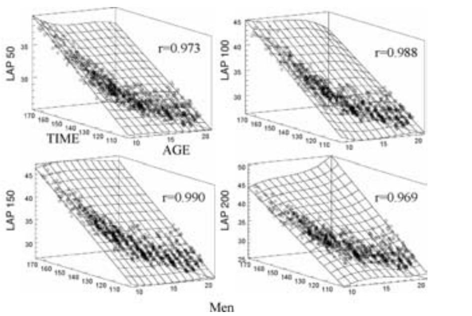

Figure 3. Three dimensional relationships among LAP, TIME and AGE for men.

In the LAP50, the mesh of estimated LAP values from TIME and AGE was distorted reduction-ward during a period of schoolchildren (10 to 12 years). It was thought that it depended on improvement in a fundamental swimming ability. A tendency for the LAP100 and the LAP150 to develop during adolescence (13 to 18 years) was observed. It was considered that development of aerobic capacity leads to it. In the LAP200, the mesh of estimated lap distorted increase-ward for adult swimmers (19 to 22 years). This may be due to the fact that difference of fatigue tolerance was reflected in the race. These estimation equations formula applied to international level swimmers that participated in the "2005 World Swimming Championships" has with high validity (0.904 to 0.987, n=118 and 86) on condition that the AGE factor should fix at 22 for over 22 years old men and/or at 21 for over 21 years old women. Maglischo (2003) recommended a drop-off time between the first and second halves of the 200m freestyle race of 1.00 to 2.00 sec. The drop-off times were calculated using estimated LAPs on condition that TIME=110sec for men and TIME=120sec for women. The drop-off of men was larger than 1.00 and less than 2.00sec, except in the case of 22 years old (2.47 sec) and in the case of under 11 years old (under 1.00 sec). On the other hand, the drop-off of women was over 3.00 sec except in the case of under 12 years old. This is explained by the poor anaerobic capacity attributed to children by the fact that female swimmers seem to have difficulty in increasing speed during the final 50m.

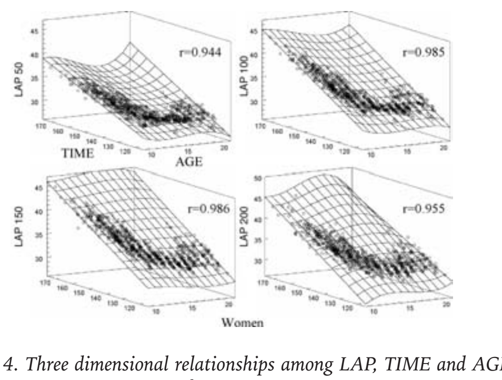

Figure 4. Three dimensional relationships among LAP, TIME and AGE for women.

CONCLUSION

From the results of this study we can conclude that: 1) The event time of national level 200m freestyle reach the maturity at an age of about 20 years old for men and/or 18 years old for women. 2) The estimation formula had validity and was applicable to international level swimmers. 3) It is suggested that young swimmers use even pace, women use the fast-keep-slightly fast pace, and men use the fast-keep-fast pace.

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DETECTION OF REAL-TIME PATTERNS IN BREASTSTROKE SWIMMING

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The objective of this research was to search for a particular type of repeated behaviour patterns in swimming movement cycles. The search used a new data analysis approach based on a process known as T-Pattern detection of the temporal and sequential structure of a given data set. The temporal patterns can be related to performance specific actions (e.g. comparison intra-cycle movement patterns similar to the one described by Coleman at al., 1998). Theme can be used for the analysis by using the relevant types of swimming T-data files created with ThemeCoder or other qualitative codification set. Certain breaststroke patterns of swimmers were detected, demonstrating the changes the swimmer had introduced in each swimming cycle. Coaches could possibly use this kind of structural information's when in need of optimizing the swimmer performance or find the particular hidden patters in swimming behaviour.

Key Words: qualitative analysis, T-pattern, breaststroke swimming.

INTRODUCTION

During the coaching process a great importance is given on coach ability to observe and recall all critical discrete incidents with impact on the athlete performance. However coaches cannot accurately observe and recall all the detailed information that is required for a complete understanding, interpretation or assessment of performance (Franks and Miller, 1986), especially if we agree that performance can be deduced to complex series of interrelationships between a large variety of variables.
The aim of this paper is to introduce a data analysis method that examines temporal structure and interrelationships between events (movements) within breaststroke swimming actions. This analysis method, based on the T-Pattern detection algorithm and the corresponding Theme software developed by

Magnusson (4, 5), can identify consistent temporal patterns that exist within the behaviour flow, and thus providing a different view of the complex interrelationships between movements. A temporal pattern (T-Pattern) is essentially a combination of events that occur in the same order with a relatively invariant time distance between consecutive pattern components with respect to an expectation assuming, as a null hypothesis, that each component is independently and randomly distributed over time. As stated by Magnusson (5, p.94) *"if A is an earlier and B a later component of the same recurring T-pattern then after a occurrence of A at t, there is an interval [t+d1, t+d2] (d2≥ d1≥ d0) that tends to contain at least one occurrence of B more often then would be expected by chance. This relation is called a critical interval relation between the distributions of A and B"*. The critical interval enables the admissible temporal distance between successive identical occurrences in order to consider the existence of a temporal pattern, allowing the detection of repeated temporal and sequential structures in real-time behaviour records. The pattern detection algorithm is based on the probability theory and, more specifically, the binomial distributions (Magnusson, 2000).

The search strategy is to detect simple patterns first, identifying relationships between two event-types and then to detect more complex patterns, being composed by combinations of simpler ones. A newly detected pattern may then become a part of even more complex patterns as it combines with others. Along the process of detection, a selection of patterns is made by deleting the less complete versions (4, 5).

This analysis method in sports is frequently associated to the observational methodology (1). This methodology is a particular strategy of the scientific method that has as an objective to analyse the perceptible behaviour that occurs in habitual contexts, allowing them to be formally recorded and quantified and which uses an *ad hoc* instrument in order to obtain a behaviour systematic registration that, since they have been transformed in quantitative data with the necessary reliability and validity determined level, will allow analysis of the relations between these behaviours.

One *ad hoc* instrument often used in observational research is the field format. The main characteristics of the field format are: (i) it does not require a theory support, although it is desirable to have one; (ii) It's an open system; this means that it allows adding new behaviours, included in any of the initially proposed criteria, during the research process; (iii) it's an instrument adequate to use in complex situations, like sport activities, as it permits to deal with several criteria or dimensions simultaneously (multidimensional); (iv) its basic unity is the configuration obtained by the combination of several codes that represent an event.

To construct this instrument it is needed to establish the criteria or axis of the instrument. These criteria are determined by the study objectives and may be based on theory contents and/or empirical situations. The criteria may be subdivided hierarchically into others. Within each criterion are listed behavioural units, observed during the exploratory stages, and whose characteristics are coherent with the content of the corresponding criteria. The criteria list is an open system where each behaviour unity receives a code. The code system is decimal so that we may unfold each criterion code into others, hierarchically of inferior order, correspondent to the behaviour unities included in each specific criterion.

The main objective of this research is to search for a particular type of repeated behaviour patterns in swimming movement cycles using a new data analysis approach based on a process known as T-Pattern detection. By isolating complex breaststroke patterns of swimmers coaches/swimmers could possibly use this kind of structural information's when in need of optimizing performance. This kind of information may be particularly interesting to be used in conscious movement control (Chollet, 1990).

METHODS

This study was based on the observational methodology (1). The empirical data were obtained by using the coding of thirty breaststroke cycles (Campaniço et al., 2006), swum at maximal speed, of a national champion swimmer video recorded underwater in several moments. The video images were captured from front and side-view by classical underwater criteria and converted the stroke cycle to a digital format seen with the computer. For this study field formats have been prepared. To test the instrument's validity we asked experts to describe the technical model of breaststroke. This instrument was composed by seven criteria representing the significant stroke phases adapted from Colman et al. (3), represented in figure 1: (i) beginning of leg support: BLS; (ii) first leg propulsion action: FLPA; (iii) second leg propulsion action: SLPA; (iv) first arm propulsion action: FAPA; (v) second arm propulsion action: SAPA; (vi, vii) arm recovery divided in two criteria: highest point of the hands (HAR) and forward movement of the hands (FAR).

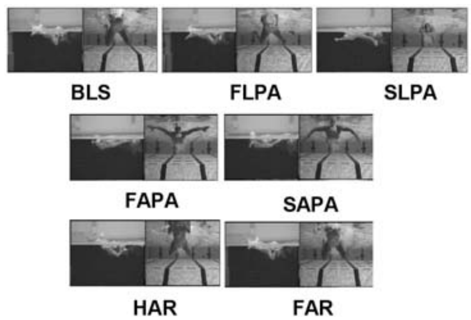


Figure 1. Image used under Colman authorization. The figure focused the criteria point used to separate the critical behaviour developed in the field format criteria.

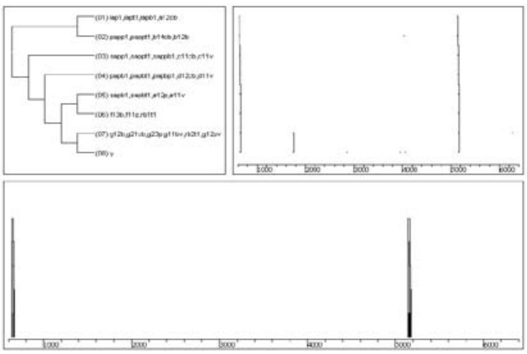
Each criterion included, as behaviour unities, the most relevant segment relation occurrences between trunk, head, arms and legs positions, hand trajectories and acceleration. For each criterion and for each unity the correspondent code was defined. The code definition was followed by the coding process of the recorded swimming behaviour. The codification method produced a raw data (event) time-coded for each phase of each of each cycles, reaching, this way, its description.

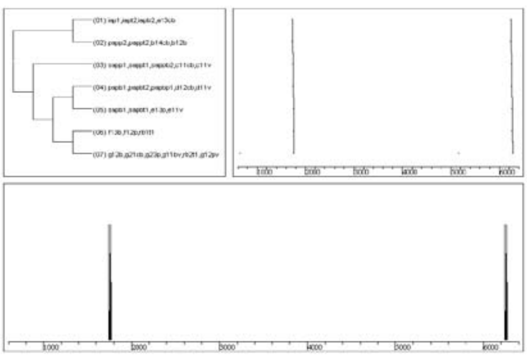
The video recorded swim sessions were coded by ThemeCoder, which enables detailed transcription of digitized video files. It included 55 events composed by 28 event type. The quality of data is dependent of the observation capacity, specific swimming knowledge and practice of the observer. To test its quality, the reliability evaluation was made by retest, using Kappa coefficient calculation. All data were analysed using the Theme 4.0 software package.

RESULTS

To illustrate the results we've selected complete and incomplete T-Patterns obtained at two different moments and composed by three cycles each. Complete patterns are those that

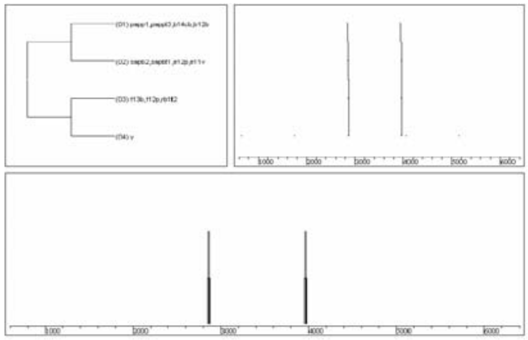
integrate all seven phases of the cycle described above; incomplete are those patterns that only present some of the phases.
The software displays a Three-box T-Pattern diagram as shown in figures 2, 3, 4 and 5 were we can visualize the structure and details of patterns and the way in which particular points are connected to form each instance of the pattern. The top-left box shows all the event types of the pattern and how they gradually connect, level by level into the full binary tree T-Pattern. The top right box shows the occurrence series. The connection lines reveal how the particular critical related occurrences of events types and/or sub patterns are connected level by level. The lower box shows the occurrences of the full t-pattern tree on the real time axis.

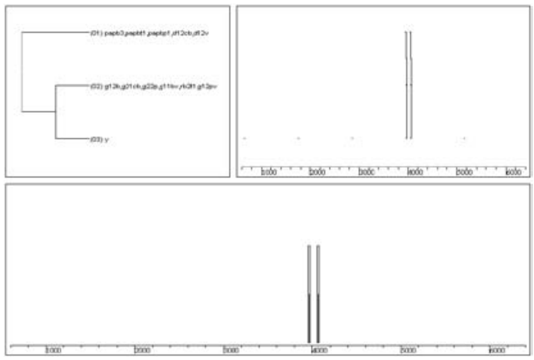




Figures 2 and 3. Description of all details of cycle pattern. Each branch includes simultaneous occurrence of leg, trunk, arms and head codes (01) beginning of leg support phase; (02) first leg propulsion action; (03) second leg propulsion action; (04) first arm propulsion action; (05) second arm propulsion action; (06) first phase of arm recovery; (07) second phase of arm recovery; (08) end of cycle. Among the two swimming cycles we can observe small variations introduced by the swimmer.

In this breaststroke registration two complete (figures 2 and 3) and two incomplete (figures 4 and 5) T-Patterns representing the hierarchical structure in which the less complex subordinated constituent correspondent to inter-segmental relationship and gestures, within each described cycle phase.





Figures 4 and 5. Pattern 3. Includes only the branches of (01) first leg propulsion action phase; (02) second arm propulsion action; (03) first phase of arm recovery; (04) end of cycle. Next figure, pattern 4. Includes only the branches of (01) first arm propulsion action; (02) second phase of arm recovery; (03) end of cycle.

Comparing these patterns, we can verify that the swimmer introduces changes in all the phases, except the last one. The real time axis allows locating these patterns in time occurrence. The first one corresponds to first and sixth cycles and the second to second and seventh cycles.
During the beginning of leg support phase we find angular variation in the hips, knees and ankles and head and trunk position related with water line. In the second phase the swimmer presents changes between the trunk and legs position as well.
During the second leg propulsion action phase it's relevant to sign that the arms actions get started before ending the legs action; in this case, this aspect allows to improve synchronization between arms and legs propulsive actions. In the following phase we find that the swimmer does not maintain the high elbow position. As consequence of the events occurrence in the previous phase, we find, during the second arm propulsion action, a variance of angle between trunk and arms. This leads to reduction of the propulsive arms support. The arm recovery phase shows rapid standard actions.

DISCUSSION
Given the temporal structure of the data, we can see in the figures that the software is sensitive to temporal reoccurring configurations in swimming behaviour. This is in accord with the specific references of observation proposed by Colman et al. (3).

Having as a starting point the analysis of the differences between detected T-Patterns, it's possible to identify systematic errors sources, its implications in swimmer efficiency or reveal swimmer's efficacy singularities. These are important questions to swimming optimization as stated by Chollet (2).
The process of combining the individual steps within a task analysis can be the key to correction and improvements. This could be done both by forward and backward chaining of individual phases of a given stroke. It also allows the detachment of some procedures to integrate in future analyses, having as an orientation the sequence of behaviours and the quality of the movement, required to gestures of advance breaststrokes variants. The potential for use of T-Pattern detection in swimming is enormous. The identification of patterns that are not identifiable through simple observation has great benefit not only in the actual swimming behaviour but also in establishing the physical demands through time-motion analysis. With regards the latter, highly specific physical conditioning practices can be employed through the use of the current movement criteria and Theme which might enhance the condition of the swimmers and optimize time spent in training. A comprehensive study is though required investigating for example the demands between the different training techniques. Once the physical demands have been identified, as well as the complex hidden patterns that occur in the process, it becomes possible to perform further research into establishing the physiological and biomechanical demands which will further assist the enhancement of coaching and physical conditioning practices.

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DIAGNOSTIC, TRAINING AND REALISATION OF STRENGTH CONDITION OF SWIMMERS WITH USE OF FEEDBACK DIAGNOSTIC SIMULATOR "ART"

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This paper describes opportunities of use of the computer diagnostic exerciser in diagnostic, training and realisation of sportsmen's strength potential. The researches were held using the diagnostic exerciser "ART", allowing to simulate water conditions in "force-velocity" parameters. The provided visual feedback allow "controlled variations" in absolute parameters of force, power, stroke rate, length and dynamical structure of stroke. Results showed the high efficacy of the use of "ART" in: (i) quantitative and qualitative analyses of sportsman's power potential, (ii) prognosis of athletes' achievements, (iii) correction of speed and power components of stroke movement of swimmers, (iv) correction of the dynamical structure of stroke, and (v) transfer of sportsman's power potential to real swimming ability using training modes, in which the stroke velocity will correspond the record velocities of athletes.

Key Words: swimming simulator, feedback, strength training, swim power.

INTRODUCTION

The purpose of this paper was to analyse the effect of the visual immediate feedback diagnostic swimming simulator "ART" (2) on the evaluation, training and development of strength in swimmers.
The conception of "artificial controlling environment" was recount by Ratov which implied creation of such conditions for performing the improved motion which provided, on the one hand, possibility for reproducing the motion with orientation on achievement of the stable skill, but on another hand, possibility for ensuring controlled variation in movements (5). Visual feedback is normally used with this purpose, and it adequacy is strongly reinforced by the fact that most part of the information that man receives comes from the sight. Another important argument in favour of the use of visual information to provide feedback is the concomitance of real time perception of visual information and muscular sensations of the athlete which is impossible to obtain in real swimming.
The distribution of the force, velocity and power values during the stroke cycle is very important for the best achievements in the swimming competition (3).
To increase the swimmers' strengths potential into the swim power it is important to use training modes, in which the stroke velocity will correspond or exceed the record velocities of athletes (4).

METHODS

In this study, a computerized swimming simulator "ART" was used, which has force-velocity characteristics with high correlation to in-water swimming (figs.1 and 2).

Figure 1. The swimming simulator "ART".

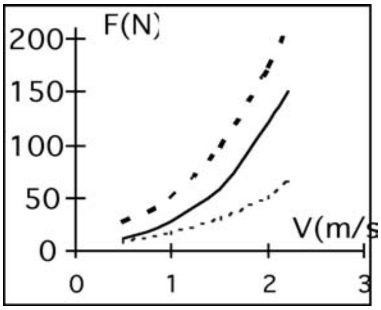

Figure 2. The force-velocity characteristics of the swimming simulator «ART» (real swimming mode by Clarys - continues line; power mode – bold dotted line; speed mode – weak dotted line).

Seven main different work-loads gave opportunity to change force-velocity ratio. One of them (real swimming mode) was to correspond to hyperbolic dependence of drag force on velocity (1), which was similar to in-water swimming (2); three of them (power modes) were of higher resistance compared to real swimming, but similar to swimming with brake, and three (speed modes) with lower resistance compared to real swimming, which was similar to towed swimming.
An athlete performed simulated butterfly style arm-pulling actions lying at a swimming bench where it was able to receive immediate feedback on the dynamical structure of the drive phase, stroke rate and power using PC display.
The following tests were carried out: 10 strokes with the maximum intensity (T-10), 1 minute with competitive intensity (T-1), and step test consisted of 10 repetitions of 1 minute with increasing power (ST-10).
The analysed parameters were stroke rate, stroke length, power, force and velocity characteristics, their distribution within the stroke, and heart rate.
Ten years of researches included some projects connected with each other: diagnostic of stroke dynamical parameters; correction of stroke dynamical structure; increasing of power possibilities; improvement of force ability transformation from dry land to real swimming power. Around 400 athletes volunteered to took part in the research.

RESULTS AND DISCUSSION

In our researches we determined wide range of power parameters in different age groups (Table 1). In a study of a group of boys, stroke power increased more than 40% in the age interval of 12-14 years. However, the qualitative parameter (ratio of power to the athlete's body weight) changes much less, and in the group of 14-years boys it reaches 87% of the national team average values.

Table 1. Power values in test T-10 in group of boys (n=102) and national level men (n=28).

Group of athletes	Wt			Wt/kg		
	X	±	SD	X	±	SD
Boys 12 years	76,9	±	13,1	1,82	±	0,28
Boys 13 years	98,1	±	21,6	1,82	±	0,37
Boys 14 years	108,0	±	29,7	1,84	±	0,42
National level	165,8	±	48,0	2,11	±	0,59
National level (maximal parameter)	275,7			3,68		

Correlation of young swimmer's sport results with the absolute parameters of power in force and speed mode in tests T-10 and T-1 were computed (force mode T-10 $r=-0{,}552$ $p<0.001$, T-1 $r=-0{,}469$ $p<0.001$; speed mode T-10 $r=-0{,}476$ $p<0.001$, T-1 $r=-0{,}535$). Two years later their sport results were high correlated with quality parameters (ratio of stroke power to body weight) in speed mode in T-10 ($r=-0{,}554$ $p<0.001$) and T-1 ($r=-0{,}503$ $p<0.01$) that were determine two years before.
The analysis of the stroke dynamical structure allowed us to assess the typical pattern of stroke (fig. 3).
Analysing the stroke dynamical structure in step-test (ST-10), it was determined that the stroke structure was changed when work intensity was increased (fig. 4, Table 1). This fact showed that long use of swimming exercises with low intensity can produce stroke dynamical structure that does not correspond to the structure needed on competition velocity.

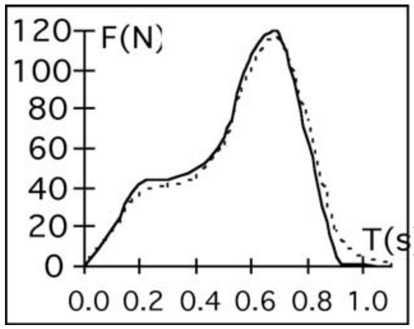

Figure 3. The dynamic force characteristics in typical cyclic swimming movements on the exerciser "ART" (simulating butterfly style).

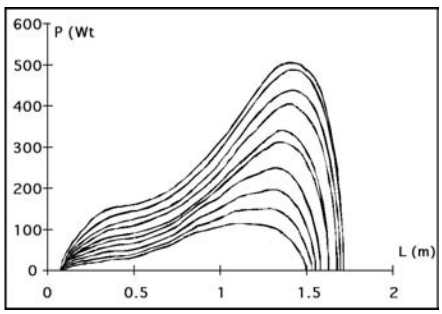

Figure 4. Change of stroke dynamical structure in ST-10 (simulating butterfly style).

Table 1. Change of investigated parameters in ST-10 (simulating butterfly style).

Parameter	1	2	3	4	5	6	7	8	9	10
SR	38	39	41	42	43	44	45	46	47	49
Length of stroke (m)	1.39	1.44	1.46	1.50	1.54	1.54	1.59	1.61	1.63	1.64
Faver.(N)	58	69	82	97	114	123	140	151	163	171
Fmax (N)	99	118	139	166	200	215	248	266	288	295
Fmax/aver.(%)	171	171	168	171	176	175	177	176	177	173
Fmax(% length of stroke)	69	75	82	85	90	90	91	90	94	94
Asymmetry Faver.(%)	-10	-12	-10	-8	-1	-1	1	2	5	5
Paver. (Wt)	57	71	88	109	133	145	172	187	210	228
Pdrive phase(Wt)	105	131	169	209	261	289	352	390	438	475
HR(1/min)	136	147	152	166	171	182	185	190	193	200

The use of a training program for stroke dynamical structure correction using visual immediate feedback had high efficacy on the improvement of sport results. Use of power mode to increase the stroke power (during 4 weeks, twice a week, interval training 3x(5x15s) with maximal intensity using "power mode") allowed to improve the maximal stroke power on 20% ($p<0.05$) in a group of national level athletes, preserving, at the same time, the stroke dynamical structure (fig. 5).

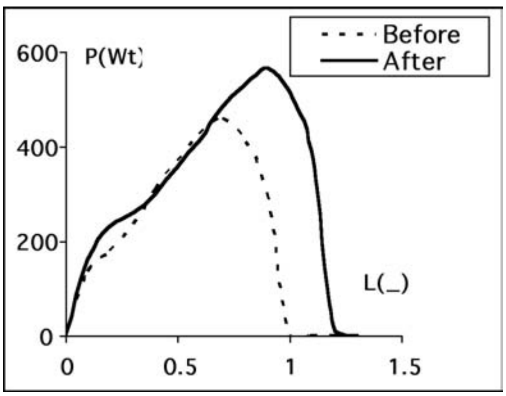

Figure 5. Change of dynamical structure after a "power mode" training program (simulating butterfly style).

The use of interval training programs in different modes of diagnostic exerciser (during 4 weeks, twice a week, interval training 3x(5x15s) with maximal intensity using "power mode" and during 4 weeks, twice a week, interval training 3x(5x15s) with maximal intensity using "speed mode") showed different influence on the increase of power and on stroke rate changes. Using "speed mode" in the same interval training, the stroke rate was increased (7%) with a low increase of stroke power (2,5%). Meanwhile, using the "power mode", the average stroke power was improved (13%) with a low increase of stroke rate (1,5%) ($p<0.05$). It means that we can use different modes of load, depending on training aims, for correction of stroke rate and stroke lengths.

CONCLUSION

These researches showed the high efficacy of the use of the exerciser with visual immediate feedback in the training process of swimmers. Used exerciser allows to qualitative and quantitatively evaluate the dynamical characteristics of stroke, to train, to develop stroke specific power, and to correct stroke dynamical structure, that is quite difficult in real swimming. Our data also showed that high volume of training can produce a stroke dynamical structure which is not typical on swimming velocity competitions.

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DETERMINANT FACTORS RELATED TO PERFORMANCE IN YOUNG SWIMMERS

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The construction of models aiming the identification of the best predictors of swimming performance at each age level is one of the most pursued issues of swimming research. In this study, different approaches have been used, including Data Mining algorithms and multi-regression analysis. Anthropometric, strength, flexibility, metabolic, hydrodynamic and experience of training data of 494 young national level swimmers (13 to 16 years old boys and 12 to 14 years old girls) were measured. Best predictors were mean velocity in "T30" aerobic test for all age groups, plus height and maximal isometric elbow extension strength for older female swimmers, and glide after start for younger male swimmers. The explanation of performance reached almost 70%. The most predictable variables were similar when using different algorithms like Decision Tree, K-Means (5-clusters) and Kohonen.

Key Words: predicting performance, testing swimmers, age group swimming.

INTRODUCTION
Predicting performance is one of the most pursued issues of swimming research, aiming to found since very young ages, the most important markers of mastering performance. Usually, sport technicians and coaches, are aware for particular traces, not only supported on workload and training experience, that enhance best performances on future. Often they look to the morphologic and anthropometric characteristics of the adult champions of a particular style or event (1). Coaches want their swimmers to come close to these traces. Nevertheless, for swimming performance technique is quite everything. To reach technical excellence, experience is required. So, looking for good young performers, falls many times, on more experienced swimmers with the best results at that moment, and not necessary on those who have the best characteristics for future development. Efforts on talent identification must concentrate at a time where swimmers show that they dominate swimming technique enough. Statistical techniques were extensively used to this intention. Models based on multi regression analyses aiming to explain performance, including many physical, biomechanical and psychological variables, were used to demonstrate the importance of same of these characteristics to performance (1, 8, 9, 10).
The main goal of this study was to find relevant characteristics to swimming performance at young ages, working with different approaches, namely Data Mining algorithms, and multi regression analysis.

METHODS
During 5 years, data were collected at national and regional evaluation meetings. All swimmers met the level of Portuguese National Championships. The sample included 494 swimmers (males - 13 to 16 years old, and females- 12 to 14 years old). Their distribution for age group / gender groups, as well as performance level of their best event are expressed on table 1.

Table1. Number of subjects of the sample by age group / gender and LEN points classification of their best event.

		LEN Points	
	N	Mean	SD
Male 13-14 years	97	460	67
Male 15-16 years	219	610	79
Female 12-13 years	125	441	54
Female 14 years	53	595	68
Total	494		

The variables were grouped in: (i) anthropometrics - including stature, sitting height, body mass, arm span, breadths (biacromial, biiliac), deep chest, hands and feet length and breadth (7), the sum of 6 skinfolds as an indicator of body fatness (1) (triceps, subscapular, abdomen, suprailium, front thigh, medial calf; (ii) experience of training - including years of training and actual training load (mean session and week volume) were recorded ; (iii) general and special physical condition - including several protocols (8, 9) aiming to access the maximal isometric strength of arms and trunk muscles (adduction, internal rotation of the arm and forearm extension), the handgrip test, the power of lower limbs (squat jump and counter movement jump), and abdominal and dorso-lombar, were controlled for resistance using the maximal number of repetitions on 30 seconds as criterion, flexibility measures to evaluate the range of mobility on extension and flexion at shoulder, trunk and ankle; (iv) hydrodynamic and hydrostatic characteristics - controlled by the glide distance after push on the wall, as well as after start and turn of ventral style, and by a buoyancy test (3); (v) the maximal velocity test (15m) and the maximal mean velocity in a 30 min test (T30 test) (7) were selected as specific swimming tests. Correlation between performance (LEN points) and the different tested variables were calculated for each gender and age group apart.

RESULTS
Mean results for the tested variables by gender and age group are shown on table 2.

Table 2. Mean ± standard deviation of the scores attained in each parameter for each age group.

	Male		Female	
	13 – 14 years	15 – 16 years	12 – 13 years	14 years
Training experience				
years of training (years)	3.9 ± 1.0	6.0 ± 1.3	3.4 ± 1.1	4.6 ± 1.3
mean session volume (m)	4198 ± 541	5381 ± 838	3947 ± 871	5315 ± 994
mean week volume (m)	24371 ± 6676	39485 ± 9064	23830 ± 8358	30829 ± 5750
Anthropometry				
mass (kg)	55.5 ± 8.3	62.1 ± 7.7	45.7 ± 5.9	52.6 ± 6.1
stature (cm)	166.9 ± 7.3	172.3 ± 6.6	157.7 ± 6.4	161.9 ± 5.5
sitting height (cm)	84.1 ± 4.3	88.1 ± 3.7	80.6 ± 3.4	83.5 ± 3.3
arm span (cm)	169.6 ± 7.6	177.1 ± 7.3	158.9 ± 7.7	164.3 ± 6.2
hand length (cm)	19.0 ± 1.0	19.4 ± 0.9	17.5 ± 0.9	18.0 ± 0.9
hand breadth (cm)	7.9 ± 0.5	8.1 ± 0.4	7.1 ± 0.4	7.4 ± 0.4
foot length (cm)	25.4 ± 1.1	25.8 ± 1.2	23.2 ± 1.0	23.7 ± 1.1
foot breadth (cm)	9.3 ± 0.6	9.4 ± 0.8	8.4 ± 0.5	8.6 ± 0.5
biacromial breadth (cm)	37.9 ± 3.1	39.0 ± 2.3	34.9 ± 2.0	35.9 ± 1.8
biiliac breadth (cm)	25.4 ± 1.8	25.7 ± 1.9	24.1 ± 1.8	24.8 ± 2.2
chest depth (cm)	18.9 ± 1.8	19.8 ± 1.8	17.1 ± 1.4	18.3 ± 1.6
6 skinfold sum (mm)	66.7 ± 24.3	59.1 ± 18.7	83.2 ± 18.1	82.8 ± 24.1
Flexibility				
plantar flexion (º)	40.7 ± 7.7	34.8 ± 11.3	36.1 ± 7.0	31.3 ± 10.1
dorsal feet extension(º)	16.3 ± 6.3	23.8 ± 9.6	17.8 ± 8.7	30.1 ± 35.6
shoulder flexion(º)	16.7 ± 19.5	19.6 ± 18.2	14.3 ± 20.7	23.4 ± 24.9
shoulder extension(º)	78.8 ± 15.9	79.5 ± 20.7	88.6 ± 15.3	86.3 ± 20.5
trunk flexion (cm)	3.8 ± 8.3	7.9 ± 8.5	7.4 ± 9.4	11.7 ± 6.8
trunk extension(º)	51.5 ± 12.2	50.0 ± 14.4	62.0 ± 9.8	54.4 ± 16.2
Strength				
abdominal (nº rep)	29 ± 3	29 ± 4	26 ± 3	24 ± 3
dorso lombar(nº rep)	29 ± 4	31 ± 5	28 ± 4	28 ± 4
squat jump (cm)	33.2 ± 6.1	37.2 ± 7.7	28.7 ± 5.7	29.2 ± 6.2
counter movement jump (cm)	32.3 ± 4.5	35.9 ± 5.7	27.5 ± 4.2	27.6 ± 4.6
handgrip (kg)	35.9 ± 7.5	42.7 ± 7.1	25.6 ± 3.9	30.8 ± 4.6
maximal isometric arm adduction (N)	—	348.1 ± 89.7	—	233.7 ± 68.5
maximal isometric arm internal rotation (N)	—	129.1 ± 39.1	—	81.2 ± 24.3
maximal isometric forearm extension (N)	—	109.4 ± 31.4	—	82.2 ± 28.2
Hydrodynamical tests				
glide (m)	6.3 ± 0.7	7.0 ± 1.0	6.1 ± 0.7	6.7 ± 0.9
glide after start (m)	9.0 ± 0.9	9.7 ± 1.0	8.6 ± 0.7	9.1 ± 1.0
glide after turn (m)	6.3 ± 0.8	6.6 ± 1.0	5.7 ± 0.7	5.9 ± 0.8
horizontal buoyancy (sec)	5.2 ± 1.1	5.7 ± 2.0	7.6 ± 3.6	9.3 ± 7.8
Aerobic Velocity				
T30 test ($m.s^{-1}$)	1.20 ± 0.07	1.30 ± 0.09	1.10 ± 0.08	1.21 ± 0.08

As it was pointed before (1), at these ages the association between performance and isolated factors are weak. The influence of age on anthropometrical characteristics is evident. The experience of training, as we were able to quantify it, did not relate to performance as much as expected. Interesting is the importance of hydrodynamic factors, namely the glide capacity. This parameter may depend mainly on technical proficiency and, in a minor degree, on better hydrodynamic body shape associated with growth. Above all, the specific aerobic adaptation showed by T30 test marked the greatest association with performance. According to the correlations found, the performance level of older boys seem to depend more on conditional factors of physical performance (strength, flexibility) than in the case of the younger swimmers. The female older group showed identical pattern, but with lower association with physical conditional factors compared to males.

Table 3. Significant correlation r values obtained between competitive performance and tested variables by age-group (girls: 12/13 and 14 years old; boys: 13/14 and 15/16 years old). Only significant correlations are shown. (*) $p < 0.05$*; (**)* $p < 0.001$

	LEN points			
	Girls 12/13	Girls 14	Boys 13/14	Boys 15/16
Age	0.587 (**)	0.530 (**)		0.482 (**)
Years of training				0.166 (*)
Mean weekly volume	0.573 (*)			
Mass			0.258 (*)	0.406 (**)
Stature		0.218 (*)	0.320 (**)	0.332 (**)
Sitting height			0.330 (**)	0.310 (**)
Arm span		0.285 (**)	0.266 (*)	0.345 (**)
Hand length		0.317 (**)		0.159 (*)
Foot length				0.154 (*)
Biacromial breadth		0.366 (**)		0.369 (**)
Biiliac breadth				0.155 (*)
Chest Depth				0.245 (**)
Dorsal feet flexion				0.158 (*)
Shoulder flexion				0.423 (**)
Shoulder extension				0.164 (*)
Trunk flexion				0.341 (**)
Trunk extension		0.289 (*)		0.297 (**)
Dorso-lombar strength			0.216 (*)	
Hand grip			0.319 (**)	0.224 (**)
Maximal internal rotation				0.313 (**)
Maximal elbow extension		0.299 (*)		0.225 (*)
Squat jump			0.273 (*)	0.214 (**)
Counter movement jump				0.330 (**)
Glide	0.389 (*)			0.542 (**)
Glide after start		0.299 (*)	0.572 (**)	0.610 (**)
Glide after turn		0.464 (*)		0.609 (**)
T30 test	0.740 (**)	0.671 (**)	0.375 (**)	0.615 (**)

DISCUSSION

When we split the sample by age groups, we found same particularities of determinant influence of the variables on performance (table 3). Attempting to find a model for each age group, which could explain the predictive utility of the variables of this protocol, a multiple regression analysis was conducted using only the variables that were significantly correlated with performance (LEN points) and that met all assumptions for this kind of analysis (11).

For females of 14 years old, a significant model emerged ($F_{9.34} = 10.548$, $p < 0.0005$, adjusted $r^2 = 0.666$):

*LEN points = 72.384 - 0.391*height + 0.313* Maximal isometric strength of elbow extension + 0 .731* Aerobic velocity (T30 test)*

Using the same strategy for females of 12 and 13 years old, we found a significant model ($F_{3.11} = 10.862$, $p < 0.001$, adjusted $r^2 = 0.679$):

LEN points = -87.434 + 0.901 Aerobic velocity (T30 test)*

For males of 15 and 16 years old, the following significant model ($F_{16.60} = 10.368$, $p < 0.05$, adjusted $r^2 = 0.664$):

LEN points = -915.082 + 0.461 Aerobic velocity (T30 test)*

For males of 13 and 14 years old the Enter method, found a significant model ($F_{9.17} = 5.171$, $p = 0.002$, adjusted $r^2 = 0.732$):

LEN points = -841.335 + 0.381 glide after start + 0.386* Aerobic velocity (T30 test)*

Despite the evident correlation of physical traits and performance, the potential for the explanation of the late in young swimmers is limited, which confirms previous findings (1, 8, 10), where only about 60 to 70% of performance could be explained by this approach.

CONCLUSION

Above all, the aerobic development in young swimmers seems to be the main determining factor for performance, as it is corroborated trough the weight of T30 aerobic test to regression models. Other attempts were made to analyze Data using different algorithms: Decision Tree, K-Means (5-clusters) and Kohonen (4). The variables that appear in all algorithms and show importance to predict performance are, for males: height, sitting height, mass, leg length, ankle extension, ankle flexion, abdominal strength, hand grip,-glide distance, vertical buoyancy, T30. For females the variables are: height, sitting height, arm span, mass, leg length, shoulder extension, ankle flexion, glide distance, T30. Many variables show association with performance, but few are able to predict it. In this study approximately 30 to 35% of performance can't be predicted by morphological, general and specific protocols. Other factors like swimming technique, psychological traits and the social influence, certainly play an important role on competitive performance (1).

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ISOMETRIC FORCE, TETHERED FORCE AND POWER RATIOS AS TOOLS FOR THE EVALUATION OF TECHNICAL ABILITY IN FREESTYLE SWIMMING

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The aim of this study is to determine the relationships between isometric force, tethered force and force developed during maximal power test. Eighth international swimmers realised maximal isometric forces for 3 arm–trunk angles (Fiso30°, Fiso90°, Fiso120°). Then, a 5s full tethered swim allowed the measure of the maximal propulsive force in water (Fpmax). Finally, a 25m maximal power test was realised in a 1/2 tethered condition. Isometric forces were not significantly different for the 3 angles. Large individual variations were observed for the ratio Fpmax/Fiso30° as for the ratio Fp/Fpmax reflecting different technical abilities and/or different compromise force-velocity. Fiso30° was significantly correlated to Fpmax and to Fp. The technical ability appeared determinant to transform strength capacity in specific swimming force. These results could be useful to determine the swimmer's insufficiencies, i.e., low isometric force and/or bad technical ability.

Key Words: freestyle, isometric force, tethered swimming, power, ability.

INTRODUCTION
For many authors, performance in swimming is related to the isometric strength (2, 3) or to the arm power in dry land exercises (8). Other studies concluded that swimming velocity is more related to the specific force and power produced in swimming conditions (1). The tethered swimming has been largely used for the evaluation of the swimmer, either in the full condition (subject swam without any body displacement) or in the semi condition (the subject swam on few meters). Although Maglischo et al (1984) underlined the differences in the hand movements between tethered and free swimming, the force developed in full tethered swimming could be a good estimation of the propulsive force developed in the free swimming (4). Furthermore, Wirtz et al (1999) mentioned that the 1/2 tethered condition is an useful tool to evaluate the technical ability of the swimmer. Most of these studies considered the relationships between the swimming velocity and the force or power in dry land or water conditions without any considerations on the relationships between these different parameters. In regard to these previous results, the aim of this study was to determine the relationships between dry isometric forces, full tethered force and 1/2 tethered force produced in power test.

METHODS
Eighth international swimmers (age 22.5 ± 2.3 yr, height 1.87 ± 0.07 m and weight 79.0 ± 6.5 kg) participated to this study. All were medallists or finalist at the European championship (2002).
Each swimmer performed maximal isometric forces for 3 arm–trunk angles, (Fiso30°, Fiso90°, Fiso120°), the upper-arm in full extension and the body in a lying position on a swim bench. The 3 angles corresponded to the beginning of the main phases of the arm stroke according to Strass et al (1999). The force was measured using a strain gauge fixed on a hand paddle hold by the swimmer. This first test allowed to evaluate the strength capacity of the swimmer. Then, a 5s full tethered swim allowed the measure the maximal propulsive force in water (Fpmax) according to Fomitchenko (1999). Finally, a 25m maximal power test was realised in a 1/2 tethered condition with an added resistive force of 5% of Fpmax. Force (Fp), velocity (Vp) and power (P) were measured using a specific ergometer fixed on the block of the start area of the swimming pool ("Ergos" (6)). The swimmer was attached by a cable-pulley system to a powder brake (Lenz). Means force, velocity and power were calculated over a stabilised portion of 5 s in the middle part of the 25 m power test.
Different ratios were established from the 3 measurements. The ratio Fpmax/ Fiso30° (%) allowed to characterise the use of maximal force capacity in the maximal propulsive force production. The ratio Fp/ Fpmax (%) represented an indicator of the use of the maximal propulsive force in the force-power production, i.e. an evaluation of the force-velocity compromise. Mean and standard deviation was calculated for each studied parameter.

RESULTS
Isometric forces were not significantly different for the 3 studied angles (figure 1).
Large individual variations were observed for the ratio Fpmax/Fiso30°as for the ratio Fp/Fpmax, (figure 2). For example, the swimmer 1 presented the higher Fiso30° with the lower ratio Fiso30°/Fpmax when subject 2, one of the less stronger was characterised by higher ratio (figure 3).

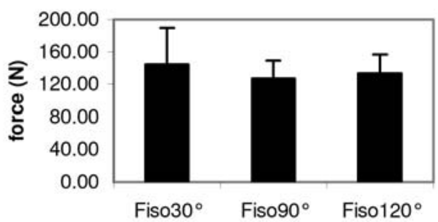


Figure 1. Maximal isometric forces for 3 arm-trunk angles (30°, 90°, 120°).

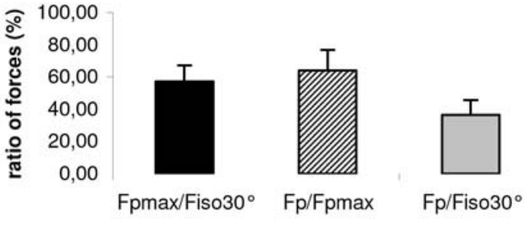
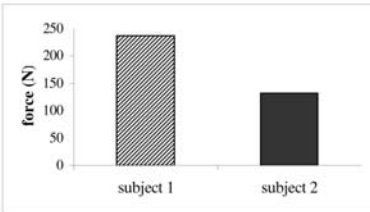


Figure 2. Ratios Fpmax/Fiso30º, Fp/Fpmax, Fp/Fiso30°.



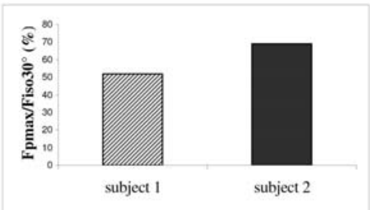


Figure 3. Fiso30° and Fpmax/Fiso30° for 2 subjects.

Fiso30° was significantly correlated to Fpmax (0.83) and to Fp (0.74).

DISCUSSION

As observed by Fomitchenko (1999), the similar values of Fiso30°, F90° and F120° indicated no differences in strenght capacity whatever the trunk-arm angle when higher propulsive forces were observed at the end of the swimming stroke which corresponded to a 120° angle (7). The ratio Fpmax/Fiso30° reflected the low use of the strength capacity in the maximal propulsive force production. The high correlation between these 2 parameters indicated that strength is required to provide propulsive force. The large individual variations observed in Fpmax/Fiso30° reflected the different technical ability to use the strength capacity in the production of the swimming propulsive force. The technical ability appeared determinant to use the strength in the swimming movement, i.e. to adapt the force production to the fluid constraints. Consequently, the ratio Fpmas/Fiso30° could be useful to evaluate the swimming technical expertise.

Other way, the ratio Fp/Fpmax indicated the ability to negotiate the compromise force-velocity in power production. The large individual variations could reflect the compromise force-velocity specific to of each swimmer. Some swimmers presented high Fpmax and a low ratio. They did not arrive to develop a high propulsive force when they have to swim fast. In this way, the ratio Fp/Fpaxm could reflect the quality of the hand support on the water. This result was in agreement with Wirtz 'findings (10) who concluded that 1/2 tethered swimming could be a tool for the evaluation of the swimming ability.

CONCLUSION

Results on different forces measurements indicated that strength capacity is required to produce propulsive. The technical ability appeared determinant to transform strength capacity in specific swimming force. Large individual variations were observed either for isometric force or for the ration Fpax/Fiso30° or Fp/Fpmax reflecting different technical abilities and different compromise force-velocity. These results could be useful to determine the swimmer's insufficiencies, i.e., low isometric force and/or bad technical ability.

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START TECHNIQUE QUALITATIVE EVALUATION OF INTERNATIONAL SPANISH JUNIOR AND PRE-JUNIOR SWIMMERS: AN ANALYSIS OF ERROR FREQUENCY

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This is a 4 year study compilation of the analyses developed with the Spanish Junior National Team during their summer training camps before their participation in the European Junior Championships. The purpose of this study is to determine the frequency of errors observed in the start phases to the entry. 177 junior and pre-junior male and female elite swimmers performed the pike start. The most frequent problem found in the pike start is the incorrect head position at the moment of the entry in the water. 66% of the swimmers keep their heads up and 55% flexed knees. The push is not supported by the lack of force application of the hands on the pool block (45%) considering this a more evident problem in women. The frequencies of the mistakes found in the pre-junior swimmers were reduced in the junior group indicating an enhancement in the observed start technique after this period of development.

Key Words: technique errors, pike start, young swimmers.

INTRODUCTION
The swimming start is an important performance factor, especially in short-distance events. Hay (3) suggested to minimize the resistance encountered during the glide in practice in order to reduce the starting time. It also must be considered that contact time should be the shortest as possible, while the take-off conditions should provide the maximum horizontal speed and an optimum vertical speed (7). Few studied accounted the frequency of technical mistakes after evaluating the swimming start (2).
There are at least two steps associated with technique analysis, one is the diagnosis or identification of faults in performance and the other is the process of remediation or intervention to achieve the desired outcome, that in qualitative technique analysis, appear more readily incorporated (4).
The purpose of this study is to determine the frequency of observed mistakes during the swimming start performance in young international Spanish swimmers (junior and pre-junior), by means of a qualitative assessment carried out during a four-year period, considering gender differences and their evolution with age category.

METHODS
A total of 177 swimmers of junior and pre-junior categories were analysed in a four-year period; its distribution, depending on categories and gender, is presented in Table 1. The assessment was performed during training camps organized by the Spanish Swimming Federation before their participation in International Championships.

Table 1. Basic characteristics of subjects studied.

	Male		Female	
Group	Junior (MJ)	Pre-junior (MPJ)	Junior (FJ)	Pre-junior (FPJ)
Age	16-17	15	14-15	12-13
N	48	47	39	43

Each subject performed a trial of the swimming start followed by a 25 m sprint using its main stroke. The trials were performed in the Olympic swimming pool of Serradells (50x21) in Andorra. The swimmers were video-recorded (SONY CCD-FX700E) till the entry in the water (sagittal view). Swimmers used the lane number three; the camera was localized at 2.0 m from of the edge of the pool and at 1.50 m of the start wall. It was employed a video cassette recorder of 8 mm with image shuttle. A control sheet based in the technique of the start showed by Maglischo (5) was used to record the mistakes observed, defining the next phases: preparatory position (PP), pull (P), drive from the block (D), flight (F), entry (E). It was defined at each phase a specific number of possible mistakes: PP (3), P (4), D (17), F (6), and E (16). Only the errors observed with the same frequency or higher than 25% of the subject sample, were considered in the study. After this procedure, ten items were selected for both genders and for the established age categories. The same experienced observer recorded the errors as they appeared on the video recorded. The reliability was measured using a repeated observation method in randomized trials. An analysis of frequencies was performed.

RESULTS
The table 2 shows the finding errors with a higher frequency classified by age category and gender. The figure 1 presents the incidence of one error comparing the error frequency of each gender with total frequency, pointing the predominance of particular errors. The figure 2 shows the evolution of the errors between junior and pre-junior groups.

Table 2. Percentage of the most frequent start mistakes (T=total group, M=Male, F=Female).

Code-phase	Errors	T%	M		F	
			PJ%	J%	PJ%	J%
855-E	Head is not between arms during the entry	74	72	79	74	69
802-PP	Head is not down in preparatory position	66	70	48	67	82
801-PP	Excessive knee flexion at preparatory phase (knee angle <140º)	55	74	44	70	28
831-D	Misaligned trunk-legs at the take-off	49	30	27	77	67
811-P	Hands not apply force in the block during pull phase	45	30	31	60	64
858-E	Arms/hands are separated in the entry	44	36	40	51	49
834-D	Arms move beyond perpendicular position related to the water	33	41	31	33	30
821-D	Neck does not extend during flight phase	29	11	10	60	38
841-F	Excessive arching of the back during the flight phase	24	43	27	14	10
860-E	Legs are separated during the entry	24	28	15	37	15

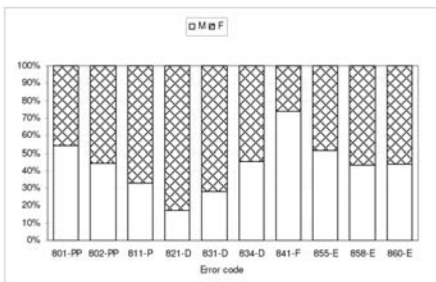

Figure 1. Errors frequency in male and female groups.

In general, female group showed more errors than male group (57% vs 43%) and pre-junior group made more mistakes than junior group (55% vs 45%), showing a tendency to correct errors with the age.

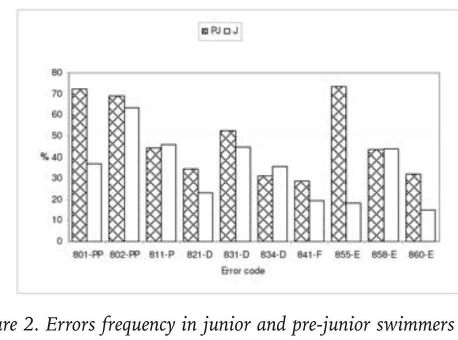

Figure 2. Errors frequency in junior and pre-junior swimmers groups.

DISCUSSION
The more common error was: the head is not between the arms at the entry. This is a serious problem because the increased resistance is produced while the velocity of the body is higher. It seems that swimmers do not have a clear perception of their hydrodynamic position at the entry.
A high percentage of swimmers seemed to displace their the center of mass backward during the preparatory phase, by keeping the head up (66%) or a knee flexion bigger than it is advisable (55%). Lower frequencies of error occurrence (knee flexion at PP) were found at the FJ (28%) and MJ (44%) groups, while the frequencies were about two times higher in the MPJ and FPJ groups. It seems to exist a lack of knowledge about the correct leg position during PP or inappropriate mental image.
We found some mistakes more frequent in the female group: 831-D and 821-D. The 75% of the subjects who shown the 821-D error shown the 831-D too. We can consider that these errors were related. The impulsive actions need to be performed in a specific order (segmental interaction principle) and they have to conclude with the body extended forward. Both actions could produce a reduction in the horizontal displacement of the body before the entry.
The 33% of the subjects moved the arms beyond the perpendicular position related to the water surface (834-D), in addition to no being necessary, it not ensure the correct coordination to transfer the power during push, since the moment of rotation of arms is not transferred in a right way to the body through the shoulders (1). We found that almost half of swimmers adopted a non hydrodynamic position with their upper extremities during the entry (858-E), while the percentage due to the mistake 'legs separated in the entry' (860-E) was less than 25%, in both cases female group presented the highest percentage, and FPJ group showed more problems to control their lower extremities at the entry. These results showed similar frequencies than the previous studies in the same subject (2).
The error 811-P was mostly observer in the female group, and although the pull of hands against block does not contribute to the final impulse (3), it initiates the movement of the body forward and helps to adopt a more convenient body position before the impulse on the block (6). The female group therefore leaved the hands of the block before they helped to move the body forward. Considering the total group, the mistakes frequencies were reduced in older groups, about a 30% in the error 821-D, and about a 50% in 801-PP and 860-E. The MJ group, related to the PJM group, tended to improve the preparatory position (802-PP, 801-PP) in more than a 30% and about a 47% in the entry (860-E). The improvement of the coordination in the entry phase is more evident in the hip extension during the entry, an error with a frequency of 28% in the MPJ group that decreased to a 6% in the MJ group; improvement that did not occur in FJ group. In the FJ group, in comparison with the FPJ group, 801-PP was improved about a 42%, and the mistakes 821-D and 860-D in more than 35%.
The excessive arching of the back (841-F), when the swimmer keeps his head up during the flight, was observed more frequently in the PJM group, although their legs did not enter before their trunk, as Maglischo stated (5).

CONCLUSION
A study about the qualitative analysis of the start technique in a group of international Junior and pre-Junior Spanish swimmers was performed. Problems related with entry and impulse phases showed higher frequencies of occurrence and it were recommended an additional work for the improvement of these phases. The frequencies of the mistakes found in the pre-junior swimmers were reduced in the junior group indicating an enhancement in the observed start technique after this period of development. To relate the qualitative observation of the start with quantitative data seems the more appropriate way, to perform the assessment of this kind of swimmers, including a basic and theoretical description of the relevant points of each phase of the start.

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ALTERNATIVE STYLES TURN TECHNIQUE QUALITATIVE EVALUATION TO INTERNATIONAL SPANISH JUNIOR AND PRE-JUNIOR SWIMMERS: AN ANALYSIS OF ERROR FREQUENCY

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This study is a compilation of the analyses developed over four years of the Spanish Junior National Team. The purpose of this study is to determine the frequency of observed errors while front crawl and back crawl turns are performed. 176 junior and pre-junior male and female elite swimmers performed the front crawl turn and 43 performed the back crawl turn. The video-record was made through an underwater window while a 50 m front crawl or back crawl trial was performed at competitive speed. It was employed an 8mm video cassette recorder. 78% of the group performed an anticipated turn on the longitudinal axis previous to contact with the wall; differences between categories were found. Starting the turn far from the wall and the lack of support for hands during the turn were problems found in over 40% in crawl. The biggest frequency found in backstroke turn was localized in glide and push-off phases (53%).

Key Words: freestyle, backstroke, turns, errors, young swimmers.

INTRODUCTION

A high competence in technique movement has the same importance in elite group athletes that a high physical performance level and a well developed tactical abilities (8). The technical workout with the recognition of some fundamental principles of the technique is necessary to produce an effect on the swimmers formation according to their age because in learning sports technique it is unavoidable to commit failures in the movement (3). The turn can be consider still more important than the start in the final result of a competition, most of all when the trial distance increases; so that not only the percentage of lead time in the realization of various turns have to be considered, but also his contribution to the final time (9). The purpose of this study is to determine the frequency of observed errors in young international Spanish swimmers, by means of a qualitative assessment carried out during a four-year period considering gender differences and his evolution with the age category in the different phases of the front crawl and back crawl turn.

METHODS

176 international swimmers junior and pre-junior categories performed the front crawl turn and 43 performed the back crawl turn, 15 swimmers considered the backstroke like his second style, 11 of them were women. The distribution of subjects by categories and gender is shown in Table 1. The analysis was realized in a four-year period.

Table 1. Subjects' basic characteristics.

Turn	Front crawl				Back crawl			
	Male		Female		Male		Female	
Group	Junior	Pre-junior	Junior	Pre-junior	Junior	Pre-junior	Junior	Pre-junior
Age	16-17	15	14-15	12-13	16-17	15	14-15	12-13
N	48	47	39	42	9	9	17	8

In a swimming pool (50x21), the swimmers were video-recorded with a Hi8 camera through an underwater window, to obtain a sagittal view while a 50 m front crawl or back crawl trial at competitive speed swam from the middle of the third lane was performed. An 8mm video cassette recorder with frame by frame image stop was employed. A control sheet based in the errors presented by Maglischo (6) was used in order to record technical problems, considering the following phases for the qualitative analysis of the turn: approach (A), turn (T), push-off (Poff), and glide (G) and pullout (Pout). Only those actions that have the 25% or superior frequency are shown. The same experienced observer recorded the errors as they appeared on the video recording. The reliability was measured using a repeated observation method in a randomized check. An analysis of frequencies was performed.

RESULTS AND DISCUSSION

The Tables 2 and 3 show the found errors, in front crawl turn and back crawl turn, with a higher frequency, classified by age category and gender. The Figures 1 and 3 present the incidence of one error (crawl turn and back crawl turn) comparing the error frequency of each gender with regard to the total frequency of registered errors, pointing the predominance of particular errors. The Figures 2 and 4 show the evolution of the errors frequency between junior and pre-junior groups (crawl turn and back crawl turn, respectively).

Table 2. Percentage of crawl turns errors frequency (T=total group, M=male, F=female).

Code-phase	Description errors	T%	M		F	
			PJ%	J%	PJ%	J%
421-T	Turning on the long. axis earlier > 1/8 twist (previous feet support)	62	64	42	76	69
406-A	Support back of the hands or unsupported hands	40	40	44	43	31
411-T	Starting the turn far from the wall (knees extended)	39	38	35	40	41
437-Poff	Neck flexed	38	49	38	43	23
428-T	Approximation or separation of arms (1 or 2) regarding the trunk	37	28	31	57	32
450-Poff	Hands are not joined during the phase	37	32	15	48	59
413-T	Start of the turn without finishing the last stroke	35	36	27	21	53
473-G	Hands are not joined	29	41	17	40	21
463-G	Neck flexed	28	41	13	36	28
486-Pout	Using the head like a rudder (flexion-extension of neck)	27	26	29	26	26
427-T	Hip very flexed (turn with submerged legs)	26	23	27	29	23
465-G	Arms separated	26	41	15	24	26

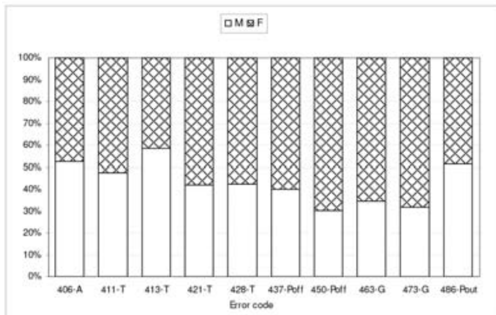

Figure 1. Crawl turns errors frequency in male and females groups.

In general, the junior group committed less error than pre-junior group in turn and pull-out phases, but more in the impulse phase, mainly in the backstroke turn. FJ group tended to improve more than MJ group; however, they had a higher errors frequency.

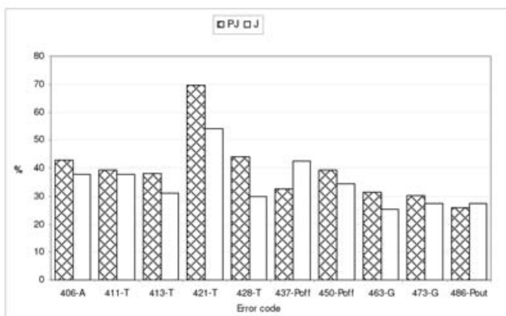

Figure 2. Crawl turns errors frequency in junior and pre-junior swimmers groups.

Table 3. Percentage of back crawl turn errors frequency (T=total group, M=male, F=female).

Code-phase	Description errors	T%	M	F		
			PJ%	J%	PJ%	J%
663-G	Neck flexed	53	33	44	75	59
637-Poff	Neck flexed	37	22	56	25	41
627-T	Hip very flexed (turn with submerged legs)	33	33	33	38	29
686-Pout	Using the head like rudder (flexion-extension of neck)	30	44	56	25	12
611-T	Starting the turn far from the wall (knees extended)	28	44	44	13	18
631-Poff	Support of feet above the level of the hip	28	33	44	13	24
626-T	Spine continues the turn over 180º (transversal axis)	26	44	11	25	24
633-Poff	Misaligned body in the instant of support	26	0	11	50	35

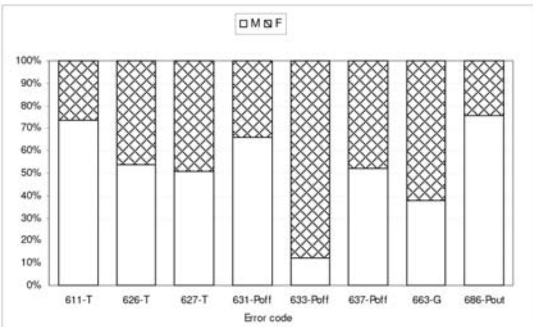

Figure 3. Back crawl turns errors frequency in male and females groups.

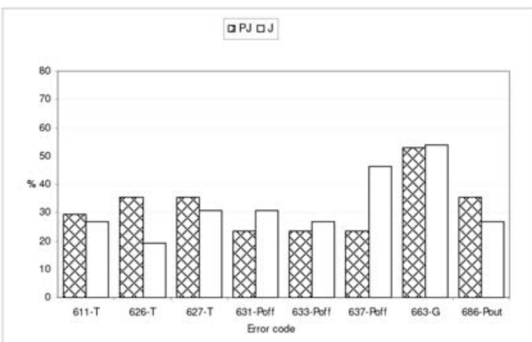

Figure 4. Back crawl turn errors frequency in junior and pre-junior swimmers groups.

In crawl turn, the 78% of swimmers anticipated the turn in the longitudinal axis before foot support, while they performed the turn in the transverse axis. The 62% of swimmers surpassed 1/8 twist to prone position (421-T). The incorrect arms and hands position during the turn phase did not allow turn down the palms and press down against water, movement traditionally considered in the technique of flip free style turn (1) to help pulling the head toward the surface (6). These inadequate positions had his origin for the most of cases in 406-A. The 40% of the swimmers had to extend the knees to contact with feet in the wall; a problem of space adjustment in the approach phase could be considered; however, it was found that faster age-group swimmers tended to initiate their turns further out from the wall (2) and it has been indicated the turn will be faster if the angle of the knee was in the region of 110-120º (5). It is necessary to consider that the 35% of the swimmers presented 413-T, coinciding with 411-T only in the 26% of cases. In back stroke turn the swimmers extended their knees to reach the wall (611-T) but with error frequency lower than in crawl turn; this movement was not recorded in swimmers that have the errors 631-Poff and 633-Poff, because was not their cause. The body not aligned when the feet reach the wall (633-Poff) forces to swimmer to waste time before pushing off in appropriate position (7). Arching the back can be necessary to compensate a poor position during push off (5). Practically the rest of the observed problems were related to the adoption of an incorrect hydrodynamic position after the turn phase (437-Poff, 450-Poff, 463-G, 465-G, 473-G, and 486-Pout). Haljand (4) suggests avoid the unnecessary movements, and these movements during the turn phase (428-T) coincided in a 43% with 450-Poff. In the back turn we found again 'neck flexed' (663-G, 637-Poff, and 686-Pout) even with similar percentages than in crawl turn push off phase.

CONCLUSION

A higher percentage of turn mistakes were found in front crawl related to backstroke. The effect of stroke specialisation (backstrokers) decreased the number of errors compared with freestylers group (specialist and non-specialist swimmers). The high frequency of mistakes found, related with the feet contact phase (before and after the contact), it demonstrates the complexity of this action for this group of swimmers when visual control is lost and a fine perception of the rotated body position is needed to start the impulse phase properly. A combination of a qualitative approach with quantitative information of the turn technique seems a logical improvement of our present research.

