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).

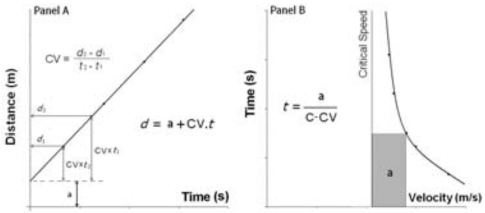

Figure 1. Illustration of two different but equivalent representations of the 2-parameter CV model.

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.

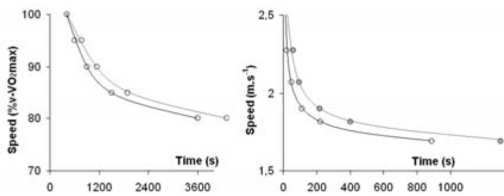

Figure 2. Schematic of the speed-time relationship of two different swimmers having different aerobic potentials.

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.

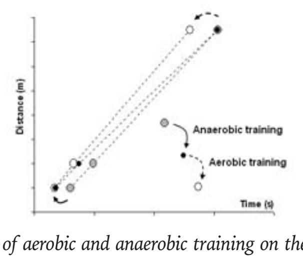

Figure 3. Effects of aerobic and anaerobic training on the d-t relationship.

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.

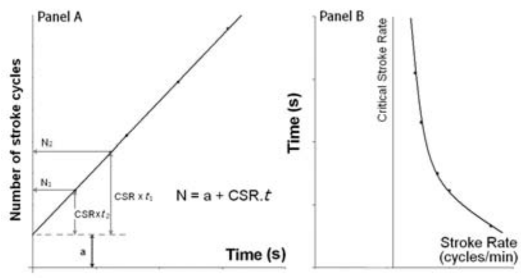

Figure 4. Illustration of two different but equivalent representations of the 2-parameter CSR model.

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.

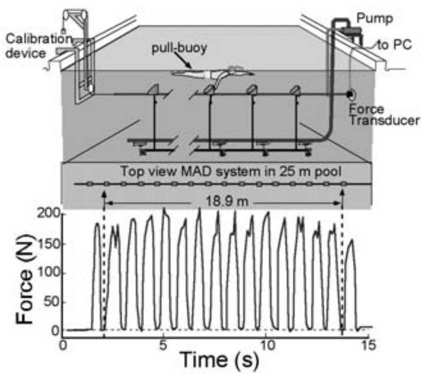

Figure 1. Schematic drawing of the MAD-system mounted in a 25 meter pool. The MAD-system allows the swimmer to push off from fixed pads with each stroke. These push-off pads are attached to a 22 meter long rod. The distance between the push-off pads can be adjusted (normally 1.35 m). The rod is mounted ± 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.

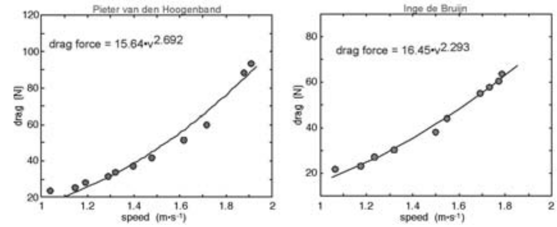

Figure 2. Active drag dependent on speed for a male (left) and female (right) elite swimmer.

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: $D = 16 \cdot v^2$. 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).

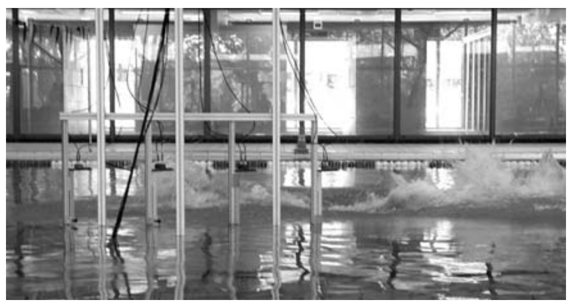

Figure 3. Left panel: The four wave probes, registering wave amplitude, were located at a fixed distance from the MAD-system. The distance between the wave probes was 0.5 meter; the probes covered half a stroke-cycle of the swimmer. For each probe the wave resistance was calculated. It seemed that the wave resistance varies during the stroke.

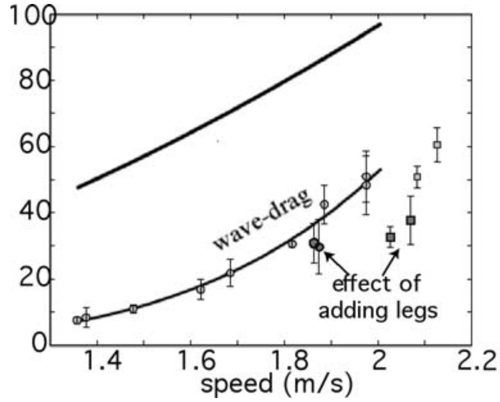

Figure 4. Individual estimates for wave drag dependent on speed. Error bars indicate the uncertainty interval of each estimate. The wave drag swimming free arms only is not different from that swimming on the MAD-system (filled dots). The addition of leg activity (swimming whole stroke; filled squares) 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

$$P_d = F_d \cdot v = K \cdot v^2 \cdot v = K \cdot v^3 \quad \text{(Eq. 4)}$$

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:

$$e_p = \frac{P_d}{P_o} = \frac{K \cdot v_{free}^3}{K \cdot v_{M.A.D.}^3} = \frac{v_{free}^3}{v_{M.A.D.}^3} \quad \text{(Eq. 5)}$$

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% ($p < 0.01$).

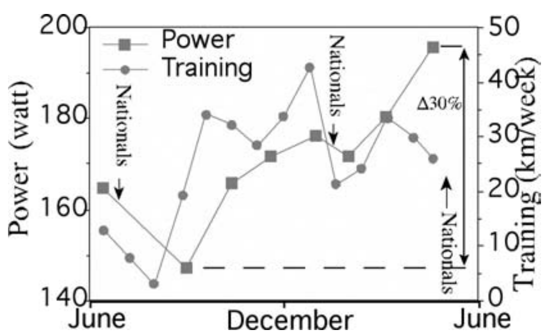

Figure 5. Power output of the arms measured during a full year of training, in relation to the training volume

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.

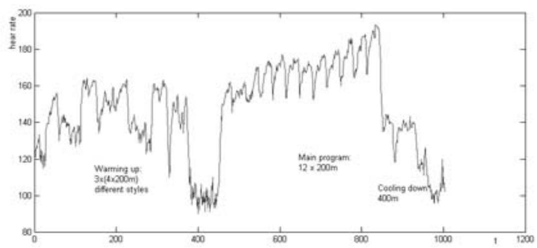

Figure 6. Hear rate recorded during training is used to quantify TRIMP.

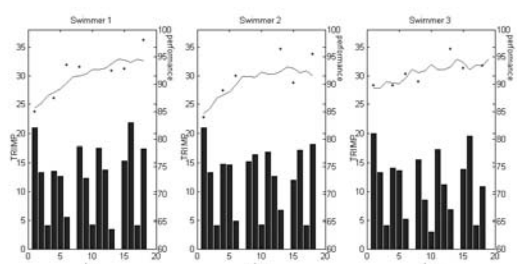

Figure 7. Bars represent TRIMPs; line represents predicted performance; dots represent criterion performance.

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 (2^{nd} 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).