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THE STABILITY OF IDC DURING MAXIMAL AND SUBMAXIMAL SWIM TRIALS QUESTIONED

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This study used video analysis to examine how similar the coordination values obtained in a submaximal protocol were to those obtained in maximal testing. This three-part experiment examined the effect of relative intensity, the distance swum and expertise (during maximal 400-m testing) on the Index of Coordination (IdC) as defined by Chollet et al. (2000). The results showed that IdC increased with increased relative intensity during 300-m freestyle testing and that it did not vary significantly with the distance swum, whatever the level of expertise, during maximal 400-m freestyle testing. These findings suggest that the IdC adaptations can be assessed at all swimming speeds on the basis of a short-distance protocol, as proposed by Chollet et al. (2000).

INTRODUCTION
The method introduced by Chollet et al. (5) proposed to measure swimmers' adaptations to speed increases using the Index of Coordination. The index is based on eight swim trials at different speeds over a short distance (generally 25 m). In each trial, swimming speeds are thus simulated, from the speed of the 3000-m to maximal speed, over only 25 m, which means that the effect of fatigue due to distance swum is not taken into account (Garcin and Billat, 2001). Alberty et al. (1), for example, showed an increase in IdC with distance in maximal 200-m freestyle swimming. This tendency was also noted by Seifert et al. (9) in 100-m freestyle swimming. Whether the IdC value obtained on the basis of a short-distance trial protocol is representative of real IdC can thus be questioned, especially for longer race distances.
Therefore this study had two goals:
– First, to determine whether the data obtained on the basis of simulated swimming speeds during short-distance trials are similar to the values obtained with maximal testing.
– Second, to determine whether IdC changes during maximal testing of more than 4 minutes.

METHODS
The experiment has three distinct parts.
First, the effect of relative swim pace at constant speed was determined. Seven triathletes competing at the international level volunteered for this part (6 men, 1 woman; 23.1±1.2 years; 280±7 s for 400-m freestyle swimming). They performed a 300-m trial three times, at 85%, 95% and 100% of their maximal swimming speed at this distance. Second, the effect of distance for a particular swim pace was investigated. Twelve national level swimmers (6 men, 6 women; 18.5±2.7 years; 82.2±2.9% of the world record for speed in the 400-m) performed a 400-m freestyle swim at maximal speed. The next day, they performed 100-m, 200-m and 300-m trials at the speed of the previous 400-m. Third, the effect of skill level on the changes in IdC during a maximal 400-m freestyle swim was examined. Twenty-two subjects of three levels of expertise were tested: experts (20.4±1.3 years; 93±3.1% of WR in the 400-m), triathletes (20.4±1.4 years; 78.5±4.2% of WR in the 400-m), and recreational swimmers (20.5 years; 69±1.5% of WR in the 400-m).

Video analysis
The swim trials were filmed by three mini-dv video cameras (50 Hz, Sony DCRTRV6E). Two were placed underwater, two were aerial, and all were genclocked with DartFish software.

Spatio-temporal parameters
Video analysis allowed the calculation of mean speed (V) and stroke rate (SR) from three complete cycles expressed in stroke.min^{-1}; stroke length (SL) was then calculated from the V50 and SR values (SL = V x SR / 60). For these parameters, the data were measured every 50-m.

Arm stroke phases and coordination
The arm stroke was divided into four distinct phases, similar to those presented in the front crawl study of Chollet et al. (2000): Phase A: *Entry and catch*, Phase B: *Pull phase*, Phase C: *Push phase*, and Phase D: *Recovery phase;* Ppr: *Propulsive phase*, which corresponds to the sum of B+C. The duration of each phase was measured every 50-m on three complete strokes of all trials. Then, the IdC was calculated and expressed as the percentage of the mean duration of the stroke.

Metabolic parameters
In the second part of the experiment, peak heart rate (HR, polar S610) and lactate (Lactate Pro, Arkray) were measured at the end of each swim trial. The mental workload was assessed with the NASA-TLX questionnaire.

Statistical analysis
The normality of distribution (Ryan-Joiner test) and homogeneity of variance between populations (Bartlett test) were checked for all parameters and allowed parametric statistics. Those analyses were completed by Tukey post-hoc test to examine the differences. For the first part of the experiment, 3-way ANOVAs were performed [relative intensity (3 levels) x swimming distance (6 levels); random factor: subject (7 levels)] on V, SL, SR, IdC and swimming phases (A, B, C, D, Ppr). In the second part of the experiment, 2-way ANOVAs were performed [swimming distance: 4 levels; random factor: subject (12 levels)] on V, SL, SR, IdC and swimming phases (A, B, C, D, Ppr), HR, Hla and TWL.
For the third part, 3-way ANOVAs were performed [distance swum: 8 levels x expertise (3 levels); repeated factor: subject] on V, SL, SR, IdC and swimming phases (A, B, C, D, Ppr). A coefficient of variation was calculated per level of expertise for each of these parameters. For all parameters, level of significance was set at $p<0.05$.

RESULTS
The results of the first part of the experiment are shown in Table 1.

Table 1. Changes in spatio-temporal and coordination parameters with swim pace during each trial.

	V ($m.s^{-1}$)	SR ($Stroke.min^{-1}$)	SL (m)	IdC (%)	A (%)	B (%)	C (%)	D (%)	Ppr (%)
85%	1.13±0.05	30.5±2,00	2.24±0.20	-4.70±3.60	30.60±5.10	22.40±3,50	23.10±3.20	23.90±3.20	45.40±3.60
95%	1.21±0.06	33.8±2.40	2.18±0.20	-1.80±3.20	29.30±4.60	23.50±3,40	24.10±3.30	23.10±3.30	47.60±3.60
100%	1.31±0.07	38.13±2.30	2.05±0.20	-0.60±4.20	26.70±4.90	25.10±4,70	24.80±4.50	23.40±3.40	49.90±4.60
Relative speed effect	$F_{2,105}$ = 8.3; $p<0.05$	$F_{2,105}$ =105.1; $p<0.05$	$F_{2,105}$ =9.1; $p<0.05$	$F_{2,105}$ =11.26 $p<0.05$	$F_{2,105}$ 5.9=4.4; $p<0.05$	$F_{2,105}$ $p<0.05$	NS	NS	$F_{2,105}$= 11.2; $p<0.05$
Distance swum effect	NS	NS	NS	NS	NS	NS	NS	NS	NS

Effect of the distance swum within each trial
Neither change nor swim pace x distance swum interaction was noted for any parameter.

Second part of the experiment
Table 2 presents the changes in physiological and psychometric parameters with race distance during the 400-m.

Table 2. Changes in metabolic and psychometric parameters with distance swum.

	Men				Women				
Race distance (m)	100	200	300	400	100	200	300	400	
HR (bpm)	165.00 ±11.80	174.00 ±8.90	180.00 ±9.30	188.00 ±5.00	167.00 ±6.40	176.00 ±6.90	180.00 ±4.30	186.00 ±4.80	*
Hla ($mmol.l^{-1}$)	3.60 ±0.60	6.60 ±1.00	7.50 ±1.40	10.50 ±2.00	4.10 ±10	5.90 ±1.70	6.20 ±2.00	8.30 ±2.50	*
TWL	4.00 ±1.90	4.50 ±1.70	5.00 ±1.90	6.30 ±1.10	2.80 ±1.40	4.10 ±1.50	5.00 ±1.60	5.00 ±0.50	*

**: race distance effect with p<0.05.*

Table 3 presents the mean values of spatio-temporal and coordination parameters for all race distances.

Table 3. Comparison of mean values of spatio-temporal and coordination parameters for the race distances.

	Distance swum (m)	V ($m.s^{-1}$)	SR ($St.min^{-1}$)	SL ($m.cy^{-1}$)	IdC (%)	A (%)	B (%)	C (%)	D (%)	Ppr (%)
Men	100	1.33±0.10	35.40±3.20	2.30±0.30	-14.20 ±1.70	43.50 ±2.40	15.90 ±1.50	20.10 ±1.40	20.50 ±2.00	36.00 ±1.40
	200	1.30±0.10	36.40±2.70	2.20±0.30	-13.80 ±2.20	43.10 ±2.70	16.30 ±20	19.80 ±2.30	20.60 ±2.10	36.30 ±2.20
	300	1.30±0.10	35.80±2.20	2.23±0.20	-14.10 ±1.70	43.80 ±2.00	16.20 ±2.20	19.90 ±1.90	20.00 ±1.80	36.20 ±1.80
	400	1.30±0.10	36.10±2.90	2.17±0.20	-14.20 ±1.80	42.60 ±3.00	15.90 ±1.60	19.80 ±1.60	21.70 ±2.10	35.70 ±1.80
Women	100	1.22±0.07	35.50±4.20	2.09±0.30	-17.00 ±2.20	44.80 ±3.60	11.90 ±2.30	21.10 ±1.80	22.20 ±3.20	32.90 ±2.30
	200	1.21±0.06	35.40±3.70	2.06±0.30	-16.20 ±1.80	44.60 ±3.20	13.10 ±2.40	20.50 ±1.60	21.90 ±3.20	33.60 ±1.90
	300	1.20±0.06	35.70±3.90	2.06±0.30	-16.60 ±1.60	45.60 ±2.70	14.00 ±1.40	19.60 ±1.60	20.80 ±3.20	33.60 ±1.80
	400	1.23±0.07	36.30±3.90	2.05±0.20	-16.80 ±2.20	44.80 ±3.50	13.10 ±2.80	20.10 ±1.60	22.00 ±2.80	33.20 ±2.20
	Distance swum effect	NS	NS	NS	NS	NS	*	NS	*	NS

** distance swum effect with p<0.05*

Third part of the experiment
Distance effect as a function of expertise
A distance effect was found for V50 ($F_{7,\ 168} = 3.12$; $p<0.05$). The 3-way ANOVAs also showed a distance swum _ expertise interaction ($p<0.05$). The post-hoc Tukey test showed that swimming speed was significantly higher during the first 50 m ($p<0.05$) and then stabilized for experts and triathletes. In the recreational population, however, V50 decreased up to 150 m ($p<0.05$) and then stabilized until the end of the 400-m.
The 3-way ANOVAs [distance swum: 8 levels _ expertise (3 levels); repeated factor: subject] showed no significant change in IdC with distance.

The coefficients of variation in Table 4 show that only V50 ($F_{2,18}=11.43$; $p<0.05$) was significantly higher in the recreational vs. expert swimmers.

Table 4. Coefficients of variation for the spatio-temporal and coordination parameters.

	V50	SR	SL	IdC	Ppr	A	B	C	D
Experts	3.80±0.60	5.60±2.70	5.90±1.40	16.20±11.20	5.50±2.90	7.20±3.60	10.00±4.20	8.60±4.50	8.20±3.30
Triathletes	7.20±2.50	4.60±2.60	5.90±2.20	13.50±4.30	5.60±2.00	6.50±3.70	8.90±1.60	5.80±2.70	8.00±3.60
Recreational	9.10±2.70	3.60±1.60	7.50±3.50	21.30±12.20	4.20±1.20	4.80±1.10	8.40±2.30	6.70±1.60	12.00±4.40
Differences	a								

a: expert-triathlete difference; b: expert-recreational difference; c: triathlete-recreational difference

DISCUSSION
In the first part of this work, we tried to determine the changes in coordination parameters with increases in relative intensity during a 300-m swim test at constant speed. The results showed an increase in IdC with increased relative intensity, explained by an increase in Ppr and the push phase (B), and a decrease in the A phase. These results can be found in several studies based on simulations of swimming speeds (5, 8). It thus seems that the change in coordination parameters with swimming speed is similar in these two kinds of protocol. Moreover, the results showed no significant change in these coordination parameters with distance swum, whatever the relative intensity. The mean values of the coordination parameters in each trial thus seem representative of the coordination mode adopted during these tests.
In the second part of the experiment, we tried to determine if the distance swum at a fixed swimming speed had an influence on the coordination parameters. The results of the metabolic and psychometric parameters indicated that there indeed was an increase in both objective (HR and Hla) and subjective (TWL) indicators. Although changes in the swimming phases were noted, with phase B significantly decreased and D phase increased, these change had only a limited impact on global coordination, since IdC and Ppr did not significantly vary.
Last, in the third part, we tried to determine whether the level of practice had an impact on the changes in spatio-temporal and coordination parameters during 400-m freestyle swimming performed at maximal intensity. The analysis of the coefficients of variation indicated the variability in V50 of the recreational swimmers, which was significantly higher than in the expert swimmers, in line with previous studies (3, 5, 9). However, this difference was not found for the other parameters taken into account, in particular for IdC, whose coefficient of variation did not significantly differ with expertise level. Moreover, whatever the level of expertise, no significant change in IdC with distance was found within the swim trial.

CONCLUSION
Our data indicate that the IdC exhibits the same evolution when steady-state and short- distance protocols are compared. Despite the changes in V50 noted during the maximal steady-state swim trial, the coordination parameters did not vary significantly, whatever the level of expertise. This change in swimming speed could thus be the consequence of some modification in the efficient component of propulsive force (6, 7). Last, the IdC and coordination parameters did not seem to be influ-

enced by the submaximal protocol, in which distance varied. So protocols based on short-distance swimming trials, as proposed by Chollet et al. (5), seem to be justified, meaning that swimmers' adaptations at all swimming speeds can be assessed in a short period of time. However, these results have to be interpreted cautiously, since results from Seifert et al. (9) on the 100-m and Alberty et al. (1) on the 200-m showed an increase in IdC with distance swum. Our conclusions may thus be adapted only for relative intensities that involve mostly aerobic pathways, which mean work durations of more than 4 minutes (2).

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USE OF INDEX OF COORDINATION TO ASSESS OPTIMAL ADAPTATION: A CASE STUDY

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This communication examines the feasibility of assessing the inter-arm coordination of individual swimmers to determine the optimal adaptation. Two highly-trained swimmers of different skill levels (95.3% vs. 87.9% of the world record for speed in 100-m freestyle swimming) swam at eight paces corresponding to the speeds adopted during competitive events (from V3000-m to maximal speed on 25-m). The Index of Coordination (IdC) was calculated for each swim pace. A velocity device was used to calculate the intra-cyclic speed variability (IVV). The results showed that the better swimmer was characterized by higher IdC at all swim paces. Moreover, the IVV of this swimmer did not significantly vary across swim paces, whereas it increased in the less skilled swimmer. It thus seems that IVV stability could be an interesting criterion to assess the optimal adaptation of coordination with swim pace increase.

Key Words: index of coordination, intra-cyclic speed variability, optimal adaptation of coordination.

INTRODUCTION
Chollet et al. (1) proposed to assess coordination in freestyle swimming with the Index of Coordination (IdC). This is a temporal value that measures the lag time between the end of the propulsive phase of one arm and the beginning of the propulsive phase of the other. Although IdC functions as a parameter that discriminates skill level (1), studies have shown that its value increases with swimming pace whatever the swimmer's characteristics (1, 4, 6). These modifications may be adaptations to changing environmental constraints (4), particularly the increase in drag with higher swimming speed. Chollet et al. (1) reported experimental evidence in support of this hypothesis, but no definitive conclusions can yet be drawn. On another hand, freestyle swimming is characterized by intra-cyclic velocity variation (IVV). The best swimmers have been characterized by smaller IVV than less skilled swimmers (3, 7). Smaller IVV should thus be linked to greater swimming efficiency (2). In this case study, we hypothesized that the higher IdC values of a better skilled swimmer would be associated with less velocity fluctuation at various self-selected speeds than in a less skilled swimmer. To test this, we compared two highly trained subjects who nevertheless differed in terms of expertise. We sought to determine whether this difference could be partly explained by an inadequate adaptation of motor coordination to changing environmental constraints.

METHODS
Two female subjects were compared.

Table 1. Main characteristics of the subjects

	Age (years)	Height (cm)	Weight (kg)	%WR
Subject 1	23	175	57	95.3
Subject 2	17	172	55	87.9

%WR: percentage of world record for 100-m freestyle swimming.

Swim trials
In a 25-m pool, the swimmers performed eight freestyle trials at successively increasing velocity. Each trial required an individually imposed swim pace (V_p) corresponding to a specific race distance or training distance, as previously detailed for front crawl and breaststroke: 3000-m (V3000), 1500-m (V1500), 800-m (V800), 400-m (V400), 200-m (V200), 100-m (V100), 50-m (V50) and maximal speed (Vmax). The trials consisted of swimming at the imposed pace for only 25 m to avoid fatigue effects and keep the focus on the motor control adaptations.

Video analysis
The swim trials were filmed by four mini-dv video cameras (50 Hz, Sony DCRTRV6E, Tokyo, Japan).
Two were placed underwater in lateral and frontal views. A third camera (50Hz, Sony compact FCB-EX10L, Plaine Saint

Denis, France) filmed the swimmers underwater from a frontal view. A fourth camera, genlocked and mixed with the lateral underwater view for time synchronization, filmed all the trials of each swimmer with a profile view from above the pool. This camera measured the time over a distance of 12.5 m (between the 10-m and the 22.5-m marks to avoid wall constraints) to obtain the real velocity. All cameras were connected to a double-entry audio-visual mixer, a video timer, a video recorder and a monitoring screen to genlock and mix the lateral underwater and aerial views on the same screen, from which mean SR was calculated. The stroke length (SL) was calculated from the mean velocity (V) and SR values (SL = V x SR / 60).

Arm stroke phases
The arm stroke was divided into four distinct phases, similar to those presented in the front crawl study of Chollet et al. (2000).
The phases were the following:
Entry and catch of the hand in the water (entry of the hand into the water and the beginning of its backward movement); *pull phase* (time between the beginning of the backward movement of the hand and its entry into the plane vertical to the shoulder); *push phase* (time between the positioning of the hand below the shoulder to its exit from the water); and *recovery phase* (time between the exit of the hand from the water and its following entry into the water).
The duration of each phase was measured for each stroke with a precision of 0.02 s and was expressed as a percentage of the duration of a complete arm stroke. The IdC was calculated as the mean time between the end of the push phase for one arm, and the beginning of the pull phase for the other arm, and expressed as a percentage.

Video-velocity system
Video analysis was synchronized with a velocity-meter (Fahnemann 12 045, Bockenem, Germany). The swimmers wore waist belts connected to an unstretchable cable driving an electromagnetic angular velocity tachometer in order to analyze the intra-cyclic velocity variations. The measurements were taken using 25 m of stainless steel light cable coiled around the tachometer and connected at the distal end to a harness belt attached to the swimmer's waist. The sampling rate was set at 50 Hz. The resistance applied to the swimmer's forward displacement was 10 N. The lateral view of the video and the video timer were associated with the instantaneous velocity curve read on the computer.
For each subject, three to four complete strokes were filmed and analyzed. The corresponding time-velocity curves were smoothed (6 Hz) by Fourier analysis and the areas under the curve were computed.
Eight complete strokes were filmed for each subject. The accelerations and decelerations of the hip measured by the swim the velocity-meter (at 0.01s) were synchronized with the arm movements measured by the video device (at 0.02s). For both coordination parameters and intra-cyclic speed analysis, three swimming cycles per trial were analyzed.

Determination of intra-cyclic velocity variability (IVV)
Data from the velocity-meter were collected with Acquiert software. These data were then filtered with Origin 5.0 software (Microcal Inc., Northampton (UK), 1997) with a low pass filter. The cutoff frequency was set at 8 Hz.
Then, IVV was quantified by determination of the coefficient of variation, which is the standard deviation from the velocity data divided by the mean velocity of the self-selected speed.

Statistical analysis
For all the tested variables, a normal distribution (Ryan Joiner test) and the homogeneity of variance (Bartlett test) were verified and allowed parametric statistics (Minitab 14, Minitab Inc., 2003). Two-way repeated-measure (RM) ANOVAs (pace, 8 levels; repeated measurement: subject, 2 levels) were used to determine the pace effect for both subjects (Minitab 14, Minitab Inc., 2003). For the velocity curve analysis, two-way repeated-measure (RM) ANOVAs (pace, 8 levels; repeated factor: subject, 2 levels) were conducted on IVV to determine the pace effect and compare both subjects.
Then, we proceeded to a regression model to establish the link between pace and IdC, and pace and IVV.
For all tests, the level of significance was set at $p < 0.05$.

RESULTS
The repeated-measurement ANOVA model indicated that subject 1 had a significantly higher swimming speed than subject 2 at all paces (1.57 ± 0.1 m.s^{-1} vs. 1.41 ± 0.13 m.s^{-1}; $p<0.05$).

Link among swim pace, swim speed and IVV
Table 2 indicates the values of IVV with swim pace

Table 2. Values of IVV with swim pace for both subjects.

Swim pace (V_p)	IVV Subject 1	IVV Subject 2
3000	0.12	0.12
1500	0.13	0.27
800	0.12	0.26
400	0.13	0.27
200	0.11	0.28
100	0.10	0.28
50	0.12	0.29
25	0.12	0.30

The ANOVA shows that subject 1 had a significantly smaller IVV than subject
2 (0.12 ± 0.01 vs. 0.25 ± 0.06; $F_{1,14} = 30.3$; $p<0.05$).
The following regression model between IVV and swimming speed was found for subject 2 (V):
IVV = -0.69 + 0.75 V $F_{(1,5)} = 18.26$; $p<0.05$; $R^2=74.2\%$.

No significant link was noted for subject 1 between IVV and swimming speed.

Links among swim pace, swim speed and IdC
The IdC was significantly higher for subject 1 ($9.1\pm3.7\%$ vs. $-3.2\pm3.6\%$; $F_{1,14}=10.37$; $p<0.05$). For both subjects, IdC increased with swim pace ($F_{2,7} = 53.57$; $p<0.05$).
The following regression models between IdC and V were validated:
Subject 1: IdC = - 62.0 + 37.6 V $F_{1,7} = 74.1$; $p<0.05$; $R^2= 91.3\%$
Subject 2: IdC = - 47.3 + 27 V $F_{1,7} = 174.7$; $p<0.05$; $R^2 = 96.1\%$

The covariance analysis indicated a significant difference in the relationship between IdC and V for these two subjects.

DISCUSSION
Table 1 shows that these two subjects had similar anthropometric characteristics. But the swimming speed at each swim pace indicated that subject 1 had greater expertise. The examination of the IdC changes with swim pace revealed that it was higher for subject 1 at all swim paces. These data agree with the results of Chollet et al. (1). Moreover, the covariance analyses indicated that the increase in IdC with swimming speed was greater for subject 1. The IVV data indicated that subject 2 had higher mean values of this parameter and that they increased with swim pace, whereas IVV did not vary with swim pace in subject 1. We can thus consider that subject 1 presented better technical efficiency than subject 2 (2, 7).
It thus seems that the higher superposition of motor action of subject 1 resulted in lower velocity fluctuation, which indicates greater adaptability to increases in mechanical constraints (due to speed increase).

IMPLICATION FOR SWIM TRAINING
These data indicate that the assessment of IVV could serve as a basis for evaluating the effectiveness of IdC adaptations with swim pace increases at an individual level. This is a new finding because up to now the scientific communications dealing with IdC have been unable to propose a method to assess the adequacy of coordination adaptations at an individual level, since a large inter-individual difference was found within a group of homogeneous skill level (5). Indeed, swimmers have to adapt to different types of constraints that may be mechanical, biomechanical or anthropometric, which might explain the great variability in IdC values between subjects. From this point of view, a simple combination of IVV and IdC could serve as a basis to assess the optimal adaptation of individual swimmers. In this case, the stabilization of IVV with swim pace would be the main criterion.
However, this case study is not conclusive and further investigations are needed to confirm our findings.

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ANALYSIS ON LEARNING THE FRONT CRAWL STROKE BY USE OR NON-USE OF INSTRUCTIONAL FLOTATION DEVICES

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A current methodological problem for Italian swimming teachers is the suitability of the instructional flotation devices as a useful tool for the learning process of swimming. In literature, there are several studies reporting contrasting results in the use of these aids. The present study analyses the results of the front crawl stroke learning process in Italian children aged 8-9 years after a 10 lessons program developed by the use or non-use of instructional flotation devices. Both a qualitative (by MERS-F scale) and a quantitative (armstroke cycles, breathings, stroke rate, stroke length, efficiency index) analyses were performed. No significant differences between the two methods were found.

Key Words: swimming, learning, instructional flotation devices.

INTRODUCTION
The use of instructional flotation devices represents a controversial method for the learning process of swimming among Italian swimming teachers. Several studies reported contrasting results in the use of these aids. According to Severs (7) their use could delay the learning of independent stroke. According to other authors, on the other hand, their use might inspire confidence in beginner also if not yet enough skilled (1), then it should to be recommend at the beginning of the learning in order to allow the child to get more confidence with the water and to easier assume the correct position in the water. The use of flotation aids would be also effective on learning new stroke elements (3), on reducing the water fear and on improving the motivations (2, 5).
On the contrary, Parker et coll. (6) did not found differences between teaching methods based or non-based on the employment of these aids. The same results were also found in a previous study of our group (4).
The aim of this study was to analyse the results on learning the front crawl stroke learning carried out by use or non-use of instructional flotation devices in Italian children aged 8-9 years.

METHODS
The testing involved 20 Italian children aged 8-9 years. The subjects were divided into two groups (group IFD = Instructional Flotation Devices: height cm 130.7±3.6, weight kg 28.8±3.3; group NIFD = No Instructional Flotation Devices: height cm 132.3±3.9, weight kg 29.4±3.2) of the same stroke level. Their homogeneity was verified after grouping.
Both groups followed the same learning program: 10 lessons of 40 minutes each with the same analytical didactic progression carried out with (IFD group) or without (NIFD group) instructional flotation devices.

At the end of each lesson, all subjects were tested by an 18-meter stroke, filmed and timed.
Two kind of analysis were conducted: a qualitative analysis by means of a MERS-F scale and a quantitative analysis by survey of arm stroke cycles, number of breathings, stroke rate, and stroke length. The efficiency index has been calculated to evaluate the learning level.
The results have been compared by the Student's *t* test ($p<0.05$).

RESULTS
With regard to the qualitative stroke analysis carried out at the end of each lesson (table 1), significant differences have been found only in the armstroke evaluation at the end of the second ($p<0.05$) and the third ($p<0.01$) lesson. The group using buoyancy (IFD group) achieved better results than non-using buoyancy group (NIFD group).

Table 1. Mean and SD of MERS-F scale evaluations of armstroke and flutter kick obtained in the tests submitted at the end of each lesson to IFD group (using instructional flotation devices) and to NIFD group (non-using instructional flotation devices). Significant differences are shown: (*) when p<0.05, (**) when p<0.01.

LESSON Nr.	Evaluated skill	MERS-F scale evaluation IFD group	NIFD group	
Lesson #1	Flutter kick	1.20±0.63	1.20±0.63	
	Armstroke	Not evaluated	Not evaluated	
Lesson #2	Flutter kick	1.40±0.52	1.30±0.48	
	Armstroke	1.60±0.52	1.20±0.42	(*)
Lesson #3	Flutter kick	1.70±0.67	1.60±0.52	
	Armstroke	2.60±0.70	1.80±0.42	(**)
Lesson #4	Flutter kick	2.10±0.74	1.90±0.74	
	Armstroke	3.60±1.78	2.70±0.48	
Lesson #5	Flutter kick	2.40±0.70	2.10±0.57	
	Armstroke	5.00±1.63	4.40±1.71	
Lesson #6	Flutter kick	2.50±0.53	2.30±0.48	
	Armstroke	5.30±1.63	4.80±1.55	
Lesson #7	Flutter kick	2.60±0.52	2.60±0.52	
	Armstroke	6.10±1.20	6.00±1.16	
Lesson #8	Flutter kick	2.70±0.67	2.70±0.67	
	Armstroke	6.60±1.35	6.50±0.53	
Lesson #9	Flutter kick	2.70±0.67	2.70±0.67	
	Armstroke	7.60±0.52	7.20±0.63	
Lesson #10	Flutter kick	2.70±0.67	2.70±0.67	
	Armstroke	7.10±0.57	7.30±0.67	

The quantitative stroke analysis highlighted only a significant difference in the armstroke average number per breathing ($p<0.05$), lower in the non-using flotation devices group (table 2).

Table 2. Quantitative analysis in IFD group (using instructional flotation devices) and in NIFD group (non-using instructional flotation devices) at the end of the learning program. Values are Mean and SD. Significant differences are shown: (*) when p<0.05.

	IFD group	NIFD group	
Time 18 mt. (sec.)	38.24±9.15	36.92±6.52	
Arm Cycles	17.95±3.14	15.95±3.40	
Stroke Rate (cycles/sec)	0.48±0.07	0.44±0.11	
Stroke Length (mt/cycles)	1.03±0.16	1.17±0.24	
Efficiency Index	0.52±0.17	0.59±0.19	
Breathing nr. 7.20±1.03	7.40±0.84		
Armstrokes/Breathings	5.00±0.54	4.32±0.80	(*)

DISCUSSION
From the analysis of the results, it appears that after a 10-lesson program the learning of front crawl in beginners is not significantly affected by use or non-use of instructional flotation devices.
The significant difference in armstroke average number per breathing (no guidelines were given about armstroke and breathing action to follow in the tests) could depend on the fact that subjects taught by kickboard used a short armstroke, whereas subjects taught without flotation devices kept a slow and stretch armstroke.

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LONGITUDINAL EVALUATION OF BREASTSTROKE SPATIAL-TEMPORAL AND COORDINATIVE PARAMETERS: PREPARING OF THE 100-M BREASTSTROKE BRONZE MEDALLISTS OF THE ATHENA 2004 OLYMPIC GAMES

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This study shows how a model of arm to leg coordination in the breaststroke was used to prepare the 2004 French national champion in the 50-m, 100-m and 200-m breaststroke for the Athens 2004 Olympic Games. His coordination was periodically evaluated and the detailed information provided by this model served to guide the subsequent training decisions. Seven evaluations were made over a two-year period and assumed a parallel with the competitive performances during this period. At each evaluation, the swimmer swam 25-m at his 100-m race pace and the spatial-temporal parameters (velocity, stroke rate and stroke length) and coordination (temporal gaps between the stroke phases of the arm and leg: $T1_a$, $T1_b$, T2, T3 and T4) were calculated over three stroke cycles identified from underwater cameras with lateral and frontal views.

Key Words: motor control, expertise, performance.

INTRODUCTION

The coordination used in the four swim strokes has been modelled to improve the evaluation of performances by expert swimmers. In breaststroke, four temporal gaps assess this coordination: T1 measures the glide in body-extended position, while the degree of superposition of the arm and leg recoveries is measured by T2 for the beginning of these recoveries, by T4 for the 90° recovery and by T3 for the end of these recoveries. Based on these temporal gaps, recent studies have emphasised the importance of high coordination between arm and leg key events to minimise propulsive discontinuities (1, 2, 3).

Propulsive discontinuities can be reduced by decreasing the relative glide time, which is commonly observed when race paces increase (1), although glide time generally appears to be longer for female than male elite swimmers (3). Propulsive discontinuities can also be reduced by overlapping two contradictory phases, notably in sprint: the best elite men overlap the beginning of leg propulsion with the end of arm recovery to maintain a high average velocity (1, 3). Other elite male swimmers overlap arm propulsion with the leg insweep to swim faster, showing their capacity to overcome the great active drag due to contradictory phase superposition (3). This superposition coordination between the arm and leg phases is also seen in non-expert swimmers at every race pace, indicating a lack of coordination since this creates a high active drag that they cannot overcome (2).

The measurement of temporal gaps has been individualized and repeated at key moments so that swimmers' performances can be monitored over time. The example of the French national champion in 2004 for the 50-m, 100-m and 200-m breaststroke, also the silver medallist in the Madrid European Championships in 2004 for the 100-m breaststroke, was chosen to illustrate the interest of seven evaluations over a two-year period for preparing the swimmer for the Athens 2004 Olympic Games. We assumed a parallel between the evaluated performances and the competitive performances during the same period and were thus able to follow the evolution in arm to leg coordination to detect any deterioration in technique.

METHODS

The elite swimmer (23 years, 85 kg, 193 cm, 60.84 s for the 100-m breaststroke) was evaluated seven times (E1, E2, E3, E4, E5, E6 and E7) as he swam 25-m at his 100-m race pace. These evaluations were separated by four to ten months (Figure 1). Figure 1 provides a parallel between the spatial-temporal (velocity, stroke length, stroke rate) and coordinative parameters of the seven evaluations and the competitive performances (the time for a 100-m breaststroke, with expertise expressed in % of the current world record and ranking) during the same period.

Two underwater video cameras (Sony compact FCB-EX10L) filmed from frontal and side views (50Hz). They were connected to a double-entry audio-visual mixer, a video timer, a video recorder and a monitoring screen to mix and genlock the frontal and lateral views on the same screen, from which the mean stroke rate was calculated. A third camera, mixed with the side view for time synchronisation, filmed all trials with a profile view from above the pool. This camera measured the time over the 12.5-m distance (from 10-m to 22.5-m) to obtain the velocity. Stroke length was calculated from the mean velocity and stroke rate values.

From the video device, three operators analysed the key points of each arm and leg phase with a blind technique, i.e. without knowing the analyses of the other two operators. Thus, the arm stroke was divided into five phases: 1) Arm glide. 2) Arm propulsion. 3) Elbow, the phase 2 and 3 corresponded to the upper limb propulsion push. 4) The first part of the recovery, which went until an arm/forearm angle of 90° was reached. 5) The second part of the recovery. Each phase was expressed as a percentage of complete arm stroke duration. The leg stroke was composed of five phases: 1) Leg propulsion. 2) Leg insweep. 3) Leg glide. 4) The first part of the recovery, which went until a thigh/leg angle of 90° was reached. 5) The second part of the recovery. Each phase was expressed as a percentage of complete leg stroke duration.

Five temporal gaps were defined: The glide time was measured by two temporal gaps: 1) $T1_a$ corresponded to the time between the end of leg propulsion in an extended position and the beginning of arm propulsion, and 2) $T1_b$ corresponded to the time between the end of the leg insweep and the beginning of arm propulsion. The coordination of the recoveries was measured by three temporal gaps: 3) T2 was the time between the beginning of arm recovery and the beginning of leg recovery. 4) T3 was the time between the end of arm recovery and the end of leg recovery. 5) T4 was the time between 90° of flexion during arm recovery and 90° of flexion during leg recovery. The sum of the absolute values of the T2, T3, T4 durations was calculated to indicate the whole coordination of the recoveries. Each temporal gap was expressed as a percentage of complete leg stroke duration. For spatial-temporal and coordinative parameters, three strokes were analysed at each of the seven evaluations.

The differences between the seven evaluations were assessed for spatial-temporal and coordinative parameters by one-way ANOVAs and a post-hoc Tukey test (Minitab 14.30) with a significance level set at $P<0.05$.

RESULTS

Figure 1 shows that at the seven evaluations: 1) The velocity was decreased at E3 and E4 because of a shorter stroke length ($F_{6,14}=14.39$; $P<0.05$) and an increase in stroke rate($F_{6,14}=10.94$; $P<0.05$). 2) The glide ($T1_a$ and $T1_b$) was decreased at E2, E3 and E4 in comparison with E1, E5, E6 and E7 (respectively, $F_{6,14}=21.62$, $F_{6,14}=12.72$; $P<0.05$). 3) The coordination of recoveries showed a negative increase at E3, E4 and E5 in comparison with E1, E2, E6 and E7 ($F_{6,14}=15.19$; $P<0.05$), which was due to T2 ($F_{6,14}=12.72$; $P<0.05$) and T3 ($F_{6,14}=11.55$; $P<0.05$), while T4 only changed at E7 ($F_{6,14}=11.1$; $P<0.05$). These changes in arm to leg coordination were related to modifications in stroke phase organisation, particularly the greater relative duration of the upper limb propulsion (32% vs. 24%) ($F_{6,14}=27.75$; $P<0.05$) and arm recovery (32% vs. 26%) ($F_{6,14}=47.31$; $P<0.05$), and the consequently shorter relative duration of the arm glide (36% vs. 50%) ($F_{6,14}=43.09$; $P<0.05$) at E3 and E4 in comparison with the other evaluations. Similarly, the leg stroke phase organisation showed a decrease in the relative glide time (24% vs. 42%) ($F_{6,14}=15.64$; $P<0.05$) and an increase in the relative recovery time (35% vs. 25%) ($F_{6,14}=10.7$; $P<0.05$) at E3 and E4 in comparison with the other evaluations, while the relative duration of the leg propulsion (24% vs. 20%) and leg insweep (17% vs. 13%) did not change significantly between E4, E4 and the other evaluations.

DISCUSSION

The evaluations at E1 and E2 were made during the period in which the swimmer was setting his personal record and were thus considered as a reference of correct arm to leg coordination. Then at E3 and E4, his coordination showed deterioration, with an increase in the relative duration of the contradictory superposed movements (T2: leg recovery before the end of arm propulsion; T3: beginning of leg propulsion before the end of arm recovery) that resulted in a shortened glide (T1). In fact, some of the best swimmers adopt this superposition coordination to maintain high mean velocity in sprint (1, 3). This strategy consists of overcoming greater active drag due to contradictory superposed movements but also avoiding great instantaneous velocity fluctuations (1, 3, 4). At E3 and E4, the swimmer had a greater relative duration of upper limb propulsion, which did not mean greater force but may rather have indicated slower acceleration of the arms. Indeed, at E3 and E4 the stroke length decreased, which the swimmer tended to compensate by increasing stroke rate. At the same time, the swimmer decreased the relative duration of the arm and leg glide while the arm recovery increased. These stroke phase modifications resulted in more time in an un-streamlined position and thus great active drag. To sum up, this motor change was inefficient because, despite a new French record in the world championships of July 2003, for the first time his performance in the finals was not as good as in the semi-finals.

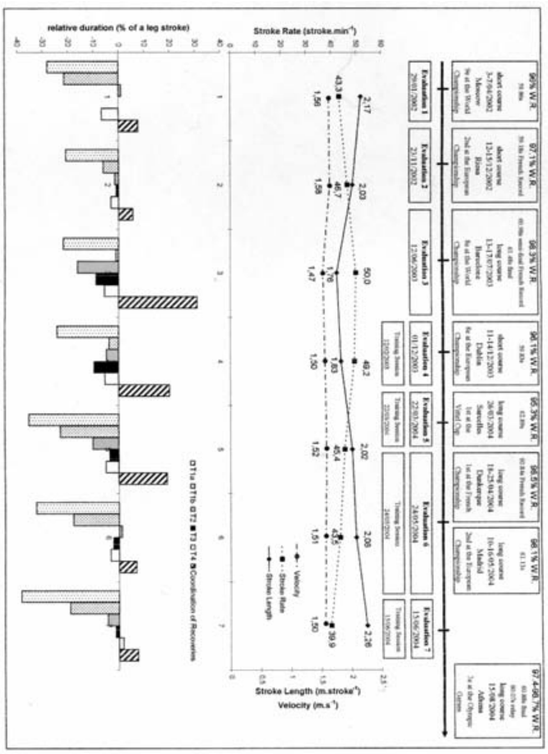

Figure 1. Relationships among performance, spatial-temporal parameters and coordination across seven evaluations.

Therefore, just after E4, four technical sessions were held to focus on the dissociation of the arms and legs and then on the continuity of propulsive movements (and these were repeated in training). An elastic band was used to pull the swimmer at a supra-velocity and, in this condition, the active drag due to coordination mistakes was amplified. When the elastic was used to hold the swimmer back and render forward movement difficult, he was asked to decompose the stroke cycle by deliberately alternating the arm propulsion and then the leg propulsion and to introduce a glide time with the body fully extended. In this second condition, the swimmer had to progressively reduce the glide time to reach the other end of the pool.

The results of the technical sessions and training were greater glide time (T1) and less superposition of negative arm and leg movements (T2 and T3), indicating a better degree of coordination recovery at E6 and E7. These results agreed with those of Takagi Sugimoto, Nishijima and Wilson (4), who noted a higher percentage of simultaneous arm-leg recovery times for the higher performing swimmer. Moreover, at E6 and E7, the swimmer re-adopted the stroke phase organisation of E1, i.e. greater relative duration of the arm and leg glide and smaller relative duration of arm recovery and upper limb propulsion than at E3 and E4, which led to greater stroke length and consequently to lower stroke rate. Finally, he improved his national record in the French Championships, in April 2004 (60.84s), beating two world-ranked British swimmers, which indicated that the technical work on coordination was stabilizing. The seven evaluations were thus useful in guiding decisions in the training process.

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EXAMINATION OF FEEDBACK TOOL USING INTERACTIVE MOVIE DATABASE FOR SYNCHRONISED SWIMMING

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The purpose of this study was to determine apposite quality conditions (movie format, bit rate, etc…) and apposite methods for visual feedback service via the Internet in synchronised swimming. Therefore we examined the most common movie formats (movie quality encoded at 1Mbps bit rate) and, examined efficacy of searching for movies in a database. We suggest that generally the Windows Media movie format is the most useful movie format. When users (athletes) browse movies via the Internet, they usually can not obtain any advices from their coaches, as a solution for this problem we suggest that users (athletes) should be able to browse annotation at the same time.

Key Words: movie feedback, synchronised swimming, interactive movie database.

INTRODUCTION

During competition or training, video recording is often used to feedback the movement / performance to the athletes. This is a very helpful tool, which allows the athletes to objectively observe their performance, determine mistakes and improve their performances. We provided instant visual feedback service at a synchronised swimming venue not only for one athlete / team but for all athletes / coaches and the general public (6). Therefore we brought a distribution server to the venue and installed a LAN, allowing several users to browse movies at same time at their preference. Movies were recorded, digitized and registered in the distribution server. Movies could be freely browsed, using streaming technology, with laptop PCs that we also provided. About 1500 movie files including current and past competitions, could be browsed at the venue. For the efficient browsing of the huge video library a search function was available allowing the users to search for criteria as: athlete's name, discipline name, event name, etc…

Several studies about the effect of movie feedback have been published by Del Rey (1) and Guadagnoli et al. (2) reviewed the use of movies for coaching and reported on efficacy of movie feedback. It appeared that there are interactions between movie feedback and athlete's skill, leading to the conclusion that instant visual feedback is an efficient technique.

Although instant visual feedback at the competition venue was highly appreciated, this service was only available at the venue, and athletes could browse the movie only during competition. Although feedback right after the action (while the image is still present in the athlete's "head") is most effective, athletes need repetitive browsing of the movie files to detect small mistakes and determine points for improvement. Depending on the performance level of the athletes, it takes more time to affect their performance.

There are different methods to feedback recorded movies; one of the feedback methods is based on using Internet streaming technology. As long as an Internet connection is available, feedback can be conducted anywhere at anytime. This technology is able to serve many users and with streaming technology it is easy to solve problems concerning movie rights (3). But, before it can be smoothly used, some problems need to be solved. Since the amount information (size of data), which can be simultaneously sent is limited on the Internet, we have to sacrifice movie quality to some extent. Consequently, the movie quality for browsing needs to be assessed. Another problem is how to provide the service; since feedback via the Internet has not been done before, including search functions for movie files in a huge movie library. The purpose of this study was to examine suitable condition of movie quality and suggesting methods for effective movie feedback service via the Internet for synchronised swimming.

Figure 1. Appearance of visual feedback in venue (Japan Open 2005).

METHODS

Movie bit rate is one of the points to consider movie distribution via Internet since it influences the quality of the movie files. Bit rate describes the volume of information a distribution server can send. The higher the bit rate, the more information can be sent; hence the better is the movie quality. Unfortunately the bit rate is limited by network environment, if the bit rate would be uncared for, most users (athletes) could not browse the movies. As published in Point Topic (5), the number of broadband Internet connections in the world exceeds 2 billion, it appears that broadband lines are increasingly spread. Internet connections faster than 500kbps (DSL, cable modem, etc…) are called broadband, and the bit rate must be decided after considering these conditions. Generally a bit rate between 250kbps-1Mbps is used to allow users to browse common contents. The bit rate is also affected by the content of the movie. The more movement in the movie itself, the higher the bit rate. Synchronised swimming is a water competition, so naturally the movie files content a lot of water surface. The continuously moving of the water surface is a disadvantage for movie compression. In case a high compression is used, details of the motion can hardly be confirmed. So the bit rate is not only decided by the network conditions but also by the movie content. With these points in mind it is necessary to carefully select the movie format and property for distribution. But this is difficult to decide unless you have compared all options. We selected generally used movie formats (AVI2.0, MPEG2, MPEG4, Windows Media, Real Media) and compared those. Recorded mini DV tape movies were captured and encoded into the previously described formats (Procorder manufactured by Canopus). Encoding conditions were, movie size 640_480(pixel), frame rate 29.97(fps), non interlace, bit rate 1Mbps. We compared the results and selected the most suitable movie format based on movie quality and operation. Furthermore, we compared different bit rates (1, 2, 3, 6Mbps) and examined degradation of movie quality.

In a huge video library, it is very time consuming to search for the wanted movie. One method to solve this problem is to store additional information concerning the movie file, together with the movie file itself in the database. Shimizu et al. (6) used this method, and successfully managed about 1500 movie files, and provided feedback service at the in Japan Synchronised Swimming Open2005. We calculated the time spent for searching for movie files with the data from the access log. Searching time was defined as the time between the end of a movie to the start of a new movie. We also examined with data from the access log, what athletes and coaches were searching for and how they browsed the movie library.

RESULTS AND DISCUSSION

With a 1Mbps bit rate, AVI2.0 and MPEG2 are not suitable movie formats for practical use. These formats had constant block noise in the water surface, and when athletes moved quickly, block noise was generated in the motion region and the circumference. In contrast MPEG4, Real Media, Windows Media, movie formats had only a little bit of block noise in motion region and the water surface. We used Windows Media as an example and examined the movie quality at different bit rates. We examined the results using 1, 2, 3, 6Mbps bit rates. At 1Mbps Bit rate, fast motions created a lot of block noise, at a bit rate of 2 Mbps a little bit block noise was created when the movie was paused and prominent block noise was created when the movie was restarted after being paused. With bit rates over 3Mbps, we couldn't determine any prominent block noise even if the movie was paused. As described in technical books, with bit rate conditions under 1Mbps, the movies had block noise as soon as the water surface was slightly moving, as well as in areas of quick motions of the athletes. Quality of simple videotape replays could not be reached. But, even though the outline is slightly fogged by the block noise, the quality of the movie is good enough to interpret the athlete's facial expression and it appears that the quality of the movies resolution is sufficient for examining the movements. Obviously it's better to use high quality movies (higher bit rates), but after considering the recent network environment, 1Mbps bit rate seems to be the breaking point. This problem might be solved by advancements in network technology and movie compression technology in the future. Windows Media, Real Media and MPEG4 showed good movie quality under these conditions. Since Windows Media is wide spread it seems to be most efficient to use the Windows Media format.

Japan Synchronised Swimming Open 2005 lasted for three days and featured 328 competing athletes. 5 laptop PCs were provided to the athletes to browse the video library. In three days a total of 1650 accesses were registered, the total number of accessed movie files was 508. The total time for feedback service was 27.8 hours, browsed movie files had a length between 2-5minutes, movies were browsed at an average of 2.24 minutes, and average searching time was 1.71 minutes. In this study the searching time was defined as the time between the end /stopping of one movie and the start of a new movie. Although, average searching time was of 1.71 minutes, considering the fact that the video library consists of more than 1500 movie files it seems that the search function is appropriate. Event name, discipline name, athlete name, affiliation, etc. were registered together with the movie files in the database and the search for movie files was based on these criteria.

Table 1. Usage from access log.

Total accesses	1650 times
Total accessed movie files	508 files
Total time of feedback service	27.8 hours
Average browsing time	2.24 min
Average searching time	1.71 min

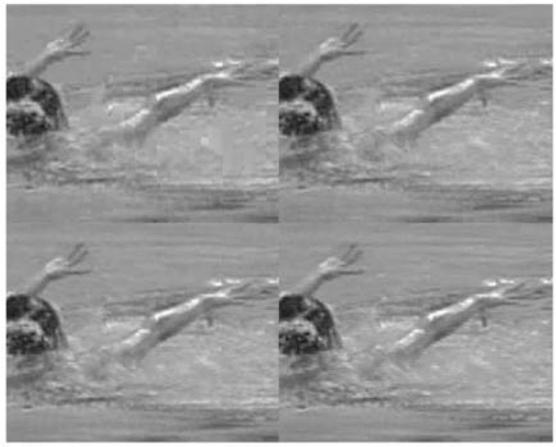

Figure 2. Differences of movie quality resulting from different bit rates. Upper left: 1Mbps, upper right: 2Mbps, lower left: 3Mbps, lower right: 6Mbps.

CONCLUSION

Miyaji (3) suggested an additional progressive search. For example, search for techniques by creating links to information tags appended to the movie files containing information about when (time) a defined technique is performed. These information tags could be accessed with a search function. If this kind of search function could be realized, movie files could be browsed in a different way for example comparing the performance of a defined technique among a lot of athletes. At the Japan Synchronised Swimming Open 2005, various athletes (basic level domestic athletes to top level international athletes) with a wide range of experiences used the feedback service. Newell et al. (4) stated that video feedback with no verbal lecture is more useful for advanced athletes than for beginners. Beginners are less experienced and still have insufficient knowledge about skills, movie feedback offers to much information for beginners since they do not know what to focus on. Guadagnoli et al. (2) stated that video feedback with verbal instruction showed higher improvement of performance than only video feedback. Movie feedback is most common used method to provide athletes information about their movements. In order to make movie feedback more efficient, athletes need the ability to focus on the most important parts / information among the big choice of information on screen. In practice athletes browse the movie files while getting advice from their coaches but when feedback is possible via Internet the athletes will access the files by themselves. For athletes with the ability to focus on the most important part feedback via the Internet without coach's advice is useful. Whereas beginners just browse the movies and cannot get any useful information that is helpful to improve their performance out it. One method to solve this problem is to overlay the movie with annotation, and the movie and annotation are distributed at once. If this technology is available, feedback without coaches' advice will become useful for beginners as well, since the annotation will point out what to focus on.

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VELOCIMETRIC CHARACTERIZATION OF A 30 SEC MAXIMAL TEST IN SWIMMING: CONSEQUENCES FOR BIOENERGETICAL EVALUATION

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The purpose of this study was to characterize the velocity curves corresponding to 30 sec maximal front crawl swimming, and to establish eventual relationships with metabolic pathways related to the anaerobic energy production. 72 swimmers of different maturational status were studied. The mathematical procedures for data treatment, including a continuous wavelet analysis, are described. Results revealed a tendency to an inverse relationship between the number of fatigue thresholds found on the velocity curves and the maturational status. The large number of the velocity curves studied presented two fatigue thresholds. The first threshold was found between 8 and 12 sec. This time interval well fits the alactic-lactic threshold enounced in the literature and leads us to speculate about the possibility of using the velocity curves to assess individual alactic-lactic thresholds in order to better plan and control anaerobic swimming training.

Key Words: anaerobic performance, fatigue, velocimetry, wavelets.

INTRODUCTION
In swimming training, the knowledge of the threshold between dominant participation of aerobic and anaerobic energy production systems it's fundamental for the aerobic training planning and control. The theoretical acceptance of the existence of a threshold between dominant alactic and dominant lactic energy production isn't, although, accompanied by the same practical application on the training field. After years of investigation on swimming exercise it was not found yet a valid direct method to assess both the alactic and lactic anaerobic capacity and power of swimmers, especially due to the difficulty in quantifying exactly the alactic and lactic energetic contributions to an effort (6). Some scientific attempts have concurred to calculate glycolisis power and capacity, namely by the use of maximal short efforts. Methods such as the Wingate test (6), a well known anaerobic evaluation tool, are unfortunately poorly adequate for swimmers. This means that besides the scientific discussion questioning if real anaerobic power and capacity are assessable through this method (6), the use of land tests could not be suitable to the swimming reality.
The feasibility of getting some energetic data from anaerobic fatigue curves is not common in the scientific literature. It seems that, in short efforts, fatigue is more related to neurological and local muscular contraction inhibition factors than to the metabolic pathways reduced capacity. Nevertheless, much more investigation is needed in this area.
The use of velocity curves during a maximal 30 sec swimming test is analyzed on the present study, and related to a possible change in alactic to lactic predominant metabolic pathways. Different maturational statuses of swimmers are considered.

METHODS
A total of 72 swimmers (see characteristics on Table 1) performed a 30 sec maximal front crawl test attached to a speedometer developed by our investigation group (8). For the older swimmers, the 30 sec test has been replaced by a 50 meter swim, since turning is not possible with the velocimetric system.

Table 1. Training level and anthropometric characteristics (mean±SD) of pre-pubertal, pubertal and post-pubertal swimmers of both genders.

	Pre-pubertal		Pubertal		Post-pubertal	
	Males	Females	Males	Females	Males	Females
n	13	13	9	9	14	14
Age (years)	9.42±0.82	8.45±0.94	13.51±0.65	12.63±0.98	18.18±2.35	16.54±2.35
Weight (kg)	34.20±7.21	28.20±3.22	55.28±7.04	47.47±5.66	69.88±7.03	58.47±7.22
Height (cm)	136.47±4.73	131.33±4.84	165.53±8.06	160.00±5.18	176.27±7.49	165.80±3.32
Training	Pre-competitive level		Regional level		National level	

The velocimetric system produced individual curves of the instantaneous velocity corresponding to each swimmer total effort time (Fig. 1). Data treatment was performed using a routine, written by our research group, in the *MatLab* program. When running the routine, we began by removing the start, glide and final (wall arrival) phases of the velocity curve (Fig. 2). Then a continuous wavelet analysis of this curve was performed.

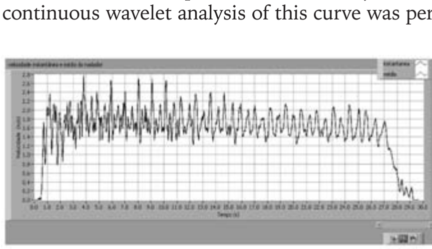

Figure 1. Instantaneous velocity curve of a 30 sec maximal swimming test obtained with speedometer.

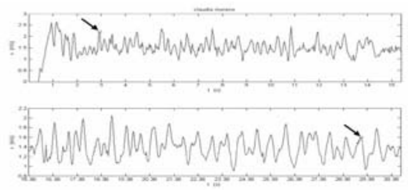

Figure 2. Cut off (→) of instantaneous velocities correspondent to start, glide and wall arrival.

The output of the continuous wavelet analysis is presented as six contour plots, each at a different fraction of the wavelet coefficient with maximum amplitude, usually 40%, 50%, 60%, 70%, 80% and 90% of maximum amplitude (Fig. 3). Each of these contour plots displays the time in the horizontal axis and the pseudo-frequency (since wavelets do not have a single well determined frequency) in the vertical axis. We may interpret the continuous wavelet transform as corresponding to a "local" frequency content of the signal. By visual inspection of these contour plots, it is possible to discriminate several 'zones' with markedly different frequency behaviour, as well as to determine the time of occurrence of the change from zone to zone (Fig. 3). In summary, from the wavelet results it was possible to discriminate one, or more, points separating zones (time intervals) of different spectral characteristics, points that we loosely call "fatigue thresholds".

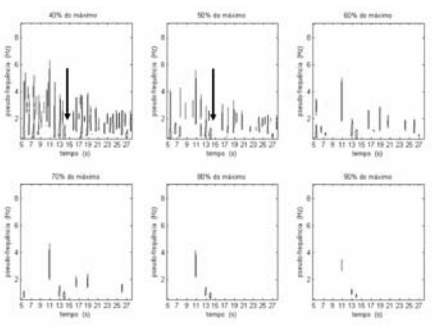

Figure 3. Contour plots from the wavelet analysis of the velocity curve of Fig. 1. It's possible to observe, in the first diagram, two distinct zones of frequency behaviour, with a separation around 14 sec (arrows). This behaviour change is confirmed on the sequential diagrams.

The accuracy of the determined point(s) was tested by observing the velocity behaviour in the different discriminated zones (Fig. 4). Sometimes this visual procedure was enough to withdraw one, or more, points, and in this case the wavelet contour plots were again inspected and new fatigue threshold points considered. After overcoming this test, the different zones were separately analyzed through a periodogram, being each periodogram normalized to its own maximum amplitude value. These normalized periodograms were all displayed in a single graph, to allow a visual comparison of them (Fig. 5). The periodogram is essentially a discrete Fourier transform of the input data and provides an approximation to the power spectrum. This diagram gives the range of frequencies that can be observed in each time interval defined by the selected points (Fig. 5). In this respect we may consider the periodogram to correspond to a "global" frequency content of the signal. After the visual inspection of the periodograms, the previously discriminated points are considered as a fatigue threshold when the frequencies amplitude and values were markedly different between zones (time intervals). Otherwise, a new analysis of the wavelets contour plots is made and all the process is repeated.

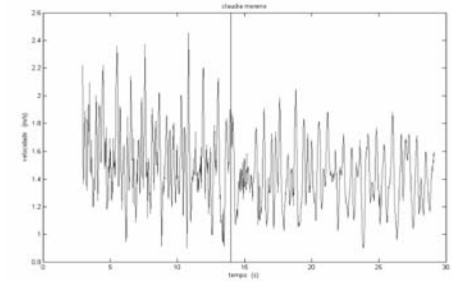

Figure 4. Velocimeter curve presented on Fig. 1 with the selected time point signed on.

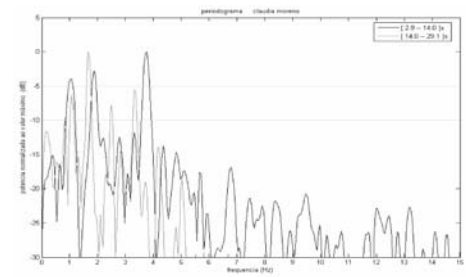

Figure 5. Periodograms for the two time intervals defined by the fatigue threshold point. The attenuations of 5 and 10dB from maximum amplitude are signed by the horizontal lines.

Finally, the program shows a graph were the velocity filtered, with a low-pass filter with cutoff frequency at 1Hz, is plotted over the instantaneous velocity corresponding to the data range treated (Fig. 6). This diagram is just an extra tool to confirm the choices made.

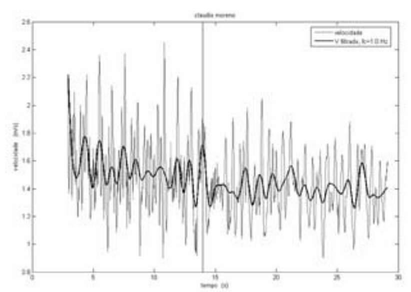

Figure 6. Instantaneous velocity in the considered time range, with the velocity filtered at 1.0Hz plotted over, and the fatigue threshold signed on.

The program also writes a data file with a list of all the frequencies that, in the periodograms, were in the 0-5 and 5-10dB attenuation ranges, from the maximum amplitude lobe. This data is presented for all the time intervals defined in accordance to the determined fatigue thresholds.
The SPSS program was used for the statistical data treatment. Since the total number of subjects for each group was less than 30, non-parametric tests were preferred. *Wilcoxon* and *Friedman* tests were applied, respectively, to two and more than two related samples.

RESULTS
The velocity curves of the tested swimmers revealed 1 to 3 fatigue thresholds. The number of fatigue thresholds tended to be higher in the less mature and less experienced swimmers. Curves that presented two fatigue thresholds were the most representative for all maturational groups (Fig. 7). The single case of a velocity curve with 4 fatigue thresholds, observed for a pre-pubertal swimmer, was not considered for further analysis.

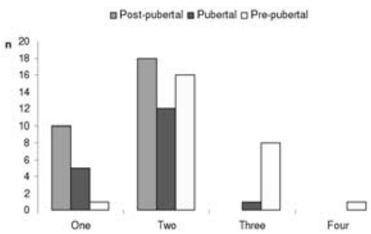

Figure 7. Absolute frequency of velocity curves with 1, 2, 3 or 4 fatigue thresholds by maturational groups.

Table 2 shows spectral analysis results in terms of the frequency with maximal amplitude, as well as the maximal frequency value, for all time intervals defined by the pre-determined fatigue thresholds.

*Table 2. Mean values and standard deviations of frequency (Hz) values. The frequency with maximal amplitude and the maximal frequency value for both 0-5 and 5-10dB intervals of attenuation are shown. Analysis was made considering curves with 1, 2 or 3 fatigue thresholds (FT). *Statistically different from sequent interval.*

Frequency with maximal amplitude (Hz)								
	0 to 5dB attenuation				5 to 10dB attenuation			
FT	1st interval	2nd interval	3rd interval	4th interval	1st interval	2nd interval	3rd interval	4th interval
One[a]	4.58±0.71*	2.67±0.78			4.14±1.42*	3.22±1.13		
Two	2.23±1.74*	2.08±0.85*	1.76±0.56		3.54±1.83	2.37±1.77	2.43±1.11	
Three	2.68±2.37	3.05±1.54	2.33±1.03	1.76±1.04	1.93±1.93	3.13±1.89	3.15±2.22	3.80±1.40
Maximal frequency value (Hz)								
One[a]	4.58±0.71*	2.67±0.78			4.36±1.95	3.46±1.40		
Two	4.26±1.68*	3.43±1.02*	2.46±0.80		4.87±1.76*	4.68±1.71*	3.20±0.94	
Three	4.19±2.06	4.21±1.48	3.81±0.67	3.21±1.00	5.63±1.16	5.75±1.89	3.98±1.64	4.10±1.20

[a]*distribution symmetry preposition violated*

A large variability within groups may be inferred by the extra-large standard deviations for some cases. Results were very similar for both variables in each attenuation interval. Since the frequency content of the time intervals is statistically different from interval to interval, for the velocity curves with 1 and 2 fatigue thresholds, we may conclude that in these cases the fatigue threshold were accurately determined. Curves with 3 fatigue thresholds were exclusive for the pre-pubertal group (the single case found in the pubertal group was not considered on the data analysis) and the frequency results of Table 2 do not reveal any statistically significant differences between these time intervals.
The time corresponding to each fatigue threshold point is displayed in Table 3, where, accordingly to the previous discussion, the data for curves with 3 fatigue thresholds should be considered as only representative.

Table 3. Mean time (sec), and respective standard deviation, corresponding to the fatigue thresholds of all the three types of velocity curves.

	One threshold	Two thresholds		Three thresholds		
	1st threshold	1st threshold	2nd threshold	1st threshold	2nd threshold	3rd threshold
Post-pubertal	12.5±1.58	8.94±1.55	16.22 ±2.65			
Pubertal	13.6±1.34	9.42±1.88	17.50±2.24			
Pre-pubertal		8.44±2.80	17.06±2.95	9.00±1.41	14.75±2.05	21.13±1.46

Analysis of the results displayed in Table 3 shows that the first velocity fatigue threshold (usually corresponding to a drop in the mean velocity) on a 30 sec maximal front crawl swimming occurs around 12/13 sec or 8/9 sec, if we consider, respectively, velocity curves with one or two fatigue thresholds. The second fatigue point occurs around 16/17 sec into maximal effort.

DISCUSSION
Since this work is a velocimetric characterization of an anaerobic effort, explanations of the observed phenomena will be somewhat speculative. Nevertheless, some results seem to fit well with the scientific knowledge on mechanical and biological domains.
The inverse relation tendency founded between the number of fatigue thresholds (or mean velocity marked drops) determined from the velocity curves and the mature status leads us to think on a probable mechanical cause. Since the maturational status is related to the training experience, namely in what concerns technical ability, the high number of "fatigue thresholds" found for some pre-pubertal swimmers may probably be more related to stroke mechanics instability, than to physiological fatigue. Ratel et al. (9) found that children are more resistant to fatigue than adults, while Chollet et al. (4), Kjendlie et al. (7) and Alberty et al. (1) found more instable swimming technical patterns in children than in adults. More over, as pointed out earlier, in our study the accurate fatigue thresholds were the ones determined from velocity curves with one or two thresholds, as found by the statistical treatment on the frequency values. The absence of significant differences between the time intervals on the pre-pubertal swimmers with 3 fatigue thresholds hints that their technique is unstable. Finally, our pubertal group results are mostly close to the adult's results, being another point in favour of the swimming technical experience as one possible determinant for the velocity drops in maximal anaerobic efforts.
Several authors refer that, until 8 to 12 sec of maximal effort, the alactic system is dominant in what concerns energetic feeding of muscular contraction (5). After that time, energy supply stays predominantly under anaerobic glycolisis domain that will maintain a high working capacity until about 2 minutes of maximal effort. What is not known is if there are some other representative *thresholds* during this golden time for glycolisis. In our results, the coincidence of the existence of a fatigue threshold after a mean time of

12/13 sec (one threshold curves, post-pubertal and pubertal swimmers) and after a mean time of 8/9 sec (two thresholds curves, swimmers of all maturational status), leads us to consider the possibility of using the velocity fatigue curves obtained with velocimetric tests for bioenergetical evaluation. This being the case, it will allow a better training planning and control on what concerns anaerobic efforts. Nevertheless, Asmussen (2) and Asmussen & Mazin (3) pointed out that in this kind of short and very intense efforts, the fatigue seems to be more related to neural factors and local muscular imbalances than to falls on energy supply by malfunction of metabolic pathways. This is the reason why such a jump conclusion needs to be clearly confirmed.

CONCLUSION

Our results revealed an inverse relationship between the number of 'fatigue thresholds' on a 30 sec maximal effort test, and maturational status. The velocity curves for all studied groups are mainly characterized by two fatigue thresholds. It seems to be legitimate to speculate about the possibility of using velocity curves to determine the individual alactic-lactic threshold and better plan and control the anaerobic training.

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THE STROKE LENGTH, FREQUENCY AND VELOCITY AMONG UNIVERSITY PHYSICAL EDUCATION STUDENTS AND ITS USE AS A PEDAGOGICAL TOOL

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This study examined the relationship between stroke length, frequency and velocity among non-competitive young adult swimmers. In a test-retest design, the stroke length, frequency and velocity triad was examined for a 50 meter crawl maximum effort. A focus on stroke length as a pedagogical tool was examined for its effect over a 12 week period. The elementary back stroke was introduced early to initiate the subjects in the concept of stroke length and T^1-T^2 sub-maximal trials were also conducted. Fifty university students participated. Results of a paired t-test analysis showed a significant improvement in time, a significant increase in stroke length and a less significant decrease in frequency.

Key Words: stroke length, frequency, velocity, non-competitive swimmers.

INTRODUCTION

Much is known about the relationship between stroke length, frequency and velocity among competitive swimmers (4-8) but little is known about these phenomena among non-competitive young adults. This study attempted to describe these phenomena to enhance our knowledge about what to expect from this age group. Evaluation as an integral part of teaching depends on a knowledge of the learners starting point and the goals. It is all too common that little information or even miss-information about what is normal in the circumstances at hand, prevents proper planning of instructional programs. Most common in a teaching situation is expecting too little, underestimating the pupils.

In swimming as in other cyclic activities, stroke length is one of the most revealing measures of technical efficiency (2, 4, 5). Technical efficiency leads to physiological economy and physiological economy must be seen as a vital element in survival/self rescue. There can be little doubt that at any level, economy of effort and survival remains one of our most important goals. While many coaches of competitive swimmers are intimately conversant with the nuances of stroke length, frequency and velocity; they are normally not concerned with survival/self rescue. They are, nevertheless obviously concerned with economy of effort with a view to increasing velocity.

Experienced instructors and teachers of non-competitive swimming are generally capable of subjectively assessing level of effort but rarely incorporate objective measures. Inexperienced instructors are too often preoccupied with smaller details that in them selves may be correct but have little to do with economy of effort. For example, details of arm stroke may not be helpful to the child who is still struggling with breathing and body position. In a brilliant graphic depiction, Haugen (3) describes the vicious circle of; head high, reduced buoyancy, diagonal body position, reduced forward motion, short and rapid strokes, incomplete breathing, rapid fatigue and the anxious child (see fig.1).

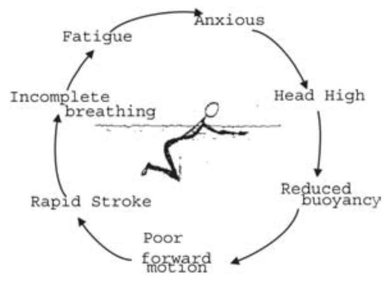

Fig. 1. The anxious child - a vicious circle

Stroke length is normally described as the distance the body travels per stroke (5). Obviously as technique improves, each stroke has the potential to move the body farther. If maximum velocity is the goal, the optimal combination of frequency and length is complex. When swimming maximally, at some point, any increase in rate will result in a decrease in length and vice versa. Furthermore, the optimal combination is specific to the individual and to the race distance. Any attempt to maximize either length or frequency will result in reduced velocity (2). However, if the goal is not maximum velocity but rather to conserve energy and body temperature in an aquatic emergency, it could be argued that increased stroke length reduces the number of strokes necessary to cover a given distance and increases the rest interval between strokes (1). Of course, even this situation is complex; saving energy reduces velocity and one could potentially succumb to unconsciousness due to hypothermia, before reaching safety.
The aim of this study was to a) describe the relationship between stroke frequency, length and velocity among non-expert young adult swimmers and b) examine the use of the concept of stroke length as a pedagogical tool in an instructional setting.

METHODS

Fifty one (25 female and 26 male) university sport science students participated in this study. Testing was conducted in the first week of a 12 week period. The tests were repeated in the12th week. Test one consisted of three x 25 meters elementary backstroke. The subjects started in the water with the feet held by a partner, toes touching the wall but no push off permitted. Trial 1 was arms only (with pull buoy); trial 2 legs only (breast stroke kick, arms folded on the chest; trial 3, the entire stroke. The number of strokes was carefully observed and noted, accurate to the half stroke. Stroke length was calculated.
Test 2 consisted of a single 50 meter maximum effort, crawl. The start was in the water with push off. The number of strokes was observed and noted for each 25m and for the entire 50 meters. A second test assistant with stop watch, recorded the split times for each 25m. The timer started the watch as the toes of the subject left the wall and stopped at contact with the wall. In this way the turn was eliminated from the total time. Experience shows dramatic differences in turning ability among non-expert swimmers which would distort the split times. A third test assistant met the swimmer at completion of the swim and immediately took a 10 sec. pulse count (manually at carotid artery). Stroke length and stroke frequency were calculated for test 2.
The instructional period of 12 weeks (2.5 hrs/wk), began with an explanation of the concept of stroke length and its relationship to frequency and velocity. Exploring this relationship in an experimental way became the goal of the students themselves. The atmosphere was one of hands-on research and personal improvement. The students themselves were active in gathering results as their own project work and each produced his/her own journal. A high level of motivation was subjectively observed.
The elementary backstroke was introduced first to assist in demonstrating the concept of stroke length. Usually described as a resting stroke with a clear glide phase, it lends itself to sub-maximal trials with an emphasis on reducing the number of strokes per length. Specific exercises were pursued both to reduce resistance and to increase propulsion. These efforts were continually related to periodic checks of stroke length. The content of the course of instruction was otherwise comprehensive with a wide variety of aquatic movement activities including 8-10 different traditional strokes. All strokes were taught in the manner described above.

RESULTS

Table 1. Mean (SD) of velocity (v), stroke length (SL), stroke rate (SR) and stroke length normalized for height (nSL) for test 1($_{t1}$) and test 2 ($_{t1}$) for male and female students.

	Male	female
v_{t1} ($m \cdot s^{-1}$)	1.18 (0.19)	1.06 (0.18)
v_{t2} ($m \cdot s^{-1}$)	1.25 (0.19)**	1.16 (0.22)
SL_{t1} (m)	1.76 (0.32)	1.68 (0.29)
SL_{t2} (m)	1.93 (0.39)**	1.87 (0.28)**
SR_{t1} (min^{-1})	40.7 (6.0)	38.3 (5.6)
SR_{t2} (min^{-1})	40.1 (7.8)	36.2 (5.8)*
nSL_{t1}(%)	98 (18)	100 (19)
nSL_{t1}(%)	107 (21)**	113 (17)**

* $p<0.05$ and ** $p<0.01$ for the difference between t1 and t2.

Improvements in the elementary back stroke were dramatic (12.45 to 10.16 strokes/ 25m). This was an increase in stroke length of 45 cm/str. It was also seen that while there were excellent improvements when swimming with arms only, improvements when only kicking were considerably more modest. Table 1 shows the result of the two gender groups. The improvement in the crawl stroke velocity over the 12 week period was nearly 20 cm/sec (.1805m/sec) for all students (male and female). The crawl stroke length increased from 1.73m to 1.90m while the frequency was moderately reduced by 38 str·min^{-1}. Testing the reliability of the measurements was done using Cronbach's α and was found to be 0.78, 0.87 and 0.87 for the velocity, stroke length and stroke rate respectively (all with n=50 and the test and retest sets of data). This shows that the reliability of the test was good. Regarding the crawl stroke, the results showed that the students started with both lower stroke length and frequency than competitive swimmers. Most dramatic however, and to be expected, was the lower velocity (see Table 2). Gender differences indicated that the female students both started closer to their competitive peers and improved more than the male students.

Table 2. Mean (SD) Stroke length (SL), stroke rate(SR) and velocities (v) at 50 m freestyle of students and elite competitive swimmers. The values for swimmers are derived from official Race Analysis Videography, The 9th World Swimming Championships, Fukuoka, Japan, 2001

	Female Students	Female Swimmers	Male Students	Male Swimmers
v ($m \cdot s^{-1}$)	1.16 (0.22)	1.88 (0.03)	1.25 (0.19)	2.09 (0.02)
SR (min^{-1})	36.2 (5.8)	61.3 (1.7)	40.1 (7.8)	64.4 (5.1)
SL (m)	1.87 (0.28)	1.82 (0.06)	1.93 (0.39)	1.92 (0.11)

DISCUSSION

As discussed in the introduction, one of the aims of swimming instruction at all levels, from baby swimming to training elite swimmers, is to increase the ability of the individual to cope with an unexpected situation. Competitive swimmers can become faster without necessarily becoming more water safety wise or more versatile. However, modern coaching has focused on versatility for it's all around developmental effects, knowing that this serves also to improve sport performance. The swimmer of today has a far more all around development than those of just 15-20 yrs ago. Modern swimming instruction for non-competitive swimmers has also become more versatile than before although among experienced instructors it has always been easy to argue the importance of versatility in relation to prevention of drowning accidents.

Quality teaching takes this into account and aims at comprehensive development. This includes striving for fluid, relaxed, well coordinated movements. Such movements become more mechanically efficient and at the same time more physiologically economic. We repeat, there can be no doubt as to the importance of economy of effort (good technique) in tackling an involuntary immersion. This should be one of the goals from the lowest levels of instruction (baby swimming).

Swimming skill of course will not replace water safety knowledge or attitudes of respect for the powers of nature but will add to them and may contribute to saving life. If it becomes necessary to swim to survive (it often isn't), the better one's technique, the better the chance of survival.

Stroke length is an important indicator of economy of effort. Yet few instructors of non-competitive swimmers use objective measures of economy in their teaching. Our results have shown that it is indeed possible to produce dramatic improvements in economy of effort as measured by stroke length, when teaching focuses on stroke length. Our subjects experienced dramatic improvement in the elementary back stroke, as shown above. Most of the improvement was due to improved arm stroke rather than kick as the improvement in kick was modest. There is every reason to believe that they would also improve similarly in any of the "resting" strokes (breaststroke, side stroke, etc). The stroke of choice in an emergency would be one(s) that is efficient and offers good vision. This will vary from person to person.

The students in this study were able to achieve (crawl) stroke lengths that were quite close to that of competitive swimmers. They had however, considerably lower stroke frequencies, lacking the swimming specific fitness that would allow higher frequencies. Once having attained reduced resistance and improved propulsion (better technique/ longer stroke length), an increase in swimming strength and endurance would permit higher frequencies and thus a higher velocity. If speed however is not the goal, then at sub-maximal effort, an improved stroke length improves economy of effort.

CONCLUSIONS

We conclude that non-competitive swimmers can achieve stroke lengths that resemble those of competitive swimmers when this is a focus of teaching. While the subjects had considerably lower stroke frequencies and velocities than their competitive age mates, maximum velocity was not their goal. We recommend the routine use of measurement of stroke length (stroke counting over a fixed distance) in teaching. This alone however, will not produce the desired results. Care must be taken to emphasize specific drills that will reduce resistance and increase propulsion and this of course must be emphasized in teacher/instructor training.

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A RELIABILITY STUDY OF A LACTATE PROFILE TEST FOR RUNNING IN THE WATER WITH "WET VEST"

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This study was a test-retest examination of the reliability of a test protocol for generating a blood lactate profile for running in the water with the wet vest. The protocol was a duplication of the protocol used in our laboratory for treadmill running except that work load was controlled by continuous monitoring of HR. Blood lactate values were determined for HR levels of 120, 130, 140, 150, 160 and if necessary, 170 and 180 BPM. Fifteen subjects performed the test with 1-3 days between tests. Results demonstrated that a) the protocol was well suited to use with the wet vest under field conditions 2) the intra-test variation in HR was minimal (mean SD for all tests, all subjects, 1.6 BPM) and c) the reliability of the repeated test was high (mean coefficient of variation, 1.46; $p>0.05$).

Key Words: running in water, wet vest, lactate profile test, reliability.

INTRODUCTION

Running in the water with the wet vest has been popular since the 1980's. It is used as alternative training, as a therapeutic measure and for persons with special physical needs (9). In its

systematic use, the need arises for prescription of training intensity. A blood lactate (La_b) profile is still the best way to choose and monitor effective training intensities (4-7).
Both research and training have reached higher levels of sophistication than just a few years ago. Coaches routinely test their athletes and design sophisticated training programs (1, 5, 7). The need is recognized for greater insight into the nuances of training physiology and the reaction to training at different intensities. Perhaps the most important development in the past 20 years is the recognition that training at different intensities draws energy from different sources and stimulates improvement in those systems. To improve different metabolic systems, it is necessary to train at different intensities (5, 7). Early work by Mader (4) paved the way for blood lactate testing as the best way to control training intensity. Later work (2, 7, 10) applied La_b testing to swimming. Today sophisticated endurance training focuses most often on 5-8 intensity levels (1, 5, 7) each of which will theoretically improve different metabolic processes, although there is obviously considerable overlap. The specificity of La_b response to different activities is also an argument for developing test protocol specific to a variety of activities. In the absence of velocity control, as in the laboratory, continuous monitoring of HR is a convenient (though less than perfect) way to control intensity. The purpose of this study was thus to examine the reliability of a La_b profile test protocol designed specifically for running in the water with the wet vest and using HR monitoring to control intensity.

METHODS

A test-retest design was employed with 1-3 days between the tests. The tests were conducted at the same time of day. The subjects were asked to refrain from eating for the two hour period before testing.
Fifteen subjects (10 male, 5 female; mean age, 23.2yrs, weight 69.8kgs and height 174.4cms) participated in the present study. All were sport science students actively involved in endurance sports including middle and long distance running, cross country skiing, orienteering and triathlon. All testing was conducted in a 25m pool with an area of deep water of 12.5m x 15m. The water and air temperatures were constant at 27-28^{O}C and 24-26^{O}C, respectively.
The test protocol was the same as that used in our laboratory for generating blood lactate profiles while running on the treadmill. The protocol consisted of a 10 min. warm up at HR = 110-115 BPM, followed by 5-7, 5 minute bouts of work with a one minute rest interval. If the La_b values and HR obtained on bouts 4 and 5 suggested that the subject was still at a relatively low exercise intensity, a 6th or even 7th bout was conducted.
All subjects had prior training in use of the wet vest to address problems of balance and buoyancy and to adapt to the mouthpiece and nose clip. In several cases the wet vest required some minor tightening to improve fit. All subjects used the same vest for both tests.
The intensity of all bouts of exercise for all subjects was controlled by continuous monitoring of HR The Polar Sport Tester Pulse Watch was used throughout. It was necessary to supplement the belt normally used for the sender with tape to facilitate contact of the electrodes. The subject wore a helmet with the receiver mounted in front to allow constant self-monitoring. A second receiver was located with an assistant at poolside. Any deviation of 2 BPM from the stipulated HR was immediately communicated to the subject. In this way both visual self-monitoring and assisted verbal feedback was used. The HR levels chosen were 120, 130, 140, 150, 160 and where necessary, 170 and 180 BPM, corresponding to 68, 73, 79, 85, 90, 95 and 100% of the peak HR obtained in the water.
Blood lactate values were obtained before and after the warm up, before the first 5 minute exercise bout and immediately after each succeeding bout. Blood samples were taken from the finger tip after being wiped clean of water and sweat, with the first drop of blood also wiped away before taking the sample. Avtolett II capillary tubes containing heparin were used to collect the sample. Analysis was performed immediately using the YSI Model 23L Whole Blood Lactate Analyser.
The Polar Sport Tester registers and records HR values every 5 seconds. Mean and SD for these values (i.e. 60 values per exercise bout), were calculated for each bout, for each subject. Mean SD's were calculated for each test, for each subject and for all subjects. While the first minute of each bout may have been required to reach a steady state, the SD's when including all 60 recorded values, were small and statistically acceptable. The lactate curves to be tested for reliability were constructed with the help of "Biostat 3.0". Because the variability of HR can influence La production, the variability was tested before calculating the formulae for generating the profile curves. Considering the statistically acceptable SD's in both inter- and intra-moment analysis, it was deemed acceptable to use the mean HR for each bout and its corresponding blood La_b value in further analysis. It was thus possible to calculate the HR each subject would have had at blood lactate values of 2.0, 3.0 and 4.0 mM La_b. These values were then examined comparing Test $_1$ and Test $_2$ for each subject. The mean differences between T_1 and T_2 were calculated and the coefficient of variation determined for the entire group. Student's t-test was used to determine the level of significance of differences between the tests.

RESULTS

An overview of the HR values collected shows that the variation for any given subject and for all subjects during all exercise bouts was minimal. The SD's for any given subject for any given trial, ranged from 0.7 to 2.9 BPM (i.e. 1 value every 5 sec. for 5 min. = 60 recorded values). The mean SD for all trials and all subjects was 1.6 BPM. Table 1 gives as an example, the values obtained for subject MM.

Table 1. An example of values obtained for subject M.M. The SD values represent variation over 60 values (i.e. 1 every 5 sec. for 5 min.). Obtained HR is the mean of the 60 values.

	Test 1					Test 2				
Stipulated HR	120	130	140	150	160	120	130	140	150	160
Obtained HR	121	130	140	150	159	120	130	140	149	159
SD for 5min	0.8	1.2	1.3	1.1	1.4	0.9	1.4	1.9	0.8	1.0
La_b	1.4	1.7	2.5	4.2	5.5	1.5	1.8	2.7	4.0	5.3

Figure 1 presents the exponential curves generated from the calculated formulae for all subjects, comparing Test 1 and Test 2. Calculated HR's are shown for La values of 2.0, 3.0 and 4.0 mM.

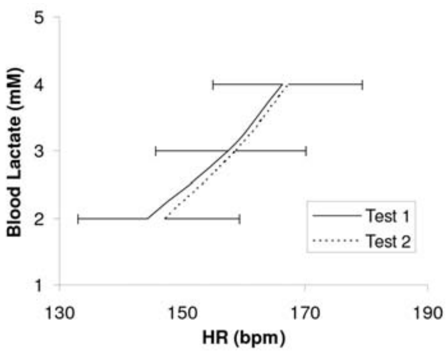

Figure 1. Mean HR (error bars are SD) for blood lactate concentrations of 2.0, 3.0, and 4.0 mM T_1 and T_2.

The large SD's in Fig.1 reflect a relatively wide range of HR values among the subjects.

From this figure we can find the mean difference in HR from T_1 to T_2 and the SD of these differences. Thus we find the coefficient of variation. The following table gives an overview of these values. When subjected to the t-test for paired differences, the differences in HR between T_1 and T_2 were not significant at the 0.05 level of confidence.

Table 2. Coefficient of variation at the stipulated blood lactate concentration (La_b) levels between T1 & T2.

La_b	MeanDiff.,HR $T_1 - T_2$	SD of Diff.	Coefficient of Variation
2.0 mM	3.88 BPM	2.14	1.47
3.0 mM	3.86 BPM	2.48	1.57
4.0 mM	3.54 BPM	2.20	1.33

DISCUSSION

Specificity of testing according to the activity performed, as discussed by Åstrand and Rodahl (10), is an argument for developing test protocol for a variety of activities. It was thus necessary to devise a test protocol specificaly for running in the water, and to test its reliability, especially when prescribing training programs or monitoring changes over time. Intensity, duration of the work load and the rest between work loads, all influence the results of profile testing (2, 5). It is therefore no surprise that several protocols exist. In addition, the training backgrounds of the subjects as well as his/her physical characteristics play a role In general, the most common form of profile test is a series of five efforts of 3-5 minutes with a 30-60 sec. rest interval at increasing intensities. In swimming, 5x400 meters with a 30 sec interval is commonly used. On the treadmill, intensity is easier to regulate. Repeated efforts of five minutes at increasing velocities are common. This is in fact that which is used in our laboratory. This protocol also lends itself to running in the water at increasing intensities (monitored by HR). In this study, variability of HR proved to be minimal as seen above in Table 1 and in the mean overall SD for HR of 1.6BPM. This justified using the obtained mean HR values, and the corresponding blood La values for each bout of exercise, to generate the profile curves. Including only HR values of the last 4 minutes of each 5 minute exercise bout would have given even greater agreement between the curves of Test 1 and Test 2 but was deemed unnecessary as the obtained coefficients of variation were statistically acceptable, as shown in Fig.1 and Table 2.

CONCLUSIONS

The variation in HR within each work load, for each subject and for both tests, was minimal (mean SD for all trials and all subjects was 1.6 BPM). This indicates that it is indeed possible for subjects to hold a consistent level of effort and at the stipulated HR level, while running in the water with the wet vest. The reliability of the protocol was demonstrated to be high with the coefficients of variation being 1.47, 1.57 and 1.33 for calculated levels of HR at blood lactate 2.0, 3.0 and 4.0 mM, respectively. It is therefore concluded that the protocol in question is an acceptable method for eliciting a La_b profile while running in the water with the wet vest. Further work is recommended to validate this protocol against a laboratory protocol.

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THE RELIABILITY OF A PEAK VO2 TEST PROTOCOL FOR RUNNING IN THE WATER WITH WET VEST

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This study employed a T_1-T_2 format to examine the reliability of a peak VO_2 test protocol for running in the water with the wet vest. Sixteen subjects 20-31 yrs of age participated. Classic Douglas bag respirometry was used. After a 10 minute warm

up (HR 110-115 BPM), five 5 minute sub-maximal work loads were performed with a one minute rest interval. Thereafter, a final effort of 3.0-3.5 min. to exhaustion was performed. Work load was controlled by continuous HR monitoring. Blood samples were taken for blood La analysis before and after every work effort. Pearson Product Moment correlations for T_1 to T_2 were r = 0.99, 0.97 and 0.96 for peak VO_2 (l/min), peak VO_2 (ml/kg/min) and HR (BPM), respectively. The differences between T_1 and T_2 were not significantly different at the 0.001 level of confidence.

Key Words: running in water, wet vest, peak VO_2, reliability.

INTRODUCTION

Alternative modes of training have become increasingly popular. In some cases the alternative is an adjunct to the chosen activity. In other cases the alternative becomes a primary competitive activity itself (indoor bandy, roller-skiing, fin swimming, etc).

Running in the water was launched in the 1970's primarily for its probable therapeutic effect. In the equestrian world, horses have trained in the water since the time of the ancient Greeks and it is unlikely that they overlooked similar human activity. Submerging the body during running has several important effects not the least of which is the effect of buoyancy, reducing stress on the joints. At the same time, the stroke and minute volumes of the heart increase (9) thus an excellent potential for training effect.

Many runners, during periods of injury, now run in the water to protect the injury but also to maintain the training effect. This may also reduce the time of recovery from injury (6). Some runners have exchanged part of their normal running training for running in the water, hoping to avoid injury believing the kinematics to be more specific to running than e.g. cycling or swimming. Nilson and Thysell (4) however, have rejected the idea of specificity by demonstrating differences in EMG muscle activity, particularly the elimination of a support phase with its eccentric contraction, when running in deep water.

Several studies have compared running in the water with running on land and treadmill running (5, 3, 6, 8, 12). Town and Bradley (11) compared running in shallow water, in deep water and on the treadmill. Generally, results show reduced maximal levels for HR and VO_2, as in swimming (1).

Deep water running assisted by a flotation device is generally credited to Glen McWaters (2) who patented the "wet vest" in 1980. Himself, a chronically injured former distance runner, he sought activity in the water to reduce impact and joint stress. In the wake of the running in the water activity of the 80's and 90's, use of the wet vest or similar devices has also gained popularity in activities for persons with movement impairment special needs. Both the target group and some of the activities tend to overlap with aqua-aerobics/ aqua-gymnastics.

Running in the water presents several unique problems which also must be solved.

The aims of this study were a) to develop a peak VO_2 test protocol for running in deep water with the "wet vest" and b) to examine the reliability of that test protocol.

METHODS

A test-retest design was used with 1-3 days between tests. The subjects were asked to refrain from eating for the two hour period prior to testing. The tests were conducted at the same time of day and in the same location. Testing was conducted in a 25 meter pool with approximately 15 m. x 12.5 m. of deep water. The water temperature was stable at 27-28 ^{0}C and the air temperature stable at 24-26 ^{0}C.

Sixteen university students served as subjects (11 male, 5 female), mean age 26 (range 20-31 years). Most were participants in endurance sports including cross country, skiing, triathlon, orienteering, middle and long distance running.

The test protocol was a slight modification of that used in our laboratory. It consisted of a 10 minute warm up at HR 110-115 BPM followed within 2 min. by five bouts of work of 5 minutes each with one minute in between. These were at gradually increasing work- loads with the load controlled by continuous HR monitoring, with both visual and verbal feedback to the subjects. The work loads selected were at HR 120, 130, 140, 150, and 160 BPM (68, 73, 79, 85, and 91% of peak HR in the water). After a rest of 2-3 minutes the subjects then performed a 3-4 minute maximum effort to exhaustion. The first minute was at a gradual increase to the maximum the subject felt could be maintained for another 2-3 minutes.

The work load was controlled, as stated above, by continuous monitoring of HR. The subject wore a helmet with a Polar Sport Tester pulse watch mounted in front for visual self control. At the same time an assistant with another receiver was on the deck, close enough to receive the same signals. Any deviation from the stipulated HR by 2 BPM, was immediately communicated to the subject.

Respirometry was performed by classic Douglas bag methods. Two Douglas bags were mounted on a trolley at pool side connected by a three way valve with stop watch control. The hose with a mouth piece was also connected to the helmet for stability.

The first bag was opened at approximately 1 minute 30 seconds after start, with some discretion according to visual signs of fatigue in the subject. In each case, 40-60 seconds elapsed before the bag was filled and the switch made to the second bag. No subject was able to continue more than 3 min.30 sec. and the one exception reached exhaustion during collection in the first bag.

In this setting, gas analysis had to be performed in the laboratory. Visual monitoring of the rising O_2 uptake as in automated systems was not possible. Maximum HR values were known from previous treadmill testing. At the time the subject signaled exhaustion HR values were within 15% of the treadmill elicited maximum HR. Blood lactate values, although known only after cessation of exercise, were also in each case over 6mM. HR and lactate levels gave every reason to believe that maximum effort was attained. In any event the subjects could not have continued. Gas analysis employed the Beckman O_2 analyzer, Model 755 and the Beckman infrared CO_2 analyzer, Model 864.

Blood samples were collected from the finger tip of the subject before and after warm up, in the 1 minute pause between each of the 5 increasing work loads and just before and after the 3 min 30 seconds maximum effort. An YSI, Model 23L lactate analyzer was used.

Statistical analysis comprised of Pearson Product Moment correlation to examine the relationship between T_1 and T_2 and Student's t-test to examine the level of significance of differences between T_1 and T_2.

RESULTS

The peak VO_2 values obtained were all within 15% of each subject's previous treadmill results. This conforms to numerous studies referred to in the introduction, with values for work capacity during submersion in water 10-15% lower than on land. Table 1 shows the highest and lowest values obtained as well as the mean, range and standard deviation (SD). Note that the range of values appears to be rather large. This is due to inclusion of both male and female subjects.

Table 1. An overview of obtained values.

Parameter	Highest value	Lowest value	Range	Mean	SD
Peak VO_2 (l/min)	4.52	2.03	2.49	3.57	0.69
Peak VO_2 (ml/kg/min)	61.94	42.68	19.26	51.47	5.68
Peak HR (BPM)	183	163	20	176.3	6.66
Peak Lactate (mM)	8.1	4.1	4.0	6.2	0.06
RQ	1.23	0.98	0.25	1.10	0.08

The major thrust of this study was the $T_1 – T_2$ reliability check. Given the anticipated practical problems and potential sources of error, the reproducibility was high. Table 2 gives an overview of the relationships between Test 1 and Test 2.

Table 2. Relationship between test 1 and test 2.

	Mean value ($T_1 + T_2$)	Mean SE ($T_1 + T_2$)	Mean SD ($T_1 + T_2$)	Mean range ($T_1 + T_2$)	Pearson PMR	t-value	*p*- level
Peak VO_2 (l/min)	3.52	0.18	0.72	2.43	0.987	0.30	NS
Peak VO_2 (ml/kg/min)	50.97	1.55	6.20	18.65	0.966	0.37	NS
Peak HR (BPM)	176.7	1.82	7.28	20	0.963	0.28	NS
Peak La (mM)	6.2	0.26	0.96	3.4	0.887	0.11	NS

DISCUSSION

Maximum O_2 uptake is generally accepted as the best measure of aerobic capacity (13). Already in 1924, A.V. Hill registered a plateau or even drop in O_2 uptake as subjects continued to increase the work- load. He called this "maximum O_2 uptake" and suggested its relationship to aerobic capacity and endurance performance. In recognition of the difficulty in establishing an absolute maximum value, the results of any given test is today usually referred to as "Peak VO_2".
Saltin and Åstrand (7) demonstrated that among participants in elite sport, cross country skiers attained the highest maximum VO_2 values (in ml/kg/min). They discussed specificity of training for aerobic power and the specificity of testing. While cycling e.g. gives values of approximately 10% less than running, the well trained cyclist who is not accustomed to running may obtain higher values in cycling than running.
This test specificity is an argument for establishing norms in a variety of activities, particularly in relation to training prescription and monitoring of improvement over time. Test protocol must be developed and evaluated for their validity and reproducibility.
Field testing of peak VO_2 presents certain practical problems. Both the nature of the activity involved and certain characteristics of the local setting present unique problems. Regarding running in the water, controlling workload intensity is necessarily less refined than in a laboratory setting. The method used in this study however, was both manageable and produced acceptable results. In a parallel study (10), the same method was used and deviation in the HR during repeated, escalating five minute work loads, was no more than 1.6 BPM throughout.
The movement of subjects was of a range and velocity allowing test personnel to easily follow with Douglas bag apparatus. No problems appeared either in monitoring HR.
Some care had to be taken in guiding the sample collection hose so as not to entangle the subject as he/she turned during back and forth running.
The results of the reliability testing, giving correlations of 0.99, 0.97 and 0.96 for peak VO_2 (l/min), peak VO_2 (ml/kg/min) and HR respectively, were more than acceptable.
Missing data made correlation analysis of the blood lactate levels values less appropriate but on the remaining data (df = 11) the r was 0.887, and the t-value was 0.11 showing no significant difference at the 0.001 level of confidence despite the lower correlation.

CONCLUSION

It is recommended that the protocol tested in this study, with demonstrated reliability, be considered for use in peak VO_2 testing for running in the water. Modifications may be necessary because of local conditions. Running in the water can be considered a useful training alternative in certain cases, given the relatively high VO_2 and HR values attained.

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THE ASSESSMENT OF SPECIFIC STRENGTH IN WELL-TRAINED MALE ATHLETES DURING TETHERED SWIMMING IN THE SWIMMING FLUME

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Eighteen well-trained male swimmers were tested during tethered swimming in swimming flume at nine different flow velocities and in selected strength tests on land. The questions to answer were: how does the value of pulling force during tethered swimming change with changes in flow velocity in the flume and how closely related that force is to competitive swimming results in comparison to other strength tests? A significant correlation was found between values of pulling force in the flume and competitive swimming velocity in 100 m freestyle. This correlation was stronger than correlation of swimming performance with pulling force at zero velocity or with strength measured in land tests. The strength of relationship increased with an increase of flow velocity in the flume.

Key Words: swimming flume, tethered swimming, pulling force.

INTRODUCTION
Strength training always was one of the most attractive types of training for swimmers and swimming coaches since in many cases it allows to achieve rapid growth of strength and improvement of swimming results, especially when it applied to individuals who had no experience of strength training or young female swimmers.
At the same time it was found that very often the effect of strength training upon improvement of the effective propulsive force during swimming is very limited in the long term prospect and in value. Petrov [3], Vaitsekhovsky and Platonov [5], Saigin, [4] showed that high level of muscle strength, developed during land resistance training shows very limited transfer into pulling force during swimming (and thus to competitive results), although different parameters of strength measured in land exercises demonstrate significant correlation with pulling force during tethered swimming at zero velocity. Studies of the pulling force during tethered swimming at zero velocity (PF V=0) involving uniform groups of swimmers of the same age, sex, training experience and performance level [3, 6, 7, 8] found moderate correlation of studied pulling force with swimming velocity in 25, 50, 100 and 200 m swimming. This correlation decreases with increase of swimming distance and becomes insignificant for such distances as 400 m and over. Thus pulling force at zero swimming velocity may be used as a reliable criterion for specific strength and swimming proficiency only for groups with large variation in swimming results. We may suggest that the best way to assess the performance potential of swimmers will be to measure pulling force during swimming (if it would be possible) or in situation, which will be closer to free swimming than tethered swimming at zero velocity. Thus we decided to investigate the possibility to use swimming flume as a tool for evaluation of specific strength of well-trained swimmers.
Objectives of the studies were:
— to determine how the values of pulling force during tethered swimming in the flume would change in respect to increase of flow velocity;
— to investigate the relationship of pulling force during tethered swimming at different flow velocities with competitive swimming speed (CSS) in 100 m front crawl;
— to establish the correlation of pulling force during tethered swimming with maximal strength in bench test (PF_L) and working capability in 30-second pulling test (WC_L) ;
— to evaluate the consistency of individual PF_W values on the base of test-retest correlation in same subjects after time interval of two month;
— to estimate the character of changes in individual PF_W values at different stages of training in the macro-cycle.

METHODS
The study was performed in the swimming flume of the Moscow Olympic Centre for Aquatic Sports ("Steinberg-Flygt" swimming flume, Sweden). Testing procedures included measurements of pulling force (PF) during tethered swimming in "dead water" (at zero velocity) and during tethered swimming at 8 different velocities of the water flow: 0.6 $m{\cdot}s^{-1}$, 0.8 $m{\cdot}s^{-1}$, 1.0 $m{\cdot}s^{-1}$, 1.2 $m{\cdot}s^{-1}$, 1.4 $m{\cdot}s^{-1}$, 1.5 $m{\cdot}s^{-1}$, 1.6 $m{\cdot}s^{-1}$ and 1.7 $m{\cdot}s^{-1}$.
The margin of error between flow velocity as measured by specially designed tachogenerator [3] at the depth 0.2 m along the flume's central axis was ±2.3-4.5 %. In order to reduce the formation of a standing wave on flume surface we floated a special heavy weight wooden buoy in front of the swimmer (as it was recommended by Persyn [2]). It effectively prevented formation of a big standing wave up to flow velocity 1.7 $m{\cdot}s^{-1}$. (Since it could not prevent the effect of the wave at flow velocities 1.8 $m{\cdot}s^{-1}$ and higher, we limited the study of pulling force by upper flow velocity value 1.7 $m{\cdot}s^{-1}$).
The subject was connected to the measuring force unit by 3 m long cable consisting of 2 m rope and 1 m rubber cord insert with a round section of 1 cm diameter (k=1.5). We used the cable with rubber cord damping instead of a plain rope or a more rigid cable in order to exclude the effect of dynamic impact at the moment when cord will be stretched as well to level the pulling force fluctuations caused by fluctuations of intra-cyclic swimming speed. The swimmer was instructed to swim along the mid-axis of the flume and exert maximal effort for 5-6 seconds after the cord was stretched. A highly sensitive mechanical gauge registered the peak force magnitude with precision ± 1.3 N.
All subjects were familiar with swimming flume as it was used for training and routine testing. They performed the flume test after a standard 800 m warm up in the pool.
Measurement started with zero velocity. The same procedure was followed for every chosen flow velocity with rest interval 1.5 min.
We also measured the maximal double arm pulling force in the bench test (PF_L) and Working Capability in the 30-sec double arm pulling bench test using Huttel-Mertens pulling device [1] with standard resistance 332.5 N for all subjects. Working Capability (WC_L) was determined in conditional units as:
WC_L = 332.5 x n,
where n = the number of "pulls" performed during 30-s test.
The subjects were 18 well-trained swimmers aged 18-19 years, students of the State Central Institute of Physical Culture (among them were several national champions and finalists of National Swimming Championships). The front crawl was used for all testing procedures in the water.

RESULTS AND DISCUSSION

It was found in all subjects that PF_W decreases with increasing water flow velocity in the flume (table 1). The relationship between PF_W and V was described as satisfactory by a linear regression equation:

$PF_V = - 8.502V + 20.052$ (R=0.924; $R^2 = 0.852$; $p<0.01$).

Table 1. Mean values and characteristics of distribution of the pulling force (PFW) at different water velocities in well-trained male-swimmers (n = 18).

	Flow Velocities ($m \cdot s^{-1}$) in the flume								
PF_W	**0.0**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.5**	**1.6**	**1.7**
X, *N*	193.6	148.2	134.3	115.9	98.5	76.2	64.4	52.9	39.2
± SD	21.0	21.0	18.0	19.3	17.5	16.2	18.2	19.6	22.2
cV %	10.8	12.2	13.4	16.6	17.8	21.2	28.3	37.0	56.8

It should be noted that some subjects with high strength potential (who demonstrated high magnitudes of PF_L and PF_W at flow velocities 0-1.2 $m \cdot s^{-1}$) were not capable of using that potential and produce high values of PF_W at higher flow velocities. They demonstrated lower than expected values of PF_W at flow velocities 1.4-1.7 $m \cdot s^{-1}$. At the same time a few swimmers who demonstrated average values of PF_L and PF_W at V=1.0-1.2 $m \cdot s^{-1}$ were capable of producing higher PF_W at flow velocities 1.4-1.7 $m \cdot s^{-1}$ than their more muscular team mates.

Among the latter were the national champion in 200 m butterfly (ranked 5th in the World) and the national champion in 4x100 m freestyle relay. We suggested that PF_W at higher flow velocities may be used as criteria of specific swimming skill. This suggestion was confirmed by the results of correlation analysis (table 2).

Table 2. Correlation of pulling force (PF_W) at different flow velocities to competitive swimming speed (CSS), pulling force in bench test (PF_L), working capability in bench test (WC_L) and test-retest correlation for repeated PF_W measurements in the same subjects (two month interval between tests).

Related	Flow Velocities ($m \cdot s^{-1}$) in the flume								
parameters	**0.0**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.5**	**1.6**	**1.7**
PFw : CSS	0.662	0.754	0.744	0.735	0.613	0.815	0.816	0.811	0.840
PFw : PF_L	0.605	0.649	0.582	0.558	0.614	0.576	0.521	0.543	0.453
PFw : WC_L	0.586	0.604	0.620	0.508	0.637	0.676	0.640	0.583	0.647
Test-retest	0.888	0.876	0.864	0.884	0.861	0.877	0.860	0.817	0.784

$p < 0.05$ r = 0.468; $p < 0.01$ r = 0.590

We found a statistically significant correlation between PF_W over the full range of studied flow velocities and CSS in 100 m freestyle (Table 2). All relations were established within a significance limit of $p<0.01$. Hence an increase in the CSS is strongly associated with an increase in PF_W. We also found that PF_W values at higher flow velocities (V=1.4-1.7 $m \cdot s^{-1}$) are more closely related to the CSS ($0.815 < r < 0.840$) than values of PF_W at V=0 and flow velocities V=1.0-1.2 ($0.613 < r < 0.754$). Thus the swimmers' PF_W values at flow velocities in swimming flume 1.4-1.7 $m \cdot s^{-1}$ appear to be the best criteria for assessment of specific strength and skills in swimmers and prediction of competitive performance. This becomes more evident during comparison of correlation between PF_L and CSS (r=0.484) and WC_L and CSS (r=0.453). The magnitude of these correlation coefficients are of a low significance level ($p < 0.05$) and much weaker than the correlation of PF_W and CSS. It should be noted that every investigator who had experience in using the swimming flume for testing purposes found it a time and money consuming process. An affordable solution may be a reduction of testing velocities for each swimmer. For example, when dealing with testing situations in swimming flume involving big groups of subjects (more than 8-10), we may use only 2-3 flow velocities (1.4 and 1.5 $m \cdot s^{-1}$) in order to save the time and still make a reliable assessment of the specific swimming strength. This assumption is supported by the inter-correlation of PF_W at different flow velocities.

It follows that PF_W at V=0 may be used as reliable predictor for PF_W in the flume at low flow velocities ($0.901<r<0.962$ for PF at V=0.6-1.0 $m \cdot s^{-1}$), while values of the PF_W at V=1.4 $m \cdot s^{-1}$ and higher velocities are good predictors of the specific strength - the values of PF_W at 1.7 $m \cdot s^{-1}$ ($0.916<r<0.980$).

CONCLUSION

1. The magnitude of PF_W indicates a linear pattern of declination at flow velocities 0.6-1.7 $m \cdot s^{-1}$. The individual "PF_W vs. flow velocity" curves reflect the particular specific strength of swimmers. It also changes during training accordingly to its content at different stages (periods).
2. The PF_W at V=0.6-1.7 $m \cdot s^{-1}$ better correlates to CSS in 100 m freestyle than strength abilities tested on land (PF_L or WC_L) and PF_W at V=0. This enables the use of PF_W in the flume to predict the level of swimming performance and to assess swimming abilities of individuals.
3. The correlation between PF_W and CSS in 100 m freestyle increases with the increase of water flow velocity in the swimming flume. It may be said that the values of PF_W at the higher flow velocities (1.5-1.7 $m \cdot s^{-1}$) characterise the specific strength of swimmers (ability to create effective propulsive force during swimming) while PF_W in standing water (at V=0) and at low flow velocities 0.6-1.0 $m \cdot s^{-1}$ indicates the level of swimmers' strength potential. The goal of specific strength training in swimming is to convert that potential into high values of effective pulling force.

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TECHNICAL CONTRIBUTION

DEVELOPMENT OF A MULTI-MEDIA SYSTEM FOR KINESIOLOGICAL EVALUATION OF SWIMMING BY EXPERTS IN ANY POOL

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A long term strategy is presented to develop a kinesiological evaluation system in breaststroke, useable by any expert, based on movement variables relevant for performance. Because relations were found between physical characteristics as well as velocity variation of the centre of mass, on the one hand, and body cambering and waving, on the other hand, these two undulating characteristics were chosen as style criterions. For the different style groups, and in women and men separately, a series of movement variables in various phases of the stroke cycle were also relevant for performance. Movement deviations can be specified by overlaying average stick figures of the most corresponding style group on video instants, but also by referring to the average stick figures of the gender group.

Key Words: kinesiological evaluation, multi-media, breaststroke, automation.

INTRODUCTION
The objective of this article is to develop, based on breaststroke movement variables relevant for performance in different styles, a quick, so-called kinesiological evaluation system, useable by a trained expert in any pool. The strategy followed to develop progressively this system was presented step by step in a number of Congresses of Biomechanics and Medicine in Swimming.
At the Congress in Brussels (1974), an Olympic breaststroke finalist in the Games of Munich (1972) was described, who jumped with the trunk excessively above the water surface, rotating backward by cambering and forward by launching, as can be observed in dolphins. She had a more even swimming velocity than the others, who maintained a flat body position. This could be explained by inertial effects on consecutively drag and propulsion (5). On the congress folder, another animal-like propulsion concept was visualised in butterfly: body waving below the water, as observed in eels by Gray (3).
At the Congress in Bielefeld (1986), Van Tilborgh introduced a movement analysis system (using 16mm film), measuring trunk mobility and calculating the centre of mass of the body. In 23 swimmers at national level, he found significant correlations between more even resultant impulses and more cambered body rotation as well as body waving, more precisely a deeper leg kick and more upward arm spreading (9). Body cambering and waving, allowing particular propulsion concepts, were defined as undulation. This findings influenced a rule change (1987), permitting to dive the head below the water surface and enabling to undulate more.
At the Congress in Liverpool (1990), Colman introduced a quick movement analysis system (using video digitizing on an Amiga-PC). In 35 swimmers at (inter)national level, she found significant correlations between physical characteristics and cambering and waving (1). These characteristics included to body structure, flexibility and strength. Based on her findings, combined with these of Van Tilborgh, body cambering and waving (being related to physical characteristics and to propulsion concepts), were chosen as style criterions.
At the Congress in St-Etienne (2002), Silva (7) and Soons (8) presented statistical data (using Colman's video digitizing system). In 62 swimmers at international level (N= 37 women; 25 men), using more heterogeneous styles than before the rule change, they found significant correlations between velocity variation of the centre of mass and specific undulation characteristics (related to specific propulsion concepts) and even swimming performance. Consequently, the whole population was divided in four style groups (N= about 15, genders mixed), taking as criterions only the maximum waved and cambered body positions: an undulating and flat group were formed and two intermediate groups, one typified by most waving and least cambering and another vice versa. In each style group, and in women and men separately, a series of movement variables in various phases of the stroke cycle were statistically relevant for performance.

METHODS
To evaluate swimming technique, the expert needs video recording from side view (below and above the water), synchronised with a front view. This allows to select nine instants in the stroke cycle on the side view, delimiting phases in the leg kick and arm pull. In addition, he needs a physical profile chart (not discussed in this article) (2).
In figure 1 a and b, first, an overview is given in average stick figures of the nine selected instants for the two genders separately (A, F) and for the four style groups (B, C, D, E). On these stick figures, performance relevant angles, amplitudes… are specified by arrows; the direction shows the variation in technique corresponding to better performance.
In figure 1a and b, next, per style group the nine video instants for one individual are shown. Movement deviations can be specified by overlaying the nine average stick figures of the most corresponding style group on these nine video instants; but, also by referring to the nine average stick figures of the gender group.

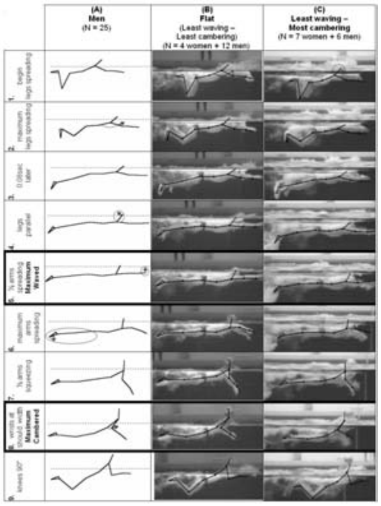

Figure 1a. Overview in average stick figures of nine selected instants for the men, the flat and the least waving-most cambering styles. Performance relevant angles, amplitudes,… are specified by an arrow; the direction shows the variation in technique corresponding to better performance. Movement deviations of an individual can be specified when overlaying the stick figures of the most corresponding style group and of the men on the video instants.

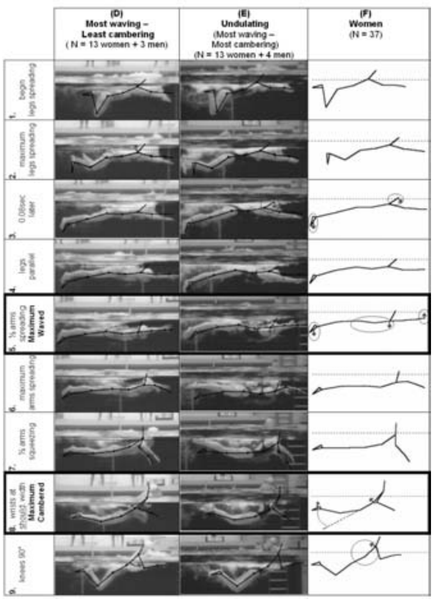

Figure 1b. Overview in average stick figures of nine selected instants for the most waving-least cambering style, the undulating style and the women. Performance relevant angles, amplitudes,… are specified by an arrow; the direction shows the variation in technique corresponding to better performance. Movement deviations of an individual can be specified when overlaying the stick figures of the most corresponding style group and of the women on the video instants.

Figure 2 shows how, beforehand, the most corresponding style group for each individual is chosen: after digitising the instants of the maximum waved and cambered position. To classify the style in 50% most or 50% least waving and cambering, the two stick figures of the individual obtained are compared to the two average stick figures of the whole population. Therefore, a digitizing procedure on PC is being developed (based on Colman's method), allowing to reconstruct the body parts below and above the water surface. (Moreover, the choice of the most appropriate style is influenced by the individual physical characteristics). Immediately after the evaluation, using a multi-media presentation printed automatically, the report is ready to be given to the coach.

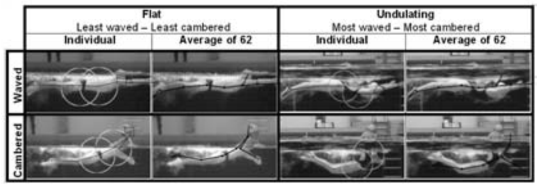

Figure 2. To classify the style in 50% most or 50% least waving and cambering, a digitizing procedure on PC is being developed, allowing to reconstruct in the maximum cambered and waved positions the body parts below and above the water surface. The two stick figures of the individual obtained are compared to the two average stick figures of the whole population (N=62).

RESULTS & DISCUSSION

First, particular relevant movement variables in the two gender and four style groups are described. The nine average stick figures of women and undulating style groups, on the one hand, and of men and flat style groups, on the other hand, are similar, as well as the relevant movement variables (fig. 1: A and B, E and F).

In the women and undulating style groups, various movement variables specifically related to undulation remain relevant for performance (fig. 1b: E and F):

- The importance of body waving is indicated by the relevancy of the depth of the kick (fig. 1b: from E3, F3 to F5), the height of the arm spreading (fig. 1b: F5) and the depth of the counteraction of the front part of the trunk (fig. 1b: from E5, F5 to E6). These findings confirm the evidence of propulsion by body waving, found by Sanders (6).
- The importance of trunk rotation and cambering is indicated by the relevancy at the end of the pull of the vertical head displacement (fig.1b: E8), the small distance between elbows and trunk (fig.1b: F8) and the hyperextension of the hip (fig.1b: F8). The importance of trunk rotation lasts still to half way the recovery (fig.1b: F9). Mc Elroy and Blanksby (4) already measured the largest trunk rotations in Olympic medallists, but they had no "readily apparent explanation".

Even in the men and flat style groups (fig. 1a: A and B), the importance of waving is indicated by the relevancy of the depth of the legs (fig. 1a: from B4 to A6), expected to smooth the peak acceleration typical for the flat style (8). Moreover, the relevancy of a less backward pull and an earlier arm recovery (fig. 1a: B7, A8 and B1, A2) are expected to smooth the typical peak deceleration in the flat style.

Also in the most waving and least cambering style group (fig. 1b: D), the importance of waving is indicated by the relevancy

of the height of the arm spreading combining with the depth of the counter-action of the front part of the trunk (fig. 1b: D5). Even in this least cambering group, the importance of cambering is indicated by the relevancy of the small distance between elbows and trunk during the first part of the recovery (fig. 1b: D8 and D9). Moreover, the upward inclination of the trunk during the beginning of legs squeezing after cambering, needed to wave, is relevant (fig. 1b: D2).
In the least waving and most cambering style group (fig. 1a: C), the importance of a straight body position is indicated by the relevancy of the depth of the head at the beginning of the kick (fig. 1a: C1) and of the flexion of the ankle halfway the kick, allowing to hit the length axis of the body (fig. 1a: C3). When the maximum waved and cambered instants of the two individual swimmers in figure 2 and their stick figures are compared with the average of the whole population at international level, it is clear that one is using a typical flat and another an undulating style.
In what follows, the four individual swimmers will be discussed.
In figure 1a, the nine images of the individual swimmer using the flat style correspond almost perfectly to the nine average stick figures. This arm recovery is slightly more forward than average (fig. 1a: B1), which is positive, while his leg recovery is more forward, which is expected to be negative. His kick could be slightly deeper (fig. 1a: from B4 to A6) and his pull slightly less backward (fig. 1a: from B7 to A8).
In figure 1b (as well as in figure 2), one can see in the individual undulating style more waving (fig. 1b: E5 and F5) and cambering (fig. 1b: E7 and E8) than the average, which is positive. The kick should be deeper (fig. 1b: from E2, F3 to F5) and appears to be very small (fig. 1b: E2), while cambering starts much too early (fig. 1b: from E6 to E7).
In figure 1a, one can see also that in the individual least waving and most cambering style, the kick could be deeper (fig. 1a: B4, A6), the arm spreading much higher (fig. 1a: from C5 to C6 and A5) and the end of the pull much less backward (fig. 1a: from C7 to C8 and A8), instead of using the old 'Jastremski' style.
In figure 1b, one can see that in the individual most waving and least cambering style, the trunk is not sufficiently upward during legs spreading (fig. 1b: D2) and the legs are not sufficiently deep (fig. 1b: from D2 to D6, F3 and F5). The maximum waved position should be more pronounced (fig. 1b: D5 and F5). Moreover, cambering should start earlier.

CONCLUSION
To evaluate swimmers, not only the application of this quick kinesiological evaluation system, based on overlaying appropriate stick figures, presented in this article is advised but expertise remains required. To introduce the expert, an interactive multi-media package was developed for distance learning, containing stroke mechanics (on propulsion concepts, balance…), investigated step by step, and case studies, including follow-ups. In a Master Degree module, e.g., the future expert can be prepared not only to specify the statistically relevant deviating movement variables from side view but also to detect movement deviations from front view. It is evident that also a subjective observation of, e.g., shape of hands and feet, rhythm aspects…, based on a checklist, remains necessary. Moreover, a user friendly digitizing system is being developed as well for research purposes.

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TECHNICAL CONTRIBUTION

PROPELLING EFFICIENCY IN SPRINT FRONT CRAWL SWIMMING

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In swimming not all of the total mechanical power (P_o) generated by the swimmer is available to overcome drag. The propulsive efficiency (e_p) is defined as the ratio of power to overcome drag (P_d) relative total mechanical power. The system to Measure Active Drag provides fixed push of pads below the water enabling propulsion generation without loss of energy to the water. Therefore, all-out sprints performed on the M.A.D.-system enabled faster swimming than all-out sprints swimming free. Assuming that P_d relates to swimming speed cubed (v^3) and assuming equal power output in two 25 m sprints (free and MAD), the ratio of v^3 sprinting all-out 'free' relative to v^3 on the M.A.D.-system reflects e_p. For 13 elite swimmers e_p of 75% (range 68 – 84%) for v = 1.64 m•s^{-1} were found. The determination of e_p based on sprints free and on the M.A.D. system, is fast and is used to evaluate changes in performance with training.

Key Words: technique, performance, M.A.D.-system, maximal power output, testing.

INTRODUCTION
It is tempting to think that swimming performance depends solely on the interaction of propulsive and resistive forces. However, this approach neglects the fact that some of the mechanical power generated by the swimmer is necessarily expended in giving water a kinetic energy change, since the propulsive thrust is made against masses of water that acquire a backward momentum (2). Hence, only a proportion of the total mechanical power the swimmer delivers is used beneficially to overcome body drag. Thus in competitive swimming two important mechanical power terms of the total power (P_o) can be discerned: power used beneficially to overcome drag (P_d) and power 'lost' in giving water a kinetic energy change (P_k). The ratio between the useful mechanical power spent to overcome drag (P_d) and the total mechanical power output (P_o) is defined as the propulsive efficiency e_p (1):

$$e_p = \frac{P_d}{P_o} = \frac{P_d}{P_d + P_k} \qquad (1)$$

For a group of highly trained swimmers an average e_p value of 63.5% (range 50 - 77%) was found at a speed (v) of 1.29 $m \bullet s^{-1}$ (8). Hence, even in highly skilled swimmers (among them several Olympic athletes) still 36.5% of P_o is lost to P_k. In well-trained, but not so technical skilled swimmers (triathletes) a value for e_p of 44% was found, which suggests the importance of technique (i.e. optimizing the e_p) as a performance determinant (7). This observation provides an explanation that proficient swimmers are much more economical in terms of energy expenditure than less skilled swimmers (6). Swimming fast will therefore depend on 1. ability to reduce drag, 2. capacity to generate high propulsive forces, while 3. keeping power losses to pushed away water (P_k) low, i.e. swimming with a high e_p. It is thus interesting to measure e_p such that effectiveness of technique can be evaluated. If improvement of maximal performance is at stake, it is important to determine e_p during sprints.
The high speed e_p measurements are possible using the System to Measure Active Drag (M.A.D. System, 4) that enables swimmers to push off from fixed points. While swimming on this system, propulsion is generated without moving water (P_k = 0) and consequently all of P_o *can be used to overcome drag*. Thus, on the M.A.D. system swimmers can swim faster.
P_o equals drag force (D) times v. D relates to v^2. Consequently, P_d will equal

$$P_d = K \bullet v^3 \qquad (2)$$

If it is assumed that during all-out sprints, P_o is maximal and thus equal in the two swimming conditions (see Kolmogorov et al. (5)), e_p can then be calculated as follows: When swimming (arms only) on the M.A.D. system, all power is used to overcome D and thus v^3 is proportional to P_o the swimmer produces, while during free swimming v^3 is proportional to P_d. Consequently:

$$e_p = \frac{P_d}{P_o} = \frac{K \bullet v_{free}^3}{K \bullet v_{M.A.D.}^3} = \frac{v_{free}^3}{v_{M.A.D.}^3} \qquad (3)$$

The purpose of this study was to examine the e_p during maximal sprint swimming of elite swimmers. At higher v, wave drag effects induce a more than quadratic increase of D. To ensure that relative simple measurements of v in the two conditions are sufficient to determine e_p, it was necessary to investigate whether use of the true D-v relationship would lead to different results. Thus, we present the justification for the simple v approach and provide an indication of potential error in estimation of e_p assuming D dependent on v^2.

METHODS
Thirteen top-level (international) competitive swimmers, 6 males and 7 females (means: height 1.82 m, mass 69.1 kg, age 20.8 years, 100 m performance 53.7 s). participated in this study after a written informed consent was obtained. Subjects performed 4 all-out 25 m front crawl sprints with push off from the wall to determine e_p; two sprints swimming arms only on the M.A.D.-system and two sprints swimming arms only in a 'free' swimming condition. During these sprints subjects always used the same pull buoy to float their legs/feet. Enough rest was allowed to prevent subjects from becoming fatigued. Before each sprint swimmers were motivated to deliver maximal performance. All subjects had performed at least 30 all-out sprints on the M.A.D.-system prior to participating in the present study. The relationship between drag and swimming speed was determined on a separate day (for method see 9). Speed/drag data are least square fitted to the function:

$$D = A \bullet v^n \qquad (4)$$

If D deviates from a quadratic relationship, P_d will be proportional to $A \bullet v^{n+1}$ and e_p calculations can be corrected:

$$e_p' = e_p \cdot \frac{v_{free}^{n-2}}{v_{M.A.D.}^{n-2}} \qquad (5)$$

To measure true swimming speed without the effect of the push off from the wall, two video cameras positioned 15 m apart with synchronised time code registration were used. The speed was computed from the time difference between the head passing the start line on the 1st camera and the finish line on the 2nd camera.
It should be noted that use of the legs (as occurs in competition) cannot be allowed for a calculation of e_p using the present test, since the power produced by the legs cannot be measured in the M.A.D. swimming condition.

Table 1: Speed ($m \bullet s^{-1}$) swimming free and on the M.A.D.-system for the two all-out sprints using arms only. e_p is calculated using equation 3 either on the basis of the average of the 2 sprint speeds in each condition or the maximum speed of the 2 sprints in each condition.

Speed swimming free			MAD swimming speed		e_p	e_p
Subject	sprint 1	sprint 2	sprint 1	sprint 2	(average)	(maximum)
C	1.578	1.578	1.746	1.756	0.733	0.727
E	1.827	1.806	2.056	2.083	0.677	0.675
T	1.671	1.662	1.871	1.883	0.700	0.700
J	1.883	1.860	2.042	2.056	0.762	0.768
R	1.708	1.698	1.871	1.860	0.761	0.760
S	1.746	1.727	1.917	1.917	0.743	0.755
L	1.502	1.474	1.653	1.653	0.729	0.750
A	1.563	1.619	1.766	1.727	0.756	0.771
P	1.717	1.756	1.894	1.917	0.757	0.768
Me	1.517	1.517	1.645	1.671	0.766	0.748
Ma	1.481	1.495	1.578	1.619	0.806	0.787
I	1.628	1.653	1.756	1.756	0.816	0.835
Mn	1.539	1.495	1.662	1.689	0.742	0.757
Mean	*1.643*	*1.642*	*1.804*	*1.814*	*0.750*	*0.754*
SD	*0.128*	*0.126*	*0.152*	*0.151*	*0.037*	*0.039*

RESULTS

An average value for e_p of 75.4% (S.D. 3.9 %) for the group of subjects was found when the maximal speed of the two sprints in both test conditions was used (Table 1). To check whether effects of motivation had an effect, e_p was calculated using the average speed of the two sprints in each condition. This resulted in e_p values of 75.0 % (S.D. 3.7%). This is not different from the value found when maximal v is used: T = 1.121, 12 degrees of freedom, $p = 0.284$). In addition, results from both calculation methods correlate well: r = 0.942.

In this group of male and female swimmers, a rather large range of v is observed during swimming 'free' arms only (1.48 – 1.88 $m \cdot s^{-1}$). The average v swimming arms only in the free-swimming condition was with 1.64 $m \cdot s^{-1}$ clearly slower (T-value 16.3, 12 degrees of freedom, $p<0.0001$) than the average v (1.81 $m \cdot s^{-1}$) swimming arms only on the M.A.D. system (see Table 1). The repeatability of v on the two sprints is quite satisfactory: r = 0.97 for the sprints swimming free and r = 0.99 for the two sprints on the M.A.D. system.

Calculation of e_p relies on the assumption that D relates to v^2 and hence P_d relates to v^3. On average D relates to $v^{2.28}$ rather than v^2 (Table 2). This leads to an overestimation of e_p when using equation 3. Using the true drag velocity relationship e_p was recalculated. The values decreased on average only slightly (from 75.0% to 73.0%, when calculated using the average v of the two sprints, and from 75.4% to 73.4% using the maximum v).

Table 2: Least squares fitted parameters describing the curves of D *dependent on* v ($D = A \cdot v^n$). A = *coefficient of proportionality,* n = *power of the speed and the corrected values for* e_p.

	Drag dependent on speed		e_p'	e_p'
Subject	*A*	n	(average *v*)	(maximum *v*)
C	17.035	2.462	0.698	0.692
E	24.034	2.246	0.655	0.654
T	28.928	2.181	0.685	0.685
J	26.025	2.018	0.760	0.767
R	16.547	2.891	0.701	0.700
S	20.627	2.237	0.725	0.739
L	21.197	2.153	0.718	0.739
A	23.230	2.148	0.746	0.762
P	23.152	2.293	0.736	0.748
Me	18.996	2.549	0.730	0.709
Ma	19.750	2.158	0.797	0.778
I	23.810	2.067	0.812	0.832
Mn	20.080	2.279	0.722	0.738
Mean	*21.801*	*2.283*	*0.730*	*0.734*
SD	*3.519*	*0.233*	*0.043*	*0.047*

DISCUSSION

e_p values of on average 73% (range 65.5 – 81.2%) were found. The e_p value of 81% observed in one of the subjects is remarkable, albeit that this subject is a world record holder and an Olympic Champion during the time of testing.

Previously an average value for e_p of 63.5% (range 50 - 77%) was reported (8). In the present study average v is with 1.64 $m \cdot s^{-1}$ 27% higher than the 1.29 $m \cdot s^{-1}$ employed when oxygen uptake measurements were used to estimate e_p. It should be noted that in fish e_p depends on v. For trout values range from $e_p = 15\%$ (swimming at 20% of maximum v) up to $e_p = 80\%$ at maximal v (12). It could be possible that also in swimming humans, e_p depends on v that would explain for the higher e_p values observed at the faster v.

The calculation of e_p using a simple quadratic drag-speed relationship (i.e. using equation 3), yielded slightly higher values than those in which the true power-speed relationship was incorporated in the analysis. The difference in mean e_p values (75.0% vs. 73.0%) was not significant. It shows that with relative simple equipment to measure v and with a series of Push Of Pads (i.e. M.A.D.-system without instrumentation), e_p can be determined. The determination of e_p based on sprints free and on the M.A.D. system is fast and can be incorporated in a test to evaluate changes in performance factors with training. In addition, e_p is determined during sprints, albeit swimming arms only, which resembles exercise intensity as occurs in competition. However, it remains to be determined whether e_p in highly trained swimmers can show much progress with technique training and thus whether routinely testing of e_p will be valuable.

The presented method to determine e_p relies on the assumption that P_o delivered in all the sprints was maximal and thus equal. If so, it is expected that v of the two sprints in each condition would be equal. The small non-significant differences (sprint 1 *vs*. sprint 2, see Table 1) support the equal power assumption. The assumption that P_o recorded during MAD-swimming (swimming arms only) represents P_o when swimming free, also using the arms only is supported by following observations:

EMG measurements during MAD and 'free' swimming revealed that intensity and muscular activation patterns are similar (3). The measured power output is calculated from D times v. Indeed a key assumption in the employed methodology is that D measured with the M.A.D.-system equals that during free swimming. Recently, the MAD-system was shown to yield similar D values to those obtained using the approach proposed by Kolmogorov and Duplisheva (1992) as detailed in Toussaint et al. (9) and confirmed in tests to estimate D using 2 different buoys (in preparation).

Finally, using the MAD-system as a water based training device, a training study revealed that a group sprinting on the MAD system 3 times a week showed a significantly greater improvement in force, velocity, and power compared to a control group despite the fact that for both groups training time and volume were equal. More importantly, the training group showed a significant better improvement in race times for 50 m, 100 m, and 200 m (11). These results suggest that the swimming-like movements on the MAD-system are specific for the 'free' swimming condition and are especially suitable for increasing maximal P_o during swimming.

The magnitude of e_p depends on the propulsion mechanism. e_p is higher if the swimmer accelerates a large mass of water per unit time to a low velocity, than if it obtains the same propulsion by accelerating a small mass to a high velocity (1). Consequently, maximal v can be achieved by a swimming technique where optimal propulsive force is obtained with an optimal e_p and a minimal body drag.

The observed values for e_p are with 75% nearly as high as the 80% found for fish swimming at high v (12). This is rather unexpected considering the relative small propulsive area (e.g. hand and fore arm). In this context, it is interesting to note that Toussaint et al. (10) demonstrated that arm rotation could play a significant role in the generation of propulsion. Arm rotation leads to a proximo-distal pressure gradient along the arm, which induces significant axial flow along the arm towards the hand, thus transporting fluid masses to the propulsive surfaces. This enables the involvement of larger masses of water in propulsion generation thereby increasing e_p.

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INVITED CONTRIBUTION

STATE OF THE ART ON SWIMMING PHYSIOLOGY AND COACHING PRACTICE: BRIDGING THE GAP BETWEEN THEORY AND PRACTICE

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The aim of the present paper was to survey the state of the art on swimming physiology as related to coaching practice in order to help bridging the gap between theory and practice. Systematic literature searches were performed through the years 1990 – 2006 utilising EBSCOhost Research Databases and SportDiscus. Ovid Medline was used to scan materials for randomized controlled trials. The searches were done in three steps using both key words and thesaurus decodes. In the first phase, "Swimming" without limitations was fed to the system and repeated with animals excluded, second, "Swimming" and "Physiology" were used and third, some subdivisions were connected to the precedents. One may conclude that the body of knowledge for the improvement of sports coaching and fitness training in Swimming is large and well represented in the subdivisions of Swimming Physiology.

Key Words: Swimming, physiology, literature review.

INTRODUCTION
The description of the art of swimming dates back to 5000 y BC by Egyptian hieroglyphs and paintings. Kahein papyrus 3000 y BC mentioned medical findings related to protection against Schistosomiasis while swimming. (1) The modern history of Swimming Physiology dates back to early 1900's where we recall pioneering work of e.g. Du Bois-Reymond (7) and Liljenstrand & Stenström (14) in cardiovascular and metabolic aspects of swimming as well as Hill (9) who explored the basic relationships between the maximal performance and maximal oxygen consumption describing also the role of lactic acid in the muscle after exercise. Holmér & Åstrand laid the basics for physiological testing of swimmers in 1970's (10). Since then the literature has accumulated rapidly. The aim of the present paper was to survey the state of the art on swimming physiology as related to coaching practice in order to help bridging the gap between theory and practice.

METHODS
Systematic literature searches were performed through the years 1990 – 2006 utilising EBSCOhost Research Databases and SportDiscus. Ovid Medline was used to scan materials for randomized controlled trials (RCT). The searches were done in three steps using both key words and thesaurus decodes. In the first phase, "Swimming" without limitations was fed to the system and repeated with animals excluded, second, "Swimming" and "Physiology" were used and third, some subdivisions were connected to the precedents. Table 1 presents the studied subcategories which were further scanned for content analysis.

Table 1. Scientific papers on Swimming Physiology as divided into subcategories. The frequencies have been obtained by key words and (thesaurus decodes).

Sub-categories	All papers	1990–2006	Advanced	Intermediate
Cardiovascular system	448	228 (180)	188 (146)	23 (22)
Metabolism	531	142	112	14
Training	395 (187)	179 (74)	88 (21)	26 (16)
Exercise	111 (28)	50 (11)	37 (3)	6 (4)
Coaching	62 (47)	37 (29)	1 (1)	8 (4)
Testing	147 (70)	62 (33)	37 (13)	8 (5)
Lactate		362	149	27
Aer / Anaer Thresh / Metab		189	140	23
Critical velocity / speed / power		19	19	
VO_2, VO_2max, Aer Cap, CO_2		189	162	21
Heart Rate		120	83 (46)	13 (12)
Respiratory / ventilatory response		58	32	4
Oxygen Consumption		92	86	5
VO_2max		57	57	0

RESULTS
When the time line was kept unlimited a total of 22.192 hits by key words (16.362 by thesaurus decode) were observed with Swimming. When animal experiments were excluded 21.882 (16.067) hits were found. During the 1990 – 2006 there were 9.778 (7092) papers in English including 2.212 (1451) in advanced and 688 (507) in intermediate category. When Swimming and Physiology (no animals) were connected 1975 hits were found, out of which 833 (557 advanced, 110 intermediate) appeared during 1990 – 2006. When the subdivisions were added to the searches the number of papers remained at reasonably low levels to enable content analysis (table 1). RCT was found in 61 papers, none with population based sampling. Materials concerning data to be utilised by practitioners in sports coaching and fitness training were well represented in all subdivisions.

DISCUSSION
The major finding of the study was that the subdivisions of swimming physiology included approaches that may be considered valid for sports coaching and fitness training. Previously Keskinen (11) reported 539 items (peer reviewed, books chapters and books) on Swimming Physiology through the years 1893 – 1990. Clarys (1) reported that by the mid 1990's there were 685 peer reviewed papers on Swimming out of which 18 % were on Swimming Physiology. When these data connect to the present one, an expansion of scientific approaches in swimming literature may be observed.
RCT has become the golden standard to obtain empirical evidence on the effectiveness of comparable treatments. In Medical and Nutritional sciences RCT has become established as the primary and in many instances, the only acceptable source of evidence for the efficacy of new treatments (16). The present data showed that in Swimming Physiology 61 papers used RCT during the years 1990 – 2006. Nearly half of the papers studied the effects of nutritional supplements, mostly creatine phosphate, on the performance. One third of the papers concentrated on making comparisons between concurrent protocols for training. The studies seemed to have adopted the commonly accepted policy in statistics that an active control group be used (3). A mere handful of papers, with competitive swimmers as the study group, concentrated on studies of

some kind of training effects or swimming conditions (e.g. wet suit) affecting the performance. All studies, however, used relatively small number of subjects so that only weak evidence on the efficacy of treatments could be obtained. It is promising that RCT has been adopted by swimming scientists as a method of choice in training studies.

There are several testing protocols available for regular testing of swimmers with lactates. Commonly most used protocol seems to be the two speed test (15) even though incremental series of e.g. 7 x 200 m have increased popularity. There are studies pointing out the differences between concurrent methods to interpret the results into practice (12).

Analyses of the thresholds to observe points of aerobic to anaerobic metabolism, has been based either on fixed blood lactate concentrations (2-4 mmol_l^{-1}) or on visual inspection. A replacement has been proposed by Cheng et al (4).

Development of portable miniaturised technology, have helped both practitioners and scientists to use lactate measurements after mid 1990's. Since then several approaches have utilised quick analyses in both diagnosing individual lactate profiles to define training zones as well as to collect data for research purposes. Basic physiological approaches seldom use portable analysers but instead prefer analysing lactates by the traditional method of reference, i.e. enzymatically from samples originally stored in percloric acid. During the latest years, however, Yellow Springs®, Accusport® and LactatePro® apparatuses have become more and more popular in the laboratories world wide and being used for lactate determination. Even though not well documented, competitive swimming teams use primarily portable technology for immediate feedback during training and competitions.

Open indirect calorimetric methods have been progressively preferred to the classical Douglas bag technique by some investigators for the measurement of expiratory gases to assess oxygen consumption and energy expenditure in athletes involved in endurance sports, mostly due to its more advantageous sampling capability and practicality. Requisite machinery to explore human aerobic energetics during field conditions have become available with the improvement of miniaturized metabolic measurement systems within an acceptable level of accuracy (Cosmed®, Metamax®, Deltatrack®, Cortex®). However, environmental factors have hindered measurements in swimming. A respiratory snorkel and valve system as described by Toussaint et al. (18) was originally developed to collect respiratory gases in Douglas bags during swimming, although the collection procedure is not easily handled in field testing conditions and require relatively long steady-state sampling if accuracy has to be guaranteed. Accordingly, this piece of equipment has been modified for BxB gas analysis to be used in connection with the K4 b^2 portable metabolic cart in swimming pool conditions, and biologically validated in the laboratory with human subjects (13). First findings of using BxB technology in swimming was reported by Rodriguez et al. (17) describing oxygen uptake on-kinetics responses to maximum 100-m and 400-m swims. The determination of VO_2 by post-exercise measurements (5) is still in active use. Attempts have been made to explore the slow component of the VO_2kinetics (6) as well as an interesting new concept of time limit has been presented (2, 8) to diagnose effects of swimming training and performance. It is the time duration a swimmer can perform at lowest speed corresponding to maximal oxygen uptake.

Since its validation (19), the Critical Speed concept has been a topic or a co-topic in some 37 studies. This concept is easily available for coaches to follow the conditioning of the athletes. However, there is no information available about the popularity of the method among practitioners. The same yields for the measurement of HR which can be easily measured by swimmers themselves either manually or by HR monitors.

CONCLUSIONS

The body of knowledge for the improvement of sports coaching and fitness training in Swimming is large and well represented in the subdivisions of Swimming Physiology.

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EFFECTS OF STROKING PARAMETERS CHANGES ON TIME TO EXHAUSTION

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The aim of this study is to assess the technical modifications under constrained swimming during time to exhaustion tests (TTE). Ten swimmers performed a maximal 400-m front crawl test (V_{400}), and 3 sets (S_1, S_2, S_3) of 4 TTE at 95, 100, 105, and 110% of V_{400}. In S_1, swimmers had to sustain the velocities for the longest time as possible and the mean stroke rate (SR) was calculated (SR_{S1}). In S_2 and S_3, velocities and SR were imposed (at SR_{S1} and SR_{S1}-5%, respectively). TTE of S_2 and S_3 were shorter than those of S_1. During S3, an increase of the glide time was observed while propulsive time remained stable compared to S_2. Swimming with a longer stroke length does not induce only a specific improvement of force production, but also the ability of the swimmers to adopt a more streamlined position to reduce drag.

Key Words: Front crawl, task contraint, technique.

INTRODUCTION
Reaching high velocities depends on the ability of swimmers to cover a long distance per stroke (SL) and to reproduce it with a high frequency (SR). Even if the experts have to find the best combinasion between their SL and SR to swim at the highest velocity (8), they have improved their SL to reach such a level (3). A high SL value is associated with a high swimming economy [4]. In fact, it reflects a high propulsive efficiency (11) and the ability of the swimmer to decrease drag (10). Based on this statement, coaches base their training program in an attempt to develop SL and improve the ability of the swimmers to maintain it. As SL is also related to force production (9), training programs include muscular reinforcement sessions to develop general strength and convert it into a specific one. This conversion can be made notably with a set in which a given velocity has to be maintained with less stroke cycles per length. An increase in SL should induce temporal and kinetics changes of the differents phases of the stroke cycle, thus modifying the propulsive and resistive impulses that govern the aquatic displacement of the swimmers (10). The literature dealing with the acute effects of SR/SL changes on technique is scarce in swimming. Indeed, how do swimmers modify the duration of the different parts of the stroke cycle while swimming with a reduced stroke rate?
Coaches impose an average SR, regularly used by the swimmer, with the aim to increase the ability to maintain SL constant despite the apparition of fatigue. This ability caracterizes a high performance level (3). No data have been yet reported on TTE at given speeds while imposing a fixed SR. This could be useful for coaches to know the maximal duration while swimming under these constraints as they used to train in this way in an intermittent set.
Hence, the aim of this study was twofold: 1) to provide data about the time during which the swimmer is able to sustain selected swimming velocities with and without imposed stroke rate; 2) to evaluate the modifications of the stroke cycle regarding the duration of the different stroke phases while decreasing SR at an imposed constant speed.

METHODS
Ten well trained swimmers (20.3 ± 1.7 years; two females and eight males) volunteered for this study. Height, body mass and arm span mean values were, 180 ± 6 cm and 170 ± 7, and 73 ± 5 kg and 62 ± 5, and 187 ± 5 and 172 ± 7 cm respectively for males and females. They have a 12 ± 2 years of mean training experience, and trained at a frequency of 6 ± 2 training sessions per week during the study. Their performances in the 400 m front crawl stroke corresponded to a mean percentage of 76.3 ± 3.6 % of the world record on the short course pool. They were informed of the procedure and gave written consent to participate.
First, swimmers performed a maximal 400-m front crawl test. The 400-m velocity (V400) is usually used by coaches as a reference to set training intensities. It has been shown to correspond to the slowest velocity that elicits VO2max during an incremental test lying within the severe intensity domain according to Dekerle et al. (6). Then subjects had to perform three sets of four TTE, each performed at 95, 100, 105 and 110% of V_{400} (TTE_{95}, TTE_{100}, TTE_{105}, TTE_{110}). During the first set (S_1), the velocity was imposed and swimmers had to maintain it for the longest possible time. For each TTE, a mean individual SR was calculated (SR_{S1}). For the second and third set of TTE (S_2 and S_3), swimmers were required to sustain the same velocities until exhaustion while maintaining constant their SR at values equal to SR_{S1} (S_2) and SR_{S1} minored by 5% (S_3). The subjects performed all the trials with at least 24 h of rest. To avoid any influence of circadian variance, they performed their trials at the same time of the day. All the TTE were performed in a randomized order to avoid a fatigue effect on the results. The subjects were encouraged during each trial to perform as well as possible in each TTE.
The tests were performed in a 25-m indoor swimming pool. During each TTE, swimmers were continuously videotaped by two cameras placed on a trolley (one above in a plunging view and one below the water surface) and pushed by a researcher. Velocities were imposed by a visual pacer with flashing lights (Baumann) which is composed of an independant computer and a row where lights are placed every 5 m from the wall of the pool. If necessary, two operators walked on each edge of

the pool at the prescribed velocity so that the swimmers could see them. Some marks were laid out according to the lamps of the visual pacer and the corresponding split times were provided by the operators. The swimmer was asked to maintain their feet at the level of the pacer/light. When the researcher's feet or the light reached the swimmer's head, the test was stopped. The duration of each TTE from the start of the trial till the point to exhaustion was measured at the nearest second. SR was imposed by a waterproof metronom placed on the swimmer's cap (Tempo Trainer, Finis ®)
The duration of TTE in each set is measured (s) and the durations TTE of S_2 and S_3 are expressed also in percentage of the duration of TTE in S_1 of the same relative intensity.
During the TTE of S_1, the period (T in s) of the cycle was measured cycle by cycle each lap with personnal PC software, hence SR was calculated with the following formulae SR=60/T where SR is in cycle.min^{-1}.
Swimming velocity (V in m.s^{-1}) was measured for each lap to ensure that the correct velocity was imposed and to determinate SL (m.cycle^{-1}) using the following equation:
SL = V/(SR/60)
The absolute durations (in s) of the different stroke phases [glide (A), traction (B), push (C) and recovery phases (D)], and the sum of propulsive (B+C) and non propulsive time (A+D) were measured. For the calculation of the Index of Coordination (IdC in percentage of the stroke cycle duration), according to the methodology of Chollet et al. [1].
Values are presented as Mean ± SD. The Normal Gaussian distribution of the data was verified by the Shapiro-Wilk's test. A paired student "*t*" test (comparison of 2 sets of data) or a one-way analysis of variance (ANOVA) were used to detect any significant difference between parameters. The threshold for significance was set at the 0.05 level of confidence.

RESULTS
Mean TTE values and the range of distances covered during each tests are summarized in Table 1.

Table 1. Mean (±SD) exhaustion times (in s) and range of distances (m) covered during each test.

		TTE_{95}	TTE_{100}	TTE_{105}	TTE_{110}
Exhaustion	S_1 (s)	670 (117)	238 (43)	122 (27)	68(14)
times	S_2 (s)	333 (54)*	177 (58)*	77 (25)*	47 (10)*
	S_3 (s)	262 (80)*	111 (46) *,Δ	60 (19)*	37 (8) *,Δ
	S_2 (% of S_1)	49 (11)	74 (19)	62 (18)	69 (8)
	S_3 (% of S_1)	40 (12)	46 (20)	49 (16)	54 (10)
Range of	S_1	1075-600	400-225	200-125	125-75
Distances (m)	S_2	500-300	275-175	125-75	100-50
	S_3	450-200	200-75	125-50	75-50

** Significant difference compared to S_1 for each speed ($p<0.05$)*
Δ Significant difference between S_2 and S_3 for each speed ($p<0.05$)

For each intensity, TTE of S_2 and S_3 were significantly shorter than TTE of S_1 ($p<0.05$). The duration of TTE_{100} and TTE_{110} of S_3 were significantly shorter than TTE_{100} and TTE_{110} of S_2 ($P<0.05$).
Mean values of V, SL, and SR at the beginning and the end for each TTE of S_1 are shown in Table 2. For each intensity, V remains constant while SL decreases significantlty and SR increases significantly (only significant for TTE_{95} and TTE_{100}).

Table 2. Mean values (±SD) of Velocity (V), Stroke Length (SL), Stroke Rate (SR), at the beginning and the end of the different Time to Exhaustion (TTE) of the first set (S_1).

	TTE_{95}		TTE_{100}		TTE_{105}		TTE_{110}	
	Start	End	Start	End	Start	End	Start	End
SL	2.49	2.23**	2.46	2.27**	2.41^{1}	2.21*	2.40^{1,2}	2.31*
(m.cycle^{-1})	(0.22)	(0.14)	(0.25)	(0.22)	(0.2)	(0.2)	(0.19)	(0.22)
SR	31.12	34.2**	33.74	36.55**	37.16^{1,2}	39.30	39.06^{1,2}	39.75
(cycle.min^{-1})	(3.73)	(2.93)	(3.54)	(2.94)	(3.53)	(2.89)	(3.29)	(4.1)

, : significant difference between the beginning and the end of the TTE at $p<0.05$ and $p<0.01$ respectively*
^{1} Significantly different from TTE_{95} ($p<0.05$)
^{2} Significantly different from TTE_{100} ($p<0.05$)
^{3} Significantly different from TTE_{105} ($p<0.05$).

Mean values of V, SL, SR, A+D, B+C, and the IdC, for each TTE of S_2 and S_3 are shown in Table 3. Mean duration values of phase A, B, C, and D are represented in the fig. 1. The SL increased significantly within each TTE of S_3. A+D always increases significantly. Except from TTE_{105} mean duration values of phase A increased significantly (0.66 ± 0.16s to 0.71 ± 0.18s, 0.59 ± 0.14s to 0.66 ± 0.14s, 0.51 ± 0.14s to 0.57 ± 0.16s for TTE_{95}, TTE_{100}, and TTE_{110} respectively). Mean duration values of phase D remained stable or increased significantly (0.38 ± 0.07s to 0.41 ± 0.05s and 0.34 ± 0.03s to 0.37 ± 0.04 for TTE_{95} and TTE_{110} respectively). Mean duration values of B+C increased significantly only for TTE_{105}. Phase C increased significantly for TTE_{105} (0.36 ± 0.03s to 0.37 ± 0.03s). Except from TTE_{105} of S_3, the mean IdC values decreased significantly for the studied intensities.

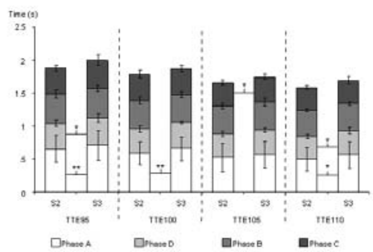

*Figure 1. Representation of the mean durations of the phases A, B, C, and D during TTE of S_2 and S_3. *,**: Significantly difference between S_2 and S_3 at $p<0.05$ and $p<0.01$ respectively.*

Table 3 : Mean Values (±SD) of velocity (V), stroke length (SL), stroke rate (SR), different stroke phases (A, B, C, and D in s), Index of Coordination (IdC).

	TTE_{95}			TTE_{100}			TTE_{110}	
	S_2	S_3	S_2	S_3	S_2	S_3	S_2	S_3
V	1.28	1.28	1.38	1.38	1.47	1.45	1.51	1.50
($m.s^{-1}$)	(0.1)	(0.1)	(0.1)	(0.11)	(0.13)	(0.1)	(0.11)	(0.12)
SL	2.44	2.54**	2.46	2.60***	2.43	2.52**	2.38	2.54*
($m.cycle^{-1}$)	(0.19)	(0.17)	(0.31)	(0.33)	(0.24)	(0.27)	(0.21)	(0.3)
SR	31.79	30.23***	33.93	32.25***	36.70	34.92***	38.23	35.8**
($cycle.min^{-1}$)	(3.44)	(2,54)	(3.12)	(3.17)	(4.37)	(3.98)	(3.3)	(3.43)
A+D (s)	1.03	1.13***	0.96	1.04**	0.89	0.94*	0.84	0.94*
	(0.16)	(0.18)	(0.13)	(0.13)	(0.18)	(0.17)	(0.14)	(0.16)
B+C (s)	0.88	0.87	0.82	0.82	0.76	0.80*	0.74	0.75
	(0.07)	(0.08)	(0.07)	(0.07)	(0.05)	(0.06)	(0.02)	(0.04)
IdC (%)	-3.82	-6.17*	-3.72	-5.76**)	-3.37	-3.82	-2.84	-4.83*
	(2.89)	(5)	(3.85)	(3.54	(4.52)	(4.1)	(4.54)	(4.2)

,,*** : significant difference between S_2 and S_3 at $p<0.05$, $p<0.01$, and $p<0.001$, respectively.*

DISCUSSION

The main findings of the present study are the technical modifications induced by swimming with a lowered SR at imposed velocities. Moreover, the present results provide an estimation of the range of the duration/length of the repetitions that could be proposed to the swimmers with an averaged of lowered SR.

Analyses of stroking parameters during tests performed at constant velocities surrounding the velocity at maximal lactate steady state (Vmlss) underlined that below it, swimmers are able to maintain their SL and SR constant over the entire duration of exercise, but above, they have to change the SL-SR combination to maintain the required velocity (6, 12). Accordingly, in the present study, in order to maintain an imposed severe speed (V400), i.e. higher than VMLSS, swimmers increase their SR and decrease their SL (see TTE of S1). Without this SL-SR manipulation, times to exhaustion are shortened as highlighted by the shorter exhaustion times in S_2 and S_3. This decrease in TTE is dependent on the intensity imposed (7) and is greater when swimmers have to swim with lower stroke rate (S_3). The latter phenomenon could be explained via the analysis of the different phases of the stroke cycle. To satisfy the conditions of the tests in S_3, swimmers had to increase their stroke lengths inducing their stroke cycle to be reorganised. It is well accepted that SL reflect the resistive and propulsive impulses, and the propulsive efficiency (10). Hence, the examination of the modifications of the temporal structure of the stroke cycle during the TTE of S_3 could provide some information about the modification of the time of application of forces. Results showed that the swimmers always increase the non propulsive parts of their stroke cycle whereas the sum of the propulsive phases remains stable, except for TTE_{105}. The swimmers increase especially the glide phase (A) and concomitantly decrease their IdC. It means that the time during which resistive forces are applied, with absence of propulsion, is increased. Hence, to avoid an increase of the resistive impulse, a more streamlined position can be suggested. Thus, results of the present study show that asking the swimmers to increase their SL while keeping a given velocity, does not necessary induce an improvement in the production of propulsive impulses.

The increase of the whole propulsive time is observed only for one intensity, whereas the duration of phase C increases in TTE_{105}. During this test, swimmers seem to put emphasis on their stroke phases to produce forces for longer periods. Nevertheless, propulsive time generally did not change, suggesting that the times during which the propulsive forces are applied remain constant. As stroke length increases, and velocity remains constant, it can be supposed that the magnitude of propulsive force increases too. This could be accomplished with a modification of the orientation of the propulsive surfaces and/or higher muscular forces. Each one could induce an unusual muscular sollicitation that can not be sustained during a long time, and could explain the shorter TTE of S_3 compared to those of S_1 and S_2.

The decreases in TTE of S_3 are lower with the increase in the velocity. This was not expected. Indeed, the highest the velocity, the fewest the number of SL-SR combination the swimmer is able to employ (5). Physiological phenomenum, according to the energy supply system, could play a role to explain these results (2). Finally, the mean durations of TTE of S_2 seem to follow the same logic, except from TTE_{100}.

CONCLUSION

This study shows that constraining swimmers to increase their stroke lengths at given velocities is not only associated with an improvement of propulsion. In fact, the duration of the glide phase mainly increase. Hence, this kind of technical work has to be carefully used in training. The ability of the swimmers to adopt a more streamlined position to reduce drag during the glide phase has to be taken into consideration.

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DIFFERENCE BETWEEN GENERAL AND SPECIFIC SWIMMING ABILITIES OF JUNIOR TOP WATER POLO PLAYERS BASED ON THEIR POSITION WITHIN THE TEAM

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Tactical, technical and functional demands of each position during game are a very significant factor for planning the training. The basic aim of this paper was to define the differences in basic and specific swimming characteristics of junior water polo players based on their position within the team. The sample of 31 players was divided into three groups: 1. players in wing positions (N = 19); 2. centers (N = 6); 3. backs (N = 6). 12 variables were the result of the following swimming tests: crawl 25m, 50m and 1500m, 25m crawl with ball, 25m back, specific swimming using legs 25m, legs crawl, breast and mixing and swimming 10x50m crawl. Cluster analysis has singled out five variables in which the observed groups differed. After the Student T-test, we obtained the difference between the groups. The players in wing positions are weaker then the others and that is not suitable for game.

Key Words: water polo, training, position within the team.

INTRODUCTION
Organisation of the training process is determined by various factors. A tactical, technical and functional demand of each position during game is a very significant factor for planning the training. Players, according to their morphological characteristics specialize for certain position, as the different position with their specific demands during the game influence the morphological aspect of a player (3). Differences with the players in different positions within the team can be greater (wing-back, wing-center), but they can be morphologically very similar (back-center) (3). Although this research followed the junior players, differentiation already exists since at the age of 18 they are in the final phase of specialization (1).
Tactical – technical demands of the game, which means a great number of swimming sections (4, 6, 7), especially in wing positions and great number of duels particularly in center and back position (2, 6, 7) caused the greatest differences exactly between these positions. The basic aim of this paper was to define the differences in basic and specific swimming characteristics of junior water polo players based on their position within the team.

METHODS
Sample and measuring methods
The sample of 31 players was divided into three groups: 1. players in wing positions left and right (N = 19) (Bm-179.99±4.07kg and Bw-75.72±5.54cm), group 2. are players who play in center positions (N = 6) (Bm-185.55±4.01kg and Bw-92.67±9.49cm) and group 3 are players ho play in back positions (N = 6) (Bm-181.70±6.50kg and Bw-76.20±3.25cm).

The following swimming tests were performed:
— crawl 25m, 50m and 1500m ($25m_{crawl,}$ $50m_{crawl}$, $1500m_{crawl}$)
— 25m crawl with ball ($25m_{crawlB}$)
— 25m back ($25m_{back}$)
— Specific swimming using legs 25m, crawl stroke kicking, breast kick and egg beater kicking ($25m_{crawlkic}$, $25m_{legbre}$, $25m_{egg}$)
— 10x50m crawl ($10x50m_{crawl}$) – 1 minute order
All tests were performed in the 50m swimming pool, the players started from water at the signal of the timekeeper, and tracks of 25m were measured by stopping the stopwatch when the head crossed the imaginary line of the finish of the distance. The obtained time was expressed in seconds with two decimals.

Variables
Each of the previously mentioned tests is of one variable, and another three index variables were singled out:
— Index of specific swimming efficiency (specific) – relation between 25m crawl and 25m crawl with ball
— Index of coordination of crawl technique ($crowl_{armleg}$) – relation between 25m crawl and 25m crawl stroke kicking
— Index of specific coordination of leg movement ($legs_{crowlegg}$) – relation between 25m crawl stroke kicking and 25m egg beater kicking
The values of the deduced variables were expressed in index numbers.

Methods of statistic elaboration
The overall set of 12 variables was subjected to Discriminant analysis and Student T-test (5). Data elaboration was done on a PC Pentium IV at 3.0 GHz applying statistic software programs STATISTICA (Stat Soft, Inc 2005) and EXCEL XP.

RESULTS AND DISCUSSION
The Table 1 gives the results of the discriminant analysis. On the general level, the differences are singled out in five variables - 25m back ($25m_{back}$), ($F=3.826$, $p=0.034$), specific swimming using legs crawl 25m ($25m_{crawlkic}$), ($F = 6.068$, $p = 0.06$), crawl 1500m ($1500m_{crawl}$), ($F = 3.737$, $p = 0.036$), 10x50m crawl ($10x50m_{crawl}$), ($F = 5.666$, $p = 0.009$) and index of specific coordination of leg movement ($legs_{crawlegg}$), ($F = 3.963$, $p = 0.031$) in which the observed groups differ.

Table 1. The results of discriminant analysis.

	Wilks Lambda	F	df1	df2	Sig
$25m_{crawl}$	0,962	0,555	2	28	0,580
$25m_{crawlB}$	0,913	1,33	2	28	0,281
$25m_{back}$	0,785	3,826	2	28	**0,034**
$25m_{crawlkic}$	0,698	6,068	2	28	**0,006**
$25m_{legbre}$	0,922	1,179	2	28	0,322
$25m_{egg}$	0,934	0,995	2	28	0,383
$50m_{crawl}$	0,942	0,866	2	28	0,432
$1500m_{crawl}$	0,789	3,737	2	28	**0,036**
$1050m_{crawl}$	0,712	5,666	2	28	**0,009**
specific	0,96	0,587	2	28	0,563
$crawl_{armleg}$	0,779	3,963	2	28	**0,031**
$legs_{crawlegg}$	0,866	2,167	2	28	0,133

After Student T-test it was realized that between groups 1 and 2 i.e. wing and center players (Tables 2 and 3) out of five singled elements in which the groups generally differed, only crawl 1500m ($1500m_{crawl}$) distinguished on the level of significance p=0.041.

Table 2. T-test for Equality of Means group 1-2.

	F	Sig	t	dt	Sig (2 tale d)	Mean Difference	Std. Error Difference
$1500m_{crawl}$	0,022	0,883	0,559	23	**0,041**	49,992	23,558
			0,576	8850	0,091	49,992	25,788

Between groups 1 and 3 i.e. wing and back players, the difference is in crawl ($25m_{crawlkic}$), (p = 0.002), crawl 1500m ($1500m_{crawl}$), (p = 0.027), swimming 10x50m crawl ($10x50m_{crawl}$) (p = 0.003) and coordination of crawl technique ($crawl_{armleg}$), (p = 0.004) (Tables 4 and 5).

Table 3. Group Statistic 1-2.

	Position	N	Mean (s)	SD (s)	St.Err. Mean
$1500m_{crawl}$	1	19	1288,597	46,792	10,734
	2	6	1238,607	67,166	23,338

Table 4. T-test for Equality of Means group 1-3.

	F	Sig	t	dt	Sig (2 tale d)	Mean Difference	Std. Error Difference
$25m_{crawlkic}$	0,245	0,625	3,453	23	**0,002**	3,165	0,916
			4,014	11171	0,002	3,165	0,788
$1500m_{crawl}$	4,759	0,04	3,267	23	**0,027**	61,560	25,998
			1,804	6,138	0,120	61,560	34,124
$1050m_{crawl}$	0,714	0,407	3,267	23	**0,003**	1,676	0,513
			2,679	6,562	0,034	1,676	0,625
$crawl_{armleg}$	0,721	0,404	-3,151	23	**0,004**	-5,00E-02	1,61E-02
			-2,771	7,067	0,027	-5,00E-02	1,83E-02

Table 5. Group Statistic 1-3.

	Position	N	Mean (s)	SD (s)	St.Err. Mean
$25m_{crawlkic}$	1	19	16,7058	0,7232	0,1659
	3	6	16,1050	0,6970	0,2845
$1500m_{crawl}$	1	19	26,0742	2,0575	0,4720
	3	6	22,9083	1,5478	0,6319
$1050m_{crawl}$	1	19	1288,5974	46,7923	0,4720
	3	6	1227,0367	79,3429	32,3916
$crawl_{armleg}$	1	19	0,5317	3,234E-02	7,420E-03
	3	6	0,5825	4,106E-02	1,676E-02

The difference was also determined between groups 2 and 1 in 25m back ($25m_{back}$), (p = 0.025) and specific swimming, legs 25m ($25m_{legcrawl}$), (p = 0.030) (Tables 6 and 7).

Table 6. T-test for Equality of Means group 2-3.

	F	Sig	t	dt	Sig (2 tale d)	Mean Difference	Std. Error Difference
$25m_{back}$	0,232	0,641	2,632	10	**0,025**	1,19	0,452
			2,632	9,586	0,026	1,19	0,452
$25m_{crawlkic}$	0,036	0,853	2,536	10	**0,030**	2,508	0,989
			2,536	9,673	0,030	2,508	0,989

Table 7. Group Statistic 2-3.

	Position	N	Mean (s)	SD (s)	St.Err. Mean
$25m_{back}$	2	6	17,2950	0,8606	0,35
	3	6	16,1050	0,6970	0,2845
$25m_{crawlkic}$	2	6	25,4167	1,8644	0,7611
	3	6	22,9083	1,5478	0,6319

CONCLUSION

Different positions in water polo have their specificities that should be responded to by the players who play in those positions. Analyzing general and specific swimming abilities of the players in different positions, we obtained the results showing the differences between the observed groups. Variables that singled out, 25m back ($25m_{back}$) (F=3.826, p=0.034), specific swimming using legs crawl 25m ($25m_{crawlkic}$), (F = 6.068, p = 0.06), crawl 1500m ($1500m_{crawl}$), (F = 3.737, p = 0.036), 10x50m crawl ($10x50m_{crawl}$), (F = 5.666, p = 0.009) and index of specific coordination of leg movement ($legs_{crawlegg}$), (F = 3.963, p = 0.031), point out the structure of activities in which the groups are different. Between the players in wing positions and those who play in center – group 2, the difference occurs in aerobic capacities i.e. crawl swimming 1500m ($1500m_{crawl}$). In the case of the tested sample, the players in center position have better aerobic capacity from the wing players table 3. which is unexpected form the tasks and demands of these positions, and is not characteristic for the teams on high training level (6,7). The difference between backs, group 3 and centers, group 2 reflects in the difference in specific speed 25m back ($25m_{back}$) and specific swimming using crawl stroke kicking 25m ($25m_{crawlkic}$) where the back position players are more dominant. Dominance of back players is expected with regard to their role in the game where they are expected to react and move fast especially in the phase of defence. Between group 1, players who play in wings and group 3 players who play in back position, the differences are in greater number of variables: in swimming legs crawl ($25m_{crawlkic}$), crawl 1500m

($1500m_{crawl}$), crawl 10x50m ($10x50m_{crawl}$), and coordination of crawl technique ($crawl_{armleg}$). In all parameters, the players in back position are more dominant except in coordination of crawl technique ($crawl_{armleg}$). Such results show that general and specific swimming preparation does not suit to game necessities, i.e. that players in wing positions do not have adequate readiness according to the needs they should satisfy. With regard to the swimming sections and tactical tasks that players in wing positions have and related to the canters, and particularly related to backs, the level of their swimming readiness is insufficient (6).
The obtained results indicate that definitely there are differences in swimming features of the players in different positions. These differences are expected, but in relation to the tested sample are not regularly displaced according to the characteristics, and therefore coaches can, based on the obtained results, correct and direct further training work of each individual towards improvement of both general and specific swimming abilities in conformity with the demand of the position in which he plays.

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STRUCTURE OF GENERAL AND SPECIFIC SWIMMING ABILITIES IN JUNIOR TOP WATER POLO PLAYERS

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Motor and tactical technical demands in playing water polo are increasing. The task of this research was to establish the most important factors which define the structures of general and specific swimming preparation of junior water polo players, Slovenian national team. 31 water polo players were tested: crawl 15, 25, 50 1500m, 25m crawl with head up 25m crawl with ball, 25m back, specific swimming by using legs 25m, crawl stroke kicking, breast kick and egg biter kicking and 10x50m crawl, and 15 variables were derived. Four factors were set describing 78.068% of joined variability. The results indicate the existence of four various areas of preparation of swimmers. The first factor indicates that the general and specific speed of swimming, the second factor recognizes coordination swimming abilities of players; the third indicates specific leg movement, while in the fourth one swimming efficiency singles out.

Key Words: water polo, training, swimming tests.

INTRODUCTION

Motor and tactical technical demands in playing water polo are increasing (2), therefore the training demands from the early age are getting more complex in order to prepare the player to achieve top results through a quality training process. Control of the level of swimming preparation (3) from the aspect of evaluation of absolute and relative potential of energy mechanisms by swimming, as well as the level of swimming abilities of players with regard to the intensity zones are of great importance for training work. By defining methodological procedures, easily applicable in the training process in the framework of observation of the training system of players would enable easy evaluation and verification of the applied training methods (5), aimed at development of swimming preparation with regard to the sports conditions. The task of this research was to establish the most important factors which define the structures of general and specific swimming preparation of junior water polo players, members of Slovenian national team so that the method itself and the way of evaluation are easily applicable in the course of training by the coaches themselves.

METHODS

Sample and measuring methods

In order to determine the level of preparation of players, members of the national team, generation 1987 and younger, swimming abilities were tested. In the season 2004/05 31 players were tested.

The following tests were done:
◦ crawl 15, 25, 50 and 1500m ($15m_{crawl}$, $25m_{crawl,}$ $50m_{crawl}$, $1500m_{crawl}$)
◦ 25m crawl with head up ($25m_{crawlH}$)
◦ 25m crawl with ball ($25m_{crawlB}$)
◦ 25m back ($25m_{back}$)
◦ Specific swimming by using legs 25m, crawl stroke kicking, breast kick and egg biter kicking ($25m_{crawlkic,}$ $25m_{legbre}$, $25m_{egg}$)
◦ 10x50m crawl ($10x50m_{crawl}$) –1 minute. order.

Variables

Each of the above tests is one variable and another four variables were deduced:
◦ stroke index (SI) – (4)
◦ index of specific swimming efficiency (specific) – relation between swimming 25m crawl and 25m crawl with ball
◦ index of coordination of crawl technique ($crawl_{armleg}$) – relation between swimming 25m crawl and 25m crawl stroke kicking
◦ index of specific coordination of leg movement ($legs_{crawlegg}$) – relation between 25m crawl stroke kicking and 25m egg biter kicking

Methods of statistic elaboration
According to this, we got the overall of 15 variables and subjected them all to basic descriptive statistics where the following parameters were calculated: MEAN, SD, cV%, MIN and MAX, while the structure was defined by applying explorative factor analysis (5). Data elaboration was done on a PC Pentium IV at 3.0 GHz applying the statistic software program STATISTICA (Stat Soft, Inc 2005) and EXCEL XP.

RESULTS AND DISCUSSION

The results of the index of variation (cV%) show that they range among 3.55% for variable 25m crawl with head up ($25m_{crawlH}$) up to 10.54% for variable index of specific coordination of leg movement ($legs_{crawlegg}$). As the given values are in the range of less than 30%, it can be asserted that, the results are reliable and can be used for further analysis and valid interpretation.

Table 1. Descriptive Statistics.

	$25m_{crawl}$	$25m_{crawlB}$	$25m_{crawlH}$	$50m_{crawl}$	$15m_{crawl}$	$25m_{back}$	$crawl_{armleg}$	$25m_{crawlkic}$	$legs_{crawlegg}$	specific	$25m_{legbre}$	$25m_{egg}$	SI	$1500m_{crawl}$	10_50m_{crawl}
Mean(s)	13.79	14.27	14.02	29.22	7.57	16.70	0.55	25.33	0.92	0.97	24.69	27.77	1.55	1267.1	34.23
SD(s)	0.52	0.56	0.50	1.28	0.44	0.81	0.04	2.25	0.10	0.03	1.51	1.85	0.14	60.69	1.22
cV%	3.78	3.90	3.55	4.37	5.77	4.68	7.82	8.86	10.54	2.93	6.11	6.68	9.26	4.79	3.57
Min(s)	13.09	13.13	13.01	27.29	5.57	15.57	0.47	21.20	0.76	0.91	22.20	24.41	1.30	1139.70	31.20
Max(s)	15.13	15.57	15.16	31.48	8.41	18.42	0.63	30.73	1.12	1.04	27.50	32.13	1.18	1385.20	26.28

Table 2. Total Variance Explained.

Component	Initial Eigenvalues			Extractions Sums of Squared Loadings			Rotation
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	5,394	35,958	35,958	5,394	**35,958**	35,958	4,702
2	2,617	17,449	53,407	2,617	**17,449**	53,407	3,126
3	2,236	14,906	68,313	2,236	**14,906**	68,313	2,193
4	1	9,755	78,068	1,463	**9,755**	**78,068**	3,087
5	0,984	6,557	84,625				
6	0,627	4,179	88,804				
7	0,505	3,370	92,174				
8	0,4	2,664	94,838				
9	0,244	1,628	96,466				
10	0,218	1,453	97,919				
11	0,157	1,048	98,966				
12	0,128	0,853	99,819				
13	,554E-02	,170	99,989				
14	,404E-03	9,357E-03	99,998				
15	,566E-04	1,711E-03	100,000				

Factor analysis by means of using Oblimon criterion defined four factors that describe the overall of 78,068% (Table 2.) of joined variability, on the statistically significant level of reliability (KMO measure of sampling adequacy - 0.748, Bartlett's test of Sphericity – F = 2431.76, p = 0.000).
In the explained variability, the first factor saturated 35,958% (Table 2), and consisted of the following variables: $25m_{crawl}$-0,894, $25m_{crawlB}$-0,890, $25m_{crawlH}$-0,845, $50m_{crawl}$-0,770 (Table 3.). The given structure of factors indicates that the greatest difference between players is exactly in the general and specific speed. The second factor that saturated 17,449% (Table 2) consisted of the following variables: $crawl_{armleg}$-0,942, $25m_{crawlkic}$- -0,894, $legs_{crawlegg}$- -0,768 (Table 3.), and it recognize the difference in coordination swimming features of the players. The third factor saturated 14,906% (Table 2.) of the explained variance defining the following variables: $25m_{legbre}$-0,924, $25m_{egg}$-0,794 (Table 3.). The given structure clearly points that the ability describing a specific legwork is separated. The fourth factor with 9,755% (Table 2.) of the explained variances was defined by the following variables: SI-0,876, $1500m_{crawl}$- -0,769, $1050m_{crawl}$- -0,711 (Table 3.). Based on the selected structure, the given factor can be defined as efficiency of swimming by using crawl technique in aerobic and anaerobic strain regime.

Table 3. Structure Matrix.

	Component			
	1	2	3	4
$25m_{crawl}$	**0,894**			-0,476
$25m_{crawlB}$	**0,890**	-0,424		
$25m_{crawlH}$	**0,845**			
$50m_{crawl}$	**0,770**			-0,503
$15m_{crawl}$	0,690		-0,476	-0,399
$25m_{back}$	0,633		0,339	-0,413
$crawl_{armleg}$		**0,924**		
$25m_{crawlkic}$	0,432	**-0,894**		
$legs_{crawlegg}$	0,369	**-0,768**	-0,483	
specific		0,563		-0,491
$25m_{legbre}$			**0,924**	
$25m_{egg}$			**0,794**	
SI				**0,876**
$1500m_{crawl}$	0,396			**-0,769**
$1050m_{crawl}$	0,643	-0,407		**-0,711**

CONCLUSION

The obtained results indicate that it is possible to estimate the level of swimming preparation of players in the observed sample with regard to the structure of general and specific swimming abilities (1). It was also determined that there were great differences with regard to influence of separated factors in function of measuring area i.e. used set of tests. The first factor indicates that speed of swimming, achieved both by general and specific water polo techniques, ($25m_{crawl}$-0,894, $25m_{crawlB}$-0,890, $25m_{crawlH}$-0,845, $50m_{crawl}$-0,770) (Table 3) is the ability that defines qualitative swimming preparation of water polo players i.e. the ability that determines most the difference of swimming preparation between players in the given age category and competition level. Such results point the way to continue the training process, i.e. that it is through training process that these features of players should be developed, in order to increase the level of competition preparation of the whole team by raising the individual swimming abilities. The second factor, which recognizes coordination of swimming abilities of players ($crawl_{armleg}$ -0,942, $25m_{crawlkic}$- -0,894, $legs_{crawlegg}$- -0,768) (Table 3) indicates that not all the players are on the satisfactory coordination lever, offering thus also some space for progress of individuals and therefore of the whole team. Great dynamics of position changes during the game, realization of various techniques of movement with or without a ball, requests that the players must be well trained (educated) with trained coordination, in order to successfully play water polo. The third factor indicates specific leg movement ($25m_{legbre}$-0,924,

$25m_{egg}$-0,794) (Table 3), which is very significant in water polo games, so the improvement of these features also improves the level of playing readiness of the players or the team is improved. The fourth separates the swimming efficiency of crawl technique in aerobic and anaerobic working loading (SI-0,876, $1500m_{crawl}$- -0,769, $1050m_{crawl}$- -0,711), (Table3). The most dominant technique in the course of water polo game is crawl, and during a game players swim between 900 and 1300 meters, a player realizes about 60 to 80 different combinations of acceleration or swimming of short distances between 5 to 20 meters (7, 8). Those players who swim crawl more efficiently i.e. have better crawl swimming technique, can more easily stand the swimming efforts during the game and trainings that are realized in both aerobic and anaerobic work strains. Besides, the difference in swimming indicates insufficient or inadequate training. Therefore, basic training work to be carried out in clubs is not everywhere on the desired level.
On the other hand, limited number of players for selection in the national team imposes the urge to intensify training in clubs, in order to decrease the obtained differences in swimming abilities (7). That would increase the general level of readiness of the members of the national team and lead, consequently, to easier overcoming of technical – tactical tasks and better results of the national team.

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FREESTYLE RACE SUCCESS IN SWIMMERS WITH INTELLECTUAL DISABILITY

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Athletes with intellectual disability (ID) competing at international level show lower levels of explosive strength and cardiovascular fitness when compared to age matched trained persons. Behavioural characteristics such as motivation, and ability to deal with stress are more difficult to examine. In the 100-m freestyle race Paralympic competitors with loco-motor disability all use similar race speed and stroking strategies. But do trained and experienced swimmers with ID also generally adapt these patterns? Video race analysis data was collected on 81 elite male swimmers including ID athletes, loco-motor disabled, visually impaired as well as able bodied. In long course races there is a typical race pattern used by all swimmers with sufficient race experience regardless of absolute performance level. Individual race tactics do not generally determine the outcome.

Key Words: swimming, freestyle, intellectual disability.

INTRODUCTION

Race speed differences among Olympic and Paralympic swimmers with intellectual disability (ID) are determined by physical aptitude, fitness (training), use of correct techniques (knowledge) and adapting optimal race patterns (experience) (3). Furthermore suitable nutrition and rest as well as an environment conducive to proper training are necessary to achieve a maximal level of performance. Potential participants must show impaired intellectual functioning and limitations in adaptive behaviour according to criteria set by the World Health Organisation and the American Association of Mental Retardation. Previous study of ID athletes participating at world championship competitions (basketball, football, swimming, table tennis, and track and field) has shown that in comparison to population data, both males and females score better for flexibility and upper body muscle endurance, but have similar or lower values for running speed, speed of limb movement, and strength measures (4). Compared to age-matched physical education students, male athletes with ID score better for running speed and flexibility, and poorer for strength. Female athletes with ID are not different from able-bodied individuals for flexibility, running speed and upper body muscle endurance, but score less well for strength measures. Athletes with ID also have poorer cardio respiratory endurance capacity compared to sportive peers without ID. Within this group of athletes, swimmers were younger, more flexible, had better cardiovascular fitness in a running test but scored lowest in explosive leg strength.
Sport specific behavioural characteristics such as motivation and ability to deal with stress (experience) are more difficult to examine than physical characteristics. These might, however, be reflected in deviating race speed or arm movement patterns. In the 100-m freestyle race almost all Paralympic competitors with a loco-motor disability use similar speed and arm stroking race patterns (1). The question at hand hence is, do trained and experienced swimmers with ID also generally adapt these patterns?

METHODS

Video competition analysis data was collected at the 2004 Global Games World championships for swimmers with ID and from 2000 Sydney Paralympic Games finalists including swimmers with ID (class S14), loco-motor disability (classes S10 + S9) and visual impairment (classes S13 + S12). Further reference data was available from finalists at the 2000 Sydney Olympic Games, the 2000 Australian Olympic trials, the 2005 European indoor championships (2) and the 2005 Scandinavian youth championships. In total data on Clean Speed (CSS), Stroke Rate (SR) and Stroke Length (SL) was available for four 100-m freestyle race sections in 81 male competitors. In addition starting, turning, and finishing speed was measured. Furthermore indexes were determined relating starting, turning, and finishing speed to swimming speed in the adjacent race section. Relative race time (percentage) was calculated for each race segment. A point score was also given to performance in relation to the group (class) world record (=1000pts). Descriptive statistics, ANOVA, and Spearman correlations were calculated. Race speed and arm movement patterns were defined by the relative change in these parameters between adjacent race sections. Groups of swimmers with similar race speed patterns could be isolated using Cluster Analysis including these speed changes.

RESULTS

Performance and race analysis results are shown for the Global Games, 2005 European indoor championships and 2005 Scandinavian youth swimmers (short course) in table 1 and for the Sydney 2000 Olympic and Paralympic Games (long course) in table 2. For lack of space not all groups used in this analysis are shown. Cluster analysis of the within race speed changes resulted in only one large race speed cluster (n=72). Eight additional clusters were formed containing 9 extra swimmers indicative of unusual race speed patterns. These were temporarily set aside. Five groups were then formed:
1) loco-motor impaired (M = 58.95s; ±2.33, n=16), 2) visually impaired (M=58.21s; ±1.24, n=16), 3) ID swimmers (M=57.73s ±1.79, n=11), 4) international able bodied (AB) swimmers (M = 48.68s ±0.92, n=21) and, 5) youth international AB swimmers (M = 52.69s = 0.99, n=8). Within race speed changes between 4 segments were -3.2% (±2.45), -4.3% (±2.41), and -4.6% (±2.53) as the race progressed. Only ID swimmers lost significantly more speed in the middle of the race than International AB participants (F=3.17, p< .019). A decreased loss of speed between segments 2 and 3 was significantly related to race success (.58).
There were no significant differences among groups in within race changes for either SR or SL. Mean changes in SR were -6.80% (±4.91), -1.91% (±5.02), and -1.76% (±4.63) and for SL 3.17% (±4.21) -2.59% (±4.24), and -2.96% (±4.74) respectively as the race progressed. Within race changes in SR were significantly related to changes in Clean speed (.36, .54 and .33). Less reduction of SR resulted in less reduction of swimming speed. No similar relationship was found for SL. Based only on Sydney results there are also no differences between groups in the percentage of time spent in any race swimming section or starting, turning, or finishing. The various results collected in short course differed slightly in starting distance so that it is not advisable to compare these types of results too closely.

DISCUSSION

Race speed, stroke rate, and stroke length patterns of swimmers with ID do not appear to be different than any other group of experiences competitive swimmers. Swimming speed decreases as the race progresses in a stable way. Stroke rate shows a strong decrease initially and then stabilises and in general SL increases at the beginning of the race and then declines. Although not significant SR decreases are greater in ID swimmers although this is not necessarily reflected in the speed changes. Apparently it seems that there are some slight differences when swimming in short course or long course pool which need further investigation
Of the 9 swimmers not fitting the large cluster, 3 were ID swimmers, 2 were youth Internationals and 3 were AB elite. While 6 of these swimmers were observed in short course races only 33% of all swimmers were analyzed in short course events. The unusual race patterns of the 3 ID swimmers not included in the main cluster as well as the more conform patterns of the 3 other ID short course finalists were verified during preliminary heat swims. No ID swimmers participating in the long course competition at the Sydney Paralympics demonstrate any specific race pattern deviation. This disproportion looks therefore to be a trait of short course races rather than a feature of ID swimmers.

Table 1. Means, Standard Deviations, and within race speed changes (%Δ) for competition analysis data in world championship participants with intellectual disability (Global Games: 2004), 2006 European Indoor swimming championships, and Scandinavian youth championships. Competitions held in short course (25-m) pool.

	Global Games (n=6)			European Indoor (n=8)			Scandinavian Youth (n=10)		
	M	*SD*	%Δ	*M*	*SD*	%Δ	*M*	*SD*	%Δ
Time (sec)	57.78	2.19		47.7	0.58		52.67	0.89	
Class point	876	97		912	34		869	45	
8th place (pt)	733			874			823		
Index(1)									
Start	128.03	8.18		119.44	5.07		118.21	7.46	
Turn1	112.37	10.13		111.98	1.52		109.11	2.03	
Turn2	110.14	5.19		110.23	2.19		109.44	3.74	
Turn3	110.83	2.50		112.68	2.20		108.89	3.12	
Finish	103.16	2.61		112.44	4.99		103.70	2.80	
CS Speed (m/s)									
Section 1	1.77	0.08		2.09	0.08		1.91	0.14	
Section 2	1.66	0.09	-6.67	1.99	0.02	-4.99	1.79	0.10	-6.45
Section 3	1.60	0.06	-4.11	1.93	0.05	-2.84	1.73	0.06	-3.52
Section 4	1.05	0.07	-6.76	1.82	0.03	-6.11	1.74	0.19	-2.53
Stroke Rate (str/min)									
Section 1	55.14	5.70		56.62	2.40		54.18	6.20	
Section 2	53.65	5.10	-2.70	53.12	3.10	-6.70	52.69	5.20	-3.20
Section 3	50.68	5.00	-5.90	52.80	2.80	-0.50	52.14	5.40	-1.90
Section 4	49.05	2.80	-3.10	51.75	2.80	-2.10	49.60	4.70	-5.70
Stroke Length (m)									
Section 1	1.95	0.22		2.23	0.17		2.15	0.33	
Section 2	1.88	0.21	-3.90	2.26	0.12	1.50	2.07	0.24	-4.44
Section 3	1.92	0.23	1.81	2.21	0.12	-2.32	2.02	0.22	-3.16
Section 4	1.84	0.17	-3.64	2.12	0.10	-4.00	2.05	0.23	1.02

(1) Index = start, turn or finish speed/adjacent segment Clean Swimming Speed.

Table 2. Means, Standard Deviations, and within race speed changes (%Δ) for competition analysis data in Sydney 2000 Olympic and Paralympic swimming finalists (n = 8) with Intellectual Disability (S14), visual impairment (S13) and loco-motor disability (S10) (Competitions in long course 50-m pool).

	Olympic			S14			S13			S10		
	M	SD	%Δ	M	SD	%Δ	M	SD	%Δ	M	SD	%Δ
Time (sec)	48.94	0.40		57.85	1.18		58.81	1.34		57.07	1.54	
Class point	934	22.6		926	55.6		896	63.5		864	72.7	
8th place (pt)	906			831			851			788		
Start (%)	12.12	0.26		12.44	0.25		12.17	0.28		12.66	0.31	
Turn (%)	14.68	0.30		14.67	0.26		14.59	0.30		14.45	0.18	
Finish (%)	5.09	0.11		5.1	0.15		5.16	0.24		5.11	0.23	
Start Index (1)	120.58	2.79		116.59	2.60		120.84	4.75		117.28	2.94	
Turn Index	107.55	3.47		108.89	2.71		107.77	2.44		109.13	0.77	
Finish Index	97.76	1.93		98.25	2.40		98.94	2.97		96.87	3.4	
Time Section 1 (%)	8.74	0.19		9.67	0.21		9.79	0.27		9.89	0.15	
Time Section 2 (%)	17.66	0.13		17.48	0.24		17.68	0.31		17.54	0.28	
Time Section 3 (%)	18.41	0.28		18.64	0.18		18.34	0.22		18.39	0.18	
Time Section 4 (%)	22.18	0.2		21.79	0.39		22.21	0.52		21.99	0.42	
Speed Section 1 (m/s)	2.10	0.03		1.79	0.05		1.77	0.07		1.77	0.04	
Speed Section 2 (m/s)	2.02	0.02	-3.65*	1.73	0.05	-3.34	1.71	0.05	-3.12	1.75	0.03	-1.36
Speed Section 3 (m/s)	1.94	0.03	-4.21*	1.62	0.03	-6.61	1.65	0.05	-3.81	1.67	0.06	-4.85
Speed Section 4 (m/s)	1.85	0.03	-5.08*	1.59	0.04	-2.3	1.56	0.05	-5.97	1.6	0.06	-4.86
SR Section 1 (str/min)	55.55	3.36		57.38	6.94		52.62	5.23		55.42	4.08	
SR Section 2 (str/min)	51.47	3.01	-6.02*	53.44	6.06	-7.35	49	4.68	-7.40	53.41	5.14	-4.03
SR Section 3 (str/min)	50.80	2.77	-1.44	51.64	4.67	-3.31	49.33	5.89	0.30	52.41	4.14	-1.83
SR Section 4 (str/min)	50.40	4.02	-0.99	50.53	3.56	-2.43	47.7	5.04	-3.40	51.58	3.46	-1.68
SL Section 1 (m)	2.31	0.11		1.89	0.20		2.02	0.17		1.93	0.15	
SL Section 2 (m)	2.36	0.14	2.35*	1.96	0.19	3.63	2.11	0.18	4.03	1.98	0.2	2.63
SL Section 3 (m)	2.29	0.13	-3.18*	1.90	0.15	-3.25	2.03	0.18	-4.26	1.92	0.19	-3.09
SL Section 4 (m)	2.21	0.17	-3.89*	1.90	0.19	0.06	1.98	0.17	-2.73	1.86	0.16	-3.12

(1) Index = start, turn or finish speed/adjacent segment Clean Swimming Speed.

It now appears that at least in long course races there is a typical race pattern used by all swimmers with sufficient race experience regardless of the absolute performance level. This is not influenced by direct external factors. Class S13 (see table 2), for example, are legally blind. Where persons without visual impairment can read normal newsprint at 1m distance, these athletes could only read this at 10cm. So the ability e.g. to "see" the opposing swimmer or the pool surroundings may not be as important as experience (movement rhythm, feeling of the water and perceived exertion) in employing a suitable race pattern. This further indicates that there is little tactical component to this particular race which may be an advantage to ID swimmers. Moreover a race is always conducted in the same manner and presently at high level competition problems such as poor lighting, cold or warm water and slow (turbulent) pools are somewhat a thing of the past. There are few "surprises" if the preparation is sufficient leading up to the race. So a large number of extraneous factors are eliminated resulting in a race speed pattern that is distinct to the race at hand and not the individual.
Another factor supporting the hypothesis of only one general race tactic in the 100-m freestyle is the fact that there are no differences between groups in the amount of time spent starting or turning. Neither ID athletes nor those with visual impairment have more trouble than other athletes in turning for example. To confirm this further work is needed to examine the women competitors as well as heat swims, however. Closer study is also required on the differences between long and short course races. For visual impaired and ID athletes addition turns might add to the problems encountered.

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CHALLENGES OF USING CRITICAL SWIMMING VELOCITY. FROM SCIENTISTS TO COACHES

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So far, a few studies have been conducted on the Critical swimming velocity concept. The current available knowledge suggests there is merit in using CV for training. The model offers potential to swimming in that it is non-invasive and easy to administer. The CV concept appears as a useful tool for setting training intensities, monitoring training effects, and predicting performances. All these applications are reviewed in the present article.

Key Words: critical velocity, usefulness, assessment, training.

INTRODUCTION
The *d-t* relationship is almost strictly linear in swimming (Figure 1; Panel A; Equation 1). It has been verified in groups of trained adults (23) and children (9, 19).
Equation 1: d = a + CV x t
Its slope has been called Critical velocity (CV) referring to previous works done on the muscular capacity (see (1, 11) for review). CV is also represented by the asymptote of the velocity-time relationship and is mathematically defined as the velocity that can be maintained (in theory) indefinitely (Figure 1; Panel B).

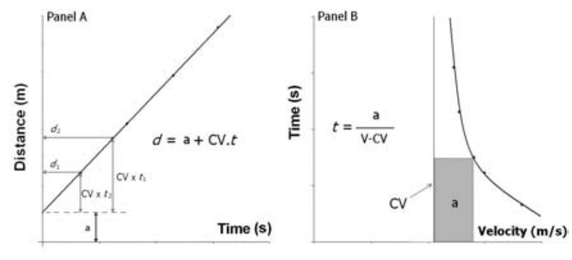

*Figure 1: Schematic of the 2-parameter model (*d-t *relationship - Panel A;* v-t *relationship – Panel B). On Panel B is represented the distance (*d1 *and* d2*) covered during to events and equal to the sum of a plus the product of CV and time (*t1 *and* t2*).*

The CV determination has been shown to be reliable even if exhaustion times are variable (13, 22) and physiological responses at CV have also been shown in swimming, to be reproducible (3). Further research is required investigating the

CV concept but current available knowledge suggests there is merit in using CV for training. The model offers potential to swimming in that it is non-invasive and easy to administer. When being aware of its underlying assumptions (see complementary article; Dekerle et al.), the CV concept seems a useful tool for setting training intensities, monitoring training effects, and predicting performances.

PHYSIOLOGICAL MEANING OF CV

CV has firstly been thought to correspond to a sustainable intensity and has been compared to parameters such as the maximal lactate steady state (MLSS; highest intensity that can be maintained without any drift in the blood lactate concentration ([La])) or the onset of blood lactate accumulation (OBLA; intensity corresponding to a 4-mmol.L^{-1} of [La]). Wakayoshi et al. (24) and Brickley et al. (3) obtained steady [La] values during several 400-m blocks performed at CV (around 3-4 mmol.L^{-1}). But the 30-45 sec of rest enabling blood samples to be taken between the blocks could have helped the swimmer keeping his motivation, limiting the drift of [La] and maintaining a 'relatively' good efficiency. Stroking parameters have indeed been shown to change, with progressive stroke rate increases and stroke length decreases within and between the 400-m blocks (3).

Most authors today agree that CV does not correspond to a sustainable intensity. In fact, swimmers can hardly maintain their CV for longer than 35 min (unpublished data from our laboratories) and CV has been shown to be close to the velocity of a 30-min test (8) and higher than MLSS (7) and OBLA (9, 20, 24, 25). These results are in agreement with results obtained in cycling reporting drifts of heart rate, [La], and VO_2 with values closed to their maximal at Critical Power/Velocity (4).

CV is today defined as the upper limit of the heavy intensity domain, i.e. the highest intensity that does not allow VO_2max to be attained during a constant load exercise (12). Above CV, because of the slow component phenomena, VO_2max should be elicited. This definition of has not yet been directly verified in swimming but is in line with several findings reported in the literature in swimming. CV is lower than the end velocity of an incremental test, traditionally identified as the maximal aerobic velocity (around 92-96% of the 400-m velocity). It is highly correlated to OBLA (23, 24, 25), the average 400-m velocity (23, 24, 25), and MLSS (7). The first belief that CV was sustainable for a very long period of time was a misinterpretation of the mathematical (and not physiological) definition of CV, i.e. the intensity that can be maintained indefinitely (asymptote of the velocity-time relationship).

SETTING TRAINING INTENSITIES

CV allows demarcating two different intensity domains and should be used as a reference to set training intensities. The 400-m pace is usually used by coaches for this purpose. However, two swimmers with similar performances on 400 m can have different aerobic potentials (Figure 2). One can swim a 1500 m quicker than the other one (and so, for short races). The physiological stress to exercise of long duration will be different for the two swimmers. It is important to properly individualise training loads to optimise the physiological adaptations while avoiding overtraining especially when accuracy in the definition of the training loads is required as higher levels of performance.

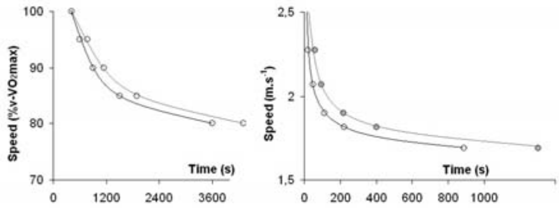

Figure 2: Schematic of the speed-time relationship of two different swimmers having different aerobic potentials.

Using CV for aerobic training programs offers great potential. It allows better setting of continuous, long and short interval training for each. Continuous training (2000-3000m) and long interval training at and below CV would induce great lactic acid production leading to accumulation of H^+ that would be buffered and La^- that would be oxidised in different body cells. An example of long interval training could be 6 to 10 x 400m swum at CV with 15-sec rest. Indeed, several 400-m blocks performed at CV can be swam with steady [La] values (around 3-4mmol.L^{-1}) when separated by 30-40s of rest (3). Among all acute adaptations, we could expect a great improvement of the buffering capacity and oxidative potential of several body cells on top of the muscular ones (10). Central and peripheral adaptations occur with training performed around CV but it can be expected that the peripheral adaptations induced by swimming at and below CV would be less predominant with the increase in the intensity, the central adaptations becoming even more important. Adequate long and short interval training above CV (20-30 x 100m at 110% CV, 30-s rest; 1min at 120% CV, 1min rest for 20 min) would enable VO_2max (very high heart rate and stroke volumes) to be solicited and maintained for a very long time. This could lead to optimise the improvement of VO_2max over time as suggested by Billat and collaborators (2). The short interval training is also of great interest as it allows swimming at high race paces while challenging the aerobic potential (200- up to 1500-m pace in this case). Training at race pace is important, especially in swimming where swimming coordination (21), energetic cost (5), and technical efficiency are changing depending on the velocity. Short interval training would enable to focus on the swimming techniques whose swimmers should attempt to maintain efficient while fatigue progressively develops during such long aerobic work performed around CV.

It has also been observed a drop of stroke length when swimming above the lactate threshold (17) or MLSS (6). Accordingly, when swimming several 400-m blocks at CV with steady [La] values, stroke parameters change, with progressive SR increases and SL decreases within and between the 400-m blocks (3). This leads to suggest that swimmers should focus on their stroke length (SL) / stroke rate (SR) ratio when swimming around CV in order to carry out a good qualitative technical work. Coaches should make an attempt to determine at which velocity and in which extend the SL and SR change. They could then train swimmers either to maintain both velocity and one of the other stroke parameters despite the increase in fatigue, or to maintain SL while increasing SR for a faster swim. As explained above, it is known that training at race pace is of importance for technical aspects of the strokes. Therefore, this training strategy relying on the multiple combinations linking the stroke parameters ("task constraint" strategy) should be performed at any velocity of the race spectrum.

MONITORING TRAINING EFFECTS AND PREDICTING PERFORMANCE

The use of the CV concept to monitor training effects and predict performance still has to be investigated. A few studies have shown the 2-parameter model to be affected by training (14, 15). Swimming aerobic training has a positive effect on CV while the change in the intercept is consistent with the training performed (16). Indeed, the value of the intercept has been shown to be more affected by low variations of exhaustion times than CV (22) and its physiological meaning has not been yet confirmed (8, 18). Therefore, we would suggest being prudent when interpreting its value and change over training. Plotting the *d-t* relationship would enable to monitor the effects of training on CV over a season (Figure 3).
When knowing the equation of the *d-t* relationship, it seems possible to predict swimming performance. Again, this should be confirmed or infirmed by further research. However, because of the good linearity of the relationship, coaches can try to predict performance as long as they are ranging between around 2 and 30 min (see complementary article; Dekerle et al.).

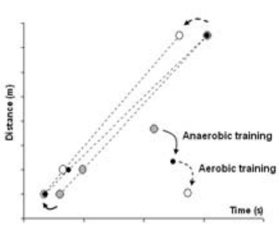

Figure 3: Effects of aerobic and anaerobic training on the d-t *relationship.*

CONCLUSION

The actual knowledge on the application of the CV concept seems sufficient to underlie its interests for training. The *d-t* relationship seems a useful tool for setting training intensities, monitoring training effects, and predicting performances. However, "luckily" for researchers, further research is required to confirm its meaningfulness in swimming (responses at and above CV) and usefulness for training (among all, effects of training at intensities around CV, effects of training on the *d-t* relationship, kicking *vs* full stroke CV, prediction of performance). Almost all the studies conducted on the Critical Swimming Velocity have been conducted on trained swimmers whose 40-m performance ranged from 72-84% of the world record. It can be wished that the concept will soon be tested on groups of elite swimmers.

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THE PROBLEM OF PEAKING IN VIEW OF EVIDENCES FROM THE ATHENS OLYMPIC GAMES

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The present study tested the assumption that several crucial factors, such as duration of the final stage preparation (FSP), gender, age, selection procedures, swimmers' ranks, swimming stroke and distance account for swimming time variance in the 2004 Athens Olympic competition. A total of 424 events performed by 301 Olympic swimmers were analyzed to obtain the relative performance gain (RPG%) that was computed as the differences between the entry swimming results and swimming time in the Olympic competition. The average RPG% gain equaled 0.58% (SD = 1.13%), indicating performance decline, embracing 68.2% of all the swimming events. Only two categories of competitors, the medal winners and swimmers ranked 4-8, surpassed their previous entry time; one-way ANOVA revealed significant (p = .04) superiority of the swimmers who were selected rigorously over swimmers selected liberally.

Key Words: peaking, olympic performance, tough and liberal selection.

INTRODUCTION

The Olympic Games, as the athletic, social and cultural mega-event of our times, provide a unique experience, which require multi-disciplinary analysis and consideration, which are important both for science and practice. Such analysis is of particular importance when aiming at achieving the best individual outcome in a specific Olympic event. Thus, peaking obtaining by the best athletic performance at a particular moment, is of primary importance for any athlete. Peaking was usually considered with regard to tapering (1, 8); the wide spread approach presupposed evaluation of peaking by means of comparison of pre-taper and post-taper results. Such type of statistical treatment led to very impressive performance improvement ranging between 1 to 6.8% (7, 8). Another estimation approach being realized in a few recent studies prescribes comparison of results obtained during selection trials and ultimate achievements on Olympic Games' performances (11, 12). The latter approach does not consider taper, as the short-term period, when the workloads are reduced, but rather the Final Stage of Preparation (FSP) as the specific period, when a selected and specially organized group (team) executes a purposeful training program directed at the targeted competition. Therefore, the quality of the peaking process can objectively be assessed by comparing the results of the beginning and the end of the FSP. Competitive swimming, as an Olympic sport with absolutely reproducible standard conditions and reliable and measurable performance evaluation provides a unique opportunity to study peaking.

METHODS

Subjects

301 Olympic swimmers (153 males and 148 females) representing 24 National teams, aged between 15-33 years, took part in a total of 424 events. Selection of the swimmers for analysis was based on the following criteria: (a) taking part in the Olympic trials and Olympic Games in the same event, or (b) obtaining an official result in competitions before entering the FSP, and taking part in the Olympic Games in the same event.

The Final Stage Preparation was operationalized as a time period between the selection Olympic trials, or another competition where an athlete obtained his/her official entry time. Therefore, the length of the FSP varied between 29 (USA) – 151 (Italy) days. The training programs of the teams varied significantly: the teams with a relatively long FSP took part in several competitions including European Championships, and other international meetings. All swimmers practiced a drastic workload reduction prior to the Olympic events – taper – lasting usually within the range of 10-25 days.

Performance results' analysis. All competitions were organized in accordance with the regulations of the International Swimming Federation (FINA) exclusively in the Olympic standard 50-m pool. The results were registered by the electronic "Omega" system, and were collected from the official protocols of Olympic Trials and the Athens Olympic Games. In both cases the best result of the corresponding swimmer was taken for analysis. The absolute and relative differences between the entry swimming results obtained during trials or another competition, and during the Olympic competition were calculated. Thus the main indicative estimate called Rate Performance Gain (RPG %) was obtained. The following factors were used as independent variables:
- *selection mode* – two modes were considered: *tough selection*, which has been used by the world-leading countries with official Olympic trials, and *liberal selection* practiced mainly by teams with small number of world-ranked swimmers, which can meet Olympic criteria during the whole Olympic year, and even earlier;

- *FSP duration* – 29-33, 34-90, 91-130, and 130 and more days were accounted;
- *stroke types and events* - all data were analyzed with regard to four swimming strokes and individual medley; twenty six individual events were analyzed, namely: 50, 100, 200, 400-m,800 and 1500-m in freestyle; 100 and 200-m in backstroke, breaststroke and butterfly; 200 and 400-m in individual medley;
- *gender and age* - gender and three age categories: young, 15-19 yrs; adults, 20-24 yrs; and veterans – 25 yrs and more;
- *personal athletic ranking* - four categories of Olympians were considered: medal winners; swimmers obtaining 4th – 8th places; swimmers ranked 9th – 16th places; and swimmers ranked 17th place and lower.

Statistical procedures
Descriptive statistics were computed for RPG% with respect to 24 National assignments, stroke-type, swimming distance, swimmer's rank, gender, and FSP duration. Analysis of variance (ANOVA) and cluster linear regression after logistic transformation procedure were employed to capture the factors determining RSPG% in the Olympic swimming competition.

RESULTS
Fig. 1 displays estimates of RPG% and duration of FSP in world-leading countries. The mean RPG% among all 24 Nations equaled 0.58% (*SD* = 1.13%); this indicates general trend of performance decline that embraces 68.2% of analyzed events. The graph shows the teams with minimal average performance decline (the least values of RPG%); and the FSP duration in these teams varies between 28 – 109 days (Poland, USA, Japan and Germany). The general trend of FSP duration indicates that the shortest FSP is beneficial; in fact this tendency didn't reach significance.

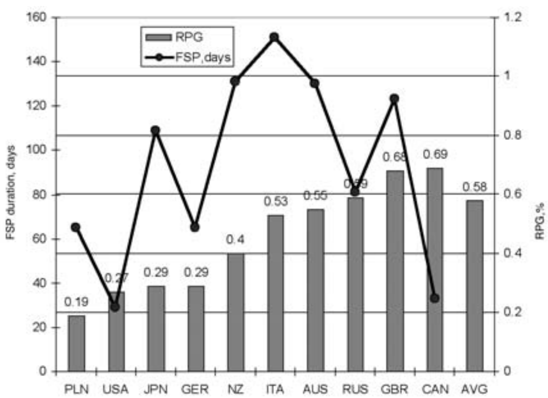

Figure 1. Rate Performance Gain and duration of Final Stage Preparation in several National teams.

The analysis revealed two statistically significant facts: one-way ANOVA considering nations with "tough selection" vs. "liberal selection", revealed significant (*p* = .04) superiority of the swimmers who were selected rigorously over swimmers selected liberally: their RPG equaled 0.46 vs. 0.84 respectively. Further more, medal winners and swimmers ranked 4-8 were the only one to obtain negative RPG, meaning enhanced performance during the Olympic competition (Figure 2).

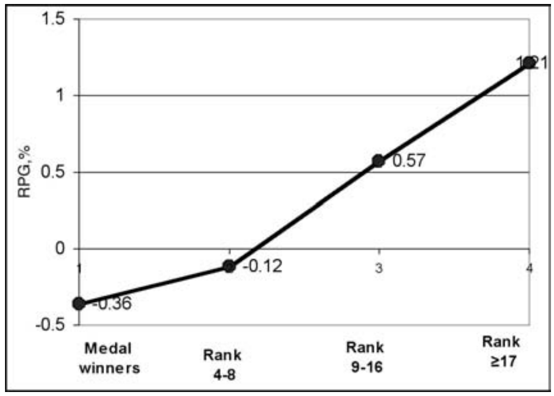

Figure 2. Relationship between RPG and athletes' rank.

No gender difference was found in RPG%: 0.66 vs. 0.50 respectively ($p \geq .05$). Comparison of three age categories didn't reveal any visible superiority of one over the other; the RPG% values of "youngsters", "middle age", and "veterans" equaled to 0.74, 0.51 and 0.59 respectively. Stroke Type failed to reach significance (Table 1). Similarly, no significant differences were found for swimming distance (Table 2).

Table 1. Mean values and SD's of RPG by Stroke Types.

	Crawl	Backstroke	Breaststroke	Butterfly	Medley
n	170	63	70	61	53
$M_{RPG\%}$	0.68	0.58	0.47	0.34	0.65
$SD_{RPG\%}$	1.20	1.21	0.96	1.00	1.14

Table 2. Mean values and SD's of RPG by distance.

	50	100	200	400	800	1500
n	34	138	159	60	15	17
$M_{RPG\%}$	0.84	0.56	0.57	0.53	0.75	0.32
$SD_{RPG\%}$	1.26	1.13	1.01	1.27	1.32	1.33

DISCUSSION
General trend. The most unexpected outcome of this study is the fact of performance decline that embraces 68.2% of analyzed events. This fact was never marked in previous Olympics, and is inconsistent with findings of Pyne et al. (11), which reported average performance improvement in USA and Australian Olympic squads over the period between selection trials and Sydney Olympics, i.e. -0.2 and -0.6% respectively. It should be noticed that four world-leading teams (USA, Australia, Japan and Germany) in Athens earned 56% of 97 swimming Olympic medals (57.7%), however no one of them achieved average results' progression for the entire swimming squad. Surprisingly these teams are coached by highly professional coaches and scientific experts, and enjoy high level conditions during the pre-Olympic preparation were the motivation and stimulation were extremely high. Hence, there were other factors affecting performance impairment in world-class competitors.

*The selection mode***,** as a factor of peaking, has never been studied and analyzed previously. This doesn't mean that this factor was not in focus of sport experts. It was suggested, for instance, that earlier and more liberal selection provide the swimmers with a better psychological comfort and prevents emotional strain associated with the Olympic trials. The other experts, mainly from the countries, which enjoy large amount of high-level swimmers, believed that official Olympic trials are the only method for fair and reasonable selection. Present analysis revealed highly significant superiority of tough selection that can be explained by two reasons: (a) the athletes who passed stressful peaking stage before the Olympics within the same season received valuable experience that helped them in the ultimate phase of preparation, and (b) swimmers undergone a stressful tough selection developed efficacy beliefs, which enables them to tolerate more efficiently the emotional strain (16).
Athletic rank was found to strongly effect peaking. The analysis reveals that only winners and finalist swimmers improved their personal entry time, while the other swimmers failed to meet their personal best (see Figure 2). This is consistent with data of Trewin et al. (14), where swimming medalists in the Sydney Olympic Games obtained higher performance gains then other Olympians. Therefore, the outstanding Olympic achievements of the medal winners and finalists were substantially predisposed by their high improvement potential over the FSP. Review of genetic factors shows that the outstanding athletes are individuals, who inherited ability to respond better to training stimuli (2). Hence, the higher improvement rate over the FSP marked in successful Olympians attributed to both more favorable heredity and professional practices.
Duration of FSP. The study's findings don't give unequivocal position regarding the FSP duration. The marked tendency "the shorter – the better" is associated with outstanding performances of USA team, which practiced FSP lasted 29 days. However the majority of this leading squad (57.7%) failed to improve their entry times in the Olympic events. In addition, Canada National team used a similar FSP length (33 days), but was less successful then other world-leading squads (Figure 1). In light of recently published theory of Block Periodization (4, 5) the FSP should consist of three sequencing mesocycles, which total duration varies between 45-55 days, and this provides the optimal superposition of residual training effects. This length is also consistent with general positions of the theory of training (3, 10, 13). Nevertheless, the mentioned theoretical postulations were not confirmed by the present findings, thus requiring more studies of FSP duration and content.
Age and gender. The sport science analysts defined the optimal zones of top-performances in several sports; they pointed that these beneficial conditions for swimmers vary within 18-24 yr for men and 17-20 for women (9, 10).The present data don't confirm these positions – no significant benefits were found in any age category. Hypothetically, taking into account that female sex hormones activate other hormones (15), some gender effect could be expected and stress reaction of female swimmers can be different from the males. In fact no gender related difference was marked. It is likely that peaking problem is not gender dependent.
Swimming strokes and distances length were analyzed in view of the marked previously differences of metabolic responses in different strokes (6) and apparent physiological specificity of sprint, medium-, and long-distance training (17). These suppositions were not confirmed by statistical analysis; the similar performance decline was marked in different strokes and distances.

CONCLUSION

The results suggest that the marked tendency of performance decline during the Olympic competition was *not* determined by any of the common observable variables, such as FSP duration prior to the competition, age, gender, swimming strokes and distance. The probable reasons are rather associated with unobservable variables such as:
(a) *Emotional strain and anxiety during the FSP and Olympic competitions*; factors such as the media, social commitments, expectations of sport administrators, anticipated bonuses, etc; all increase dramatically the incidence of emotional stress;
(b) *Hormonal and metabolic changes induced by emotional and physical stress*; the emotional stress replaces physical stress a days prior the competition and this predisposes excessive catabolic responses; furthermore, increased catecholamines' excretion can reinforce anaerobic metabolism and modifies aerobic/anaerobic interaction;
(c) *Training insufficiency during the FSP*; hormonal perturbations shift metabolic reactions into a direction of anaerobic prevalence and shortening of the aerobic and anabolic training residuals; this can follow to reduction of aerobic ability, muscle mass and power, which result in the marked tendency of performance decline.

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EVOLUTION OF BUTTERFLY TECHNIQUE WHEN RESISTED SWIMMING WITH PARACHUTE, USING DIFFERENT RESISTANCES

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The purpose of the study was to measure the effect on the stroke variables in speed (S), stroke rate (SR), stroke length (SL), and stroke index (SI) during swimming. Six tests were carried out. These tests consisted in swimming butterfly style 25 metres at maximum intensity using normal swimming (NS) and resisted swimming with parachute (RSWP) with a front span of 30cm and a back diameter of 30, 22.5, 15, 7.5 and 0cm. The study was carried out with 18 swimmers between 19 and 22 years of age. An intra-group design of repeated measures was used. The results obtained showed how the SF does not significantly vary with different diameter, but there are significant differences between NS and 0cm, 15cm and 30cm. Significant differences ($p<0.000$), are produced in SL, S, SI between NS and all other diameter. This information will allow trainers to improve the mechanics of swimming butterfly style when performing RSWP.

Key Words: speed, stroke rate, stroke length, stroke index.

INTRODUCTION
The need to improve competition times encourages trainers to use different training methods. One of the methods used is sprint-resisted training. Sprint-resisted training aims at improving the strength of a swimmer by increasing the resistance a swimmer works against. The methods most used are resisted swimming with surgical tubing, the power rack and the parachute. Resisted swimming with parachute is a training method that allows the swimmer to have more mobility in the water compared to other methods. The possibility of modifying the back diameter of the parachute allows the trainer to adjust the force of the swimming and make modifications according to the needs of the swimmer. The problem with using resisted swimming with parachute is the difficulty of the trainer to measure the stress or resistance that the swimmer applies during training. Fully tethered swimming has been used as measured to record the propulsive force of the swimmer (10, 8, 13, 7). Some authors have observed that the use of these training methods of resisted swimming modifies the cinematic parameters (5, 3, 12). The trainer needs to know the exact changes that are produced during resisted swimming with parachute to be able to modify some aspects of training that may affect the speed and the technique of the swimming. The purpose of this study is to observe how the variables of speed (S), stroke rate (SR), stroke length (SL) and stroke index (SI) are modified when normal butterfly swimming is used and when the resisted butterfly swimming is used with parachute. The study also analyzes the change that is produced in resisted swimming with parachute when back diameters are changed to 30cm, 22.5cm, 15cm, 7.5cm and 0cm. The results obtained in the study will help trainers know what modifications are produced when the resisted butterfly swimming with parachute is used with the different posterior diameters. The trainers will be able to give their swimmers instructions about aspects that they must modify when this type of training is used and which period of the season is best for each type of training.

METHODS
Subjects
The study was carried out with 18 swimmers between 19 and 22 years of age 20.31 ± 1.65 years, size of 1.79 ± 0.06cm, weight of 74.48 ± 6.53 kg and height of 1.82 ± 0.07cm. Each swimmer completed 6 tests that consisted in swimming at maximum intensity 25 metres butterfly swimming using the normal swimming and 5 using resisted butterfly swimming with parachute.

Material
The parachute had a front diameter of 30cm and posterior diameters variable between 30cm and 0cm (Innosport, Parachute model 0190). The trials were performed in a 25meter indoor swimming pool. Vertical references were installed along the swimming pool lines to help measure the distance travelled during each trial. A video camera followed the swimmer's head and body in order to record displacement and to count strokes. From the video recording the average body speed, average stroke rate, stroke length and stroke index were obtained.

Variables
Dependent variables like swimming speed (MS) during distance, covered at each trial duration, average stroke rate (SR), average stroke length (SL) and stroke index (SI) were obtained or calculated and recorded. Six levels independent variables were defined: Normal butterfly swimming and resisted butterfly swimming with parachute of 30cm, 22.5cm, 15cm, 7.5cm and 0cm in back diameters.

Statistical Analysis
Average and standard deviations were calculated for each trial condition. An intra-group design of repeated measures was used. Analysis of variance of repeated measures was performed to find average differences between the independent variables. A P value of was regarded as significant.

RESULTS
In the analysis of the results in the variable of swimming speed it is observed that there are significant differences ($p<0.001$) between the normal butterfly swimming and all the diameters

used in resisted butterfly swimming with parachute. There are also significant differences ($p<0.001$) between the different diameters used except between the diameters of 0cm and 7.5cm and between the 7.5cm and 15cm where significant differences were not observed (Table 1) (Figure 1a).
Significant differences are observed in stroke rate between normal butterfly swimming and the resisted butterfly swimming with parachute when the diameters of 0cm ($p=0.015$), 15cm ($p=0.001$) y 30cm ($p=0.022$) are used, not having observed any in the diameters of 7.5cm y 22.5cm. Between the different diameters used during the resisted butterfly swimming no significant differences were observed (Table 1) (Figure 1b).
In stroke length significant modifications are produced ($p<0.000$) between normal butterfly swimming and all the diameters used in resisted butterfly swimming with parachute. They also found significant differences ($p<0.05$) between all the diameters of the resisted butterfly swimming with parachute, except between the diameters of 0cm and 7,5cm and between 22,5cm y 30cm (Table 1) (Figure 1c).
In the stroke index significant modifications are observed ($p<0.000$) between normal butterfly swimming and all the diameters used on resisted butterfly swimming with parachute. Between the different diameters used on resisted butterfly swimming with parachute you could also observe significant variations ($p<0.05$) except between 0cm and 7.5cm where no significant differences exist (Table 1) (Figure 1d).

Table 1. The descriptive statistics of speed, stroke rate, stroke length and stroke ind

Variables		Speed ($m\ s^{-1}$)		Stroke rate (Hz)		Stroke Length (m/c)		Stroke index ($m^2\ s^{-1}$)	
	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0 cm	18	0,89	0,13	0,80	0,12	1,10	0,07	0,98	0,16
7.5 cm	18	0,90	0,16	0,81	0,14	1,11	0,10	1,01	0,22
15 cm	18	0,94	0,14	0,80	0,10	1,18	0,10	1,11	0,23
22.5 cm	18	1,03	0,15	0,81	0,13	1,28	0,12	1,33	0,25
30 cm	18	1,13	0,20	0,82	0,11	1,36	0,12	1,55	0,37
Normal	18	1,48	0,17	0,87	0,11	1,71	0,14	2,53	0,40

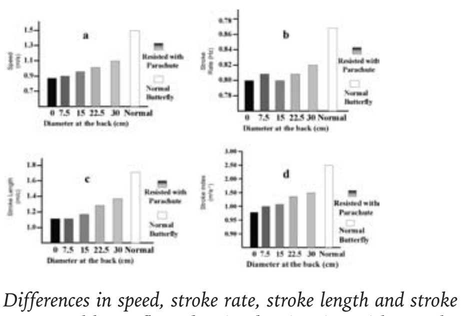

Figure 1. Differences in speed, stroke rate, stroke length and stroke index between normal butterfly and resisted swimming with parachute with a back diameter of 30, 22.5, 15, 7.5 and 0cm.

DISCUSSION
The purpose of this study was to add to the current knowledge of the effects of resisted swimming on butterfly stroke mechanics. The results indicate that there are important modifications in the variables when you compare normal butterfly swimming with resisted butterfly swimming with parachute and the different diameters used. When the resisted butterfly swimming with parachute is used, there is a decrease in the different parameters, between 39,86% and 23,64% in the speed (S), between 8,04% and 5,74% in the stroke rate (SR), between 35,30% and 20% in the stroke length (SL) and between 61,26% and 39,13% in the stroke index (SI). Resisted swimming caused a significant decrease in speed, stroke rate, stroke length, and stroke index. This suggests a negative effect on stroke mechanics; ideally swimmers are encouraged to increase stroke length while maintaining stroke rate (6). The present results are consistent with the findings of (11, 12, 3) in that resisted swimming produced a decrease in both stroke rate and stroke length with no significant change in stroke depth when compared to free swimming. As the parachute's back diameter decreases the swimmer must use higher values of contractile muscular force which and reduces his speed and decreases stroke length significantly. It may be possible to think that the changes are induced in the muscle level at a higher value than in the stroke mechanics level because more force is needed to move the hand through the water as (1, 2) concluded in their studies. There appears to be a large number of undesirable changes made to stroke mechanics during resisted swimming butterfly, which makes this form of training questionable. Trainers must consider resisted training with parachute a beneficial way to work muscle power specifically in water. They should keep in mind that the use of different parachute diameters should be progressive permitting swimmers to adapt to the mechanics of training resisted swimming. Trainers should show swimmers the adequate swimming mechanics when using resisted swimming with parachute, not permitting an important decrease in stroke length. Training with parachute should be used with large diameters when a competition is near in order to reduce its negative effects on speed.

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SWIMMING VELOCITY IMPROVED BY SPECIFIC RESISTANCE TRAINING IN AGE-GROUP SWIMMERS

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The purpose of the study was to examine the influence of a 12-week sprint-resisted training period on 10m sprint swimming time (T10) and competitive performance (P). Eighty-two (n=82) swimmers were assigned to an experimental (E, n=53) and control (C, n=29) group and followed three sprint training sessions per week, with and without resistance respectively. Resistance was applied by a bowl tethered with an elastic rope to the hip of the swimmer. Post-training T10 was improved compared to pre-training ($p<0.05$). Group E displayed significant T10 improvement compared to group C (8.5±4.1% vs. 1.2±1.6%, $p<0.05$). Percent improvement of P on distances of 50-100-200m was higher in group E compared to C ($p<0.05$). The applied form of sprint-resisted training method is recommended for development of speed and may also be effective for competitive improvement.

Key Words: sprint training, resistance, performance.

INTRODUCTION
Strength is one of several important components of swimming performance and should be developed during a training season (2). However, the strength developed out of the water fails to replicate the three-dimensional pattern of swimming movements (7) and may not be transferred on effective propulsive movements at specific velocities to improve swimming speed (8). Several specific forms of resistance training have been applied to improve swimming velocity (1, 3, 6, 9) and sprint-resisted training is suggested for swimming performance improvement (5). Resistance on swimming propulsion in the water may also be caused by having the swimmer carrying a light load tethered behind him (4). However, the effectiveness of this method has not been examined. The purpose of the study was to examine the influence of a 12-week sprint-resisted training period on maximum swimming velocity and competitive performance.

METHODS
Eighty-two (N=82) swimmers were assigned to an experimental (E, n=53, age 14.7±1.5 yrs) and control (C, n=29, age 15.0±1.5 yrs) group, balanced for sex, swimming style and competitive performance. Both groups (E and C), followed three sprint training sessions per week, with and without added resistance respectively, in addition to their daily training. Added resistance was applied by a bowl (35cm diameter, with an additional load of 170gr and 5 holes of 8mm diameter) tethered by its convex side with a rope attached to the hip of the swimmer. During a 12-week period and three times per week all swimmers performed a set of 2x50m at intensity 70% and 4x25m exerting maximum effort using their personal style and starting every 1min and 45s. The set was repeated three times during each session. Swimmers of the E group performed the repetitions of the set with the added resistance described above. Swimming time during a 10m test, performed with added (RT10) and without resistance (T10) was evaluated before and after the training period using two pairs of photocells (Lafayette instrument Model 63501IR). The photocells were adapted, 30 cm above the water surface and at a distance of 2 m between them, on tripods fixed to the bottom of the swimming pool. A snorkel worn on the head of the swimmer was used to activate the photocells. Swimmers were tested using their individual best swimming stroke. Initial swimming time on distances of 50-100-200m was considered the record achieved during the summer championship of the previous season and compared to the swimming time recorded during competition of the winter season. Analysis of variance for repeated measures and a student t-test (for % differences) were applied for the statistical analysis and the Tukey post-hoc test was used for multiple comparisons. The results presented as mean±SD and the accepted level of significance was set at $p<0.05$.

RESULTS
At the end of the 12-week training period swimmers improved the RT10 and T10 compared to pre-training (fig. 1, $p<0.05$). However, the improvement was significant only for swimmers of group E (fig. 1). In this group, after the training period, swimmers were faster for the T10 by 8.5±4.1% compared with only 1.2±1.6% improvement of the swimmers of group C (between groups, $p<0.05$). The RT10 was also improved significantly after training for group E only ($p<0.05$) and the percent improvement was greater compared to group C (E: 5.9±2.9 vs. C: 1.2±1.6%, $p<0.05$). Similar improvements were observed when the T10 and RT10 were examined for each swimming style separately (table 1).

Table 1. Swimming time for T10 in different styles.

Swimming time for each style (s)								
	Butterfly		Backstroke		Breastroke		Frontcrawl	
Group	pre	post	pre	post	pre	post	pre	post
E	7.49 (0.62)	6.90* (0.54)	7.48 (0.76)	6.89* (0.68)	8.45 (0.89)	7.80* (0.82)	6.71 (0.40)	6.18* (0.34)
C	7.32 (0.62)	7.17 (0.51)	7.68 (0.76)	7.60 (0.70)	8.91 (0.88)	8.88 (0.84)	6.83 (0.47)	6.76 (0.33)

*E: experimental group, C: control group, * p<0.05 pre vs. post-training*

Competition time for 50m was significantly improved in both groups ($p<0.05$, table 2). Group E improved by 3.6±2.2% compared to 1.9±2.4% of group C ($p<0.05$, fig 2). The competition time for 100 and 200m distances was improved in group E only ($p<0.05$, table 2) and the percent improvement was higher in group E compared to C ($p<0.05$, fig 2).

Table 2. Competition times for 50, 100, 200m before and after the training period.

Swimming time for each competitive distance (s)						
	50m		100m		200m	
Group	pre	post	pre	post	pre	post
E	33.74 (3.85)	32.55* (3.49)	73.13 (8.66)	70.83* (7.86)	159.59 (18.34)	154.5* (17.39)
C	33.63 (3.87)	32.97* (3.55)	72.91 (8.71)	71.83 (7.85)	159.19 (18.34)	157.66 (17.43)

*E: experimental group, C: control group, * p<0.05 pre vs. post-training.*

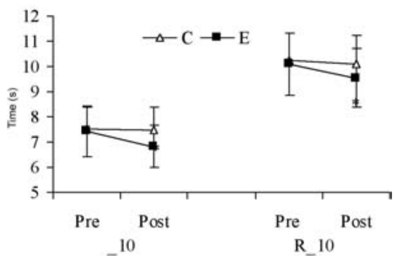

*Figure 1. Swimming times during the 10-m sprint test with (RT10) and without added resistance (T10). *p<0.05 compared to pre-training.*

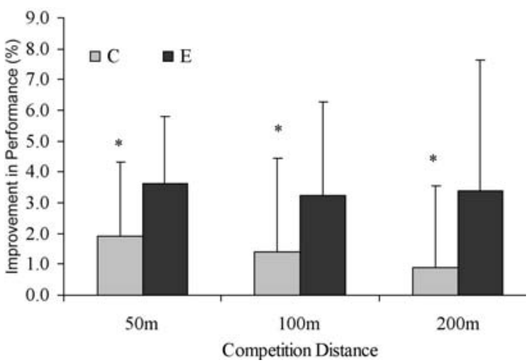

*Figure 2. Percent improvement in competition swimming time after the training period. * p<0.05 between groups.*

DISCUSSION

The application of this mode of sprint-resisted training using a bowl tethered behind the swimmer was superior compared to free swimming training for the improvement of the time to swim 10m. Additionally, this type of resistance training improved the competition time more compared to the normal swimming training.

Improvement on sprint swimming times, when a specific resistance swimming training is used, has been reported previously (1, 3, 9). The increased swimming velocity may be attributed to increased stroke length (SL), stroke frequency (SF) or both. Some gain on specific swimming strength is also a contributing factor to improvement. In the present study the technical parameters (SL and SF) and swimming forces were not measured. However, according to Toussaint and Vervoorn (9) swimming force was marginally improved but number of strokes was reduced and probably this is attributed to increased power production. In the present study the swimmers of the E group also improved the 10m time swimming with the added resistance (RT10). Since the load applied to the swimmers was exactly the same before and after the 12-week training period, but velocity to carry it was higher, it is possible that this occurred with improvement in swimming power. Competitive performance was improved more in the E compared to C group. Swimmers of the C group improved only in the 50m but not in 100 or 200m. Improvement in performance of the E group could be attributed to increased power output during swimming (2) and this probably occurred in our study if we consider the increased velocity during the RT10 test. It should be noted that swimmers followed different swimming training sessions since they trained on different swimming clubs. Therefore, training history before the 12-week period was different and may have affected the competition performance. Other factors such as taper may also have influenced performance. Furthermore, the change on performance of the E group was similar to the expected from year to year improvement in swimmers of this age-group (5). A more controlled examination is needed to establish a clear competitive performance gain with this type of resistance training.

CONCLUSION

The applied form of sprint-resisted training method had a positive outcome in developing speed on all four competitive strokes. Thus, it is recommended for development of maximum swimming speed. Further research is needed to examine the effect of this type of training on performance during competition.

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ANALYSIS AND COMPARISON OF RESULTS OF THE MADER TEST IN DIFFERENT STROKES IN AGONISTIC SWIMMERS

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Several studies were performed to analyze both the blood lactate concentration after competitions and to set the optimal intensity level during the training. The aim of this study was to evaluate the differences in lactate production between high level male and female four-strokes-swimmers and the differences in lactate concentrations among these strokes in swimmers of the same gender. Forty male and forty female swimmers performed a modified Mader test in their own discipline. The time for 200m at the threshold speed, the [La-] peak and the [La-]/time at the anaerobic threshold ratio were considered. Male athletes produced more lactate for each stroke than the female counterparts. The higher peak lactate concentration in the male athletes were found in breaststroke, whereas in females athletes the higher peak was found in butterfly.

Key Words: swimming evaluation, blood lactate, Mader test.

INTRODUCTION
In literature several studies appears on the analysis both of the blood lactate concentration after competitions and of the optimal intensity level set up, during the training. These studies can be classified into the following categories: (i) those who tried to found justifications for the use of Mader test such as an useful tool of monitoring training effects on aerobic and anaerobic systems (4, 7, 8); (ii) those who tested the modification of the Mader test in distance and trials number (5, 8, 10); (iii) the ones that analyse and compare the swimming velocity at the anaerobic threshold in athletes of different levels (10); (iv) those who analyse the improvements after specific periods of training (10); (v) the ones that compare the concentrations of lactate in athletes of different strokes and gender at the end of competitions (1, 3, 12) and, finally, (vi) those who try the comparison of different tests to set the anaerobic threshold (9). The original Mader's protocol is often used to find the speed that corresponds to the anaerobic threshold; this consists in two separate trials of 400m swimming at a constant speed: the first one at about 85% maximal speed, the second at maximal speed (2, 7). In this study, we used the modified Mader test that provides trials of 200m instead of 400m (2).
The aim of this study was to evaluate the differences in lactate concentrations between high level male and female four-strokes-swimmers, and the differences in lactate concentrations among these strokes in swimmers of the same gender.

METHODS
We studied 40 high level males swimmers (age 17.3±0.2, height cm 179.1±4.7, weight kg 74.0±1.7, BMI 22.0±1.2) and 40 high level females swimmers (age 16.0±0.2, height cm 163.8±3.3, weight kg 54.1±2.5, BMI 20.4±0.8). Athletes were divided into four male groups and four female groups of 10 subjects each.
The groups performed the modified Mader test in their own discipline (crawl, butterfly, backstroke, and breaststroke), with a rest period of 20 minutes between the first and the second trial. First trial was performed at sub-maximal speed, where the lactate concentration did not exceed over 4 mmol/l, while second trial was performed at maximal speed. The request to perform the test at a pace corresponding at a lactate concentration near or under a 4 mmol/l is due to the fact that, according to the literature (8), a fixed blood lactate concentration of 4 mmol/l overestimates the anaerobic threshold speed.
The tests were performed in a 25m indoor swimming pool using in-water starts (without diving). A fingertip sample of capillary blood was collected three minutes after the end of each trial. Blood [La-] were assessed using a "Lactate Pro" auto-analyser.
The swimming velocity corresponding to the anaerobic threshold was calculated mathematically. This velocity results from the equation y=mx+q, obtained from the data collected in the two speed test. We conducted a comparison of the *time for 200m at the threshold speed*, of the *[La-]/time at the anaerobic threshold* ratio and of the *[La-] peak* (peak lactate concentration) between groups of the same stroke and different gender. Moreover, we compared the values among groups of the same gender.
These comparisons were carried out using the Student's *t* test for $p<0.05$.

RESULTS
The values of *time for 200m at the threshold speed* showed significant differences between male and female swimmers for crawl, butterfly and breaststroke (table 1).
The values of *[La-] peak* showed significant differences on four strokes between males and females. The *[La-] peak* was within 9 – 11 mmol/l

Table 1. Gender comparison of 200m event time at threshold speed and [La-] peak per swimming stroke group, and ratio [La-] peak / 200m time at threshold speed ($mmoll^{-1}.s^{-1}$). (Mean ± SD). In bold the higher [La-] peak mean value found for each gender in each stroke.

	Time at threshold speed (s)			[La-] peak ($mmoll^{-1}$)			[La-]/time anaerobic threshold		
	Male	Female		Male	Female		Male	Female	
Free	145.72±13.97	159.12±8.02	**	11.00±1.59	9.34±1.91	*	0.0275±0.002	0.0251±0.001	**
Fly	171.93±10.19	178.70±5.85	**	11.24±1.30	**10.17±1.46**	**	0.0233±0.001	0.0223±0.007	*
Back	166.36±14.24	171.80±14.14		11.35±2.36	8.96±1.74	**	0.0241±0.002	0.0233±0.002	
Brst	180.32±7.61	198.16±9.71	***	**11.93±1.15**	9.01±1.76	**	0.0241±0.009	0.0202±0.001	***

Significant differences are shown: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$.

DISCUSSION

According to Bonifazi (1) and Chatard (3), male athletes produce more lactate for each stroke than their female counterparts. Some authors explain this phenomenon with a lower muscular mass/blood volume ratio in female subjects (11), other authors state that they produce less lactate and eliminate it faster than male subjects because of a lower glycolytic activity of musculoskeletal system, associated with a higher capacity of lactate oxidation (6). However, it is not possible to exclude that the differences found could depend on the fact that, on average, females athletes practice less than the males (1). Telford and coll. (12) did not found any difference on lactate concentration after race between male and female swimmers. For male athletes we found the higher peak lactate concentration in breaststroke, according to Chatard (3), whereas in females athletes the higher peak was found in butterfly, not in backstroke, as it was found by Chatard (3).

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A THREE-YEAR FOLLOW-UP STUDY OF AGE GROUP SWIMMERS: ANTHROPOMETRIC, FLEXIBILITY AND COUNTER-MOVEMENT JUMP FORCE RECORDINGS

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The purpose of this study was to investigate the changes brought about both by this development and by training on anthropometrics, swimming, flexibility and CMJ force recordings variables over a period of three years (2000-2003) of swimming training in a sample of age-group swimmers. The improvement obtained in swimming times seems related to a combination of anthropometrics factors plus absolute and relative force development after ending this long-term period of swimming age-group training, but the growing changes seems to produce a masking effect on the force evolution observing the relative force results. Considering that we evaluated the general jumping force, not strictly related with the swimming needs, it is difficult to recommend, to this group of age-group swimmers, the application of a rigid and progressive strength-training program.

Key Words: growth, pubertal, development, swimming training.

INTRODUCTION

Young swimmers training and performance can be affected by many factors, but it seems that the most relevant are induced by the growth, development and maturation of pre-pubertal and pubertal periods (2). With normal development, the greatest structural change in the motor skills occurs at the ages of 10 to 11 and 15 to 16. At these ages there is also a change in the athletic movements (5). Prepubertal subjects, both boys and girls, do demonstrate improvements in strength with resistance training that are quantitatively similar to those of older subjects (3). But the typical training programs developed in swimming did not include a specific work related with muscular force in theses ages. The expected changes in growth and developments are considered sufficient to accompanying the volume and technical work evolution of training program and therefore improve the performances continuously. This seems logical when the reported data from young development experts show an increase of the muscular force (hand-grip) about three times in male and two times in female from ten to eighteen years without specific training (3). But the question

remains unsolved. Is the absolute and natural strength development enough to improve the performance in all type of swimmers? The situation is more complex when other qualities as flexibility (thought important in swimming) do not improve in the same path during this maturation period furthermore it does not improve at all (2) without specific and enough training. Physical growing determines more relevance to performance than other factors when the water active drag is considered as studies applying the MAD system confirmed. The body size improvement did not increase active drag, kept constant during the pubertal development period (4).
The purpose of this study was to investigate the changes brought about both by this development and by training on anthropometrics, swimming, flexibility and CMJ force recordings variables over a period of three years (2000-2003) of swimming training in a sample of age-group swimmers.

METHODS
Subjects: Twenty-one swimmers (female=12 and male=9) participated in the study (average age at beginning =12, 19 years). They were included in a regular training program for national and state level swimmers. The ages of the subjects group are specified in the table 1.

Instrumental: Body measurement instruments were applied to measure all the anthropometric characteristics. A standard force plate was used to measure the legs impulse variables during a counter movement vertical jump (DinaScan/IBV600M). Flexibility measurements were performed using videography (see Figure 1) plus a specific software able to measure angles after digitising body landmarks (1). The swimming times were collected from competition results (first measurement, year 2000) and from training testing in the second assessment (year 2003). These changes in the testing environment could mask greater improvements.

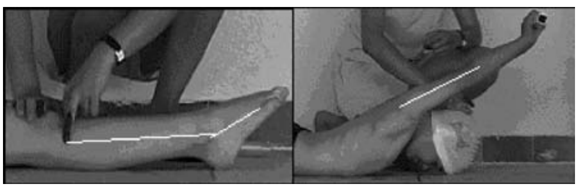

Figure 1: Measurement of ankle and shoulder flexibility using videography.

Variables. Independent variable: The different levels of training loads performed by the subjects during the three years of training and data collection combined with the physical growth.
Dependent variables: The anthropometric variables considered were height (cm), weight (kg) and arm spam (cm). The flexibility measures were ankle flexion (º) and shoulder hyper-flexion (º, related to the horizontal line). The analysis of counter movement jump (CMJ), resulted in the following data: peak vertical force (N), peak vertical force related to body-weight in N, height of the jump (m) and maximum vertical velocity (m/s). The 50m freestyle time (s) was collected using an official electronic timing system.

Statistics. SPSS 12.1 was used for statistic analyses. Descriptive data were obtained and showed as mean and standard deviation (SD). Homogeneity and normality of data were analyzed before applying the T-test to related samples. Pearson product moment correlation was calculated among variables. The interval of confidence accepted for all comparisons was less than 0.05.

RESULTS
The results are shown in table 1. Weight, height, and arm spam showed a significant increase (21%, 4% and 4%) respectively. The different found in weight related to height and arm spam denotes an evolution not expected after this period of formal training (about two hours five or six times every week). The flexibility variables denoted a decrease of motion range, specially the ankle flexion where the difference is significant. The peak vertical force increased a significant 14%, while the peak vertical force related body-weight showed a non-significant decrease. This data is in agreement with the previously reported and unexpected increase of body weight. The peak vertical force improvement obtained is related to the body weight. This is explained by the results of height of jump that were not significantly changed (with slight reduction). The take-off vertical velocity showed a similar trend. A significant improvement (4%) of average 50m time was recorded.

Table 1. Mean and standard deviation (SD) of the variables studied. The significant changes are marked with asterisks.

	2000		2003	
	Average	S.D.	Average	S.D.
Weight (kg)	50,01	9,64	60,71**	10,12
Height (cm)	160,07	8,17	166,90**	6,02
Arm Spam (cm)	163,09	9,56	170,75**	7,88
Shoulder Flex. (º)	167,90	5,22	163,68*	7,70
Ankle Flex. (º)	10,57	11,73	9,00	26,04
Max. Force (N)	1233,73	271,47	1415,78**	238,07
Relative Force (N)	2,50	0,19	2,42	0,25
Height of jump (cm)	29,67	0,64	31,33	0,78
Take-off vel. (m/s)	2,40	0,25	2,46	0,28
50 m swim freestyle	31,32	1,90	30,29**	1,98

**p<0.05; **p<0.01*

Low and very low coefficients of correlation (not significant) resulted after performing a correlation matrix between all the variables obtained at 2000 year. Similar results were obtained at 2003. Only the vertical take-off velocity showed a high and significant correlation (r=0.99, p<0.01) with height of jump. Similar results were found between all the anthropometric variables studied and among these variables and peak vertical force. The 50m times obtained a medium and significant correlation's coefficient with arm spam (r=-0,62, p<0.01), peak vertical force (r=-0.72, p<0.01) and relative force (r=-0.56, p<0.01) at the second test (after three years).

DISCUSSION
As was to be expected, the subjects after this period had increased weight, height and arm span due to the growth process. Flexibility has very specific characteristics and slowly diminishes with age, a diminution that is accelerated if it is not worked at. These data verify previous findings (2), they argued that at the beginning of the pubertal period the amplitude of movements diminishes significantly. For this reason most

authors suggested that the training of this quality should be intensified at the end of the pre-pubertal period. Our results confirm the process of the evolution of force (3). The subjects in this group obtained significant improvement in maximum force probably due to their growth and development, while the relative force and height of jump did not change. This result is caused by unfavourable improvement of the body-weight a 21%, higher then expected in a group of young sport practitioners. The improvement obtained in swimming times seems related to a combination of anthropometrics factors plus absolute and relative force development after ending this long-term period of swimming age-group training, but the growing changes seems to produce a masking effect on the force evolution observing the relative force results. Considering that we evaluated the general jumping force, not strictly related with the swimming needs, it is difficult to recommend, to this group of age-group swimmers, the application of a rigid and progressive strength-training program. It seems more logical, to recommend a simple diet control routine to avoid the excessive body-weight development observed in this group of swimmers, combined with a progressive increase of the training loads. This control will increase the value of the relative force.

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EFFECT OF TEACHING POINTS ON TURN MOTION OF BREASTSTROKE FOR BEGINNING-SWIMMERS

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The purpose of this study is to evaluate the effect of teaching points on turn motion by investigating the relationship between subjective sense and objective temporal information during breaststroke turn motions for novice swimmers. Eight non-skilled college swimmers participated in this study. They were taught the turn motion three times for 15 min. The times for T-turn (Pre, 1.71 s; Post, 1.84 s) and T-hand (Pre, 0.65 s; Post, 0.86 s) were significantly longer ($P < 0.01$) than those before teaching. Many positive comments were offered, such as “I learned to be able to turn my body with no trouble” and “ I was able to kick the wall firmly”, implying that these teaching points eased turning for beginning swimmers. Results suggest that the teaching program led swimmers to acquire good tips on turn motion and led them to turn confidently.

Key Words: breaststroke turn, teaching, turning coordination, beginning swimmers.

INTRODUCTION

Breaststroke turns require a simultaneous two-hand touch at the wall, followed by body rotation and pushing off into the next swim. For competitive swimmers, the body must change direction in the shortest possible time, and the legs must extend powerfully when pushing off the wall, thereby achieving the highest possible speed in the opposite direction. Tourny-Chollet et al. (4) showed that, for the butterfly-stroke turn, longer contact times of feet on the wall were associated with a faster push-off speed. Huellhorst et al. (2) showed similarities in the displacement curves of the centre of gravity in spite of individual differences.

On the other hand, novice swimmers must have a stable turn motion for leading into the next swim. They experienced difficulties in performing breaststroke turns in a smooth and easy motion because of its complexity. For those reasons, specific skills are required in order to produce an efficient turn motion. Few studies have been conducted on the turning motion for beginners. Guzman (1) showed a turning description and focus points, in “Swimming Drills for Every Stroke”.

Using investigation of the relationship between subjective sense and objective temporal information, this study was intended to evaluate the effects of teaching points on turn motion during novice swimmers’ breaststroke turn motion.

METHODS

Experimental design

Eight non-skilled college swimmers participated in this study. They were taught the turn motion three times for 15 min. Turn trials were conducted to analyse the turn motion before and after teaching (fig. 1). Before free practice, an example of a competitive swimmer’s demonstration was shown. Pre-test (Pre) trials were conducted after the practice. The first lecture’s point showed how to touch the wall, from the fingertips to the palm. The second lecture’s point was the direction of the eyes during body rotation. The third lecture’s point explained how to push off the wall.

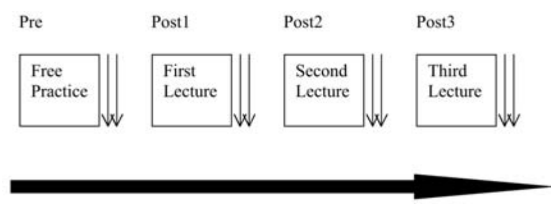

Figure 1. Experimental design.

Measurement methods

Each test was recorded using two digital video cameras for motion analysis, and another camera for measuring the overall turning time (T-turn – the time from touching with hands to pushing off with the feet) and the hand contact times (T-hand – the time from touching with hands to releasing).

Teaching points

The breaststroke turn was separated into three phases: (i) the approach, (ii) turning the body, and (iii) push-off. The turning phase is divisible into three sub-phases: (i) the hand contact phase, (ii) the rotation phase, and (iii) the foot contact phase. Respective contents and focus points of teaching were: (i) how

to touch at the wall from fingertips to palm, (ii) direction of the eyes during body turning, and (iii) how to push off the wall.
First, a training menu for "how to touch" was followed: the hand falls toward the wall; the hands support the body, then the body pushes off. Second, the menu for rotation was to stop turning during touching with the feet. The third was pushing off to the side.

Questionnaire survey
Questionnaires on subjective sensations of the turn motion were completed after the test. These teaching points were evaluated by swimmers for their effectiveness from three points (rapidly, correctly and easily) using a five stage standard (see the caption of fig. 2). In addition, the swimmers freely described changes in the turning motion.

RESULTS
Turning time changes
Table 1 shows the turning times before and after instruction. The T-hand times (Post1, 0.83 s; Post2, 0.95 s; Post3, 0.86 s) were significantly longer ($p < 0.01$) than those before teaching. The T-turn times (Post1, 1.68) were not longer after the first lecture, in spite of longer hand contact. The T-turn times (Post2, 1.86 s; Post3, 1.84 s) were significantly longer ($p < 0.01$) than those before instruction. It seemed that other times, aside from those of T-hand (Pre, 1.06 s; Post1, 0.85; Post2, 0.91; Post3, 0.98 s), were shorter before teaching. Results showed that the ratio of T-hand/T-turn times changed greatly.

Table1. Turning Time before and after teaching

	Pre	Post1	Post2	Post3
T-hand(sec)	0.65	0.83 **	0.95 **	0.86 **
T-turn(sec)	1.71	1.68	1.86 **	1.84 **
T-hand/T-turn	37.9%	49.1%	51.4%	46.8%

** $p<0.01$

Questionnaire survey results
Figure 2 shows responses to the question of whether the lecture was effective. All subjects felt that the present teaching was effective in improving their turn motion in spite of a short teaching program. Particularly, it was effective to turn easily. Point2 tended to be higher than either point1 or point3.
Many positive and a few negative comments were received. After the first lecture, exemplary comments were "I learned to have no trouble turning my body" and "I was not able to kick the wall firmly because my body left the wall." After the second lecture, positive comments such as "my body did not leave the wall and it is now possible to strongly push off of it" and "I was able to push off straight and kick the wall firmly" were most common. After the third lecture, some negative comments were received, such as "I was not able to push off straight" and "Because I kept thinking about what I was doing, I became confused."

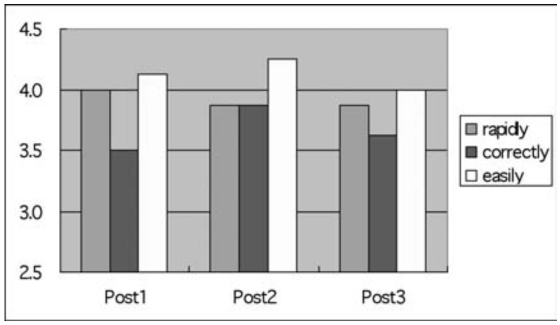

Figure 2. Questionnaire results (Was it effective?). 5: Very; 4: Probably; 3: I can't really say either way; 2: Probably not; 1: Definitely not.

DISCUSSION
After the first lecture, the hand contact time (T-hand) lengthened significantly. The associated major comments were: "I learned to be able to have no trouble turning my body." The subsequent rotation movement was inferred to become smooth because the swimmer came to get support from the wall by hand contact. On the other hand, comments such as "I was not able to kick the wall firmly because my body left the wall" also existed, suggesting that it was difficult for beginners to push moderately.
Very positive comments were received after the second lecture. The T-hand and T-turn times lengthened significantly. Especially, the instruction was effective to ease swimmers' turning. Point 2 tended to be higher than either point1 or point3. Apparently, it was very important to maintain the head position at the beginning of the rotation phase. The second lecture was very effective for stable turning of beginning swimmers. On the other hand, some negative comments were received after the third lecture. It is apparently extremely difficult for novice swimmers to push off on their side.
Results show that the ratio of T-hand/T-turn times changed greatly before and after instruction. In a study of competitive swimmers (3), the ratio of T-hand/T-turn was about 45%. Although the turning time is much longer than that of competitive swimmers, the ratio after instruction closely approximates that of competitive swimmers (46.8%). Results suggest that a moderate balance exists for breaststroke turning and that such balance is necessary for swimmers. I decided to name that balance "turning coordination".

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TRAINING INDUCED CHANGES IN CRITICAL VELOCITY AND V4 IN AGE GROUP SWIMMERS

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The aim of this study is to determine the relationships between different methods of assessing aerobic capacity and the changes induced by a heavy aerobic training period in age group swimmers. It was found that critical velocity in front crawl, determined using 50, 200 and 400 meters distances, is similar to velocity correspondent to lactate concentration of 4 $mmol.l^{-1}$. Critical velocity determined using just 200 and 400 meters distances, however, was significantly different form the former but similar to the mean velocity of the 2000m test. All variables increased significantly after a 9 weeks aerobic training phase, simultaneously with best performance at 400m front crawl. The results of this study confirm that critical velocity is sensitive to performance changes induced by aerobic training in young swimmers.

Key Words: critical velocity, training, age group swimmers.

INTRODUCTION

The effectiveness of the demanding training processes to which swimmers are frequently exposed must be periodically verified. Several parameters have been used in the last decades for this effect, most of them using the determination of lactate concentrations in protocol progressive testing situations. The invasive nature of these procedures raised the need for alternatives, especially in what regards age group swimmers.

The slope of the regression of total work performed against the corresponding time to exhaustion, the critical power was thought to correspond to the intensity above which no oxygen uptake steady state is possible (11). The velocity asymptote of the hyperbolic relationship between velocity and time to exhaustion, or by conversion the slope of the linear relationship between distance and time to exhaustion, usually termed critical velocity (Vcri), has the same physiological meaning than critical power. In theory, the maximal lactate steady state (MLSS), which is the highest work rate that can be maintained over time without continual blood lactate accumulation (2), is the same as the concept of critical velocity.

In swimmers, Vcri has been shown to be highly correlated with the oxygen uptake at the anaerobic threshold, the swimming velocity at a fixed blood lactate concentration of 4 $mmol.l^{-1}$ (V4), the MLSS and race velocities of 200- and 400-m front crawl (13, 15, 16) suggesting that it could be adopted as an index of endurance performance, contrarily to what has been found regarding the interpretation of y-intercept as a marker of anaerobic work capacity, within the 2-parameter model (14). However, several studies indicated that Vcri overestimates MLSS velocity (3, 10), contesting its validity for training prescription. Studies with young swimmers have not produced consensual results as well, revealing Vcri to be lower (5, 6, 13) or similar (7, 13) to V4, depending on the duration and the number of trials used for its calculation.

However, mean velocity in long duration constant intensity swim exercises, as the 30 min duration exercise or in distances of 2000 or 3000 m, providing another indirect estimation of MLSS velocity (12), has been found to match Vcri very closely (4, 6, 8).

Furthermore, the sensitivity of critical velocity to training adaptations in the course of the competitive season has not yet been verified for age group swimmers.

The aims of this study were 1) to verify the relationships established between non-invasive methods of monitoring training, critical velocity and mean velocity obtained in a 2000 meters trial in font crawl and V4 and 2) to assess the training induced changes in these parameters in age group swimmers.

METHODS

Twenty nine national level age group swimmers, 18 males and 11 female (age = 12.9 ± 1.15 years, weight = 54 kg ± 10.7, height = 165.7 cm ± 9.4) participated in this study, after giving written consent.

Each subject was tested in the beginning of the general preparation period (1st stage) and after nines weeks of a predominantly aerobic training phase, incorporating a volume of 20–40 km/week (2nd stage). Testing procedures took place in a 25 m indoor swimming pool and at the same time of the day to minimize circadian influences. In the first day, the subjects were asked to swim 2 trials at maximal velocity: 50 and 400 meters front crawl, after a warm-up of 1000 meters and with 40 minutes rest between the trials. After 24 hours, each subject executed a 2000 meters trial at maximum but constant intensity for determination of mean swim velocity (V2000). Blood was sampled after one minute and lactate concentration was determined (La2000). In the third day, subjects performed two repetitions of 200 meters freestyle, one at 85% and another at maximal speed with 40 minutes rest, for determination of V4 (12). Mean velocity obtained at the 200m maximal trial was integrated in Vcri calculations. Vcri was calculated from the slope of the regression analysis between the distances performed and the correspondent time (15). Vcri1 was estimated from 50, 200 and 400 meters trials, and Vcri2 only from 200 and 400 meters trials.

Paired-samples t-test was used to compare intra and inter–stage mean values for each variable. Pearson's linear coefficient was used to test correlations. Statistical significance was accepted at $p<0.05$.

RESULTS

The mean velocities measured in 400 e 2000 meters trials, jointly with the Vcri1, Vcri2 and V4 calculated in each testing stage are exposed in table 1. Table 2 shows the correlation coefficients among the performance variables. All the Vcri individual linear estimates had r^2 values greater than 0.99 ($p<0.01$).

Table 1. V50, V200, V400, Vcri1, Vcri2, V4, V2000 and La2000 values in the two testing stages.

	V400 ($m.s^{-1}$)	Vcri1 ($m.s^{-1}$)	Vcri2 ($m.s^{-1}$)	V4 ($m.s^{-1}$)	V2000 ($m.s^{-1}$)	La 2000 $mmol.l^{-1}$
1st stage	1.17±0.1	1.12±0.10	1.08±0.11	1.11±0.086	1.07±0.096	5.75±2.3
2nd stage	1.23±0.1	1.20±0.11	1.14±0.08	1.19±0.09	1.13±0.09	4.5±1.7

In each stage, Vcri1 was not significantly different from OBLA velocity, but was significantly higher than V2000 and Vcri2. Although all the inter-stages differences were statistically significant, the increase of the variables was not identical. In fact, V400 (4.2%±2.2), Vcri1 (4.8%±2.5), Vcri2 (5.2%±2.7) and V4 (6.6%±2.1) showed remarkably higher increases than V2000 (1.6%±1.4). Vcri1 and Vcri2 corresponded to 96.4% (1st stage) and 96.8% (2nd stage) and to 92.9% and 94.5% of V400, respectively.

Table 2. Correlation matrix for variables measured in 1^{st} stage/2^{nd} stage.

	V400	Vcri1	Vcri2	V4
Vcri1	0.996/0.998			
Vcri2	0.934/0.965	0.957/0.969		
V4	0.931/0.95	0.937/0.943	0.914/0.880	
V2000	0.891/0.917	0.900/0.921	0.891/0.856	0.903/0.880

DISCUSSION

As expected, V4, V2000, Vcri1 and Vcri2 were highly correlated. However, Vcri1 and Vcri2 were significantly different. Distance used for the determination of Vcri interfered on its value, irrespective of the evaluation stage. The inclusion of a shorter distance, the 50m, with duration ranging from 28.2 to 32.35 sec increased the estimate of Vcri by 5.5%, in average. As noted before (4), lower duration times to exhaustion produced higher slopes. The use of such short duration exercise bouts for the calculation of Vcri, in the context of the two-parameter model, is questionable. In fact, this model presupposes that, regardless of exercise intensity or duration, a fixed percentage of maximal oxygen uptake is immediately available at the onset of exercise and can be sustained throughout the exercise, assuming also that the anaerobic work capacity will be fully used during each exercise bout (11). Thus, extrapolation of the relationship to extremes of intensity or duration requires that some velocity can be sustained for an infinite time and that an infinitely high velocity can be sustained for a very short time. These are unrealistic assumptions and the model may turn out to be inadequate when time to fatigue is less than ~1 min or much greater than 30 min.

Vcri2 seems to be more suitable to determine a intensity possible to be maintained for longer periods of time than Vcri1, for its values are similar to V2000 and the distances applied (200 and 400) are in the range of exhaustion times sustained by Morton (11) and confirmed by Dekerle (3) in swimming: from 2 to 15 minutes, allowing the maximal oxygen uptake to be reached and the anaerobic resources to be depleted.

In spite of highly correlated, Vcri2 and V4 did not identify the same power output. In adult athletes, MLSS velocity elicits a blood lactate concentration average of 4 mmol.l^{-1}. For that reason, it has long been estimated by V4 (9). However, MLSS has been reported to have great variability between athletes (from 2-8 min capillary blood) and not to be related to performance (2). Moreover, lactate levels are lower in children than in adults at the same relative exercise intensities possibly due to a lower extravascular increase combined with a faster elimination of the blood lactate concentration dependent on muscle energetic metabolism (1). Therefore a value of 4 mmol.l^{-1} is too high an estimate of MLSS in children (18). Given that, it can be hypothesised that V4 overestimated MLSS in the subjects of the present study, which ranged in age between 12 and 13 years old.

Improvement in performance, illustrated by V400, was accompanied by similar increases in Vcri2 and V4 velocity and much higher then the observed in V2000, which may reflect the disadvantage of longer tests, where the motivational and volitional capacities of the swimmer are more decisive, especially in younger and less experienced.

Determination of Vcri2 constitutes a useful and accessible evaluation procedure along the season, although the corresponding velocity seems to illustrate a different physiological intensity from V4. Vcri sensibility to training induced changes in aerobic performance had not yet been verified in age group swimmers.

CONCLUSION

This study confirms the usefulness of Vcri2 as an index of aerobic performance in young swimmers, as wells as a reliable indicator of training induced changes during a competitive season. In spite of the remnant discussion about the metabolic meaning of this parameter, its easy assessment and non invasive characteristics indicates it as an adequate procedure with young swimmers.

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THE FACTORS AFFECTING VELOCITY AT OBLA IN WELL-TRAINED COMPETITIVE SWIMMERS

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This study was intended to investigate the factors affecting velocity at OBLA (V@OBLA) in well-trained male college swimmers. Continuous progressive swimming was evaluated at three times (pre-test, mid-test and post-test) to measure VO_2max and an intermittent progressive swimming for measuring V@OBLA and stroke length at various velocities. The subjects carried out endurance training for 6 weeks during those tests. The VO_2max and V@OBLA values at mid-test and post-test were significantly higher ($p < 0.05$) than those at pre-test. No significant differences in SL@OBLA were apparent among the three tests. Rates of VO_2max change correlated significantly ($p < 0.05$); the rate of SL@OBLA change was not significantly correlated with the rate of V@OBLA change. Increasing V@OBLA in this study might be caused not by stroke efficiency improvement but almost entirely by improved aerobic capacity.

Key Words: endurance training, OBLA, stroke length.

INTRODUCTION

It is generally accepted that endurance training should account for a substantial part of swim training for competitive swimming (6). The lactate curve test for measuring the velocity at blood lactate accumulation of 4 mmol/l (V@OBLA) is the most precise method for monitoring endurance-training (4). For that reason, the lactate curve test has been conducted periodically during training, and V@OBLA has been used for evaluating the effects of endurance training (7, 9).
Wakayoshi et al. (9) demonstrated that stroke length (SL) at 400 m maximal swimming effort was improved by six months of aerobic swim training. Results of previous studies showed that the possibility exists that endurance training can improve not only aerobic capacity, but also stroke efficiency at submaximal velocities. Consequently, V@OBLA measured using the lactate curve test might increase when strokes become more efficient as well as when aerobic capacity improves through endurance training. This study is intended to investigate factors affecting the change in V@OBLA by endurance training.

METHODS

Subjects

Twelve well-trained male college swimmers (19.7 ± 0.8 yrs) participated in this study. They were varsity swim team members who trained for an average of 2–3 h per session, eight times per week. They specialized in freestyle swimming: sprint n=8, middle distance n=2, and long distance n=2. They took part in national level competitions; seven subjects were finalists at competitions. Their mean height, body mass, and body fat percentage were, respectively, 1.80 ± 0.05 m, 73.9 ± 5.5 kg, and 12.4 ± 2.7%. They were informed of the risks of the study and signed a statement giving their informed consent.

Experimental schema

Figure 1 illustrates the experimental schema. The pre-test was carried out at the beginning of the swim training following the off-season, and the mid-test was conducted after the first endurance period of six weeks. The first endurance-training period was designed to fast improvement of aerobic capacity. Approximately 90% of the total training regimen was endurance-type exercise. The weekly training distance was increased gradually from 30 km to 60 km. The post-test was performed six weeks after the second endurance training period. Endurance training accounted for more than 80% of the total training volume. Weekly training distance at this period was approximately 60 km.

Experimental Design

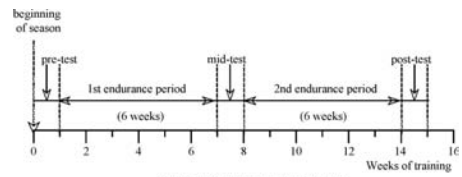

Fig. 1 Experimental schema of this study

All experimental measurements were conducted in a swimming flume using freestyle. A standardized warm-up, which consisted of approximately 2000 m for 30 min, was performed in preparation for each test. Within a week, each subject performed two tests as follows:
1. Continuous progressive swimming test for measuring VO_2max,
2. Intermittent progressive swimming test for measuring V@OBLA and stroke length at various velocities.

Continuous progressive swimming test

Subjects completed continuous progressive swimming tests from submaximal up to exhaustion in a swimming flume for measuring VO_2max. The swimming velocity was started at 50% of each swimmer's 400 m personal best. The velocities were increased by 5% every 2 min, up to 60%. They were increased thereafter by 5% every 1 min. An automatic breath gas analyzer (AE-280S; Minato Medical Services Co. Ltd, Japan) with a 10-s sampling rate was used to examine the expired gas continuously during the swimming test to measure the oxygen uptake: VO_2max was recorded.

Intermittent progressive swimming test
Subjects performed intermittent progressive swimming tests that consisted of a 3 min swim trial and a 5 min rest period in a swimming flume (5). Subjects were instructed to swim from 60% velocity of each swimmer's VO_2max derived during the pre-test, and increased 5% at each trial up to 100% VO_2max. The SL was measured from 30 s for the last 2 min of each trial using a video camera. Blood lactate was taken from a fingertip immediately after completion of each trial. Blood was analyzed using a blood lactate analyzer (Biosen 5030; EKF Industrie-Elektronic GmbH, Germany).

Statistics
Results were expressed as mean ± standard deviation. One-way analysis of variance with repeated measures (one-way ANOVA test) was used for comparisons among the tests. In cases where significant *F* ratios existed, an additional Fisher's post hoc test was performed. Regression analyses were used to analyze the variables in this study. Statistical significance was inferred for $p<0.05$.

RESULTS
Figure 2 shows that the mean values of VO_2max at the pre-test, mid-test, and post-test derived from the continuous progressive swimming test. The values of VO2max measured at the mid-test and the post-test were significantly higher ($p < 0.05$) than those at the pre-test, but no significant difference was found between the mid-test and post-test.

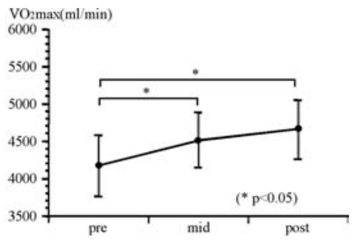

Fig.2 The mean VO2max at pre-, mid-, and post-test derived from continuous progressive swimming test.

Figure 3 portrays the relationship between swimming velocity and blood lactate concentration in intermittent progressive swimming tests during the pre-test, mid-test, and post-test. Blood lactate concentrations at 85, 90, 95, and 100% VO2max decreased significantly ($p < 0.05$) from the pre-test to post-test. There was a marked tendency to shift to the right and below at higher velocity from the pre-test to mid-test and post-test.
The relationships between swimming velocity and SL in intermittent progressive swimming test at pre-test, mid-test, and post-test are shown in Figure 4. No significant differences of SL at the same velocities existed between the pre-test, mid-test, and post-test.

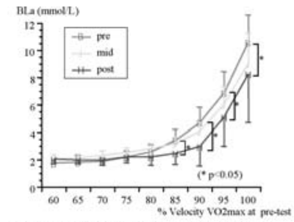

Fig.3 The relationship between swimming velocity and blood lactate concentration in intermittent prgressive swimming test.

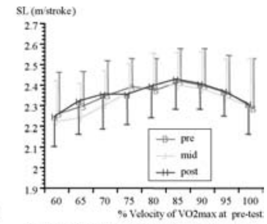

Fig.4 The relationship between swimming velocity and SL in intermittent prgressive swimming test.

Figure 5 illustrates the V@OBLA from the results of the intermittent progressive swimming test at pre-test, mid-test, and post-test. The value of V@OBLA at mid-test and post-test were significantly higher ($p < 0.05$) than during the pre-test, but no significant difference was apparent between the mid-test and post-test.
We demonstrate the SL at V@OBLA (SL@OBLA) in Figure 6. No significant differences in SL@OBLA were visible among the three tests.

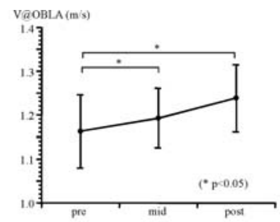

Fig.5 The mean V@OBLA at pre-, mid-, and post-test derived from intermittent progressive swimming test.

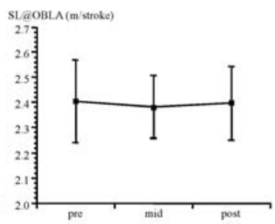

Fig.6 The mean SL@OBLA at pre-, mid-, and post-test derived from intermittent progressive swimming test.

Regarding investigation of the individual changes, we examined the relationship between rates of variable changes from the pre-test to the post-test. Figures 7 and 8 show the simple correlation coefficients between rate of each variable change and rate of V@OBLA change. Rates of VO_2max changed significantly ($p < 0.05$), and were correlated with the rate of V@OBLA change (Figure 7). On the other hand, the rate of SL@OBLA change did not correlate significantly with the rate of V@OBLA change (Figure 8).

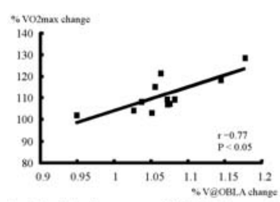

Fig. 7 Correlation between rate of V@OBLA change and rate of VO2max changes from pre- to post-test.

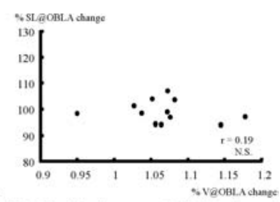

Fig. 8 Correlation between rate of V@OBLA change and rate of SL@OBLA changes from pre- to post-test.

DISCUSSION
This study was intended to investigate the factors affecting the change in V@OBLA by endurance training in well-trained male college swimmers. The major finding of this investigation was that the increase of V@OBLA by endurance training is almost

solely explained by improvement of aerobic capacity indicated by VO_2max, not by changing of stroke efficiency that was indicated by SL at various velocities and SL@OBLA in well trained varsity swimmers.
Results shown in Figures 2 and 7 illustrate that VO_2max improved considerably by endurance training from pre-test to mid-test and post-test. Because VO_2max is the most accurate method for measuring aerobic capacity (4), the present results suggest that aerobic capacity was improved by endurance training from pre-test to mid-test, and post-test.
Results of the relationship between swimming velocity and blood lactate concentration in intermittent progressive swimming test (Figure 3) show that blood lactate concentrations at higher velocities were significantly lower in the post-test, despite identical swimming velocity. Moreover, V@OBLA values measured at the mid-test and post-test were significantly higher ($p < 0.05$) than those measured at the pre-test (fig. 5). Previous studies suggested that endurance training would engender reduced lactate production and enhance the efficiency of lactate removal (2, 3). Therefore, it can be inferred that, in the present study, lactate concentrations in muscle and blood decreased at the same submaximal velocities by endurance training.
No significant differences of both SL at the same velocities and SL@OBLA were found between the three tests (Figures 4 and 6). Moreover, the rate of SL@OBLA change did not correlate significantly to the rate of V@OBLA change (fig. 8). Toussaint and Beek (8) suggested that SL gives a fairly good indication of propelling efficiency and might be used to evaluate individual progress in technical ability. Previous studies (1, 9) have demonstrated that endurance training increased SL. They suggested that endurance training engenders improved stroke efficiency. However, the present results were not consistent with those of previous studies. Apparently, this factor was responsible for the difference in the subjects. The present subjects were well-trained male varsity swimmers, including elite swimmers; seven were finalists at national level competitions. Therefore, it seems that the stroke efficiency of such elite swimmers would be already nearly maximized, even at the beginning of the season. On the contrary, the rate of VO_2max change significantly ($p < 0.05$) correlated to the rate of V@OBLA change (fig. 7). These results suggest that, in this study, stroke efficiency would not be likely to improve by endurance training. Therefore, increasing V@OBLA through endurance training was influenced not by stroke efficiency, but by improved aerobic capacity. Similar investigations using various subjects, such as age group swimmers, are necessary to elucidate this point.
In conclusion, this study demonstrated that increased V@OBLA by endurance training might be caused not by stroke efficiency improvement but almost entirely by improved aerobic capacity.

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ANALYSIS OF USA SWIMMING'S ALL-TIME TOP 100 TIMES

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The purpose of this study was to investigate the performances of elite level swimmers based on the USA Swimming's All-Time Top 100 times. We analyzed participation of 17-18 years old swimmers at Top 100 from age 10-under until the age of 15-16 years in various events by girls and boys. The data shows that the older the elite swimmer, the more likely he/she will be ranked in the Top 100. About half of the elite swimmers in the Top 100 at age 17-18 were new swimmers who were never ranked in the Top 100 at any age. Most of the future elite swimmers swim slower than age group champions, especially at ages until 15-16 years. Many participant ranked in the Top 100 as age groupers are not present in the Top 100 in the 17-18 age group. We speculate that the two reasons for losing these young Top 100 ranked champions may be related to their early biological maturation and/or an inappropriate training volume at a young age.

Key Words: age group, top 100, performance, swimming event.

INTRODUCTION
There is a paucity of studies on effects of early high-level performances on athletes' progression later in their career (1, 2). The analysis of the all-time Top 100 at different ages may provide valuable information about the long-term progression of elite level swimmers. There is constant debate in the swimming community about high-level performances at a young age in swimming. We still do not know if early high-level performances may limit a swimmer's progression later in their career. Many famous swimmers came from vastly different training programs. Unfortunately, coaches and scientists have speculated about the advantages of low-level or high-level performances at a young age based on a few examples of elite level swimmers. Some elite level swimmers were already ranked in the Top-100 as a 10-under, while other elite level swimmers only reached the Top 100 at age 18. Which strategy is better? The

lack of scientific investigations on long-term performance progression only increases speculation on this topic. The purpose of this study was to investigate the performances of elite level swimmers based on the All-Time Top 100 times.

METHODS

In order to understand the progression of elite swimmers during competition, we analyzed USA Swimming's All-Time Top 100 age group times by girls and boys. All-Time Top 100 age group times are divided into five groups according to the age of the swimmer: 10-under, 11-12, 13-14, 15-16, and 17-18. For the purpose of this study, we considered elite level swimmers the group of All-Time Top 100 at age 17-18. The following swimming events were analyzed: 100, 200, and 500 freestyle; 100 and 200 backstroke; 100 and 200 breaststroke; 100 and 200 butterfly; and the 200 individual medley. The groups of All-Time Top 100 were examined by calculating the percent of participation.

RESULTS

Analysis of Female Top 100 Athletes

All-Time Top 100 in freestyle, backstroke and breaststroke events for females are presented in Figure 1. Data presented for age groups include elite swimmers from Top 100 at age 17-18 in all events. It means that if an elite swimmer from Top 100 at age 17-18 was ranked in other Top 100 events she would be included. For example, if a swimmer was ranked in the Top 100 for the 100 freestyle in the 17-18 age group and was not listed in the Top 100 for 100 freestyle as a 10-under, but was ranked in the 100 breaststroke, she would be included. The 500 freestyle event wasn't included in Top 100 at age 10 and under.

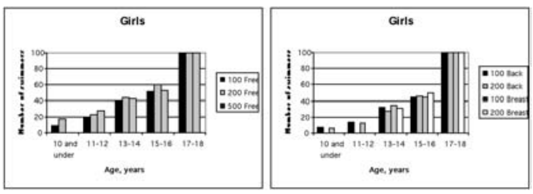

Figure 1. Participation for USA All-Time Top 100 in females' freestyle, backstroke and breaststroke events.

As was expected, the older the elite swimmer is the more likely they will be ranked in the Top 100. However, there were a relatively small number of 17-18 year-old swimmers from the Top 100 who were also ranked as a 10-under. For example, only nine swimmers at age 10 and under were listed at age 17-18 in 100 freestyle. Seventeen swimmers at age 10 and under were listed at age 17-18 in 200 freestyle. The number of elite swimmers slowly increases with each age group in all freestyle distances.

Similar tendencies occur in the stroke events as well. The low numbers of elite female swimmers are listed in backstroke, breaststroke, and fly events (see Figures 1 and 2). These numbers are even lower than in freestyle events and don't reach 50 at age 15-16. Fifty-eight 15-16 year-old girls elite level swimmers were listed in the 200 IM (see fig. 2). These numbers are higher than in other events.

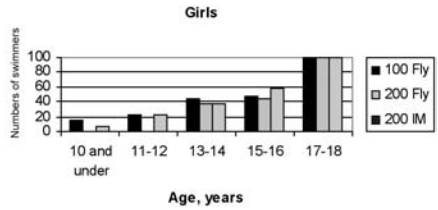

Figure 2. Participation for USA All-Time Top 100 in females' butterfly and IM events.

Analysis of Male Top 100 Athletes

Participation for the USA Swimming All-Time Top 100 in male freestyle events is presented in fig. 3. As the data shows, participation of elite male swimmers is relatively low in each age group until the age of 17-18.

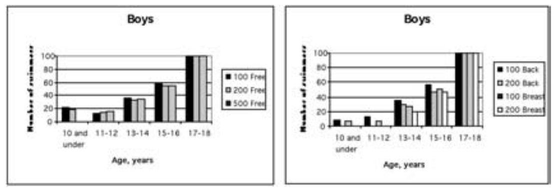

Figure 3. Participation for USA All-Time Top 100 in males' freestyle, backstroke and breaststroke events.

Similar tendencies appear in other males' events (see fig. 3 and 4).

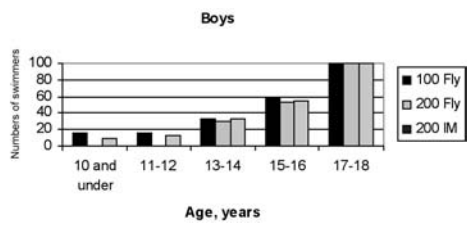

Figure 4. Participation for USA All-Time Top 100 in males' butterfly and IM events.

DISCUSSION

The analysis shows that most of elite level swimmers were unknown at young ages. Most of the future elite swimmers swim slower than age group champions, especially at ages until 15-16 years. Many participants ranked in the Top 100 as age groupers are not present in the Top 100 in the 17-18 age group. We speculate that the two reasons for losing these young Top 100 ranked champions may be related to their early biological maturation and/or an inappropriate training volume at a young age (1, 6, 8, 9). Higher participation on 500 compared to 100 and 200 freestyle events in the 11-12 group may be attributed to larger contribution of aerobic energy system at younger ages (1, 2, 11). Young athletes have lower anaerobic power and are not able to accumulate high blood and muscle concentrations (3, 4, 5, 6).

Surprisingly, there were still a low number of elite swimmers

at age 15-16 for girls and boys. About half of the elite swimmers in the Top 100 at age 17-18 were new swimmers who were never ranked in the Top 100 at any age. This statistic shows that most of the future elite swimmers swim under Top 100 times until age 15-16.
There is a small difference between elite female and male freestyle swimmers at age 11-12 and 13-14, where it appears that higher numbers of female freestyler's were ranked in the Top 100. Higher numbers for females may be related to earlier biological maturation in girls (6, 7, 10).
It was investigated how many elite level swimmers change their events at Top 100's. With that goal in mind we analyzed participation of elite swimmers from age 17-18 in Top 100's at various ages in the same and other events. For example, how many elite swimmers from age 17-18 were listed in the same or other events at age 10 and under, 11-12, 13-14, and 15-16. It is better to look at these numbers relative to the total number of elite swimmers. At age 10 and under many elite female swimmers are listed in other events. As data shows, 51.6% of elite female swimmers are listed in other events at age 10 and under. This number decreases with age and reaches 37.9%, 26.6% and 24.9% at age 11-12, 13-14 and 15-16, respectively. It shows that most of elite female swimmers select their event at age 13-14.
The analysis of elite male swimmers shows that 69.6% of elite male swimmers are listed in other events at age 10 and under. This number decreases with age and reaches 55.6%, 40.8% and 26.7% at age 11-12, 13-14 and 15-16, respectively. Thus, the elite male swimmers select their events at age 15-16 or about 2 years later than elite female swimmers.

CONCLUSIONS

1. A small number of elite swimmers from the Top 100 at age 17-18 were ranked in the Top 100 at a younger age. Typically, a little over 10 % were ranked as a 10-under, about the same figure as a 11-12 year old, a little over 30% as a 13-14 year old, and a little over 50% as a 15-16 year old. Similar numbers were found for female swimmer's, however, they have a little higher percentages in the 11-12 and 13-14 age groups.
2. The analysis shows that most of elite level swimmers were unknown at young ages. About a half of elite swimmers at Top 100 at age 17-18 are new swimmers, which never were listed at Top 100 at any age. This leads to conclusion that most of future elite swimmers swim slower than age group champions, especially at ages until 15-16 years.
3. Many participants ranked in the Top 100 as age groupers are not present in the Top 100 as they become an elite swimmer in the 17-18 age group. We speculate that the two reasons for losing these young Top 100 ranked champions may be related to their early biological maturation and/or an inappropriate training volume at a young age.
4. Elite level swimmers change their events during long-term training. Elite female swimmers tend to change their events until the age of 13-14. Elite male swimmers tend to change their events until the age of 15-16.

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ENERGY EXPENDITURE AND FOOD INTAKE OF COMPETITIVE SWIMMERS DURING TRAINING

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Poor dietary practices may accumulate and lead to deficiencies that may influence performance during training. The purpose of this study was to investigate weather the dietary intake of elite swimmers can match the energy and nutrient requirements of training. Dietary habits were evaluated in 16 elite swimmers (6 male, 10 female). Diet content and energy expenditure were estimated by using 3-day weighed dietary and activity records. Their three day training averaged 7.568 m of swimming per day. The total energy cost averaged 3146.88±494.10 kcal/day. Diet records revealed that the swimmers consumed daily 2182.25 ± 964.14 kcal/day, approximately 800 kcal less than their daily requirements. Protein intake was approximately double their energy cost. The results demonstrated the inability of swimmers to maintain a balanced diet.

Key Words: swimming, energy expenditure, food intake.

INTRODUCTION

During times of high physical activity, energy and macronutrient needs-especially carbohydrate and protein intake-must be met in order to maintain body weight, replenish glycogen stores, and provide adequate protein for building and repair of tissue (9). Poor dietary habits can influence the performance of swimmers during training. Repetitive sessions of high intensity swimming can deplete glycogen stores and important vitamins, minerals and other nutrients. In a study to assess the effect of increased training volume on nutrient intake of male collegiate swimmers it was found that energy intake did not fully compensate for expenditure, as both groups maintained weight but lost subcutaneous fat (1). Insufficient energy and carbohydrate intake have also been recorded in triathletes and other athletes. When the nutritional habits of young adolescent swimmers were evaluated, swimmers appeared to consume too much fat and not enough carbohydrate even though they consumed enough nutrients (2). It appears that individual swimmers may have very poor dietary habits and thus may not be providing adequate fuel or nutrients for optimal training or performance. The great emphasis placed on nutritional supplements underestimates the importance of nutrition. The purpose of this study was to evaluate whether dietary intakes of elite swimmers can match the energy and nutrient requirements of training.

METHODS

Sixteen (6 male, 10 female), elite teenage swimmers participated in this study. Food intake and energy expenditure were calculated through the completion of three-day weighed dietary records and activity records. Energy expenditure was estimated indirectly by taking into account the basal metabolic rate (BMR), the thermic effect of food, and energy expenditure of daily activities and swimming training. The energy expenditure of swimming was estimated indirectly taking into consideration the body mass of the swimmer, the intensity, the duration and the strokes swam (on types, duration and intensity of training) (9). Food was categorized in terms of quantity and nutrient content in order to be assessed. Food intake was analyzed by computer analysis (Food Processor II, Esha Research) for its caloric content, carbohydrate, fat, protein, dietary fiber, and saturated fat. Energy expenditure estimations were based on the Food and Agricultural Organization equations and exercise metabolic rate was calculated through the reported training records (on types, duration and intensity of training). Daily energy requirements were estimated by distributing the total calculated energy expenditure(calories) into the recommended percentages of a balanced meal (i.e.:60-70% carbohydrate, 15-20% fat and 15-20% protein). Data were statistically analyzed by a Pearson's r correlation coefficient test.

RESULTS AND DISCUSSION

Swimmers had a mean age of 18± 1.4 yr, a mean height of 176.13 ± 8.34 cm and a mean weight of 66.19±13.19 kg. Their three day training distance averaged 7.568 meters per day. The mean dietary intake was significantly lower than the estimated energy expenditure of swimming and protein intake was almost double the energy cost of swimming. Carbohydrate showed lowering but non-significant trends and fat didn't demonstrate any significant differences (table 1).

Table 1. Dietary Intake and Energy Expenditure and during a 3-day training period.

Variables	Dietary Intake and Nutrient Content	Energy Expenditure and Daily Estimated Requirements
Calories (Kcal)	2182.25*±964.14	3146.88±494.10
Protein (g)	103.23*±41.59	52.96±11.18
Carbohydrate (g)	262.38±125.08	456.19±71.57
Fat (g)	88.43±49.67	104.89±16.25
Dietary fiber (g)	18.24 ± 8.32	31.45 ± 4.94
Saturated Fat (g)	34.10 ± 20.66	34.95 ± 5.49

**Denotes that means are significantly different (p<0.05) from the Energy Expenditure values.*

It is well established that the nutritional requirements of training are far more demanding than those required for competition in short distance swimming. Poor daily dietary practices may accumulate and lead to deficiencies that may influence the improvement of performance. Many swimmers nowadays rely on nutritional supplements to counterbalance a poor diet without evaluating first the quality of their food intake. This study demonstrated that the energy and nutrient requirements of training do not match. One of the fundamental differences between an athlete's diet and that of the general population is despite the greater fluid needs, that athletes require additional energy to fuel physical activity more so than the increased needs for other nutrients. It is considered appropriate for much of the additional energy to be supplied as carbohydrate. Caloric deprivation is often accompanied with carbohydrate deficiency and decrements in swimming training performance (3). In recent studies evaluating the dietary intake and nutritional practices, swimmers of both gender consumed too much fat and protein and too little carbohydrate (7, 9). Carbohydrates in this study showed some lowering trends which however were not significant (fig. 1). Percent distribution of the three major nutrients may not always be the best recommendation for athletic populations particularly in application to female athletes whose caloric requirements are lower and proportionally the amount of carbohydrate will be lower.

In a study evaluating the dietary intakes of age-group swimmers although the contribution of carbohydrate to total daily energy intake was the same for male (55%) and female swimmers (56%), the females ingested significantly less carbohydrate (292g) than the males (404g) and could be considered deficient in dietary carbohydrate with respect to their daily training demands (5). In this study swimmers' carbohydrate consumption showed some lowering but non-significant trends but had an excess of protein intake (fig. 1).

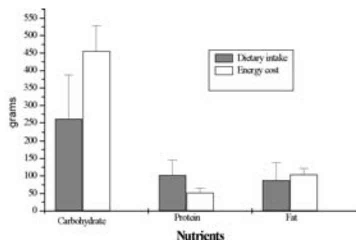

Figure 1. Dietary intake and energy cost of swimming during training.

As previously reported, the calculated energy expenditure of female athletes was greater than the reported energy intakes and as a consequence those with very low intakes reported menstrual abnormalities (6). The caloric deficiency that was evident in the present study can eventually lead to carbohydrate deficiency, whereas the excess of protein intake may unnecessarily tax the system. Swimmers are usually not well informed on balanced nutritional practices that would give them an edge during training and eventually during competition. They need to be better informed and eventually learn to value the priority of well balanced meals over supplementation. Their daily practices are demonstrating their inability to maintain a balanced diet, especially when taking into consideration the fact that most consumed an overabundance of food supplements including vitamins, protein and amino acids. Nowadays, it is well established, that if energy intake is high and a varied diet is consumed, supplementation of the diet with vitamins and minerals is not necessary, unless a specific deficiency is identified (1).

CONCLUSIONS

Nutritional evaluation of individual swimmers is not practiced routinely by coaches, swimmers or parents. Well balanced diets are necessary for swimmers of all categories and levels of competitiveness. The over-consumption of supplements may not necessarily cover all the needs of swimmers especially their energy requirements (calories), as well as their carbohydrate requirements. Too often, supplements may provide a fast boost of energy masking the real deficiencies and true requirements of the swimmer. The negative impact that a majority of supplements may have on the swimmer's health should not be underestimated. The adoption of a well balanced diet with plenty of hydration and the estimation of the energy expenditure of every swimmer individually will aid for better performances and healthier athletes.

ACKNOWLEDGEMENTS

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DIFFERENT LEVELS OF HYDRATION FOLLOWING A TRAINING SESSION ON SWIMMING PERFORMANCE

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This study examined the effects of two different levels of hydration after a training session on subsequent performance. Eight swimmers performed a morning swimming training session, and 8 hours later a testing session of 4x200m at an intensity of 95% of the critical velocity (4x200submax) and 200m maximum effort (200max). In two separate trials, swimmers consumed a fluid volume of either 150% (F150) or 50% (F50) of the morning post-training body mass (BM) loss. BM was reduced by 0.9±0.2% and 0.8±0.3% after the morning session in F150 and F50 trials respectively ($p>0.05$). Eight hours later, BM had recovered in the F150 but not in the F50 trial ($p<0.05$). Heart rate showed a tendency to increase at the end of the 4x200submax ($p=0.08$). The 200max time was not different between trials ($p>0.05$). As a result dehydration of 1% might not be a critical factor in impairing performance during a 200max.

Key Words: fluid loss, recovery, hypohydration.

INTRODUCTION

High intensity swimming training of long duration will cause dehydration (2). This may affect swimming performance as it has been observed in cycling (5); proper hydration is, therefore advisable. The effect of dehydration on performance in other types of exercise is well-documented (4). However, there is no available data on swimming performance. Most of the swimmers participate in training twice a day with a recovery period of about 8 hours. The volume of fluids consumed after a training session can be crucial for rehydration and performance on a following session (3, 4). The purpose of the study is to examine the effect of two different levels of hydration after a training session on performance eight hours later in a subsequent afternoon session.

METHODS

Eight male swimmers (mean±SD, age: 21.4±1.2 yrs, height: 179±6 cm, body weight: 74.8±4.3 kg, VO_{2max}:3.98±0.30

l/min) participated in the study. They had past competitive swimming experience but trained recreationally during the examination period. The swimmers performed, on two separate days, a 400m maximum effort and a series of 5x200m with progressively increasing intensity up to maximum effort starting every seven minutes. Expired air was collected breath by breath (Oxycon Jaeger, Germany) during the recovery period for the determination of the VO_2max and for the velocity vs. O_2 uptake relationship. Critical velocity (CV) was calculated from the time of the 400m and the last of the series of 5x200m test. On a third visit to the swimming pool a familiarization training of about 3000m was performed.
Swimmers participated in a morning swimming training session of 4800m (intensity range: 95-105% of CV, table 1), followed 8 hours later by an afternoon testing session of 4x200m at an intensity of 95% of the CV (4x200submax, table 1) and ten minutes latter by a 200m maximum effort (200max). No fluid consumption was allowed during morning or afternoon sessions. In two separate trials a week apart, and during the 8 hours recovery between the morning and afternoon sessions, swimmers consumed a fluid volume (carbohydrate-electrolyte solution, isostar® 6%) of either 150% (F150) or 50% (F50) of the morning post-training body mass (BM) loss.

Table 1. The training contents of the morning training and afternoon testing sessions.

Morning training session			Afternoon testing session		
Repetitions	Recovery (s)	Intensity (% of the CV)	Repetitions	Recovery (s)	Intensity (% of the CV)
8x200m	20 180 after the set	95	4x200m	20 10 min after the set	95
6x200m	30 180 after the set	100	1x200m		maximum
2x(4x100m)	15 (90 after set 1)	105			
400 leg kick					

CV: critical velocity.

Swimmers fasted for the morning session and their nude BM was measured with an accuracy of 0.1kg. At the completion of the morning training session, swimmers dried their body and hair and were reweighed nude. The BM was again measured before the afternoon session. Before each BM measurement the urine bladder was emptied and urine volume was measured. Breakfast was provided after the completion of the morning session (1gr/kg of BM solid plus 100ml of fluids) and was controlled for the carbohydrate (CHO) content. Following breakfast, swimmers were advised to consume the prescribed fluid volume at regular intervals during the 8-hour recovery period and to avoid any other fluid consumption. Urine volume was collected and measured at the end of this period. Blood lactate was determined at the end of each training set (Dr Lange M8; Berlin Germany) and blood glucose (LifeScan, Sure Step plus) was measured before and after each training session and 30 min after breakfast (60 min after the end of training). Heart rate (HR) was recorded continuously during both sessions (Polar x-Trainer plus). Diet was recorded two days before the testing days and during the 8 hours of recovery. All tests took place in a 50m indoor swimming pool with air and water temperature of 23-25 ºC and 27ºC, respectively. Relative humidity was 80-85%. The front crawl swimming style was used during testing. A two-way analysis of variance for repeated measures or a student t-test (200max) was used for the statistical analysis. The Tukey post-hoc test was used to locate differences between variables. The results are presented as mean±SD and the accepted level of significance was set at $p<0.05$.

Figure 1. The experimental procedure of the study.

RESULTS
The CV of the swimmers (1.183±0.080m/s) corresponded to 85±7% of the VO_2max and to 93±4% of the velocity of the maximum 400m time. The training sets were prescribed at the range of 95-105% of the CV and this intensity varied from 80±7% to 90±7% of the VO_2max. Blood lactate and glucose as well as HR were similar during the morning session in both trials (fig. 2 and fig. 3, $p>0.05$).

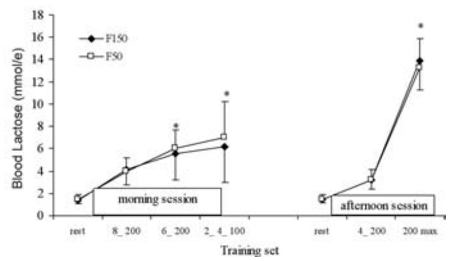

*Figure 2. Blood lactate concentration during swimming trials. *p<0.05 compared with the previous training set of the same session (mean±SD, n=8).*

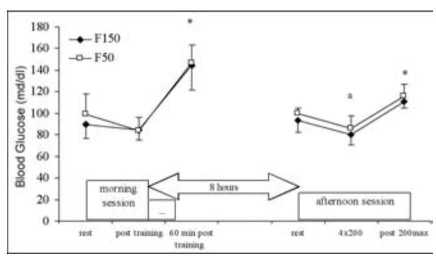

*Figure 3. Blood glucose responses during swimming trials. *p<0.05 from the previous sampling point. a p<0.05 between trials, B: breakfast (mean±SD, n=8).*

BM was reduced by 0.9±0.2% and 0.8±0.3% after the morning session in F150 and F50 trials, respectively (between trials, $p>0.05$). Swimmers ingested 1050±175 and 306±112ml of fluids and the urine output was 481±186 and 304±121ml in the F150 and F50, respectively ($p<0.05$). At the beginning of the afternoon session, 8 hours later, BM had recovered in the F150 but remained decreased in the F50 trial (fig.4, $p<0.05$).

HR showed a tendency to increase at the end of the 4x200submax ($p=0.08$) and was higher in the afternoon testing compared to the morning session in the F50 trial (fig. 5, $p<0.05$). The swimming time to cover the 200max was not different between trials (F150:143.54±5.92 vs. F50:144.29±4.30s, $p>0.05$).

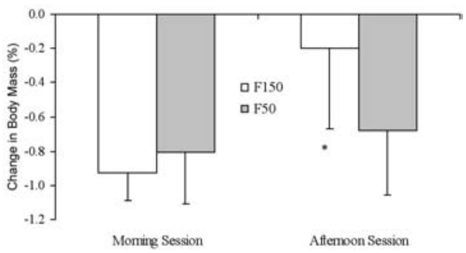

*Figure 4. Body mass changes after the morning training session and before the afternoon session *p<0.05 on F150 trial (mean±SD, n=8).*

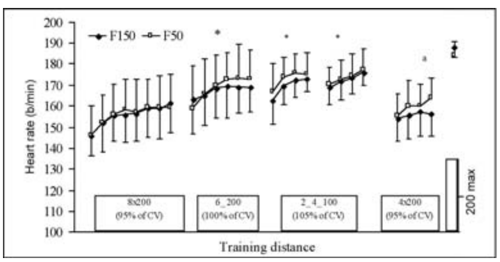

*Figure 5. HR responses during the morning and afternoon training sessions. *p<0.05 from the previous training set, a p<0.05 from the first repetition (mean±SD, n=8).*

DISCUSSION

Ingestion of fluids equal to 150% of the BM loss is marginally adequate, while a fluid volume of 50% of the BM failed to restore fluid losses. In this case, swimmers may appear in a subsequent session partially or severely dehydrated. However, this level of dehydration (i.e. 1%) may not be a critical factor in impairing performance during a 200m maximum swimming effort or in altering HR responses during sumbaximal exercise (5). Even though the BM before the afternoon testing session was not statistically different from the morning pre-training BM, incomplete recovery was still present from the previously induced dehydration. This is probably attributed to the sodium content of the consumed beverage. Increased sodium concentration will enhance the rehydration process when a volume corresponding to 150% of the fluid loss is consumed (3, 4). Nevertheless, the rehydration was better accomplished in the F150 compared to F50 trial. In addition, due to the controlled CHO content during the recovery period of both trials, any changes in performance in the afternoon testing session could be attributed to the different levels of hydration. However, performance was not different between trials. It has been suggested that a dehydration of more than 1% will cause deterioration in performance (3, 4), regardless previous data had suggested that aerobic exercise performance was not impaired with hypohydration of 2% (5). In the present study the type of aerobic exercise performed was of short duration (15min) and the swimming pace (95% of the CV) was easily maintained but with a tendency for increased HR in the F50 trial. It is likely that the consequences of dehydration on the cardiovascular system would have reached significant levels if the duration of this testing set (4x200submax) was extended. No difference in performance was observed in the 200max test. A high percentage of anaerobic contribution is incorporated in this swimming distance and it is likely that a more severe dehydration (<4%) is needed to impair performance during short duration (>3min) exercise (1,5).

CONCLUSION

The volume of fluid consumed after a swimming training session should exceed 150% of the total body weight loss. Dehydration of 1% may not be a critical factor in impairing performance during a maximum 200m swimming effort. This level of dehydration may, however, alter HR responses during sumbaximal swimming.

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DETERMINATION AND APPLICATION OF INTERVAL SWIM CRITICAL VELOCITY AND CRITICAL REST TIME IN THE 50M INTERVAL SWIM TRAINING

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The purpose of this study was to determine critical velocity (V_{criIS}) and critical rest time (t_{cri}) for interval training at four velocities higher than anaerobic threshold. Eleven well-trained college male swimmers performed four to six sets of 50m interval swim test (T_{int}) at each given velocity. The relations between total time (t_T) and the total swim distance (D_{int}) of T_{int} were expressed in the general form, $D_{int}=a+b*t_T$ in all subjects. V_{cri-IS} could be determined by the relationship between D_{int} and t_T. and t_{cri} could be calculated from V_{cri-IS} and swimming time (t_s) at each velocity. Moreover, combination swimming velocity, rest time and total swimming distance direction could be determined. It was thought that the combinations of velocity and rest period which imply interval training fatigue threshold (ITFT) could be defined from the results of V_{criIS} and t_{cri}.

Key Words: interval swim, critical velocity, critical rest time.

INTRODUCTION

Interval training is the training method utilized most frequently for swimmers and coaches. Maglischo (1993) has proposed several guidelines for the interval training categories, consisting of set distances, repeated distances, rest intervals, speed and total distance per week for improving power, anaerobic and aerobic metabolism.

The concept of critical velocity (V_{cri}) determined by the relationship between the swimming distance and the swimming time has been utilized for the many studies that investigated relations of V_{cri}, aerobic endurance, maximal lactate steady state and critical stroke rate (2, 3, 4, 5). Moreover, the interval swim critical velocity (V_{criIS}) defined as the maximal average speed to be able to swim repeatedly without exhaustion in the 50m interval swim training at one swimming velocity higher than anaerobic threshold could be determined and the critical rest time (t_{cri}), which could theoretically be repeated the interval swims without exhaustion could be estimated by using V_{criIS} (7). It was thought that V_{criIS} could be applied as an index for setting the combination of swim velocity and rest time for the interval training, matching to the performance level of the swimmers.

In the present study, the purpose of this study was to determine V_{criIS} and t_{cri} for interval swim training at four swimming velocities higher than anaerobic threshold and to apply those data to an index for setting the combination of swim velocity, rest time and swimming distance for the interval training.

METHODS

1. Subjects. The subjects who volunteered for this study were 11 well-trained college male swimmers (19-21 years). The subjects were informed of the risks involved in participating in the study and signed a statement of informed consent.

2. 50m and 2000m max swim tests. All swim tests were performed using the front-crawl stroke and started from the water in the 50m pool. Subjects were instructed to swim 50m and 2000m with maximal effort. The mean velocity (mean velocities of 50m and 2000m; V_{50} and V_{2000}) was determined for each subject. In principle, these maximal effort tests were performed with one event swum per day.

3. 50m interval swim test and determination of V_{criIs} and t_{cri}. The subjects had 50m interval swim test (T_{int}). The swimming velocity in T_{int} were set at four paces of $V_{30\%}$, $V_{40\%}$, $V_{50\%}$ and $V_{60\%}$ for each subject, which were calculated by the following equation, $V_{30\%}$ as an example, $V_{30\%}=0.3(V_{50}-V_{2000}) + V_{2000}$. A light pace marker was used to ensure compliance with predetermined velocity. If the subject could not complete interval swim 30 times in each T_{int}, the rest time was increased by 2-10 s in the next trial, until the subjects could complete T_{int}. The T_{int} was terminated when the head position of the swimmer was 1 m away from lights of the pace marker during the test. When two sets of the T_{int} were done in a day, the subject was allowed to rest for at least 3 hours between trials. Finally, the subjects performed three to six sets of T_{int} at each velocity. The total time (t_T) of T_{int} including interval swims and rest periods and the total swim distance (D_{int}) of T_{int} were determined. Table 1 shows t_T and D_{int} of T_{int} at $V_{50\%}$ for subject 11 and the relationship between D_{int} and t_T for determining V_{criIS} is illustrated in Figure 1. Subject 11 could not complete T_{int} with rest durations of 5s, 10s, 15s and 20s and could complete T_{int} with rest durations of 25s and 30s. Those points were accurately situated on a line defined by the relationship between D_{int} (D) and t_T (T).

Table 1. t_T and D_{int} of T_{int} at $V_{50\%}$ for subject 11.

Rest time	5s	10s	15s	20s	25s	30s
D_{int} (m)	219	274	479	950	1500	1500
t_T (s)	155.5	219.7	431.7	968.2	1678.8	1828.8

The equation of regression line can be expressed as follows:
$D= a*T + b$
Swimming velocity (V) multiplied by T makes D and D can be substituted by V*T;
$D=V*T$, $V=a + b/T$
Theoretically, if we could set the interval swim at which one can perform indefinitely ($T\rightarrow\infty$), b/T will be approach zero and V will approach a. Therefore, V_{criIS} can be expressed as the slope of the regression line:
$V_{criIS}=a$
V_{criIS} in T_{int} at $V_{30\%}$ for some swimmers could be determined by the relationship between D and T of two points, because they could complete interval swim with shorter rest duration.
V_{criIS} has been defined as the maximal average speed to be able to swim repeatedly without exhaustion. t_{cri} for interval swim, which can theoretically be repeated the interval swims without exhaustion in T_{int} at $V_{50\%}$, can be estimated by using V_{criIS}. In the present study, swimming time (t_s) of 50m for T_{int} was calculated with the following equation:
$t_s =50/V_{50\%}$
Theoretically, V_{criIS} multiplied by the cycle time ($t_s + t_{cri}$) makes repeated distance of T_{int} (50m) and t_{cri} can be estimated:
$V_{criIS}*(t_s + t_{cri})=50$, $t_{cri} =50/V_{criIS} - t_s$

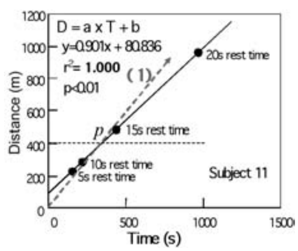

Figure 1. Relationship between swimming distance and total time of interval swim test.

5. Combination of swimming velocity, total swim distance (D_T) and rest time (t_R). Combination of swimming velocity, D_T and t_R could be determined from the equation of regression line between D_{int} (D) and t_T (T).
If we set 400m as D_T, total time (T) can be calculated by using the equation of regression line in Figure 1:
$400=0.901*T + 80.836$, $T=354.3s$
A straight line to pass the origin and point *p (354.3, 400)* can

be expressed:
y=1.129x (1)
The slope of line (1) is maximal average velocity which swimmer can swim 400m at $V_{50\%}$. Therefore, the shortest rest time (t_{cri400}) which swimmer can repeat 8 times (D_T=400m) of interval swims at $V_{50\%}$ can be calculated:
$1.129(t_{R400} + 31.0)=50$, $t_{R400}=13.3$

RESULTS
Table 2 shows the swimming style and the results of the tests for each subject. Significant correlations were found between D_{int} and t_T at $V_{40\%}$, $V_{50\%}$ and $V_{60\%}$ in all subjects. Moreover, there were significant correlations between D_{int} and t_T for subjects who had three sets of T_{int} with exhaustion at $V_{30\%}$.

Table 2. The performance and test results for each subject.

Sub ject		V_{50} (m/s)	V_{2000} (m/s)	$V_{criIS30\%}$ (m/s)	$t_{cri30\%}$ (s)	$V_{criIS40\%}$ (m/s)	$t_{cri40\%}$ (s)	$V_{criIS50\%}$ (m/s)	$t_{cri50\%}$ (s)	$V_{criIS60\%}$ (m/s)	$t_{cri60\%}$ (s)
1	F-L	1.81	1.27	1.16	8.2	1.16	10.4	0.91	22.4	0.87	26.1
2	F-L	1.85	1.38	1.30	5.8	1.19	8.3	1.02	18.0	0.87	27.2
3	I-L	1.72	1.31	1.22	6.3	1.09	12.0	0.96	19.4	0.89	24.0
4	F-L	1.81	1.30	1.17	8.4	1.06	13.7	1.01	17.5	0.86	27.1
5	F-M	1.95	1.38	1.14	11.6	0.91	17.8	1.02	19.2	0.98	27.9
6	F-M	1.86	1.25	1.19	7.1	1.07	13.1	0.91	22.6	0.87	26.3
7	I-M	1.81	1.26	1.20	6.5	1.03	14.6	0.92	21.5	0.93	22.2
8	F-M	1.85	1.22	1.18	7.0	1.07	12.8	0.90	22.9	0.90	24.6
9	B-S	1.61	1.07	0.99	9.7	0.90	16.8	0.73	31.1	0.70	35.5
10	F-S	1.90	1.23	1.10	10.5	1.00	16.6	0.86	26.2	0.74	36.9
11	F-S	1.91	1.32	1.10	12.1	0.95	20.3	0.90	24.5	0.74	37.7
Mean		1.82	1.27	1.16	8.5	1.04	14.2	0.92	22.3	0.85	28.7
SD		0.09	0.09	0.08	2.2	0.09	3.5	0.08	4.0	0.09	5.4

I; individual medley, B; breaststroke, F; freestyle, S; 50m or 100m, M; 200m, L; 400m~.

Fig. 2A illustrates the relationship between individual t_{cri} and swimming velocity at $V_{30\%}$, $V_{40\%}$, $V_{50\%}$ and $V_{60\%}$ for all subjects. There was a tendency that t_{cri} at all velocities of the short distance swimmers were remarkably longer than those of the middle and long distance swimmers.
Mean values of $t_{cri30\%}$, $t_{cri40\%}$, $t_{cri50\%}$ and $t_{cri60\%}$ in the short distance groups and the long distance groups were 10.8s (SD 1.2), 17.9s (SD 2.1), 27.3s (SD 3.4) and 36.7 (SD 1.1), and 7.2s (SD 1.3), 11.1s (SD 2.3), 19.3s (SD 2.2) and 26.1s (SD 1.5), respectively. In Fig. 2B, those data were plotted and the approximation curve line passed through the point of intersection and those data of each group was shown.

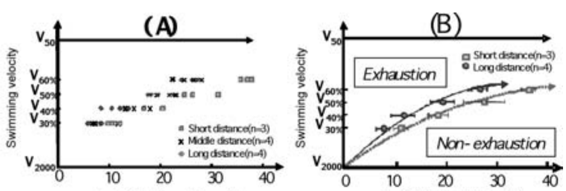

Figure 2. Relationship between t_{cri} and swimming velocity for all subjects (A) and relationship between mean values of t_{cri} in the short distance groups and the long distance groups and swimming velocity (B) at $V_{30\%}$, $V_{40\%}$, $V_{50\%}$ and $V_{60\%}$.

Figure 3 illustrates the combination of swimming velocity at $V_{30\%}$, $V_{40\%}$, $V_{50\%}$ and $V_{60\%}$, t_R and D_T of 200m (50m x 4t), 400m (50m x 8t) and 1000m (50m x 20t) determined from the equation of regression line between D_{int} and t_T for all subjects.

Moreover, the approximation curve line passed through maximal swimming velocity of D_T at 0 rest time and those data plotted relations between swimming velocity and rest time points of each D_T was drawn.

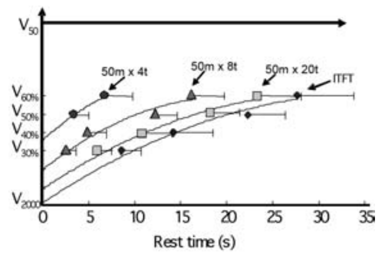

Figure 3. Combination of swimming velocity at $V_{30\%}$, $V_{40\%}$, $V_{50\%}$ and $V_{60\%}$, rest time and total swimming distance of 50m x 4t, 50m x 8t and 50m x 20t.

DISCUSSION
V_{criIS} defined as the maximal average speed to be able to swim repeatedly without exhaustion in the 50m interval swim training at a given velocity higher than anaerobic threshold could be determined and t_{cri}, which could theoretically be repeated the interval swims without exhaustion could be estimated by using V_{criIS} (7). The primary goal of this study was to determine V_{criIS} and t_{cri} for interval swim training at four velocities higher than anaerobic threshold and to apply those data to an index for setting the combination of swim velocity, rest time and swimming distance for the interval training.
We had two to five sets of T_{int} at given velocities to calculate V_{criIS} for each subject. A strong correlation between D_{int} and t_T was found for all subjects except a part of T_{int} at $V_{30\%}$, so that the certain linear relationship $D_{int}=a+b{*}t_T$ was obtained. Therefore, V_{criIS} and t_{cri} at four swimming velocities could be determined for all subjects.
t_{cri} of the long distance swimmers at four velocities were remarkably shorter than those of short distance swimmers and the relation between swimming velocity and t_{cri} was shown the approximation curve line at each group. V_{2000} of intersection in Figure 2 and 3 almost corresponds to the swimming velocity at maximal lactate steady state (2, 5) and continued to swim without exhaustion. In the results of this study, it can be hypothesized that the approximation curve line indicates fatigue threshold in relation to swimming velocity and rest period for the interval training, and approaches asymptotically to the level at V_{50} along with the extension in rest interval. Consequently, the interval training combined swimming velocities and rest intervals below the curve it possible for the swimmer to swim repetitiously without exhaustion. The interval training performed at combinations above the curve, on the other hand, does not make it possible to swim repetitiously with exhaustion. In the present study, we named the curve in Figure 2B as "Interval Training Fatigue Threshold" (ITFT). Moreover, combination of swimming velocity, rest time and total swimming distance could be determined from the equation of $D_{int}=a+b*t_T$.

CONCLUSION
It is thought that the application of ITFT concept could be a

helpful index for the coach and swimmer, in order to determine precisely and easily the combinations of the individual swimming velocity, rest time, repeated distance and number of repetitions, taking account of the fatigue characteristics and the performance level of the swimmers.

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BILATERAL AND ANTERIOR-POSTERIOR MUSCULAR IMBALANCES IN SWIMMERS

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The purpose of this study was to determine the relative magnitude of bilateral and anterior-posterior differences in swimmers. Peak hand force was measured during aquatic exercise (horizontal arm abduction and adduction in a standing position) and swimming (freestyle and backstroke). The peak force values were significantly higher ($p<.01$) for exercise adduction than abduction and for the swim stroke with the arm in the adducted position (freestyle) rather than the abducted position (backstroke). The magnitude of the anterior-posterior difference was large for both exercise (1.5σ) and swimming (.8σ). Bilateral differences were trivial (.1σ, ns) in comparison. A training regimen that strengthens the arm abductors may not only decrease the incidence of injuries in all four strokes, but also increase hand force and, therefore, improve performance in backstroke.

Key Words: biomechanics, injury, technique, measurement, strength, evaluation.

INTRODUCTION
Bilateral imbalances are common in swimmers and can inhibit performance (6). Anterior-posterior differences are not only common, but also related to injuries such as shoulder impingement (2, 7). Muscular balance in the shoulder and scapula is necessary to avoid injuries (8). The ratio of land-based abduction to adduction strength was used to quantify anterior-posterior differences and was correlated to clinical signs of injuries in swimmers (1). The purpose of this study was to determine the relative magnitude of water-based bilateral and anterior-posterior differences in swimmers, relate these imbalances to complementary clinical screening procedures, and suggest related changes to training regimens.

METHOD
The subjects were 19 competitive swimmers (12 males and 7 females) between the ages of 14 and 17. The descriptive statistics for the males were: age (M = 15.4 yrs, SD = 1.4), height (M = 176 cm, SD = 7.9), and mass (M = 66.4 kg, SD = 9.9). The female data were: age (M = 15.4 yrs, SD = 1.4), height (M = 164 cm, SD = 7.5), and mass (M = 53.2 kg, SD = 5.4). Informed consent was obtained.
Peak hand force was measured performing aquatic exercise (horizontal shoulder abduction and adduction in a standing position) and swimming (freestyle and backstroke) with Aquanex (previously described and validated in 5). For the aquatic exercise, subjects were instructed to perform five repetitions with maximum intensity. For the swim trials, the subjects were asked to sprint 20 m to a wall. Hand force data were collected over the last 10 m. Two trials of each test were performed with about 1 min rest. The single highest peak force value for each trial was used as the criterion.

RESULTS
Sample exercise and swimming trials are shown in Figures 1 and 2.

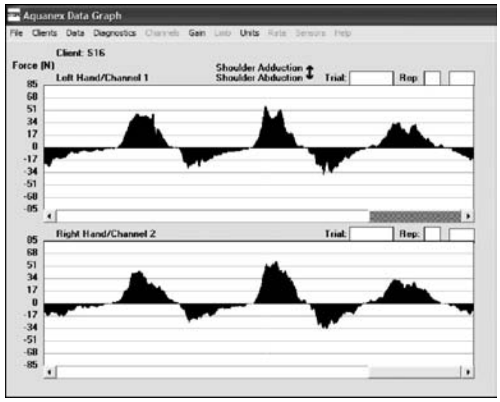

Figure 1. Aquanex image of horizontal shoulder abduction/adduction exercise.

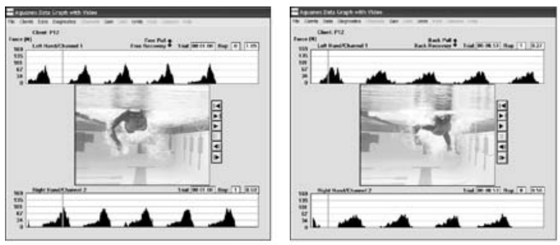

Figure 2. Aquanex+Video images of freestyle and backstroke swimming.

For aquatic exercise, the peak hand force values were significantly higher ($p<.01$) for adduction than abduction. For swimming, the peak hand force values were significantly higher ($p<.01$) for the stroke with the arm in the adducted position (freestyle) than in the abducted position (backstroke). Bilateral differences were not significant. The data are listed in Table 1 and graphed in Figure 3.

Table 1. Peak hand force values (N), reliability coefficients (Alpha), and effect sizes (ES) for aquatic exercise and swimming.

	Abduction/Backstroke			Adduction/Freestyle			
	Alpha	M	SD	Alpha	M	SD	ES (σ)
Exercise/Left Hand	.87	34.4	16.5	.97	75.7	34.1	1.63
Exercise/Right Hand	.97	35.7	19.9	.98	79.4	38.6	1.49
Swimming/Left Hand	.88	120.5	33.4	.94	148.1	50.4	.66
Swimming/Right Hand	.95	116.0	33.9	.95	154.2	49.6	.91

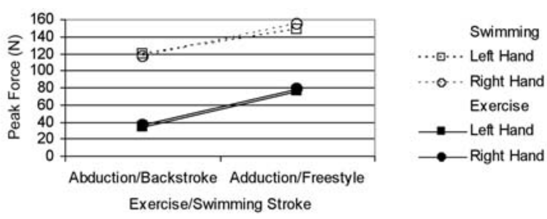

Figure 3. Peak hand force values for aquatic exercise and swimming.

DISCUSSION
The magnitudes of the anterior-posterior differences were large for both aquatic exercise (1.5σ) and swimming (.8σ). The anterior-posterior peak force ratios for aquatic exercise were similar to the values reported for land-based exercise (1, 4). The magnitude of these imbalances is less than ideal and can be related to performance restrictions and predisposition for shoulder injury.

Muscular imbalances and injuries have been attributed to stroke mechanics, inadequacies in dryland exercise, and overuse (2, 3, 8, 9). Although these are substantial issues, a coach can address each one in a typical training environment. For example, a coach can first conduct a technique analysis to qualitatively assess the mechanical basis for muscular differences. The freestyle recovery of the swimmer in Figure 4 shows a bilateral difference in the angle between the upper arm and the horizontal. The restricted right shoulder position reflects a strength decrement in shoulder abduction.

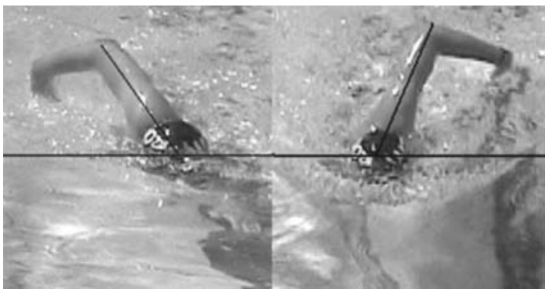

Figure 4. Stroke evaluation of freestyle recovery showing a smaller angle with the horizontal for the weaker right shoulder.

Such qualitative clinical evaluations can also identify related structural conditions. Testing that mimics the stroke mechanics can show muscular imbalance/stabilization dysfunction. The Swim Stroke Pull Test (Figure 5) is a dryland replication of the freestyle arm motion. The swimmer's hand directs force against the resistance of the examiner's hand to imitate the propulsive phase of the stroke. Strength decrement in shoulder adduction can be determined by qualitative analysis of the swimmer's force, body segment adjustments during the test, and video review. The scapular position for the affected right upper extremity shows dysfunctional elevation/protraction (Figure 6).

Figure 5. Swim Stroke Pull Test. Swimmer is initially positioned with upper extremity at full shoulder abduction and then applies pressure to the examiners hand to complete shoulder adduction.

Figure 6. Comparative demonstration of upper extremities completing the Swim Stroke Pull Test. Left upper extremity shows adduction position with no irregularities. Right upper extremity shows irregular position of the scapula and indicates weakness of the adductor function.

Once a structural problem is detected, a coach can implement changes in the training regimen. Specific strength training that targets the associated abductors can be added to the program. An adjustment of total training distance and the proportion of frontal stroke (butterfly, breaststroke, and freestyle) to dorsal stroke (backstroke) distance may also be appropriate.

CONCLUSIONS
Muscular imbalances of considerable magnitude are common in swimmers. A thorough strategy for dealing with muscular imbalances includes a minimum of three components: evaluation, remedial strength training, and adjustment of training distance and stroke. First, it is important to evaluate anterior-posterior muscular differences either quantitatively or qualitatively. Second, additional aquatic and/or land-based strength training may be necessary. Third, it may be appropriate to reduce the total training distance for the frontal strokes and/or increase the proportion of backstroke. A training regimen that strengthens the arm abductors may not only improve muscular balance and decrease the incidence of injuries in all four strokes, but also increase hand force and, therefore, performance in backstroke.

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THE CONTRIBUTION OF THE AXILLARY ARCH TO THE OVERHEAD KINESIOLOGY OF THE SHOULDER

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According cadaveric, neurosurgical and medico diagnostic evidence the Axillary Arch of Langer (AA) creates symptoms similar to those of entrapment or obstruction type syndromes. In addition to the existing anatomical evidence and based on similar functional reasoning one can assume that in swimming the AA influences the shoulder girdle kinesiology also. In order to complete our knowledge of the AA we evaluated strength, endurance, motor control, precision and proprioception in two groups of physical education students (all good and average swimmers) one with AA and a control group without AA (both N=22). The results indicate a significant ($p<0.05$) influence of the presence of an AA on strength, throw or pull/push endurance and motor control increase in women associated with a minor increase of parasthaetics. For all these parameters no significant difference occurred in men. The pull/push simulation and proprioceptive joint position sense data however indicate a decrease both in men and women ($p<0.05$).These finding do not fully confirm the anatomical predictions from the cadaveric evidence nor support the diagnoses of excision of the AA.

Key Words: shoulder, axillary arch, strength, endurance, motor control, proprioception.

INTRODUCTION
The Muscular Arch of the axilla (AA) can be described as a small muscle coming from the M. latissimus dorsi crossing the axillary cavity towards the upper arm. This supernumerary muscle can either be a well developed thumb-shaped fleshy belly or a tiny fibro-muscular band or string. It inserts on the tendon and fascia of the M. pectoralis major or between this muscle and the sulcus intertubercularis, often with fibres sent to the aponeurosis of the Mm. biceps and/or coracobrachialis and to the tunica vaginalis intertubercularis. The arch is innervated variably by branches of the plexus cervicalis or brachialis. According to the literature the AA has been the subject of numerous descriptions on cadaveric material and in a lesser extend on in-vivo populations, giving this anomaly a rather popular status and an up-grade from anomaly to muscular variant (3).
The name of Langer (5) is generally attached to the most frequent form, the Axillary Arch (of Langer). Most authors find AA's in 8 to 10% of the subjects, but the extremes go up to 27% (11). The arch can be evaluated and/or palpated (figure 1).

Figure 1. The Muscular Axillary Arch of Langer in-vivo and Post-Mortem.

Because of the incidence of the AA and because of its assumed clinical relevance (assumed compression syndrome), an in vivo screening of function and position sense in athletes is over due. This is supported by the fact that e.g. Thoracic Outlet Syndromes (TOS) have been diagnosed in aquatic athletes also (4, 8, 12). The purpose of this study is to evaluate the proprioception, strength, precision and motor control influences of the presence of an AA in healthy (overhead) athletes. The obtained information should provide a better understanding of shoulder problems in swimmers and waterpolo-players.

METHODS
Three hundred and twenty seven (327) PE students (19 to 25y.), all good to average swimmers, were screened for the presence of one or two muscular AA indepently by two manual therapy experts. Twenty five persons had at least one AA of which 22 subjects participated in all tests. An equal number of subjects were at random selected as a control group (without AA).
A series of shoulder/arm tests were selected e.g.: *Elevated arm stress tests:* because of the anatomical evidence (3) testing with the arms in abduction seemed imperative. Maximal isometric hand/arm strength was measured with a factory calibrated Bettendorff Hand-Held Dynamometer (HHD) in 4 positions: a) alongside the body; b) in horizontal abduction; c) in maximal (vertical) abduction and d) arms in horizontal abduction with the elbow-flexed (90°) with forearm/hand vertical upwards (2 trials, 15 sec rest).
Maximum isometric strength tests: In addition to HHD, maximum isometric strength of the arm-shoulder muscular chain, both in abduction, adduction and throw or push/pull position, were measured with a BTE® primus work simulator (Baltimore Therapeutic Equipment co.) (figure 2) (3 trials; 30 sec rest). Consistency of effort is quantified by a coefficient of variation score.

Figure 2. I. Abduction/adduction testing of the shoulder with extended arm; II. Max. isometric strength of vertical ante-retroflexion; III. Simulated throw or push/pull in max. isometric and the endurance test conditions (BTE® primus work simulator).

Dynamic Endurance test: The Dynamic Endurance test is measured with the BTE® primus work simulator also. Two endurance tests were measured, both at 60 RPM within 1 min. over the full range of motion against an individually normalized resistance. The force was set at half of the averaged level that was used for the maximal isometric test of the weaker of the two extremities.(i) Adduction Endurance test (+/- 135°) with an extended arm, and (ii) (simulated) Throw or push/pull Endurance test (+/- 90°) of the flexed forearm with a rotation of the abducted upper arm.

Shoulder proprioception test: Proprioception is the sensory modality of touch that encompasses the sensation of joint kinaesthesia and joint position sense (7). It involves measuring the accuracy of joint position replication. Since joint proprioception appears to play an important role in stabilizing the glenohumeral joint and the management of muscular activity (2) an active repositioning test was chosen. The "Index Finger Touch Test" (IFTT) is executed with the blindfolded subject standing at arm distance of a screen of which the midpoint corresponds with the eye level of the subject. The subject is guided with its Index finger top by the examiner to 3 vertical bars (H 30 cm, interdistance 15 cm) on the screen. After the 3 guided "finger touches" the subjects leaves the arm against the body for 5 sec and tries subsequently to reposition the index on the location touched before. This test is repeated twice left and right (Clarys et al. unpublished data, 2005).

Statistics

All data were handled with SPSS 12.0 including. Normality distribution t-test ($p<0.05$), one-sample and two-sample Kolmogorow-Smirnov test (numerical data); the Pearson Chi-Square, the Ficher's Exact test and the Linear-by-Linear association (score type data).

RESULTS AND DISCUSSION

In order to discriminate influences and effects between overhead athletes with and without an AA both groups were homogeneous and allowed for comparison of various strength and proprioceptive measurements. Figure 3 shows the HHD results for gender and both arms with and without an AA. Men and women score significantly different ($p<0.05$) as could be expected. It is interesting however to see that there is no significant difference between men with and without an AA while there is a difference ($p<0.05$) in women, e.g. the presence of an AA enhances the isometric strength in women but is almost equal for both groups in men. The strength increase in female due to an AA, may explain why paresthesia (twingling) was observed more consistently in women (with AA) than in man. This reaction suggests a nervous compression which in clinical circumstances could allow for a TOS indication (1, 13).

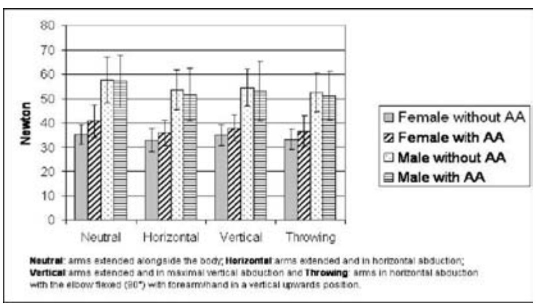

Figure 3. H.H.. Dynamometry of 4 shoulder positions.

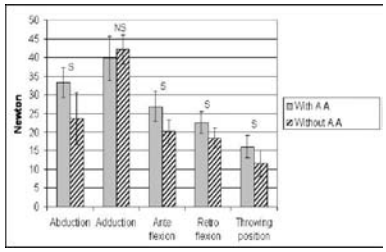

Figure 4. BTE isometric strength in women ($p<0.05$).

Both the BTE® maximum isometric strength and the dynamic endurance confirm the HHD test results: no differences in men but significant differences ($p<0.05$) in women both for the isometric maximum (figure 4) and the dynamic endurance testing (figure 5). In other words the presence of an AA increases the strength and the endurance of the overhead shoulder of the female athlete, while this effect was not significant in men. Referring to the TOS diagnose and its female to male ratio of 4:1 the question rises whether this is not overrated because of undiagnosed Axillary Arches in women? … Or the AA explains part of the ratio? As the neuromuscular control increases, the AA, will have stabilizing effect. However it remains an interesting phenomenon that in women the AA probably influences isometric, dynamic and endurance strength while the presence of an AA assumes a more stabilising capacity in men. The combination of these findings conflict with the compression theories of the AA, has led to excision (3, 10). Our findings suggest the opposite since the strengthening and stabilising function of the AA increases the quality of the overhead motion and therefore creates better opportunity to enhance performance rather than to decrease it (4, 6, 9).

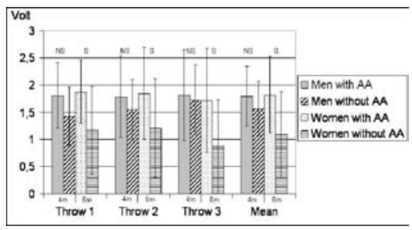

Figure 5. BTE throw/pull/push endurance in male and female ($p<0.05$).

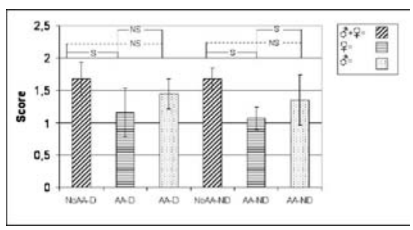

Figure 6. Average of the proprioceptive IFTT score of the Dominant (D) and Non Dominant (ND) arm with an Axillary Arch (AA) versus the control group (No AA) for men and women separated ($s=p<0.05$).

Again, the logical continuation of data acquisition is the proprioceptive testing of the articular and neuromusculo position sense. The Index Finger Touch Test (IFTT) results are averaged for both the dominant and non-dominant arm (figure 6). The AA influences the proprioceptive joint position sense both in men and women, but again more discriminative for the female, showing a lower joint position sense. These findings indicated that repositioning accuracy for ± 90° abduction/ante flexion movements again might be influenced by an AA for both in the dominant and the non- dominant arm. The sensation of movement is markedly enhanced by the contracted AA and again stresses the fact that its stabilising function is important.

CONCLUSIONS

The in-vivo detection of an Axillary Arch in a young, healthy and homogeneous population is in agreement with the incidence found on cadaveric material (non-homogeneous and aged samples). The AA seems to involve women significantly more than men. The AA increases their hand strength, their shoulder abduction and adduction strength, both static and dynamic; it increases their throw/pull/push endurance capacity but creates minor paresthetics too. The AA decreases their joint position sense.

In the "balance" the AA seems to have more positive effects than negative and does not destabilise the shoulder. These data suggest that the diagnoses of an AA no longer results in an excision of this supernumerary muscle and that the AA is an extra compression of TOS cannot be supported anymore.

ACKNOWLEDGEMENTS

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APPLICATION OF A PROTOCOL FOR EXERCISE INTENSITY PERCEPTION IN SUBJECTS WITH MULTIPLE SCLEROSIS EXERCISING IN THE WATER.

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Acute physical fatigue (APF) is one of the most common problems related to Multiple Sclerosis (MS), as the perception of fatigue is a very subjective and individual matter which can be different among subjects. Usually water activities are adopted as a healthful treatment to improve MS affected subjects' quality of life, but sometimes not respecting intrasubject variability or exercise capability. The aim of this study was to examine if CR10 scale for rating of perceived exertion (RPE) could be useful to manage with exercise intensity and effort perception in 4 subjects suffering different grades of MS. The results showed that subjects could improve their exercise intensity perception (production of intensities of 3, 6, and 9 grades in CR10 scale) after a three week treatment. Due to the results, it can be argued that RPE can be a useful tool when prescribing exercise intensity with subjects suffering MS.

Key Words: Multiple Sclerosis, physical activity, RPE, fatigue and water exercises.

INTRODUCTION

Multiple Sclerosis (MS) is characterized by variables symptoms (8) that have to be treated in an interdisciplinary way. It is widely accepted to point out the necessity of using physical activity in the programs applied with subjects suffering Multiple Sclerosis (MS), as a very useful way to improve their quality of life (6, 10). One of the most common problems related to this pathology is the acute physical fatigue (APF) that is suffered by 75 to 95% of the patients (4). Its impact into the quality of life is very high, many times implicating daily common activities. So, APF becomes one of the greatest problems to be treated, as the perception of fatigue is a very subjective and individual matter which can be different among subjects.

Changes in the temperature can produce crisis of APF; in fact, exercise and related body temperature elevation are shown as factors that can increase fatigue (2, 3). Usually activity in the water is adopted as a healthful treatment to improve MS affected subjects' quality of life, because of some characteristics of this singular environment -flotation, hydrodynamic resistance, viscosity…- (5, 7), adding that immersion in the water can decrease body temperature. This could help to practice physical activity reducing the risk of hyperthermia.

The aim of this study was to examine if CR10 scale (1) for rating perceived exertion (RPE), could be useful to manage with exercise intensity and effort perception in subjects suffering different grades of MS, when practicing out of the swimming pool but also when practicing in the water. So, it was hypothesized that subjects could regulate exercise intensity and this could be useful not to pass the individual threshold above which APF can be reached. This is very important as APF can also influence negatively MS and everyday physical activity.

METHODS

Subjects: Four participants suffering different grades of MS (1 to 4, from the lowest grade to the highest) took part in the study. They were two women and two men; age 29±4 ys; weight 57,03±12,51 kg; height 1,60±0,12 m and BMI 22,1±3,4 %). Materials: indoor swimming pool of 25 x 12.5 m and a track of 43 m; Thermometer, hygrometer, and barometer (Oregon Scientific); 4 heart rate (HR) monitors (S610i; Polar Electro, Finland); 1 Chronometer (Casio, Japan); Diaries and observation sheets. Protocol: Three pretest sessions were developed, and subjects completed in each 3 different exercises (walking in a track out of the water, walking in the water -to the sternum-, and swimming) at three different intensities during 3 min each one and constantly developed (3, 6, and 9 in Borg's CR10 scale (1)), corresponding to low, intermediate, and high intensities, respectively, in a randomized order each session (to eliminate the potentially contaminant effect of the order of prescribed intensities). Later, a treatment of 6 sessions during 3 weeks (2 per week, lasting 30 min each) was carried out using different tasks combining the 3 different intensities and giving the subjects feedback abut their performance: HR, distance, velocity, time, or repetitions; significant, useful and easy to measure indexes (9). The postest was developed repeating the 3 pretest sessions, to evaluate if subjects could produce the prescribed intensities more accurately after the treatment period. Environmental conditions were controlled in each session, reporting temperatures of 25.5° C (1.87), pressure of 1020.8 mb (3.9), and humidity of 67.3 % (6.9). Temperature of the water was 29ºC. Also, heart rate -each 5 s-, distance covered -m-, a personal diary -reporting sensations, mood state, perceived fatigue,… before, during and after the sessions-, were registered. Statistical analysis: intrasubject repeated measures ANOVA with Bonferroni *post hoc* were developed (SPSS 12.0 statistical software) to determine if the 3 intensities (HR) were clearly differentiated and produced by the participants, and also to determine the possible differences between each activity of the pretests and postests. Statistical difference was accepted when $p<0.05$.

RESULTS AND DISCUSSION

Subject 1, the less affected participant, (figure 1) was able to discriminate the 3 levels of intensity ($p<0.001$), in the majority of the proposed tasks, although after the treatment this is done in a more stable way. It was found changes in the correct perception of intensity when walking in the water, as in the second session of pretest (PRE2), HR for 6 points task was lower than for intensity of 3.

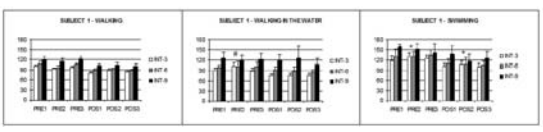

Figure 1. HR showed by Subject 1 for the pretest and postest tasks.

Swimming, subject 1, could not discriminate between 3 and 6 intensities ($p>0.05$) during PRE 2 and POS2 sessions. These correspond to the sessions that started with intermediate intensity, showing a greater difficulty to distinguish between intensities when the order was not incremental or detrimental. This feeling is reported by this subject in the personal diary. The lack of affectation of the MS symptoms in this subject and the greater experience in sport practice could explain the capacity of this subject to measure out when executing the prescribed intensities.

Subject 2 was more affected of MS (described as type 2, this subject was moderately affected -normally walking with a crutch-), and shows in figure 2 significant differences ($p<0.001$) just when the sessions started gradually increasing intensity from 3 to 9 (sessions PRE1 and POS2). When tasks were presented in detrimental order of intensity, difficulties to discriminate levels 6 and 9 of intensity ($p>0.05$) appear in PRE3 when walking, and in PRE3 and POS3 when swimming.

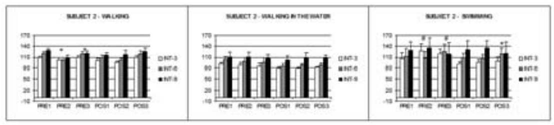

Figure 2. HR showed by Subject 2 for the pretest and postest tasks.

In these two tasks, there were no differences between 3 and 6 points ($p>0.05$) when the first intensity was intermediate -6 points- (PRE2), situation that was corrected after the treatment. In this case, similarly to subject 1, difficulties to perform different intensities were related to the order of execution, being more complex when the tasks were not developed in an incremental order of intensity, although this was corrected after the treatment. The best results were obtained walking in the water, requiring lower HR and showing a better grade of discrimination of intensities, so that it could be justified by the better stability and security that subject feels when walking without the necessity of any additional implement. The greater effort observed -HR- is when swimming, possibly due to the technique limitations (this was confirmed in the personal diaries).

Subject 3 presented in the initial measurements (figure 3) difficulties to discriminate correctly the different intensities when the order was not presented in an incremental way; for the order 6-9-3 when walking in the water, no significant differences were found -$p>0.05$-, lower HR were shown at higher prescribed intensities when walking and swimming, although these situations were corrected after the treatment except walking. The grade of affectation of subject 3 allows walking in the water without implements because of flotation. In the same way than for subjects 1 and 2, for subject 3 the greater effort appeared when swimming as the domain of the technique was not great.

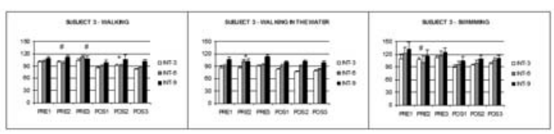

Figure 3. HR showed by Subject 3 for the pretest and postest tasks.

Subject 4 is the more affected by MS, using normally a wheelchair for the displacements. This is reflected in the greater difficulty during walking (using two crutches). In figure 4 it is observed that in PRE1, PRE2, and PRE3, subject when walking is not able to discriminate between the 3 grades of intensity, showing small differences for the HR of all the different tasks ($p>0.05$).
After the treatment, subject 4 could discriminate moderately when walking between the 3 types of intensity for POS1 and with more difficulties for POS2 (not between 3 and 6), and POS3. Walking in the water, for PRE1 intensities were developed the contrary than prescribed, decreasing HR when the order was 3-6-9. After the treatment, it is observed an improvement although with difficulties between intensities of 3 and 6 ($p>0.05$). Swimming, before and after the treatment the subject was able to discriminate between the 3 intensities (except in PRE1 for intensities 3 and 6), although after the treatment this differentiation was more clear. This subject seemed not to show clearly the order in which the different intensities were presented. The functional limitations, greater in this subject, determined the executions so that the main problem to discriminate the intensities was due to this problem more than to the subjective perception -this was corroborated in the diaries-. The best results were observed in the water, mainly because flotation effect of the water allowed this subject to execute better by decreasing the functional limitations.

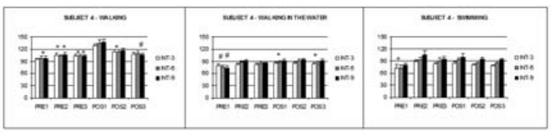

Figure 4. HR showed by Subject 4 for the pretest and postest tasks.

It can be argued that, when the affectation is moderate to high -grades 2 to 4-, it is easier to discriminate intensities for the tasks developed in the water, so that we hypothesize that hydrostatic pressure favours subjects' movements and, therefore, subjects' focusing on exercise perception rather than in the technique. Also, subjects with more affectation (2 to 4) reported in their diaries that hot conditions clearly affect them so that in the water they feel better to exercise physically.

CONCLUSIONS

1. Subjects suffering MS can use RPE scales to better discriminate and produce different and individual exercise intensities. This can be especially useful to avoid APF.
2. Special and singular characteristics of water favour perception and regulation of effort, although this is mediated by the type of task and its domain by the subject. Specifically, flotation makes easier some tasks for the subjects when the affectation is moderate or higher.

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INJURIES INCIDENCE IN BRAZILIAN SWIMMERS OF DIFFERENT STROKES

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The aim of this study was to identify the incidence, place and diagnosis of injuries in competitive Brazilian swimmers, according to the stroke. The sample was composed by 137 competitive elite swimmers. The instrument used was a mixing questionnaire. Seventy (51%) of the evaluated athletes suffered some kind of injury. During competition, 19 athletes referred injury. The most affected segment was the shoulder (53%) and the tendinitis was the most frequent diagnosis (72%). According to each kind of stroke, it was verified: a) tendinitis was the most frequent injury for the butterfly (80%), crawl stroke (86%) and breaststroke (75%) swimmers. For medley, both the tendinitis and the muscle strain were the most observed injuries (43%); b) the most affected segment was the shoulder for the butterfly (50%), backstroke (63%), crawl (56%) and medley (44%) swimmers. The knee was the most affected segment for the breaststroke swimmers (62%).

Key Words: injuries, swimming, different strokes, epidemiology, Brazil, incidence.

INTRODUCTION

According to Ciullo and Stevens (2), elite swimmers generally are submitted to 11 or more sessions of 2 hours of duration per week. The swimmer makes in average about 12000 m of swim per day. In crawl swimming, during the training, the athlete carries through 8 to 10 cycles of arm to each swimming pool, totalizing about 1 million of shoulder rotations per week (5).

Thus, the competitive and high level swimming expose the athletes to situations of constant stresses. These innumerable repetitions of technical gestures, allied to an eminent factor to the training, the unbalance between the work and the time of recovery, are considerable predisponents for injuries. The accumulation of stress or microtrauma in a region of the body depends on the movement that is executed by the athlete. For example the arm and leg movements in the crawl stroke are executed with physical valences and different mechanical requests than in breaststroke. Thus, it can be expected that the accumulation of stress/microtrauma locates differently for crawl and breast strokes.

To verify if this different muscular and mechanics requests between the swim styles will cause different forms of injury this study was carried through. It aims to identify the incidence, the place and the diagnosis of the injuries in Brazilian elite swimmers according to the stroke through the descriptive epidemiology.

To carry through the survey of which injury is more common according to the stroke is the first step in a work of injuries prevention approaching each style of different form, once the diagnosis of which injury is more frequent for each stroke is made.

METHODS

The study was characterized as descriptive study and the sample was composed by 137 swimmers that participated of the Brazilian Championship of Swimming – Brazil's Trophy 2004, in Rio de Janeiro, RJ. The characteristics of the athletes are presented in Table 1.

Table 1. Main characteristics of the swimmers.

	number	Male	Female	Age (yy)	Swim start age (yy)	Years (yy) of practice
Swimmers	137	77	60	19±3	6±3	14±4

The used instrument was a mixing questionnaire elaborated by the National Center of Sports Excellency for the National Project "Champion Profile", which objective was to identify the profile of Brazilian athletes of several modalities in order to improve the public politics of sports in Brazil. In order to stimulate the sample participants, the questionnaire has a brief explanation about the investigated topics and the importance of the research, including the guarantee of the answers secrecy. All the procedures had been taken and of this form the questionnaire was applied during the events.

The data collection was carried out generally before the beginning of each competition, through a previous contact with coaches and athletes. The questionnaire was answered at the moment of the application when the athletes were able to do it, with the researcher's accompaniment, who redressed doubts about the questions. From the gotten answers the data base was formed and analyzed through the descriptive statistics.

RESULTS

With the questionnaire data and fulfilling with the objective of tracing a profile of the incidence of the injuries in Brazilian swimmers of the elite, it was observed that from the 137 athletes, 70 (51%) had already suffered some injury We cross the data of the corporal region affected with the diagnosis of the injury to obtain the most affected body region, and these data are in Table 2.

Table 2. Data of the place of the body and diagnosis for the former injuries.

Body´s Place	Diagnosis	Tendinitis	Back pain	Muscular Strain	Instability	Ligament Rupture	Total
	Shoulder	28	-	-	2	1	31
Upper	Arm	6	-	2	-	-	8
Limb	Wrist	1	-	-	-	-	1
	Thigh	-	-	7	-	-	7
Lower	Knee	5	-	-	-	-	5
Limb	Leg	-	-	1	-	-	1
	Foot	1	-	-	-	-	1
Trunk	Back	1	2	1	-	-	4
Total		42	2	11	2	1	58

The data between the place of the body where the injury occurred and the swim style are in Table 3.

Table 3. Data of the body place and stroke for the former injuries.

Body Segment	Stroke	Butterfly	Backstroke	Crawl Stroke	Breaststroke	Medley	Total
	Shoulder	8	5	13	3	4	36
Upper	Arm	5	-	3	-	1	9
Limb	Wrist	-	-	1	-	-	1
	Thigh	-	1	2	2	2	7
Lower	Knee	1	1	-	5	1	7
Limb	Leg	1	-	-	-	-	1
	Foot	-	1	-	-	-	1
		-	-	1	-	-	1
Trunk	Back	1	-	3	-	1	5
Total		16	8	23	10	9	

The data between the diagnosis of the injury and the swim style are in Table 4.

Table 4. Data of the diagnosis and stroke for the former injuries.

Diagnosis	Butterfly	Backstroke	Crawl Stroke	Breaststroke	Medley	Total
Tendinitis	12	6	13	6	3	42
Back Pain	-	-	2	-	-	2
Muscular Strain	1	1	4	2	3	11
Instability	1	-	-	-	1	2
Ligament Rupture	1	-	-	-	-	1
Total	15	7	19	8	7	58

Intending to investigate the number of injured athletes at the moment of the questionnaire application, or either, during the accomplishment of the competition, it was investigated incidence of current injury and its respective place and diagnosis. The data of the body region where the injury occurred and the diagnosis of the injury are in Table 5.

Table 5. Data of the body region and diagnosis for the current injuries.

Region	Diagnosis	Tendinitis	Back pain	Muscular Strain	Instability	Synovitis	Total
Upper Limb	Shoulder	8	-	-	1	-	9
Lower	Thigh	-	-	1	-	-	1
Limb	Knee	-	-	-	-	1	1
Trunk	Back	-	2	-	-	-	2
total		8	2	1	1	1	

The data between the body region where the injury occurred and the swim style, for the current injuries, are in Table 6.

Table 6. Data of the body region and style of I swim for the current injuries.

Region	Style	Butterfly	Backstroke	Crawl Stroke	Breaststroke	Medley	Total
Upper Limb	Shoulder	4	3	5	1	1	14
Lower	Thigh	-	-	1	-	-	1
Limb	Knee	-	-	1	-	-	1
	Foot	-	-	1	-	-	1
Trunk	Back	-	1	1	-	-	2
total		4	4	9	1	1	19

The data between the diagnosis and the swim style, for the current injuries, are in Table 7.

Table 7. Data of the diagnosis and swim style for the current injuries.

Diagnosis	Butterfly	Backstroke	Crawl Stroke	Breaststroke	Medley	Total
Tendinitis	2	2	2	1	1	8
Back Pain	-	1	1	-	-	2
Muscular Strain	-	-	1	-	-	1
Instability	1	-	-	-	-	1
Synovitis	-	-	1	-	-	1
Total	3	3	5	1	1	13

DISCUSSION

In this study half of the athletes (70 athletes or 51%) had already suffered some injury during its career in this sport. Blanch (1) report greater frequency of former injuries in the athletes with bigger competitive level and relate this bigger number of injuries the biggest requirement in the training allied to a bigger time of practice of these athletes. Tendinitis was the former injury with bigger incidence. Since tendinitis is an injury characterized by stress located in the region of the tendon, it is credited that the biggest frequency of this injury is associated with the strong and constant training loads and the repetition of gestures that induces this dysfunction.

According to Concatorro (3) the tendinitis can result from the effort to which the athlete submits himself in the training. In this research the percentage of this type of injury increased approximately in 20% with the increase of the competitive level, passing from 54% in the athletes of the group 2 for 70% in the 3.Such results indicate that the tendinitis is related to the load increase in the training. Studies of Blanch (1), Kammer, et al. (5), Johnson, et al. (4) confirm such rank emphasizing the cause of tendinitis related to the high demand in the training and to the gestures repeatability.

The region where the biggest number of injuries occurred was the shoulder, result already expected, since this is a region of great requirement during the practice of this modality. The same data was found by Blanch (1), Kammer, et al. (5) and Johnson, et al. (4).

For the crawl, back and butterfly strokes, tendinitis was the main diagnosis and the most affected region was the shoulder. In the butterfly style the arm was also a place with great incidence of tendinitis. In these three styles of swim the upper limb is very demanded during the execution of swim and it is the main propellant for the displacement of the swimmer. For the breaststroke the tendinitis was also the most frequent injury, even so the place where it occurred more frequently was the knee. In this stroke, according to Ramos and Redondo (6), great part of the propulsion of the swimmer is executed by the leg, in which the swimmer carries through a very aggressive movement to this joint, moreover, this is executed with great frequency and intensity, what ends up stressing the structures of this segment.

In the medley stroke there was the same distribution of tendinitis in the shoulder and muscular straining, probably by the great diversity of necessary abilities for each swim and, also, by the predominance of the swimmer in determined stroke, what demands from himself great effort for compensation in considered deficient strokes, in which its technique is not so refined.

The referring results to the former injuries confirm what literature praises (1, 4, 5, 6) about the concern with the "swimmers shoulder" or shoulder tendinitis, and still with the knee joint. These facts agree with the experience in swimming and point out that it must be emphasised the factors of training and prevention of injuries in these two joints that are commonly affected in the swimmers.

About the frequency of injuries, the incidence of the current ones was lesser than observed for the former injuries. The most observed pathology for the two situations was tendinitis, and the most affected regions had been respectively the shoulder, the knee and the column. Concerning the localization, for the current injuries the distribution was similar to the former injuries, even so observed greater incidence of injuries in the column that in the presentation of the former injuries. This high incidence of back injuries was expected because according to Kammer, et al. (5) this region is also very requested in swimming, mainly for the butterfly swimmers due to the movements of trunk for propulsion, typical of this swim stroke.

CONCLUSION

There was a great percentage of injured athletes and the diagnosis of the injuries points out with respect to the biggest incidence of the tendinitis, that can be provoked by repetitive efforts, suggesting more attention to the load of training and the repeatability of the gestures. About the injury region, the biggest focus was the shoulder, followed by the knee, what suggests a bigger concern with such joints during the training of this sports modality. In respect to the swim stroke; for crawl, back and butterfly shoulder tendinitis was the main injury. For the breaststroke the main diagnosis also was the tendinitis, even so the main cited segment has been the knee. Finally, for medley there was the same distribution between tendinitis and muscular strain.

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EFFECT OF SWIMMING TRAINING ON LEFT VENTRICULAR DIMENSIONS AND FUNCTION IN YOUNG BOYS

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The aim of the present study was to determine the effect of swimming training on left ventricular (LV) cardiac morphology and function in young boys. Antropometric measurements, body composition estimation and resting M–mode and Doppler echocardiography were performed in 24 boys (15/16 years), 12 swimmers and 12 age matched non athletes (control group). Swimmers had higher rest stroke volume, LV end-systolic volume and LV end-diastolic volume than the control group. Fifty percent of the swimmers exhibited end–diastolic LV internal chamber dimension above normal (> 54 mm). As showed by parameters measured, adaptation to exercise mode induced a typical "athlete's heart" with dominance of volume and diameter (eccentric LV hypertrophy) and mild changes in LV mass. The results supported the concept of an influence of systematic swimming training on the diastolic function.

Key Words: left ventricular hypertrophy, athlete's heart, cardiac function, echocardiography.

INTRODUCTION
It is well established that the cardiac muscle adapts to an increased hemodynamic load following the specificity of the exercise training: a volume load leads to eccentric left ventricular (LV) hypertrophy and a pressure load is associated with a thickening of the ventricular wall with unchanged internal dimension, inducing a concentric LV hypertrophy (10). Long–term athletic training is associated with morphologic left ventricular remodelling, which may be substantial in elite athletes, and raise the need for differential diagnosis regarding structural heart disease, especially hypertrophic cardiomyopathy (12, 13, 14), responsible for 1/3 of sudden deaths in young athletes (17). If in adults cardiac morphological and functional adaptive changes after training are well documented, in children and young boys far less information is available (11, 15), despite the increasing involvement of young athletes in intensive training regimens, little is known about the influence of such training on autonomic regulation and cardiac structure and function (19). The purpose of this study was to determine the effect of swimming training on LV cardiac morphology and function at rest in young boys.

METHODS
Twenty four boys took part in this study (table 1). They were separated into two groups: swimmers (SA) and control group (CG). The swimmers performed 7 – 8 training sessions a week, of about 110 min duration and with a volume of 5000 m each, 85/90% on aerobic zones, together with some out of water preparation, predominantly muscular endurance weight training. Both SA and CG groups attended physical education sessions at school, twice (90 min plus 45 min) or 3 times a week (45 min each).

*Table 1. Age, physical characteristics and body composition of subjects. BSA - body surface area; BMI - body mass index; BFP - body fat percentage; BFM - body fat mass; FFM - fat free mass. *p < 0.05; **p< 0.01.*

	Control Group			Swimmers		
	Mean±S.D.	Max	Min	Mean±S.D.	Max	Min
Age (years)	15.9± 0.2	15.8	14.3	15.9± 0.2	16.2	15.5
Height (m)	1.71± 0.06	182	160	1.75± 0.06	185	167
Body mass (kg)	58.3± 6.0	68.9	48	64.2± 6.8*	75	52.9
BSA (m^2)	1.66± 0.11	1.82	1.47	1.77± 0.12*	1.94	1.57
BMI ($kg.m^{-1}$)	20.0± 1.6	22.8	17.2	20.9±1.4	22.9	19.0
BFP (%)	11.0±1.4	13.4	9.0	9.4±1.3**	11.8	7.7
BFM (kg)	6.4±1.0	8.0	5.1	6.0±1.2	8.9	4.7
FFM (kg)	51.9±5.6	61.1	42.2	58.2±6.0*	66.1	48.1

Two dimensionally guided M mode recordings were obtained parasternally in accordance with the recommendations of the American Society of Echocardiography (16). All the measurements were performed by the same investigator. Left ventricular (LV) wall thickness and internal diameter were obtained by positioning the trackball cursor on the screen. The echocardiographic parameters measured included: end–diastolic LV internal chamber dimension (LVIDd), end–systolic LV internal chamber dimension (LVIDs), posterior wall thickness (PWT), septal wall thickness (ST), LV end-diastolic volume (LVedV), LV end-systolic volume (LVesV), resting heart rate (HRr), and cardiac output (Qc). Derived parameters were calculated as follows: relative end–diastolic wall thickness (RWTd) by the quotient (PWT + ST)/LVIDd, LV mass by 0,8 x (1,04 (ST + PWT + LVIDd)^3 – LVIDd^3) + 0,6 (7), LV volumes were obtained according to Teicholz formula (7/(2,4 + LVIDd) x LVIDd^3), LV shortening fraction (FS %) by the quotient (LVIDd – LVIDs)/LVIDd) x 100 and the ejection fraction (EF %) by (TDV–TSV)/TDV) x 100 stroke volume (SV). Early (E) and late (A) diastolic peak filling velocities, disacceleration E time (DT) and E/A ratio were estimated by pulse wave Doppler measurements in the 4 chamber apical view. Echocardiographic data was expressed in absolute units and then scaled allometrically for anthropometrical data - body mass (BM), height (H), body surface area (BSA), body fat percentage (BFP) and fat free mass (FFM). Exponents for allometric scaling were generated according to the dimensionality theory and supported by cardiological studies (4, 5), exercise science research (2, 3) and elite athlete studies (9). Mean values were compared using the "t" test for unpaired data. Differences at $p \leq 0.05$ were regarded as significant.

RESULTS AND DISCUSSION

SA and CG were of similar age, but with different anthropometric and body composition characteristics (table 1). The SA group was significantly heavier ($p < .05$), had greater BSA ($p < .05$), owing to significantly reduced BFP ($p < 0.01$) and had a greater FFM ($p < 0.05$), compared to CG.

Mean values for cardiac dimensions (table 2) in the SA and CG group were within normal ranges (8, 18). Absolute LVIDd and LVIDs were significantly greater in SA than CG ($p < 0.05$). The differences between the groups persisted after allometric scaling of LVIDd by height, $BM^{-0.33}$, $BM^{-0.433}$, $FFM^{-0.33}$, $FFM^{-0.441}$, $BSA^{-0.678}$ and $BFP^{-0.251}$ ($p < .05$) and LVIDs by $BM^{-0.33}$, $BM^{-0.361}$, $FFM^{-0.33}$, $FFM^{-0.373}$, $BSA^{-0.584}$ and $BFP^{-0.253}$ ($p < .05$).

Fifty percent of SA exhibited LVIDd above normal (> 54 mm) (6, 18) and dilatation of LVIDd (mean ± 1.96 SD = 47.59 ± 1.96 (3.32) = 54.09 mm) (1,13) but not left ventricular hypertrophy, according to standard criteria of ST or PWT > 13 mm and LVIDd > 60 mm (13). CG displayed significantly greater mean values for relative end–diastolic wall thickness (RWTd) ($p < 0.01$) but both groups showed LV eccentric enlargement (RWTd < 0.44). The differences between the groups appeared after scaling of ST by $height^{-1}$ and $BSA^{-0.5}$ ($p < 0.05$) and PWT by height, $BM^{-0.33}$ and $FFM^{-0.33}$ ($p < 0.05$).

LVM was greater in SA than in CG, after allometric scaling by $BSA^{-1.5}$ ($p < 0.05$).

Table 2. Absolute and allometrical scaled left ventricular dimensions in control group (CG) and swimmers (SA).

	CG		SA			CG		SA	
	M	SD	M	SD		M	SD	M	SD
LVIDd (mm)	47.6	3.3	**53.6***	2.4	**LVIDs (mm)**	28.7	2.5	**32.7***	1.7
LVIDd.$BSA^{-0.5}$	57.4	3.3	61.0	4.4	LVIDs.$BSA^{-0.5}$	34.6	3.0	**37.2***	3.2
LVIDd.$height^{-1}$	27.9	1.8	**30.6***	1.6	LVIDs.$height^{-1}$	16.8	1.5	18.7	1.1
LVIDd.$BM^{-0.33}$	12.5	0.67	**13.6****	0.7	LVIDs.$BM^{-0.33}$	7.5	0.6	**8.3****	0.5
LVIDd.$FFM^{-0.33}$	12.9	0.72	**14.1****	0.7	LVIDs.$FFM^{-0.33}$	7.8	0.6	**8.6****	0.5
LVIDd.$BM^{-0.433}$	8.2	0.43	**8.9****	0.5	LVIDs.$BM^{-0.361}$	6.6	0.5	**7.3****	0.5
LVIDd.$BSA^{-0.678}$	33.7	1.80	**36.5****	2.1	LVIDs.$BSA^{-0.584}$	21.3	1.7	**23.5****	1.5
LVIDd.$FFM^{-0.441}$	8.4	0.46	**9.0 ****	0.5	LVIDs.$FFM^{-0.373}$	6.6	0.6	**7.2****	0.5
LVIDd.$BFP^{-0.251}$	87.3	7.8	**94.2****	4.1	LVIDs.$BFP^{-0.253}$	52.6	5.6	**57.5***	1.9
ST (mm)	8.9	1.1	9.0	1.1	**PWT (mm)**	9.3	0.9	8.8	1.0
ST.$BSA^{-0.5}$	10.8	1.3	**10.3***	1.1	PWT.$BSA^{-0.5}$	11.2	1.1	10.0	1.0
ST.$height^{-1}$	5.2	0.7	**5.2***	0.5	PWT.$height^{-1}$	**5.5***	0.6	5.1	0.5
ST.$BM^{-0.33}$	2.3	0.3	2.3	0.3	PWT.$BM^{-0.33}$	**2.4***	0.2	2.2	0.2
ST.$FFM^{-0.33}$	2.4	0.3	2.4	0.3	PWT.$FFM^{-0.33}$	**2.5***	0.2	2.3	0.2
ST.$BM^{-0.375}$	2.1	0.2	2.1	0.2	PWT.$BM^{-0.160}$	4.7	0.4	4.4	0.5
ST.$BSA^{-0.515}$	6.9	0.8	6.8	0.7	PWT.$BSA^{-0.229}$	8.3	0.8	7.8	0.8
ST.$FFM^{-0.328}$	2.4	0.3	2.4	0.3	PWT.$FFM^{-0.135}$	5.5	0.5	5.1	0.5
ST.$BFP^{-0.030}$	9.6	1.2	9.7	1.1	PWT.$BFP^{-0.004}$	11.4	1.2	10.7	1.1
LVM (gr)	150	33	177	33	**PWT/LVIDd**	**0.19****	0.02	0.17	0.17
LVM.$BSA^{-1.5}$	59.9	11.6	**66.8***	11.1	**ST/LVIDd**	**0.19***	0.02	0.17	0.02
LVM.$height^{-3}$	29.2	6.4	33.7	5.8	**RWTd**	**0.38****	0.39	0.33	0.37
LVM.BM^{-1}	2.6	0.5	2.8	0.5					
LVM.FFM^{-1}	2.9	0.5	3.1	0.5					
LVM.$BM^{-1.075}$	1.9	0.3	2.0	0.3					
LVM.$BSA^{-1.633}$	65.1	12.1	70.1	11.6					
LVM.$FFM^{-1.047}$	2.4	0.4	2.5	0.4					
LVM.$BFP^{-0.390}$	382	93	421	69					

LVIDd: end–diastolic LV internal chamber dimension; LVIDs: end–systolic LV internal chamber dimension; ST: septal wall thickness; PWT: posterior wall thickness; RWTd: relative end–diastolic wall thickness; LVM: LV mass; BM: body mass; BSA: body surface area; FFM: fat free mass; BFP: body fat percentage; * $p < 0.05$; ** $p < 0.01$

*Table 3. Left ventricular function in the control group (CG) and swimmers (SA). HRr - rest heart rate; Qc - cardiac output; SV - stroke volume; E/A - E/A ratio; EF - ejection fraction; LVesV - LV end-systolic volume ; LVedV - LV end-diastolic volume; DT - desaceleration E time; Peak E - early (E) diastolic peak filling velocitie; Peak A - late (A) diastolic peak filling velocitie; FS - LV shortening fraction. ** p<0.01*

	CG		SA		
	M	SD	M	SD	
HRr (bpm)	55.5		55.5	6.4	
Qc(l.min^{-})	4.12		**5.3**	0.7	**
SV (ml)	74.9		**95.5**	11.2	**
E.A	2.8	0.3	2.6	0.5	
EF (%)	69.7	3.1	68.3	2.8	
LVesV (ml)	32.7	7.0	**44.2**	5.4	**
LVedV (ml)	107.6	18.0	**139.7**	14.2	**
TD (ms)	92.4	33.5	90.8	25.5	
Peak A (ms)	0.32	0.06	0.32	0.05	
Peak E (ms)	0.89	0.13	0.81	0.14	
FS (%)	39.1	2.6	38.5	2.4	

In accordance with structural differences, absolute and relative LV systolic functions were significantly greater ($p < 0.01$) in SA, namely LV end–systolic volume, SV and Q as well as LV diastolic function (LV end–diastolic volume). The E/A, FE, TD, Peak A, Peak E and FS data were similar in both groups. (table 3)

The results show increase in left ventricular chamber size and a little increase in LV mass, suggesting a pattern of eccentric hypertrophy. This adaptation is congruent with the nature of exercise undertaken by swimmers at this age, with strong emphasis on aerobic stimulation and high swim volumes, promoting an hemodynamic load that induces greater Qc, with associated greater SV. The changes in SV results from the increase of the venous return and a consequently greater LV end – diastolic volume. LV dilatation together with reduced wall thickness and reduced systolic and diastolic function was not observed in any of the swimmers evaluated, demonstrating that we are facing healthy physiological LV adaptations.

CONCLUSION

This study supports the influence of systematic swimming training on the diastolic function in 15/16 year old boys. As showed by parameters measured, adaptation to exercise mode induced a typical "athlete's heart" with dominance of volume and diameter (eccentric LV hypertrophy) and mild changes in LV mass.

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SWIMMING PSYCHOLOGY

EFFECT OF COMPUTER ASSISTED INSTRUCTION WEB SITE FOR SWIMMING TO CHILDRENS' LEARNING MOTIVES AND LEARNING STRATEGY

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The present study was intended to identify the effect of a CAI web site for swimming to elementary school children's learning motives and learning strategy. Fifth-grade children participated in this study. Subjects were classified into two groups that learned with the CAI web site throughout the swimming class and a control group that merely participated in the ordinary swimming class inside the pool. Learning motives, a learning strategy and 25 m swimming performance were investigated before and after the swimming class. The superiority oriented motive and aim learning strategy decreased significantly ($p<0.05$) after the swimming class in the control group. Using the CAI web site, it was indicated that the motivation to achieve higher swimming performance was kept high through the swimming class and that students were able to achieve a clear objective for their swimming class.

Key Words: computer assisted instruction, learning motives, learning strategy.

INTRODUCTION
Computer science is developing rapidly in this last decade. New technology has been introduced to the sports science field. A salient concern in this field is developing a computer assisted instruction (CAI) program as a new learning device in the educational scene.
Numerous past studies have reported results of CAI programs' use. Steffen and Hansen (6) investigated the effect of CAI for learning bowling, and Fincher and Wright (2) reported computer use in an athletic training education. For swimming instruction, Persyn et al. (4) demonstrated a CAI program for kinesiological diagnosis. In addition, Sengoku et al. (5) developed a CAI web site aimed for elementary school children and reported characteristics of different contents (multimedia vs. textual) involved in the CAI program. These studies have shown the benefit of using CAI programs. However, some studies have reported negative effects of the new instruction system (3, 7).
Past studies differ in the purpose of using CAI programs as cognitive, mental, diagnosis and skill improvement. In addition, the subjects involved are different from elementary school children to university students. The relative benefits of CAI use compared to traditional instruction methods have not been clarified. Further studies are required to identify an efficient way to introduce CAI programs in the educational scene. Especially, it is important to develop and investigate CAI programs for elementary school children because the ability to use computers is an indispensable aspect of educational development for young people in this century.
Internet use is also a new research aspect. Using the Internet in an educational setting, children and teachers can build connections with people who are deeply interested in swimming outside the school, which enables them to expand the instruction field to solve many problems that occur inside the swimming class. We also have reported that Internet use enhances enjoyment in learning, which might stimulate motivation toward swimming education (5).
The purpose of this study is to identify the effect of a CAI web site for swimming on elementary school children's learning motives and learning strategies.

METHODS
1. CAI web site
A computer-assisted instruction web site (Fig. 1) was developed to provide information about how to swim (Front crawl, Breaststroke), along with the steps to practice each stroke. Two CAI contents were produced for novices and advanced swimmer who were able to swim more than 25 m. Movie contents both underwater and above the surface were made to explain each swimming movement. Additional information was provided to explain the viewpoints of each motion precisely using text and photographs (Fig. 2). All contents were hyperlinked so that children can understand the learning steps that they should follow for improving their swimming ability.

Fig. 1. Swimming CAI Web Site Front Crawl Top Page (Advanced level).

As contents in CAI program for novices, good examples were provided by a Quick Time Video showing demonstrations by graduate students who specifically study swimming. Movie contents included a recreational swimmer demonstrating frequently made mistakes.
As advanced level CAI contents, swimming motions of a top-level university swimmer were provided, demonstrating general stroke technique and major drills to improve stroke technique. Main CAI programs were installed inside each computer in the computer room at the elementary school. All computers were connected to the Internet and a chat-BBS system; they were linked from the CAI web site's top page.

2. Subjects
This study examined 60 elementary school children (fifth grade). All children had been educated to use the Internet for more than two years. The subjects were separated into two groups: one group learned with the CAI web site through the whole swimming class (WEB, n=29); the control group merely participated in the ordinary swimming class inside the pool (CON, n=31). The CAI web site was introduced to the children by the author before the swimming class started. The WEB group used the CAI web site on the day before the swimming class to collect information for their own study and con-

tributed questions in the chat-BBS to get more precise information from a university researcher. The duration of use was 10 min for each day. Both groups participated in the same swimming lesson, which was taught by the same teacher of the elementary school. At the first day, children were instructed to decide their personal objective to achieve through the swimming class. Then, instruction to improve swimming ability progressed.

Fig. 2. Swimming CAI Web Site Front Crawl Page. Explanation with photograph will be shown by clicking the textual explanation.

3. Measurements
Both groups answered a questionnaire before (Pre) and after (Post) the swimming class (8 classes in 4 weeks) to analyze the learning motives (practice, superiority, approval, fulfilment, group, performance oriented) and learning strategy (general, aim, effort arrangement) (1). The questionnaire responses were reported on a 5-point Likert scale.
To evaluate the swimming performance, a 25 m trial was conducted for the front crawl and breaststroke. The time to cover 25 m was measured for children who were able to swim 25 m; the total distance was measured for children who could not swim 25 m. The development ratio of the time and distance between Pre and Post were evaluated as the performance improvement.

4. Statistical analysis
All values are expressed as mean ± SD. Student's t-test was used for analysing pre and post investigation differences in each group. Statistical significance was defined as $p<0.05$.

RESULTS
WEB utilised the CAI web site at the elementary school's computer room. One computer was provided for each child so that all the children became able to use the CAI program freely by themselves. Children gathered information from the multimedia program and used chat-BBS for individual questioning to a university researcher. A university researcher answered all questions contributed within one day: 107 articles were contributed in the chat-BBS. Children contributed additional questions or impressions they received through the swimming class after viewing textual information from the university researcher.
The results of the learning motives and learning strategy are shown in Tables 1 and 2. Superiority and fulfilment oriented motives decreased significantly ($p<0.05$, $p<0.01$, respectively) after the swimming class in CON. Fulfilment-oriented motives decreased ($p<0.05$) in WEB. The aim learning strategy in CON decreased significantly ($p<0.05$) and effort arrangement learning strategy decreased ($p<0.05$) in WEB.
The front crawl performance of the 25 m time increased 112.2% in WEB and 106.8% in CON. The distance children swam using the front crawl increased 334.1% in WEB and 260% in CON. For the breaststroke, the 25 m time increased 113.6% in WEB and 102.9% in CON. The distance increased 558.3% in WEB and 195.0% in CON. WEB tended to show a higher improvement for both strokes, but no significant difference was found.

Table 1. Results of learning motive.

	practice		superiority		approval		fulfilment		group		performance	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
WEB	4.41±0.79	4.43±0.76	4.29±0.82	4.27±0.89	3.16±0.95	3.15±0.93	4.44±0.64	4.23±0.75	4.39±0.68	4.26±0.59	3.70±0.69	3.45±0.63
CON	4.00±1.05	3.79±0.96	3.86±0.82	3.63±1.04	2.91±1.00	3.01±1.07	4.23±0.71	3.88±0.87	4.26±0.93	4.19±0.79	3.63±0.64	3.39±0.80

Table 2. Result of learning strategy.

	general		aim		effort arrangment	
	pre	post	pre	post	pre	post
WEB	4.17±0.17	4.12±0.80	4.00±0.86	3.97±0.90	4.09±0.73	3.60±1.04
CON	3.86±0.84	3.75±0.85	3.80±0.85	3.55±0.90	3.61±0.95	3.57±0.83

DISCUSSION
This study was intended to identify the effect of the CAI web site for swimming to elementary school children's learning motive and learning strategy. Pre investigation data were influenced by a sports event that the children were involved in during their physical education class before the swimming class. All children were on a gymnastics program: they were attempting handsprings using a balance ball as a new instruction program in this school. Pre values suggest that children were highly motivated by the new event in which they were involved.
After using the CAI web site through the swimming class, the superiority-oriented motive retained a high value compared to CON. The superiority-oriented motive item represents the motivation to achieve higher performance than other children. The information provided in the CAI web site was used mainly for improving stroke techniques. It was indicated that the CAI contents affected the children's superiority oriented motive and led to a desire to achieve higher swimming performance compared to other children.
Even by the high motivation to achieve superior performance to others, the group-oriented motive was not influenced by the CAI web site use. The group-oriented motive is a motivation to learn together with other children. Although WEB was intended to improve their performance compared to others, results indicated that the motivation to study along with their friends did not decrease. Children were using the CAI web site individually in front of respective computers, but they were continuously in communication with other children and a university researcher through the chat-BBS. These results suggest that the chat-BBS use stimulates the group oriented motive.
The result of the high superiority-oriented motive can be inferred using the results of the aim learning strategy. The aim learning strategy score decreased significantly ($p<0.05$) in

CON. The aim learning strategy questionnaire item assesses whether the children attended the class with a concrete aim throughout the class. WEB were able to gather information using the CAI web site meeting each children's swimming ability from the multimedia contents and advice from a university researcher via the chat-BBS. From the collected information, children were able to set a clear aim on which movement they will try specifically to develop before each swimming class. After the swimming class, children contributed their perceived impression in the chat-BBS and some children asked additional questions to the university researcher. The instruction method using the CAI web site in this study supports children through enhancing learning strategies to obtain a concrete aim for swimming learning.

The fulfilment oriented motive decreased in both groups. The fulfilment oriented motive item shows whether the instruction program itself motivated the children. Although a CAI web site was introduced to WEB, traditional instructions were given inside the pool. Results suggest that the instruction program they received before the swimming class induced higher motivation than the swimming instruction conducted in this study. However, results showed that the deterioration in CON was more significant; for that reason, CAI use might restrain the decrement of the fulfilment-oriented motive.

No significant difference was observed in the performance improvement between groups, WEB showed a higher development in swimming performance for both the front crawl and breaststroke. These results can be explained using the higher superiority oriented motive and aim learning strategy that children were able to sustain using the CAI web site. Higher frequency of use and CAI contents improvement might engender a significant development in swimming performance.

CONCLUSION

Use of the Swimming CAI web site for elementary school children was investigated in this study. Using the CAI web site, it was indicated that the motivation to achieve higher swimming performance remained high through the swimming class compared to that of a traditional swimming instruction. Children were able to obtain a concrete aim to achieve in their swimming class from the CAI web site. In addition, the possibility of improving swimming performance more efficiently was observed.

It is difficult to use a CAI program inside the pool because of the water environment. However, this study demonstrates an effective CAI method for a swimming event in a short period of time outside the swimming pool. Further studies are necessary to develop a new instruction method inside the pool linked with the CAI program to achieve more fruitful results for children.

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STATE OF PRE-COMPETITIVE ANXIETY AMONG SWIMMERS AND WATER POLO PLAYERS IN RELATION TO COMPETITIVE EXPERIENCE

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This research aims at examining differences in the intensity of pre-competitive anxiety based on competitive experience between - a) the two sexes (male and female) and - b) the two sports (swimming and water polo). In the research participated 601 male and female athletes, aged 13-26 yrs old of which 425 were swimmers and 176 were water polo players? Their competitive experience varied from 1-13 yrs and according to this they were divided in five /5/ groups. As regards the sample sex it consists of 288 males and 313 females. The athletes completed, before the event the Greek version of the Competitive State Anxiety Inventory questionnaire (CSAI – 2; Marthens at al., 1990; Kakkos & Zervas; 1996). The results show that in relation to gender, there is a statistically significant difference in three factors of anxiety. With respect to the competitive experience criterion, there is a significant statistical difference only with regard to the factor of self-confidence as well as to the criterion of competitive experience in relation to the sport regarding the all three anxiety factors.

Key Words: competitive state anxiety, swimmers, water polo players.

INTRODUCTION

Anyone who participates in competitive sports, whether athletes or coaches, is exposed to a great deal of somatic and psychological stress and anxiety. By nature, competitive sports are a socio-physiological process which is administered with the presence of other people such as competitors, spectators and referees.

Individuals are striving for success which in turn is accompanied by corresponding hopes. Given that success requires the fulfilment of certain criteria and measures, it is obvious why competitive sports are indeed an everlasting cause of anxiety to participants. Therefore, the fact that competitive anxiety is a personality element examined so often is not accidental. The reaction to the state of anxiety experienced before and during a game has been considered as an important psychological factor in determining athletic performance. This reaction is a temporary sensation that can fluctuate a lot in terms of intensity due to the presence or absence of anxiety.

Sport psychologists measure anxiety using very specific questionnaires with different scales of measure of self-esteem. Everyday practice and acquired experience of those who are involved in sports show that there is a great deal of relevance between the athlete's anxiety and the quality of his/her athletic performance. Competitive anxiety is an unpleasant emotional state. Its symptoms are nervousness, restlessness, pressure and it is connected to the body's activation or alertness. It is often defined as an existing and/or ongoing emotional state that appears before or during the game (3). Anxiety is a multidimensional phenomenon that has many aspects and manifests itself through cognitive and biological changes (4, 6, 2).

It is interest to examine the pre-competitive anxiety in relation to the competitive experience. That is to say to search how change the three factors of pre - competitive anxiety as long as more experienced becomes an athlete. Also, it will be interest to observe these changes in combination with swimming and water polo, individual and team sport respectively.

In the field of Sport Psychology, Martens et al. (5) have presented a questionnaire for the measurement of the multidimensional sport state anxiety. This questionnaire is called Competitive State Anxiety Inventory – 2) (CSAI-2) and is considered to be a reliable and valid tool for measuring state anxiety. The state of athletes' competitive anxiety was assessed with the use of this questionnaire right before the games with the estimation of 3 factors, namely: cognitive anxiety, somatic anxiety, and self–confidence. This research aims at examining differences in the intensity of pre-competitive state anxiety based on competitive experience between a) the two sexes (male and female) and b) the two sports (swimming and water polo).

METHODS

In this research, participated 601 male and female athletes, aged 13-26 yrs old (M=16.9±3.2) of which 425 were swimmers and 176 were water polo players. Their competitive experience varied from 1-13 yrs (M=4.4±2.8). As regards the sample sex, it consists of 288 males and 313 females. The grouping of athletes has been made based on the years of their competitive experience in order to serve this research's aim and appears in the following table 1.

Table 1. The structure of the groups related to sex, sport and competitive experience.

	Swimming		Water Polo		
Competitive experience	**Male**	**Female**	**Male**	**Female**	**Total**
1 - 2 Years	117	19	11	24	**171**
3 - 4 Years	52	89	8	31	**180**
5 - 6 Years	35	57	13	15	**120**
7 - 8 Years	3	33	14	15	**65**
9 years and more	6	14	29	16	**65**
Total	**213**	**212**	**75**	**101**	**601**

The athletes 30–45 minutes before each event and right after their warm up filled in the Competitive State Anxiety Inventory questionnaire (CSAI – 2; Marthens at al., 1990) that has been adjusted to Greek by Kakkos and Zervas (1) and constitutes a valid and reliable measurement tool of the variables. It consists of /15/ fifteen questions and is used for the estimation of the tension of competitive state. It also consists of three sub-scales that evaluate: a) the cognitive anxiety, b) the somatic anxiety and c) the self–confidence. The athletes were called to describe "how they feel now before the game, right this minute" in a four level scale that appears as follows: *not at all =1, a little = 2, quite a lot = 3, a lot = 4*. The years of participation that athletes have in competitive spots were recorded as an element for the evaluation of their competitive experience. The hand-out of questionnaires and the data collection was undertaken by the same researcher. Besides, the fill in of questionnaires was made on a voluntary basis for those athletes who participated in games. They were informed about the aim of this research and instruction was given to them as to when to fill in the supplied questionnaire.

The research data were gathered during the competition games held in Athens in the summer season. These are the most important Pan-Hellenic swimming games and represent the ultimate efforts undertaken by the athletes for the whole year. The MANOVA with the criterion full factorial and the model 2 x 2 x 5 were used to analyse the results obtained.

RESULTS

The results of the measurement are presented in the following tables where statistic differences are shown in relation to the factors of the questionnaire concerning the swimmers and water polo players based upon their competitive experience with respect to gender and sport. In table 2 the results of the descriptive analysis are presented in relation to the factors and the structure of the groups studied.

Table 2. Means and standard deviation of all variables in relation to anxiety factors and competitive experience.

		Swimming MEAN±SD		Water polo MEAN±SD		Total MEAN±SD		
Comp. Exper.	Anxiety factors	Male	Female	Male	Female	Male	Female	Total
1	Cognitive	11.05±3.14	10.75±2.06	12.05±4.14	15.63±3.77	*11.05±3.14*	*14.15±4.27*	11.91±3.75
	Somatic	9.39±3.01	9.25±2.22	10.68±2.91	12.15±4.41	*9.39±3.01*	*11.54±3.90*	9.99±3.41
	Self Confidence	15.53±3.31	15.25±1.50	14.84±3.96	12.52±3.58	*15.53±3.31*	*13.50±3.87*	14.96±3.59
2	Cognitive	10.38±2.93	10.86±2.79	12.00±3.63	12.00±3.49	*10.43±2.90*	*11.97±3.44*	11.40±3.35
	Somatic	8.55±2.46	8.57±4.04	9.81±3.71	9.10±3.14	*8.55±2.64*	*9.55±3.62*	9.08±3.30
	Self Confidence	15.02±2.96	14.86±2.79	13.81±2.89	13.61±3.00	*15.00±2.91*	*13.47±2.52*	14.17±2.90
3	Cognitive	9.65±2.53	10.07±3.20	12.84±3.93	11.41±2.76	*9.77±2.71*	*12.51±3.72*	11.43±3.61
	Somatic	8.32±2.46	9.36±2.44	11.44±3.43	10.12±3.30	*8.6±2.50*	*11.13±3.42*	10.15±3.22
	Self Confidence	15.68±3.18	16.50±2.18	13.42±3.06	14.71±2.44	*15.91±2.92*	*13.71±2.97*	14.58±3.35
4	Cognitive	10.01±2.41	10.00±2.56	12.36±3.39	10.61±4.15	*9.94±2.49*	*11.63±3.78*	11.17±3.54
	Somatic	6.03±2.42	8.40±2.67	11.76±3.43	9.00±3.43	*8.19±2.71*	*10.60±3.66*	9.50±3.57
	Self Confidence	14.06±2.39	15.87±2.36	12.40±4.11	14.94±3.00	*15.81±2.29*	*13.46±3.87*	14.10±3.64
5	Cognitive	11.17±2.93	10.17±3.66	12.43±2.95	10.18±2.93	*10.33±3.53*	*11.44±3.09*	10.79±3.38
	Somatic	11.00±2.97	8.27±2.75	10.29±3.29	10.00±3.19	*8.72±2.93*	*10.16±3.18*	9.31±3.10
	Self confidence.	14.83±2.23	16.77±3.19	13.14±2.14	15.82±2.86	*16.44±3.11*	*14.32±2.91*	15.57±3.19
	Cognitive	**10.65±3.02**	**12.24±3.69**	**10.18±3.20**	**12.41±4.00**	10.54±3.06	12.30±3.79	11.46±3.57
Total	**Somatic**	**9.03±2.85**	**10.77±3.53**	**8.56±2.79**	**10.13±3.74**	8.92±2.83	10.56±3.61	9.78±3.36
	Self Confidence	**15.40±3.16**	**13.59±3.22**	**16.30±2.79**	**13.97±3.20**	15.62±3.10	13.72±3.21	14.62±3.29

Table 3. Differences of the anxiety factors examined in relation to the criterion for which MANOVA confirmed the existence of statistically significant differences. (test of the between – subjects effects).

MANOVA – Tests of Between – Subjects Effects

(Source)	(Dependent Variable)	(Type III – Sum of squares)	Degrees of freedom (df)	(Mean Square)	F value	Significance
Gender	Cognitive	494.09	1	494.09	40.86	0.000
	Somatic	413.25	1	413.25	39.02	0.000
	Self Confidence	608.20	1	608.20	59.51	0.000
Competitive	Cognitive	83.14	4	20.78	1.62	0.168
Experience	Somatic	72.00	4	18.00	1.60	0.172
	Self Confidence	122.68	4	30.67	2.77	0.027
Competitive	Cognitive	630.890	4	157.72	13.32	0.000
Experience	Somatic	318.124	4	79.53	7.391	0.000
* SPORT	Self Confidence	619.580	4	154.89	15.29	0.000

The results of MANOVA show that as regards the gender criterion, there is a statistically significant difference in relation to the three factors of anxiety (Wilks' Lambda = 0.882, F = 26.695, p = 0.000). With respect to the competitive experience criterion, there is also a significant statistical difference (Wilks' Lambda = 0.954, F = 2.334, p = 0.006), as well as to the criterion of competitive experience in relation to sport (Wilks' Lambda = 0.873, F = 6.865, p = 0.000).

The results of the MANOVA Tests of Between – Subjects Effects showed statistically significant differences between gender in relation to all three anxiety factor (Cognitive – F = 40.86, p = 0.000, Somatic – F = 39.02, p = 0.000, and Send Confidence – F = 59.51, p = 0.000) (table 3). In relation to the competitive experience the results showed statistically significant differences only in self-confidence factor, concerning the the groups 1 and 2 (t = 2.160, p = 0.016), as well as between group 5 and groups 2, 3 and 4 and between group 5 and group 2 (t = 2.987, p = 0.002), between group 5 and 3 (t = 1.997, p = 0.024) and between group 5 and 4 (t = 2.354, p = 0.010). In relation to the sport and the competitive experience factor, the results showed statistically significant differences in relation to the all three anxiety factor (Cognitive – F = 13.32, p = 0.000, Somatic – F = 7.39, p = 0.000, and Send Confidence – F = 15.29, p = 0.000), (table 3). The analysis of between – subjects effects differences are showed in the table 4.

Table 4. Results Student - t – test of the factors in relation to sport and the competitive experience.

Test values in relation to sport and competitive experience (swimmers and water polo players)

Group \ Factors	Cognitive	Somatic	Send Confidence
1	t=4.480 p=0.000	t=3.388 p=0.001	t=3.170 p=0.001
2	t=2.902 p=0.002	t=2.816 p=0.003	t=2.642 p=0.005
3	t=4.694 p=0.000	t=4.683 p=0.000	t=4.040 p=0.000
4	t=1.993 p=0.026	t=2.752 p=0.005	t=2.860 p=0.003
5	t=0.055 p=0.478	t=0.334 p=0.370	t=1.707 p=0.049

DISCUSSION

The results showed that there is a significant difference in the intensity of factors concerning the pre-competitive anxiety.

In particular, female swimmers and female water polo players demonstrate higher values in the cognitive and somatic factor in all groups in relation to men, table 2. This can be explained as a difference between the two sexes in relation to their competitive performance.

On the contrary as far as the self confidence factor is concerned, men show higher values as compared to women in all groups. It is worth mentioning that in the fifth group self confidence is increasing for both men and women in relation to the other four groups. This is explained because of the accumulated training and competitive experience including the selection of athletes where those who have more self confidence succeed and remain in the sports of swimming and water polo. These results coincide with those results of other researchers (5, 7).

Furthemore, in relation to competitive experience and the sport, there is statistically significant difference in all three anxiety factors namely cognitive, somatic and self confidence. Here it can be noticed that women and men in swimmimg have lower values in the cognitive and somatic anxiety compared to men and women of water polo in all groups of competitive experience. On the other hand women and men in swimmimg perform better as regards the self confidence factor in all five groups - table 2.

As a general rule, the difference between athletes who opt for team or individual atheltes lies in the fact that in individual sports the athlete himself is responsible for the results he achieves whereas in the team sports the responsibility for the results is shared between all the players. Because of this self confidence in swimming is quite high.

It is important to confirm those factors of anxiety for the better definition of rules which exist in relation to sex, athlete relating to competitive anxiety so as both coaches and trainners share the consequences of the negative results of the specific type of anxiety.

CONCLUSION

The results of this research provide interesting information concerning the relation between the competitive experience of swimmers and water polo athletes vis a vis the factors of precompetitive anxiety. Taking into account that anxiety affects to a large extent the athletic performance or the success of a team, the more information and knowledge we have the more it helps coaches and athletes to understand the anxiety factor. In this research it was found that athletes in both fields (swimming and water polo) with more competitive experience show higher values concerning the self confidence factor. Also it was found that female and men swimmers show higher self confidence that female and men water polo players. This information can be of use to coaches and other researchers and can equip them with the tools to go further in the analysis of the anxiety issue.

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MENTAL REPRESENTATION OF SWIMMING STROKES

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Swimming strokes are mentally organised as motoric actions under the condition of (flow) physics and limited energy reservoirs. Action representation is imagined to be organised hierarchically in a tree-like structure as a network of so-called Basic Action Concepts (BACs) – in long-term memory. BACs correspond to functional and biomechanical demands in concert with the situational goals and constraints of motion. BAC's are integrated mentally in a different way per individual. The degree of integration of BACs is detected via Structural Dimensional Analysis-Motoric (SDA-M). In this study SDA-M is applied to the underwater sequence of the upper limbs of two butterfly swimmers. The purpose is to give inside how a) this method can be applied in swimming, b) how the individual basis for action control in skilled voluntary motion is detected by dendrograms and c) it can be used for better communication.

Key Words: cognition, anticipation, basic action concepts, swimming stroke analysis.

INTRODUCTION
Swimming strokes are mentally organised under the condition of (flow) physics and limited energy reservoir. The mental organisation and neuronal control of any motion is an issue of growing relevance, even from the biomechanical point of view, e.g. to ease the communication between coaches and athletes (or other experts). Mental processes can be subdivided into one emotional part and a cognitive one. Here, emphasis is placed on the cognitive part, where the coding (planing, performing, storing) of motion takes place as mental control in the long-term memory. Voluntary motions are considered to be goal-directed acts which are organised and stored in a memory as based on perspectives started by Bernstein (1). According to new research approaches by Schack (2) perceptible events are representations of anticipated sensory effects following perceptual-cognitive representations. The athlete is informed by sensory feedback whether or not the motion was performed properly and effectively. In essence, an image of the "reality" is stored as a cognitive unit on the basis of existing experience, and voluntary actions are planned, executed, and stored in memory directly through representation of their anticipated perceptual effects. This is different from a position of motoric programs: supposedly nerves fires muscles individually but the numbers of fibres and the impulse patterns are different due to the goal of the motion (swimming stroke, throwing action, etc). The feel for water is part of the mental control of a given motion, which is based on anticipated perceptual effects, while permanent sensory feedback is flexibly tuning the outcome. Tuning includs the task of regulation (or co-ordination) of motion eliminating excessive (odd) variables of motion in regard to the purpose of the motion. According to present knowledge, completely different memories are merging into a network. It is an accepted fact that never all details of a motion are stored~~,~~; however, emphasis is placed on sensorial information. Consequently, motion follows perceptual-cognitive representation and control, respectively. The steering of motion(s) means perceptible events are linked to a functional performance.
As known, the spatio-temporal outcome can be determined biomechanically. The question arise in which way functional or biomechanical demands of a motion is related to perceptual-cognitive representation? According to Schack (2) so-called Basic-Action-Concepts (BACs) may serve as problem-solving-related features. First (in ontogenesis), motoric and sensoric features are stored isolated which, by rehearsal, can later merge into BACs, and motion is stored as a row of perceptual-cognitive effect representations. BACs are tools for mastering the functional demands of motion as cognitive key-points or to maximise the control of actions with lowest possible cognitive and energetic effort. Functionally elementary actions, like arm stretching, sculling the hand or rotating the trunk are mentally replaced by BAC's. BAC's are considered as mental counterparts of functionally elementary components as well as transitional states of complex movements (rotation, undulation, etc.), including spatio-temporal properties as well as the afferent-perceptive-sensoric and efferent-motoric properties of motion, plus the cognitive and emotional invariants of motion (per person). In particular, BACs are organised by hierarchical network(s) in long-term memory. BACs can be described verbally as well as pictorially. This implies that the mental representation of motion can be studied by actions determined via Functional Motion Analysis (3). The replacement is taking place without any special translation mechanism between perception, representation and motion. The purpose of this paper is to demonstrate the relationship between movement structures and representation structures, as well as the spatio-temporal structure of mental representation of butterfly arm-action.

METHODS
The study is executed using PC-supported Structural Dimensional Analysis-Motoric (SDA-M) introduced by Schack (2). This is a well-established procedure in the field of cognitive psychology for ascertaining relational structures in a given set of concepts. Hence the use of SDA-M will not detect the validity of biomechanical principles, it is more a means to detect individual representation of motion. The SDA-M contains four steps: (i) listing the BAC's, or nodes, describing the

motion in question by a special split procedure (a multiple sorting task); (ii) a hierarchical cluster analysis is used to transform the set of BACs into a hierarchical structure; (iii), a factor analysis reveals the dimensions in this structured set of BACs, and (iv) the cluster solutions are tested for invariance within and between the groups.
Besides the clustering SDA-M provides so-called dendrograms (tree-like diagram) in which the distance between BACs is shown (measured in Euklidean units), as well as the individual cognitive architecture of the motion (the BACs are expected to be listed in a logic order). In order to get a workable set of BACs, which is presented in a split-procedure, the butterfly arm motion below waterline was functionally analysed (Fig. 1).

Figure 1. Actions of a butterfly stroke from hand entry until its finish action.

The consideration of the hand motion in a fixed reference system remembers to the fact that swimming stokes have, as purpose, to create momentum-induced propulsion based on reactions of steady and unsteady flow. According to functional analysis conducted by Ungerechts et al. (3), the path of the hand relative to water (fixed reference system) is as follows, as used in teaching strokes (Fig. 2).

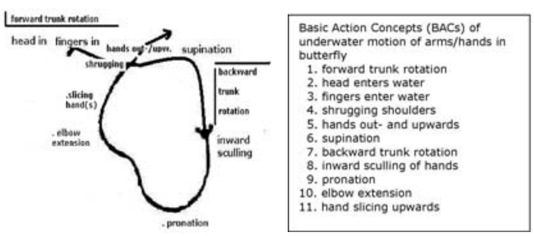

Figure 2. Side-view of the hand motion in butterfly stroke below water in a fixed reference system, plus the BAC's along the path (temporal aspects).

Some basics of the swimmer's natural actions, like proper position of the hands or elbow (upper arm in the beginning outward rotated), are not exclusively mentioned as BACs because they are "inborn" while focus was placed on superfluous BACs like "slicing hand(s)" means that the palms are facing thighs and little finger is leading (to serve the unsteady flow effects and not to "minimise" resistance); quite often swimmers still follow the concept to "push backwards" with the palm oriented orthogonally to the direction of motion.
After familiarisation with the BAC's (e.g. the meaning of each term) two swimmers are asked via a multiple sorting task to judge the functional relation between BAC's (which BAC's are direct neighbours or not) according to their best knowledge.

RESULTS
Results of this study are based on cluster analysis (Step II in SDA-M) and presented as dendrograms for two swimmers. For interpretation the following aspects are relevant: (i) the lower the value, the closer the BACs are located to each other in long-term memory; (ii) the quality of order or grouping of the BACs (symbolised by numbers in horizontal axis) reveals the understanding of the temporal aspects by the swimmer; (iii) the clustering of the BACs symbolised by the horizontal bars indicate the quality of the functional understanding of the swimmer. Inspection of the dendrogram (Fig. 3) reveals: (i) the distance between most of the BACs (6 out of 9) is low, hence they are closely related (the lower the value of a link between two items, the lower the distance between the BACs in the long-term memory), (ii) the BACs are perfectly ordered per cluster, in particular no BAC is singled out and (iii) the clusters demonstrate that the selcted classification of the representation structures match well with functional and biomechanical demands of the task (for didactical purposes, in Fig. 3 the meaning of clusters are introduced in words).

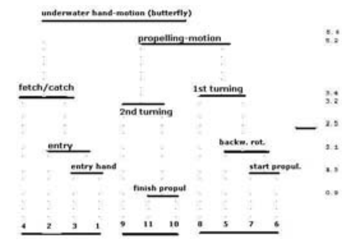

Figure 3. The dendrogram of Swimmer A (calculated distances between BACs are presented in Euclidean distances by right sided numbers; see text for further details).

The hierarchic cluster analysis for the mental representation structure of arm action in butterfly reveals three clusters (representing functionally related solutions of the entire task of motion) for Swimmer A: (i) forward rotation, head enters water and hands enter water; (ii) hands outward-upward, supination of hands and backward rotation starts, and (iii) extension of elbows, slicing hands before leaving water (the BAC "pronation" is not significantly close enough). The BACs 1-4 serve the goal "fetch/catch of flow" and sub-goals "entry of hands and body". The BACs 5-8 serves the goal "momentum-induced propulsion (1. part)" while BAC "Supination" plays a centred role to induce backward rotation of the trunk and create thrust. Finally, BACs 9–11 serve the goal "Momentum-induced propulsion (2.Part)" starting with pronation including arm extension and finished by slicing hands.

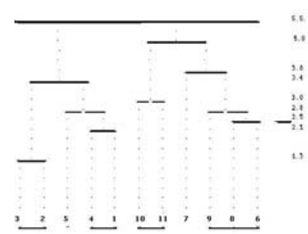

Figure 4. Original dendrogram of swimmer B (an international master swimmer).

The dendrogram obtained for the swimmer B (Fig 4) is different. Inspection reveals: (i) the distance between most of the

BACs (3 out of 9) is low, (ii) the grouping of BACs is not perfectly ordered, two BACs are singled out, and (iii) the hierarchic cluster analysis for the mental representation structure reveals three clusters: (i) fingers enter water, head enters water; (ii) shrugging shoulders, forward trunk rotation, and (iii) hands out/upwards, backward trunk rotation. The mental representation of the arm action in butterfly of swimmer B seems to be not “stable”. BACs like hands out/upwards and backward trunk rotation are not attached fluently to the appropriate functional neighbours, and shrugging shoulders is executed too early. It is likely that swimmer B likes to fulfil all goals of stroking, however, needs some communication about the functional attribution of the actions and the logic order.

DISCUSSION

Evidently the execution of swimming strokes are based on mental processes. Due to the approach by Schack (2) that individual mental representation of actions in sports, like swimming strokes, are connected to basic action concepts (BACs) which are structured topologically not far from motion structure and includes biomechanical information. Our knowledge about the mental representation is gradually improving as well as the relation to biomechanical organisation. This will improve the specific communication between coach and athlete about the detailed goals of swimming strokes beyond to create flow, transfer momentum and raise efficiency. The participation in the sorting test is a good means to increase individual mental efficiency and to decrease uncertainty how to steer motion by overcoming superfluous degrees of freedom (a larger the distance between BAC’s means more energy will be spend to make the motion happening). Based on the dendrograms structural gaps or errors in the athlete’s mental representation can be detected, e.g. when BAC occurs isolated from the others (not linked to a neighbour) or the order of BAC’s is not appropriate to the functional relation (central values of cluster analysis will serve interpretation). This study demonstrated that the relation between mental and biomechanical structures can be detected experimentally by uncovering the distances between selected basic action concepts (BACs)which are closely related to functional actions.

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ADAPTED SWIMMING SPORTS AND REHABILITATION

LOWER LIMB MUSCLES ACTIVITIES OF THE DEEP-WATER RUNNING AND INTERVENTION EFFECTS ON BALANCE ABILITY IN THE ELDERLY

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This study was intended to investigate thigh-muscle activity during deep-water running (DWR) (Exp. 1), along with the effects of intervention with upright-floating (UF) exercise on balance ability in elderly (Exp. 2). Exp. 1: Nine healthy males (25.0 ± 0.5 yrs) performed DWR and water walking (WW). The surface electromyogram (EMG) electrodes were placed on the rectus femoris (RF) and biceps femoris (BF). The mean electromyogram (mEMG) of the BF during the DWR showed significantly higher values than that during the WW. Exp. 2: Fourteen healthy elderly persons (60.8 ± 5.3 yrs) participated in a once-a-week water exercise program of 12 weeks. They were separated into a normal and an UF group. The UF group improved the body-sway area (30 s, eyes open) and tandem walk time (10 steps). It was considered that the high stimulus of the BF during DWR affected the improvement of the balance ability in UF.

Key Words: deep-water running, upright-floating, thigh muscles, EMG, balance ability, elderly.

INTRODUCTION
Various water exercises exist for rehabilitation or fitness maintenance. In water, buoyancy acts against the body to reduce the load at the joints, while water viscosity requires the subject to exert greater force than when moving on land (3).
An upright-floating situation in a water environment (feet separated from the swimming pool floor) is hard to experience in any other exercise environment. The typical form of upright-floating (UF) exercise in water is deep-water running (DWR). The advantages of this exercise are that it reduces the impact stress for lower limb joints and maintains aerobic fitness (7). Studies have investigated motion analysis and aerobic fitness during DWR and suggested its characteristics. Moening et al. (4) described that when comparing DWR and treadmill running, the subject leans forward in the DWR at the trunk to counteract the buoyancy effect on the lower limbs. They also described that the DWR is an open kinetic chain compared to the closed kinetic chain of treadmill running. Another study of DWR reported that the maximal oxygen uptake ($\dot{V}O2$) and the heart rate (HR) were lower than those for running on land, but the ratings of perceived exertion (RPE; legs and breathing) and the respiratory exchange ratio (RER) were greater during submaximal, whereas ventilation (l/min) was similar with younger males (10).
However, no studies have investigated thigh muscle activity during DWR and its intervention effects for elderly persons. This study was intended to investigate lower limb muscle activity during DWR and the effects of intervention of UF exercise on balance abilities of elderly persons. We established two experiments to explore these issues mentioned above. The first experiment investigated thigh muscle activity during DWR in young males (Exp. 1). The second experiment conducted short-time water exercise intervention for elderly persons and investigated their balance ability before and after intervention (Exp. 2).

METHODS
Exp. 1:
Nine healthy young males participated in this experiment as subjects. Their respective mean age, height, weight and %fat were 24.9 ± 2.2 yrs, 172.0 ± 3.8 cm, 69.3 ± 3.7 kg, and 19.4 ± 4.1%. Informed consent was obtained for this experiment. Subjects practiced to familiarize themselves with water walking (WW) and DWR before the experiment. The subjects underwent WW and DWR at their comfortable speeds for 8 s with two repetitions. An aqua jogger (Aqua Jogger; Excel Sports Science Inc., Japan) was attached to the subject's waist during DWR.
The left thigh muscle activities of rectus femoris (RF) and biceps femoris (BF) were measured during trials using surface electromyography (EMG). The skin cuticle was removed carefully using a blood lancet (Blood Lancet; Asahi Polyslider Co. Ltd., Japan) and cleaned with alcohol wipes so that the inter-electrode impedance was less than 20 kΩ. A pair of surface EMG electrodes (5 mm diameter) was placed in the middle of the belly of the RF and BF. Electrodes were covered with transparent film (Dressing tape No. 100; As One Corp., Japan) for waterproofing. The EMG signals were telemetered via a multi-channel telemetry system (WEB-5500 Nihon Kohden multi-telemeter system; Nihon Kohden Corp., Japan) using a time constant of 0.03 s, 2 kHz sampling rate, and 500 Hz hi-cut filter.
The trials were videotaped with synchronization to the EMG. A digital video camera was placed on the left side of the subject; it allowed coverage of one cycle at a 30 Hz frame rate. Data were collected from one cycle of the videotaped picture, from heel contact to the next heel contact in WW and from the maximum knee drive (as a maximal hip flexion) to the next maximum knee drive at DWR. Then, the mean electromyogram (mEMG) was calculated during one cycle. The water temperature was set at 27 ± 2°C and the water depth was set at 1.1 m throughout the experiment.
Paired Student's *t*-tests were used to compare differences between WW and DWR. Statistical significance was inferred at $p < 0.05$.

Exp. 2:
Fourteen healthy elderly volunteers (mean age 60.9 ± 5.3 yrs.: 2 males and 12 females) were separated into two groups: a normal water exercise group (NW, $n = 7$: 1 male and 6 females) and an upright-floating exercise group (UF, $n = 7$: 1 male and 6 females). Their mean height, weight and BMI were respectively 150.9 ± 6.6 cm, 56.2 ± 10.9 kg and 24.5 ±3.2 in NW, 153.2 ± 8.6 cm, 61.3 ± 7.3 kg and 26.1 ± 2.0 in UF. They had already become accustomed to water exercise, but did not engage in other water exercise programs. Informed consent was obtained for this experiment program. Subjects participated in a 60 min water exercise program, including 30 min divided into two groups in one session, once a week, for 12 weeks. The NW participants underwent WW, resistance training and other ordinary water exercises using a kick board (Fig. 1A). The UF participants performed locomotive motions, mainly DWR with feet separate from the bottom of the swimming pool, using a water noodle (Fig. 1B). The pool depth was 1.1–1.3 m; it was 25.0 m long and 3.6 m wide, with water temperature maintained at 30°C throughout the 12 weeks. A body-sway test for static balance ability (12) and a tandem walk test for dynamic balance ability (2) were conducted before and after 12 weeks. The body-sway test was conducted using a posturo-

graphic meter (Gravicoda GS-10, type-C; Anima Co., Japan). Subjects stood silently on the posturographic meter staring at a point marked on the wall (distance was 3 m forward, height was 1.5 m) with their feet bared and kept together. Tests were conducted for 30 s with eyes open. Body-sway distance and body-sway area were analyzed in this study. A tandem walk test was conducted for two trials. Subjects were required to walk heel to toe along a 10-step line as quickly as they could without mis-stepping. A misstep occurred when subjects stepped completely off the line or failed to follow a heel-to-toe pattern. The 10-step tandem walk time measured using a stop-watch of two trials without mis-stepping was then averaged. Wilcoxon's signed-rank test was used to detect differences in the two tests taken by each group for the conditions before and after 12 weeks. A Mann-Whitney U-test was used to assess differences in two tests between two groups before and after 12 weeks. The statistically significant level was set as $p < 0.05$.

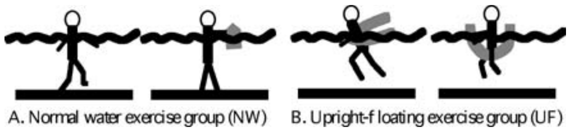

Figure 1. Typical exercise forms of respective groups.

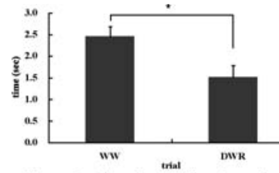

Figure 2. The time during 1 cycle in each trial. Values are mean ± SD (n = 9). *: Significant difference between WW and DWR

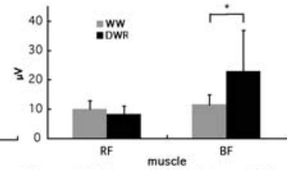

Figure 3. The mEMG values of RF and BF in each trial. Values are mean ± SD (n = 9). *: Significant difference between WW and DWR in BF ($p < 0.05$).

Table 1. Values of two tests before and after 12 weeks in each group.

		before		after	
		NW	UF	NW	UF
body-sway distance (cm)	average	45.70	46.54	53.97 *	42.80
	SD	14.54	11.28	21.19	7.74
body-sway area (cm²)	average	1.94	2.59	2.96 †	1.91 †
	SD	1.23	1.28	2.06	0.62
tandem walk (sec)	average	7.3	7.4	6.9	6.6 *
	SD	1.4	1.1	1.1	0.8

Values are mean ± SD (n = 9). *: Significant difference between before and after 12 weeks on body-sway distance in NW and on tandem walk in UF ($p < 0.05$). †: Tendency of increase in NW ($p = 0.06$) and decrease in UF ($p = 0.09$) of the body-sway area between before and after 12 weeks.

RESULTS

Exp. 1:

Figure 2 shows the mean ± SD values of the time for 1 cycle in each trial. The time for 1 cycle was 2.45 ± 0.23 s for WW and 1.51 ± 0.27 s for DWR. A significant difference in the 1 cycle time was found between WW and DWR ($p < 0.05$). Figure 3 shows mean ± SD values of the mEMG of RF and BF. The mEMG values of RF were 9.90 ± 2.96 μV in WW and 8.20 ± 2.81 μV in DWR. The mEMG values of BF were 11.46 ± 3.39 μV in WW and 22.85 ± 14.06 μV in DWR. The mEMG value of BF during DWR was significantly higher ($p < 0.05$) than that during WW, but no difference was apparent in the mEMG value of RF.

Exp. 2:

The mean ± SD values of body-sway and tandem walk tests at baseline and after 12 weeks are shown in Table 1. The values of body-sway distance were 45.70 ± 14.54 cm in NW and 46.54 ± 11.28 cm in UF at baseline, 53.97 ± 21.19 cm in NW and 42.80 ± 7.74 cm in UF at after 12 weeks. A significant increase of the body-sway distance was apparent in NW ($p < 0.05$). In the body-sway area, the values were 1.94 ± 1.23 cm^2 in NW and 2.59 ± 1.28 cm^2 in UF at baseline, 2.96 ± 2.06 cm^2 in NW and 1.91 ± 0.62 cm^2 in UF at after 12 weeks. The tendency of the body-sway area was apparent in each group, but increasing in NW ($p = 0.06$) and decreasing in UF ($p = 0.09$). The tandem walk times were 7.3 ± 1.4 s in NW and 7.4 ± 1.1 s in UF at baseline, 6.9 ± 1.1 s in NW and 6.6 ± 0.8 s in UF at after 12 weeks, respectively. A significant decrease of the tandem walk time was detected in UF ($p < 0.05$).

DISCUSSION

The first objective of this study was to compare the thigh muscle activities of WW and DWR. For that purpose, the first experiment was designed to collect the RF and BF activity data using surface EMG and mEMG during 1 cycle at each trial and compare them. The mEMG of BF was significantly higher in DWR than that of WW ($p = 0.05$), but the mEMG of RF was similar.

No studies have compared WW to DWR directly in motion analysis. Moening et al. (4) described that trunk flexion was larger for DWR than for treadmill running on land. In addition, the joint angle of hip maximum flexion in the knee drive was about 60° greater in DWR than that in treadmill running. At the knee joint, the range of motion from the back swing to the knee drive was about 55° greater in DWR than that in treadmill running. Hip and knee flexion are greater in DWR than that in treadmill running. Miyoshi et al. (3) reported that the range of motion at the hip joint in WW was similar to land walking at comfortable speed, and that the range of motion at the knee joint in WW was smaller than that of land walking. Regarding treadmill walking and running, Nilsson et al. (6) reported that the net hip angle was somewhat larger during walking than running at the same speed. The net amplitude of the hip joint was four times larger during running than walking when the speed was changed from low to high. They also reported a significantly larger net knee flexion amplitude during running than during walking.

This study measured the RF and BF muscle activities and compared WW to DWR. The RF activates hip flexion and knee extension. The BF activates hip extension and knee flexion. We hypothesized that muscle activities of RF and BF were higher in DWR than in WW, but this study showed a similar value on RF activity, probably because buoyancy served to assist hip flexion, although maximum flexion in the knee drive was greater in DWR than in WW. The higher muscle activity of BF

in DWR than in WW was attributable to the greater range of motion at the knee joint in DWR. Experiments of motion analysis that are synchronized to EMG are required to elucidate this aspect more precisely.
The second objective of this study was investigation of the intervention effects of UF exercise on balance ability in elderly. For that purpose, we designed a once-a-week water exercise program lasting 12 weeks and established NW and UF exercise groups. The body-sway distance and area were increased in NW, but the body-sway area was decreased in UF and the tandem walk time of 10 steps was decreased in UF.
It is widely acknowledged that body-sway as a static balance ability reflects the center of gravity (COG) during standing (5). Tandem walking is often used as a dynamic balance ability (2). In the present study, the static balance declined in NW, but static and dynamic balance improved in UF. No studies have reported the decline of body-sway through exercising for the elderly. Simmons et al. (8), who reported enhancement of functional reach in water exercise group, explained two characteristics during water exercise. First, the buoyancy provided by water can be considered destabilizing because it will tend to lift a subject up. Second, because water exercise was conducted for a group, this created turbulence, which might have increased the variability of the factors influencing each participant's movement. Destabilizing buoyancy and turbulence that occurred during water exercise might have affected the increased body-sway distance and area in NW.
Improvement of body-sway in women with lower extremity arthritis was demonstrated in water exercises (9). In the present study, UF improved the body-sway area. Tandem walking also improved only the UF group. Experiment 1 revealed that BF mEMG increased significantly in DWR compared to WW. The high stimulus of the BF during DWR was inferred to improve the balance ability in UF. Other possibilities are coordination between the legs and body or adjustment of body balance, as seen in Tai Chi Chuan (1), but further research is required.
The static and dynamic balance ability improved in UF in the present study. In general, the balance ability declines with age; it is an important function that prevents fall accidents because it is associated with postural control (11). Results of the present study suggest that UF exercise might be useful for elderly persons to prevent fall accidents because the balance ability was improved after 12 weeks' intervention.

CONCLUSION
This study suggests that UF exercise can improve the balance abilities of elderly persons. It might be affected by the high muscle activity of BF during DWR. Furthermore, because balance abilities were improved after 12 weeks, UF exercise in the water might be useful to prevent elderly persons' fall accidents.

ACKNOWLEDGEMENTS
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DURATION OF ONE UNIT (80KCAL) DURING TREADMILL WALKING IN WATER

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The number of Japanese people diagnosed with diabetes has been increasing. Epidemiological and intervention studies of endurance exercise training strongly support its efficacy for improving diabetes. The purpose of the present study was to make clear the difference of duration per expended one unit (80kcal) during treadmill walking in water between younger and older people. We would get the standard data by using non diabetes people. Ten healthy young men and eight healthy women participated in this study. Subjects walked at 1, 2 and 3km/h (30.3°C). The duration of exercise that expended one unit of energy was calculated from VO_2. Younger and older people's calculated results were 41'39'' and 39'44'' (1km/h), 33'22'' and 31'56'' (2km/h) and 24'51'' and 24'56'' (3km/h). There was no difference due to the difference of the age in one unit. It might be suggested that it becomes possible to prescribe underwater exercise for older diabetes patients by using the young's one unit index.

Key Words: treadmill, walking water, one unit (80kcal), diabetes.

INTRODUCTION

It is believed that in Japan 7.4 million people are suspected of having diabetes (2002). Moreover, recently the number of Japanese people diagnosed with diabetes has been increasing. Many diabetes patients suffer from complications, for example diabetic renal disease, retinopathy and neurosis. As for diabetic renal disease, it is the NO. 1 cause of artificial dialysis in Japan. Many diabetes patients also suffer from obesity.
Epidemiological and intervention studies of endurance exercise training strongly support its efficacy for improving diabetes. But exercise on land causes kidney blood flow to reduce. It will not be good for it's patient's kidney. In water, the amount of kidney blood flow is maintained during exercise. And by the action of buoyancy the weight which is loaded on the joint of the legs decreases.
The remedy for diabetes consists of diet, exercise and medication. For diet, the unit conversion which designates 80kcal as one unit has been used in Japan. For diabetes patients, by using this kind of unit conversion, they can take the calorie which is easily decided in detail (intake per a day divided by nutrition). So far we calculated the duration when one unit (80kcal) is expended in young people during underwater treadmill walking. As for diabetes, it can recognize the increase of morbidity in older people. The purpose of the present study was to make clear the difference of duration per expended one unit (80kcal) between younger and older people during treadmill walking in water, and whether or not one unit index of the young can be adapted to older.

METHODS

In this study, in order to accomplish the above mentioned purpose, we gathered standard data which is intended for people who are not diabetes as the subject. Ten healthy young men (age: 22.6±1.1 yrs, height: 171.6±5.4 cm, weight: 67.7±8.4 kg and %fat: 19.2±4.7 %) and eight healthy women (age: 61.8±4.3 yrs, height: 152.4±3.9 cm, weight: 60.0±4.9 kg and %fat: 34.1±2.8 %) participated in this study. We conducted informed consent following the Helsinki declaration for participation in this experiment.
In order to enter the water, subjects wore a swimming suit. They took a rest by standing before walking for 5 minutes each on land and then in water. Subjects walked at 3 velocities (1, 2 and 3km/h) on a treadmill in water. On the 1st day, young subjects were walking in water for 15 minutes at one velocity. They walked the other two velocities other day. On the other hand, older subjects completed three consecutive 7-minute walks at progressively increasing velocity. So they walked for 21 minutes in water. Water level was set to Trochanter major. Heart rate (HR) and oxygen uptake (VO_2) were measured. HR was measured by bipolar lead chronologically. And we recorded for each minute. Exhaled gas was gathered to calculate VO_2. We set 5 points to gather. It's rest on land for 5 minutes, rest in water for five minutes and walking in water for 2 minutes by each velocity. The duration of exercise that expended one unit of energy was calculated from oxygen uptake. Energy used per liter of expended oxygen is about 5 kcal, so we used the following formula (duration of one unit=16/VO_2).

Water temperature, room temperature and humidity during the experiments were 30.3±0.3°C, 26.9±0.7°C and 76.6±2.3%.

RESULTS

The young's average HR at rest was 72.2±8.6 bpm on land and 64.3±8.2 bpm in water. Older people's average HR at rest was 81.2 ±10.4 bpm on land and 76.2±9.3 bpm in water. Average HR for older people was significantly higher than the young's on land and in water respectively ($p<0.01$). The young's average HRs gathering exhalation for 2 minutes were 63.3±7.1bpm (1km/h), 67.1±8.0bpm (2km/h) and 76.9±8.6bpm (3km/h) respectively. Older people's average HRs gathering exhalation for 2 minutes were 83.8±13.5bpm (1km/h), 87.5±12.3bpm (2km/h) and 96.7±12.6bpm (3km/h) respectively. Older people's average HR during walking was significantly higher than the young's at all velocities (all $p<0.01$).

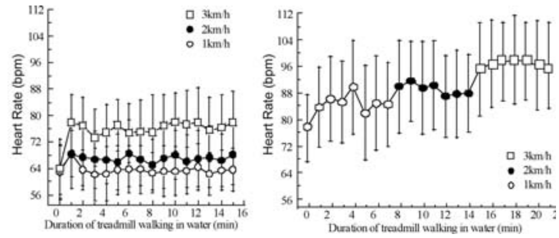

Figure 1.Changing Heart Rate during Treadmill Walking in Water for the 3 velocities (1km/h, 2km/h and 3km/h) (Left: Young Subjects, Right: Older Subjects).

Older people's VO_2 was not significantly different from the young's. On the other hand, older people's relative VO_2 was significantly lower than the young's (1km/h: $p<0.05$, 2km/h: $p<0.01$). Older people's relative VO_2 was not significantly different to the young's at 3km/h.

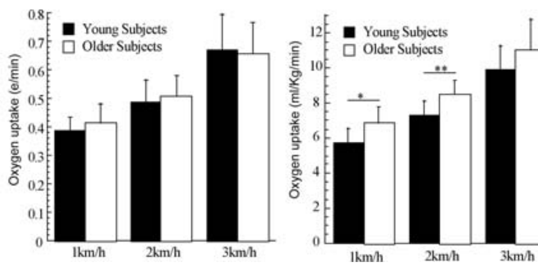

*Figure 2.The Oxygen Uptake at Each Velocity during Treadmill Walking in Water (Left: absolute value, Right: relative value) (*p<0.05, **p<0.01).*

The young's calculated results were 41.7±4.6 minutes (1km/h), 33.37±4.59 minutes and (2km/h) and 24.86±5.23 minutes (3km/h). Older people's calculated results were 39.7±6.5 minutes (1km/h), 31.9±4.5 minutes (2km/h) and 24.9±4.2 minutes (3km/h). There was no difference, due to the difference of the age, in duration expending one unit.

Table 1. The Duration of Expending One Unit (80kcal) during Treadmill Walking in Water.

velocity (km/h)	young subjects (min)	Olderly subjects (min)
1	41.66±4.56 (41'39'')	39.73±6.54 (39'44'')
2	33.37±4.59 (33'22'')	31.94±4.49 (31'56'')
3	24.86±5.23 (24'51'')	24.93±4.18 (24'56'')

DISCUSSION

It was made clear that older people's HR on land at rest was higher, the rate of decease in HR in water at rest was lower and the rate of increase in HR while exercising was higher than the young's. From this, it was suggested that older people's Venous Return could prevent promotion by comparison with the young. The aerobic ability of older people has decreased by comparison with the young. As a result, we thought that older people's absolute VO_2 became the same as the young's. So we could have to consider the duration of exercise for the patient whose body weight deviates from these subjects. For example, if patient's weight is too high when compared with the young subjects' we should change the duration by decreasing it. When introducing exercise we should start at lower durations, too. The Ministry of Health, Labour and Welfare in Japan advises that diabetes patients should exercise enough to sweat a little while having a conversation with their neighbor easily for about 30 minutes per day. So we could say that our index is fit for these patients.

As said in the introduction it is clear that exercise on land reduces the renal blood flow rate but that in water it is maintained. By exercising on land or in water our muscles can use glucose easily and glucose metabolism is improved; so they should exercise. Including diabetes patients that may develop diabetic renal disease, we could say that for diabetes patients exercise in water is the best choice of training for preventing deterioration of diabetes.

Almost all Japanese people live on rice. The energy of a half cup of rice is about 80 kcal. So, in the diet of diabetics in Japan, the unit conversion which designates 80 kcal as one unit has been used. It suggests that the index calculated in this study is useful for the patients exercising by themselves, too. We calculated the duration of water level that is at Processus xiphoideus, too. The results were 62'41'' (1km/h), 50'33'' (2km/h) and 37'51'' (3km/h). If the water level goes up to the Processus xiphoideus, the duration for expending one unit becomes long. It is showed that the strength of the exercise is lower than at Trochanter major. So introducing exercise for the patients we should start at the Processus xiphoideus level.

CONCLUSION

In this study we calculated the duration of expending one unit (80kcal) of energy during treadmill walking in water to obtain the standard data to improve diabetes. Older people's one unit data was equal to the young's. We could expect to prevent the health of those with aggravation of diabetes or improve it using the one unit index. Using this index, we can connect it to the QOL maintenance or the improvement of life for patients with diabetes patients who also are at an advanced age.

ACKNOWLEDGEMENTS

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MOVEMENT ANALYSIS IN CAD-PATIENTS

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Changes in movement parameters under various load conditions during breaststroke swimming were assessed in Coronary Artery Disease (CAD) patients. Kinematic analysis of time-discrete and time-continuous characteristics, and timing of the swim-movement was made during a breaststroke "load-step-test" in a flume for 26 male CAD-patients. Factor analysis was applied. The path of hands, feet and hips, the pause between propulsive phases and the angle of attack of hip-shoulder-water surface are of crucial importance in patients with CAD. These findings are supported by the factor analysis where comparable parameters were found to be of relevance. Results did indicate large individual variations in time-continues characteristics.

Key Words: swimming, rehabilitation, biomechanics, coronary artery disease.

INTRODUCTION

The importance of physical activity in patients with Coronary Artery Disease (CAD) is undisputable. The aim of sport related rehabilitation is to develop an optimal specific program depending on the current condition of the individual. Nevertheless such programs focus primarily on physiological adaptations although it is well known that changes in the movement may influence this. The physiological adaptation to immersion in various water temperatures and the duration of immersion have often been investigated in this population (e.g. 1,2). Few scientific reports (5, 8), however, provide information on the actual swimming movement in patients with cardiac disease. Some studies have provided indications of the influence of movement changes on physiological responses from a qualitatively point of view, for example by Bücking et al. (2) and Meyer & Bücking (9). No quantitatively analysis has been reported however. The goal of this study, therefore, was to assess the changes in movement parameters of CAD patients under different load conditions during breaststroke swimming.

METHODS

Two-dimensional movement analysis (SIMI-Motion) was made during a flume "load-step-test" in breaststroke of 26 male CAD-patients: age, 59yrs. (± 8.2), infarct age, 8yrs. (± 6.8),

height, 178.3cm, (SD= 8.4), weight, 78.5kg (± 11.4), body surface, 2.1m² (± 0.24). The test consisted of three 3 minute swims at the same mean swimming speed with added, subtracted or no extra load.
One S-VHS video camera was placed outside the flume perpendicular to the swimming direction at 3.5-m from the swimmer. The actual camera view in the swimming plane was 4-m x 3-m. At the start of each video session a 1-m calibration ruler was placed in both the vertical and horizontal direction and recorded. Reference makers were set at eight points on the left side of the body: toe, ankle, knee, hip, shoulder, elbow, wrist and top middle finger. Recordings were made during each step, in order to analyse 10 movement cycles in the middle of each step. Sampling frequency was 50 Hz. Digitizing was done using the SIMI-Motion" software package 6.1 and analysis was based on the breaststroke phase model of Wiegand et al. (12) (Figure 1).

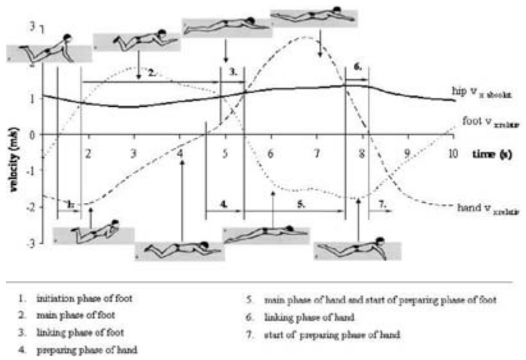

Figure 1. Breaststroke Phase-Model by Jähnig et al. (7).

To describe the complex movement, time-discrete (paths, durations, velocities, angles) and time-continuous characteristics (v_x-t-progress of the hip depend on arm and leg by Federle (4)), and timing of the swim-movement (Phase Structure Quotient-PSQ of Blaser et al. (1)) were examined. All in all 57 movement-parameters were determined in 3 swimming situations in each patient. Means and standard deviations were determined. Significant changes of parameters over 10 movement cycles between load steps were calculated using the non-parametric Wilcoxon-test. The level of significance was set at $P < 0.05$. A factor analysis (principle –component analysis) was performed as described by Hotelling (6) and Kelly (7). Phase structure quotient for both arm and leg movements were determined as follows:
PSQ = (duration of main phase/ duration of initiation phase + duration of linking phase + duration of preparation phase) x 100%(1).

RESULTS
Based on the time-discrete findings 9 parameters were found to be relevant to describe the changes in swimming movement of the CAD-patients examined. These 9 parameters showed a frequency of change of more than 5 (Table 1). All in all only one patient demonstrated no significant changes over the increasing load steps. On average 31 (±14) parameters changed.

Table 1. Frequency and Characteristic of time-discrete kinematic parameters during swimming.

Parameter	Frequency ≥ 5	Characteristic
Vertical path of hand in main phase of arm	8	1 x s; 1 x f ; 5 x d (^); 1 x d (v)
Vertical path of foot in main phase of leg	7	2 x s; 1 x d (^); 4 x d (v)
Resultant path of hand in main phase of arm	6	2 x s; 2 x d (^); 2 x d (v)
Horizontal path of hand in main phase of arm	6	2 x s; 3 x d (^); 1 x d (v)
Horizontal path of hand during arm stroke	5	1 x s; 3 x d (^); 1 x d (v)
Horizontal path of hip during leg stroke	5	2 x f; 1 x d (^); 2 x d (v)
Duration of propulsion-pause between main phase of arm and main phase of leg	8	2 x s; 2 x d (^); 4 x d (v)
Duration of propulsion-pause between main phase of leg and main phase of arm	7	2 x f; 5 x d (^)
Angle of attack of hip-shoulder-water surface	5	1 x f; 4 x d (^)

Legend: s-increasing, f-decreasing, d-discontinuous (^)=direction

From the time-continuous point of view individual time series patterns were observed in arm and leg movements. Figure 2 shows examples of an arm-swimmer (left) and leg-swimmer (right). It was also possible to distinguish so called "change-swimmers" (4) with differing propulsion of the arms and legs. Only one patient actually demonstrated an ideal velocity-time-regime of the hip according to Costill et al. (3) or Schramm (10). In total a marked divergent regime in horizontal hip-velocity was observed in this population: 12 arm-swimmers, 4 leg-swimmers and 10 change-swimmers.
The calculated PSQ describes some problems of these patients to react to increased load conditions. Six patients showed significant changes of PSQ of the arms. The other 20 patients did not change time-continuous characteristics with increasing loads. The calculated PSQ-values of the legs changed significantly in 10 patients whereas 16 patients showed no adaptation during the step-test. As an example figure 3 shows the inter-individual adaptation of the development of PSQ of the arms and legs.

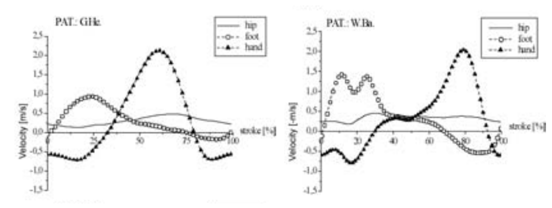

Figure 2. Breaststroke arm-swimmer (left) and leg-swimmer (right).

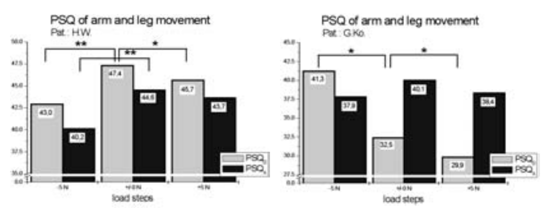

*Figure 3. Two examples of the development of PSQ of the arm (PSQ_A) and leg (PSQ_B). Significant differences between load steps (*p ≤ .05, **p ≤ .01) are indicated.*

As a result of factor analysis 4 factor-components of relevance provide indications for organizing swim rehabilitation programs with a special view to movement co-ordination. Table 2 gives on overview of the specific movement parameters of each relevant factor-component. The variance of the factor-components are: 30% for time-structure, 18% for velocity-regime, 10% posture of upper part of the body, 8% for angle of attack of thigh. The verification of reliability of the factors showned good internal consistencies (Cronbachs Alpha from .62 to .89). All main items may be evaluated as strong to very strong regarding selectivity and being greater than the limiting value of .4 (.55-.99).

Table 2. Loading of main items of each factor-component .

Factor: time-structure	Factor-load
duration of leg movement	.93
duration of arm movement	.92
movement frequency of the legs	.92
movement frequency of the arms	.92
duration of propulsion-pause between main phase of the arms and main phase of the legs	.87
duration of propulsion-pause between main phase of the legs and main phase of the arms	.78
Factor: velocity parameters	**Factor-load**
mean velocity of the hip in main phase of the arms	.92
maximum velocity of the hip during arm stroke	.91
maximum velocity of the hip during leg stroke	.90
maximum velocity of the foot during leg stroke	.74
Factor: posture of upper part of the body	**Factor-load**
angle of attack of hip-shoulder-water surface during to start main phase of the legs	.96
angle of attack of hip-shoulder-water surface at the end of main phase of the arms	.94
angle of attack of hip-shoulder-water surface at the end of main phase of the legs	.89
angle of attack of hip-shoulder-water surface during to start main phase of the arms	.88
Factor: angle of attack of thigh	**Factor-load**
angle of attack of thigh at the end of main phase of the legs	.84
angle of attack of thigh during start of main phase of the legs	.81
angle of attack of thigh-water surface during start of main phase of the legs	.69
angle of attack of thigh-water surface at the end of main phase of the legs	.65

DISCUSSION

Based on kinematic analysis of time-discrete parameters during breaststroke in patients with CAD the movement path of the arms and legs and of the hip, the duration of pause between the movements of the extremities and the angle of attack of hip-shoulder-water surface are of crucial importance to forward speed. These findings are supported by the findings of factor analysis where comparable parameters were found to be of relevance. Results indicated large individual variations in time-continuous characteristics. The PSQ as a good predictor for load specific adaptations related to movement co-ordination. When compared to the findings on healthy volunteer's from Blaser (1) or for elite swimmer by Witte (13) different values were observed. The values in CAD-patients are usually larger with no differences between arms and legs. Therefore the majority of CAD-patients are not able to react to increasing loads adequately. Patients who were not able to change the PSQ-values under increasing external loads might be increasing their cardiac stress. The movement patterns of CAD-patients react in diverse ways to increased loads. Based on these findings the importance of movement analysis in swimming of CAD-patients was underlined in order to guarantee an adapted sport-specific rehabilitation program as an additional way to control the load-stress situation and to develop movement skills.

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HYDRO-GYMNASTICS AND LEISURE AQUATIC SPORTS

RESPONSE TO RESISTANCE EXERCISE PERFORMED IN WATER VERSUS ON LAND

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The objective of the study was to verify if the cardiovascular and metabolic demands of well-designed water resistance training are at least comparable to their land-based equivalents. Five trained men were evaluated similarly with a horizontal shoulder adduction movement in water with a Hydro-Bells and on land with an elastic band (EB). Previously in order to equate resistance of movement, a rhythm rate in water and on land was established as well as distance in the holding distance of the EB. Subsequently physiologic response was evaluated with both devices by means of a set of twenty-five repetitions until reaching muscular fatigue. The results showed that there were no statistically significant differences between both material resources concerning heart rate at exertion and the response of lactates. We conclude that if the resistance training in water is performed according to the methodological indications followed in this study will produce a similar physiological response to that produced by land-based exercise.

Key Words: aquatic training, resistance exercises, heart rate, lactates.

INTRODUCTION

Strength is the neuromuscular ability to overcome or oppose external resistance by means of muscular tension. The above resistance may be created when training, for example, with weights, elastic bands, air devices or even with movements in water. Regardless of the material used, in order to gain improvements in physical performance, or in health, it will be necessary to create that muscular tension so that the muscle groups involved are stimulated. However, said muscular tension must reach a minimum threshold in order to create enough physiological stress with which to produce the desired adaptations. To this end, currently the majority of internationally renowned researchers recommend land-based resistance training with different materials and procedures. However, the use of the water environment is usually undermined as a material in itself for resistance training since there is a generalised belief that this water-based exercise cannot create an intensity of training similar to the one that is obtained by the exercises of strength in dry-land (2). For resistance training the role played by lactates and heart rate (HR) is a possible physiological indicator which could be linked to the exertion intensity. However no studies were found to have analysed this aspect using water exercises for resistance training, unlike the land-based setting where different studies are available (5, 6). So, this study aims secondarily to vouch for an objective methodology for quantifying intensity in water-based exercise by following previous proposals (2, 3), and primarily to verify if the cardiovascular and metabolic demands of well-designed water resistance training are at least comparable to their land-based equivalents.

METHODS

The sample consisted of five young, healthy males with an age of 25.75 ± 1.5 years old, a height of 1.79 ± 0.07 metres, a weight of 83.52 ± 10.95 Kg, a body fat of 17.12 ± 2.3%, an experience of training exercises of 2.5 ± 1.5 years, and a weekly training frequency of 3.6 ± 0.9 sessions, with the session lasting between 1.3 ± 0.2 hours and a perceived exercise intensity usually between moderate and high (7).

A) Equalling intensity for both exercises and evaluation tests of physiological response.

At all times the research was carried out on the premise that the technical characteristics and the resistance provided by both materials (water-based device vs. elastic band) were the same. The movement to be evaluated was a shoulder level abduction to 80°, with a 20° elbow bend and no support from any other body segment. The distance covered in each movement was such as to allow the subject to almost join hands in the horizontal shoulder adduction movement and reach a horizontal shoulder abduction of at least 20 degrees, taking as a reference point the frontal plane of the subject's body. Despite being familiar with the movement involved with both devices, the subjects received instruction prior to performing the exercise and supervision at all times in the correct execution of the movements. In order to guarantee the homogeneity between both exercises the speed of the movements was monitored as were the number of repetitions and the placing and correct use of the material. The aquatic exercise taken as the reference standard was a horizontal opening in water with Hydro-Tone Bells (3) (Aquatic Fitness Systems, Inc., Huntigron Beach, CA). The hydrodynamic position of the device was also monitored, as it could influence the overall intensity of the exercise (2, 3). So, the vertical position of the Hydro-Bell was established for the horizontal shoulder abduction phase (figure 1) and the horizontal position for the horizontal shoulder adduction phase. The subjects were immersed to shoulder level in water at a temperature of 28° centigrade. Speed of movement was established following a digitalized rhythmic sequence of the beats of a metronome. This rhythm was to delimit the alternative movements of horizontal shoulder abduction and adduction. Each subject selected a rhythmic sequence that allowed him to carry out twenty-five repetitions of the movement, reaching fatigue (maximum rate of perceived exertion; RPE of 9-10 with OMNI-RES of Robertson et al. (7)). In the event of the subject not completing the repetitions anticipated, or doing more, not following the rhythmic sequence or altering the performance technique the test was stopped, a five-minute rest was given and another rhythmic sequence of greater or lesser speed was selected depending on why the previous attempt had failed.

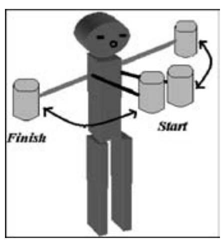

Figure 1. Aquatic movement: glenohumeral abduction on a horizontal plane.

It was essential to the study for the rhythmic sequence to be selected correctly, since the speed of the land-based exercise would be delimited by the same sequence. If not, the values obtained in the measurements would be incomparable, since subsequently in the final tests if the two exercises are conducted at different speeds could produce different metabolic responses. Therefore, once the rhythm was established in the water movement, the subjects were asked to follow the same sequence for the land exercise with the only change being the distance between thumbs when holding the elastic band in order to adjust the desired resistance, assuming that the closer together the thumbs were placed, the more resistance the subject would encounter. The elastic band was a Thera-Band model of light intensity and measuring 1 metre in length when slack. As in the water exercise, the test would be stopped in the event of not completing the desired repeats, going over the number of repetitions, altering technique or being unable to follow the rhythmic sequence, in which case a five-minute rest was given and the subject selected a different position in which to hold the elastic band depending on why the previous attempt had failed. In this way, resistance was adjusted individually, maintaining the rhythmic sequence as in the water exercise. The average width when holding the elastic band was 18.75 ± 6 cm. The subjects always were allowed to recover for 30 minutes after, respectively, determining the rhythm sequence in the water, the distance between thumbs when holding the elastic band in dry-land, and after each final tests (in water and in dry-land). Therefore, after carrying out equal intensity for both exercises the subjects conducted the final tests in which heart rate during exercise (HRE) and lactates concentration were recorded.
To monitor heart rate pulse was taken using a device of the POLAR brand, model S810i. Given that during exercise in water with this depth of water a fall in HRE of between 10 and 17 beats per minute is recorded compared with an exercise of the same intensity performed on land (1, 4), on recording HR immediately post-exercise a value of 14 beats per minute was added in order to equate it with the rate obtained during the land exercise. Subsequently, recovery HRE was recorded normally 3 and 5 minutes post-exercise when the subjects were passively seated at the poolside.
The usual protocol was followed for measuring lactates concentration. A lactate measurer from the commercial brand ARKRAY, Inc., model Lactate Pro LT-1710 was employed. The room temperature and humidity were 29° C and 53% respectively. Duration of each exercise was approximately one minute, ensuring an optimum production and accumulation of lactates for subsequent assessment. Before initiating any of the tests the basal concentration of the subjects was obtained, as was lactates concentration 3 and 5 minutes post-exercise.

B) Data analysis.
Using the programme Statistical Package for Social Sciences (SPSS), the descriptive statistics were obtained and finally Student´s t test was conducted for related data.

RESULTS AND DISCUSSION
The results are showed in table 1. For resistance training, the role played by lactates is a possible physiological indicator which could be linked to the exertion intensity, since the anaerobic metabolism is the main means of energy provision for this type of training. However in specific literature no studies were found to have analysed this aspect using water exercises for resistance training, unlike the land-based setting where many studies are available.

*Table 1. Mean and standard deviation for heart rate values with regards to percentage of heart rate reserve and percentage concentration of lactates with regard to basal values. ** p< 0,01 Statistically significant difference.*

	Water		Land			
Minute post-exercise	*Heart rate*	*Lactic acid*	*Heart rate*	*Lactic acid*	*p (Heart rate)*	*p (Lactic acid)*
0	82,25 ± 9,71		68,75 ± 19,80		0,098	
3	47,75 ± 18,77	2,34 ± 1,66	33,25 ± 16,5	1,14 ± 1,43	0,079	0,125
5	37,00 ± 14,85	4,3 ± 3,24	25,75 ± 14,45	1,55 ± 0,78	0,002**	0,82

Lagally et al. (6) measured lactate concentrations before, immediately after and several minutes post-exercise. It was observed that levels of lactate increased as the intensity of exercise increased, confirming the direct link between both parameters, and confirming that for high intensities levels of lactate remained high for several minutes as is the case in this study. Moreover, Hollander et al. (5) observed the relationship existing between exertion intensity obtained by means of local muscular endurance exercises and heart rate. So, these studies confirm that heart rates as well as levels of lactates are values which allow exertion from local muscular endurance exercises to be quantified. Following on from the evidence presented and the results obtained in this study, we might point out that HRE on completing exercise in water shows, in a statistically non-significant way, a certain increase as regards the HR reserve. The data also suggest that HR in recovery was slower after exercise performed in water. The results also suggest, in a statistically non-significant way that with the aquatic exercise there was a higher percentage concentration of lactates with regard to basal values. From the data obtained we might also underline that the concentration of lactates after exercise taken in water continued to rise for up to 5 minutes whereas the concentration of lactates stabilised after exercise performed with the elastic band from minute three onwards. All these data could show that metabolic intensity of effort in water could become higher than on dry-land for the same resistance opposed to the movement.
Based on previous works (1, 4), and provided that the subjects have the appropriate motor ability in water and employ materials such as Hydro-Tone Bells, this trend towards a higher final lactate concentration and a slower recovery of HRE could be due (i) to lower perfusion pressure in the lower extremities as a result of an abnormal distribution of blood flow caused by hydrostatic pressure, (ii) to the synergy of other muscle groups that are not involved, or are involved to a lesser extent, on land, such as for example some stabilising trunk muscles (3), and (iii) to a longer duration of global muscle activity whilst performing the exercise.

CONCLUSION
(i) No statistically significant differences exist in the cardiovascular and metabolic response between a local muscular endurance exercise performed in water with a device that increased frontal and drag resistance and its counterpart performed on land with elastic band. (ii) The quantification of resistance to the aquatic movement through the identification

of a rhythmic sequence for a material and a certain exercise allows the “load” or resistance to be compared with land exercises performed with elastic bands.

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SHORT-TERM WATER EXERCISE EFFECTS ON THE PHYSICAL FITNESS OF ELDERLY SUBJECTS FROM COLD SNOWY REGION

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The purpose of the present study was to investigate the effects of short term water exercise on the physical fitness of elderly subjects from cold snowy region. Balance, reaction time and strength are important elements to prevent slips and falls on the frozen streets during winter season. Eleven subjects of the water exercise group (W-group, mean age: 59.4±9.2yrs) participated in a water exercise class for 6 weeks (twice a week for 90 min session). Eight subjects also served as a controlled group (mean age: 62.1±8.5yrs). As a result, systolic blood pressure, sitting trunk flexion and reaction time was significantly improved in W-group despite of the short term water exercise protocol. It was suggested that short term water exercise was beneficial to improve systolic blood pressure, flexibility and reaction time of elderly subjects from cold snowy region.

Key Words: water exercise, elderly, physical fitness, cold snowy region.

INTRODUCTION
In cold snowy region, it is very important that elderly people acquire physical fitness before winter season preventing slips and falls on the frozen streets. Slips and falls among elderly people are target for public health preventive efforts because they are relatively common, and have a high cost to the community (6). Moreover, prevention against slips and falls, and preservation of a certain level of fitness are essential factors for productive aging (4).
Water exercise is one of the most popular exercises for elderly because of the characteristics of water. Buoyancy of the water is less physically demanding than exercise on land, and water resistance can be adjusted by changing the speed or direction of the movements. Therefore, it is an effective training strategy for improving physical fitness in the elderly or of those who are physically unfit (5). Also, it is an useful exercise for citizens living in cold snowy region, because allows to sustain exercise during the winter season in indoor swimming pools. Balance, reaction time and strength are important elements to prevent slips and falls (1, 6) on the frozen streets during winter season. However, few studies have reported the effects of water exercise on the physical fitness of elderly subjects from cold snowy region.
The purpose of the present study was to investigate the effects of short-term water exercise on the physical fitness of elderly subjects from cold snowy region.

METHODS
Eleven subjects (W-group: 59.4±9.2yrs) participated in a water exercise class for 6 weeks (twice a week for 90 min session) and eight subjects served as control (C-group: 62.1±8.5yrs). The characteristics of the subjects are shown in table 1. All subjects read and signed an informed consent prior to participation. The present study was approval by the Human subjects Committee of Asai Gakuen University. The W-group exercised in an indoor swimming pool (25*6 line, depth: 1.0-1.1m: waist to xiphoid level of the subjects, water temperature 30 Cº) with the water exercise program shown in figure 1.

Table 1. Characteristics of the subjects.

Groups	Height (cm)	Body weight (kg)	BMI (kg/m2)
W-group (n=11)	152.3 ± 7.2	57.3 ± 7.6	24.7 ± 3.2
C-group (n=8)	157 ± 5.0	61.2 ± 8.8	24.9 ± 4.1

(Mean±SD)

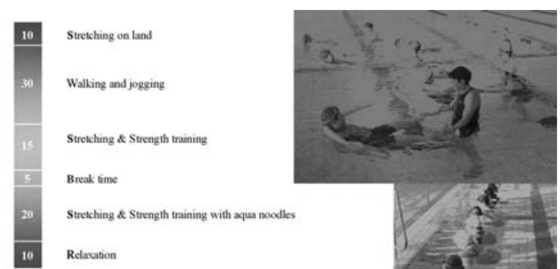

Figure 1. Contents of water exercise program. The photos showed strength training (above) and stretching (below) of lower limbs

Blood pressure (BP) was measured twice by the Terumo digital blood pressure meter P2000, and averaged data were used for analysis. Sitting trunk flexion (STF), right and left handgrip strength (GS) was also measured twice and maximal data were used. Whole body reaction time (RT) measured 5 times and from second to forth data were averaged for analysis. The sway paths of the center of gravity (locus length: LNG, environmental area: ENV area, Romberg quotients: RQ) for 30-seconds with eyes opened and closed were assessed with ANIMA gravicorder G620. In both groups, all variables were measured immediately before and after the experimental period.

RESULTS

Changes in physical fitness variables of W-group and C-group are presented in table 2, and changes in RT and RQ are shown in figures 2 and 3.

Table 2. Changes in physical fitness variables of W-group and C-group.

Variables	W-group pre			W-group post				C-group pre			C-group post			
Body weight (Kg)	55.8	±	7.2	56.1	±	7.0		61.2	±	8.8	61.7	±	8.8	**
BMI (Kg/m²)	23.8	±	2.6	23.8	±	2.5		24.9	±	4.1	25.2	±	4.2	**
Systolic BP (mmHg)	143.7	±	24.8	129.9	±	19.4	*	131.6	±	22.6	136.4	±	19.7	
Diastolic BP (mmHg)	80.3	±	11.9	74.4	±	10.7		82.3	±	8.7	79.5	±	7.8	
HR (bpm)	82.1	±	12.2	80.0	±	8.8		72.3	±	7.2	74.8	±	10.2	
Sitting trunk flexion (cm)	33.4	±	10.4	45.4	±	7.0	***	37.8	±	9.3	34.1	±	12.5	**
Grip strength: right (kg)	24.9	±	3.7	25.5	±	3.3		28.3	±	7.4	27.6	±	7.7	
Grip strength: left (kg)	25.8	±	4.5	23.7	±	4.1		27.9	±	7.2	26.9	±	7.6	
Locus length (EO)	3.1	±	2.3	3.1	±	1.5		2.4	±	0.7	2.3	±	0.7	
Locus length (EC)	4.1	±	1.7	3.2	±	1.7		2.6	±	0.5	2.9	±	0.7	
Environmental area (EO)	42.1	±	10.7	40.8	±	8.7		46.7	±	12.3	42.1	±	14.6	
Environmental area (EC)	60.2	±	15.9	55.8	±	15.8		52.8	±	12.5	52.0	±	12.8	
Romberg quotients	1.9	±	0.9	1.2	±	0.8		1.2	±	0.5	1.1	±	0.2	
Whole body reaction time (sec)	0.487	±	0.076	0.448	±	0.056	*	0.476	±	0.075	0.475	±	0.078	

BMI: Body Mass Index, BP: Blood pressure, HR: Heart rate. *p<0.05, **p<0.01, ***p<0.001 (Mean±SD)

EO: with eyes opened, EC: with eyes closed, Romberg quotients: ENV area EC / ENV area EO.

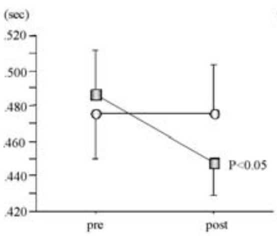

Figure 2 . Changes in whole body reaction time

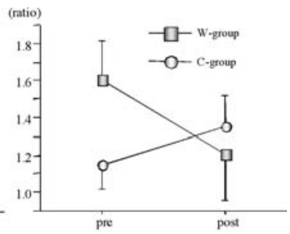

Figure 3 .Changes in Romberg quotients

After the experimental protocol, Systolic BP ($p<0.05$), STF ($p<0.001$) and RT ($p<0.05$) were significantly changed in W-group. On the other hand, body weight and BMI significantly increased ($p<0.01$) and STF significantly decreased in C-group. No significant changes were found in GS, LNG, ENV area and RQ (ENV area EC / ENV area EO) in both groups. However, RQ tended to decrease in W-group.

DISCUSSION

Inactivity during winter season because of the heavy snow is one of the serious problems for citizens in cold snowy region (4). Also, icy and snowy surfaces near melting temperature are more slippery increasing slips and falls occasions in elderly. Risk factors that have been associated with falls include decline in physical fitness, medication use, impairments to the sensory-nervous system, disorders of musculoskeletal system, and specific chronic diseases (6). To prevent slip and falls and keep healthy life in cold snowy region, it is important to sustain exercise to maintain a certain level of physical fitness before and during winter season.

Previous studies reported that balance, RT and strength are important elements to prevent slip and falls (1, 6), and exercise-based programs including agility training, balance and strength training were recommended to prevent falls (2, 6). As a result of the water exercise program, not only systolic BP ($p<0.05$) and STF ($p<0.001$) but also RT ($p<0.05$) was significantly improved in W- group. In C-group, body weight and BMI increased significantly ($p<0.01$) and STF was significantly decreased, which might result from inactivity. Previous study (5) reported that 8-week participation of water exercise program improves BP, STF and subjective pain in chronic low back pain patients in elderly. The present results showed that even shorter exercise periods have effects to improve systolic BP and STF in elderly.

However, no significant changes were found in strength, balance variables such as GS, LNG, ENV area and RQ in W-group. GS, LNG, ENV area are common variables to assess static balance, however, these variables showed individual differences and no significant changes were found in the present study. Simmons and Hansen (1996) reported that 6-week water exercise participation is an effective means of decreasing a subject's risk of falling as shown by an increase in subjects' functional reach (FR). Moreover, the authors suggested that water exerciser's postural control needs continually varied with the constantly changing pool environment while a person was moving in the water (3). These changing balance requirements would cause the subjects to acquire or enhance their postural control mechanisms in order to prevent a fall (3). By taking account of the pool environment and the results, it is likely that dynamic balance has much more possibility to show changes than static balance changes in practice of short-term water exercise. Although, not statistically significant, RQ tended to decrease in W-group. The decrease of RQ suggest that less contribution from the sense of sight and improvements of somatic senses to keep the standing posture. At postural control, the contribution of sense of sight will increase and some of the somatic senses will decrease with aging. The present results suggest that water exercises might improve somatic senses to keep balance and prevent slips and falls.

CONCLUSION

In conclusion, short term water exercise was beneficial to improve systolic blood pressure, flexibility and reaction time of elderly subjects from cold snowy region. However, strength and balance showed no significant improvements.

ACKNOWLEDGEMENTS

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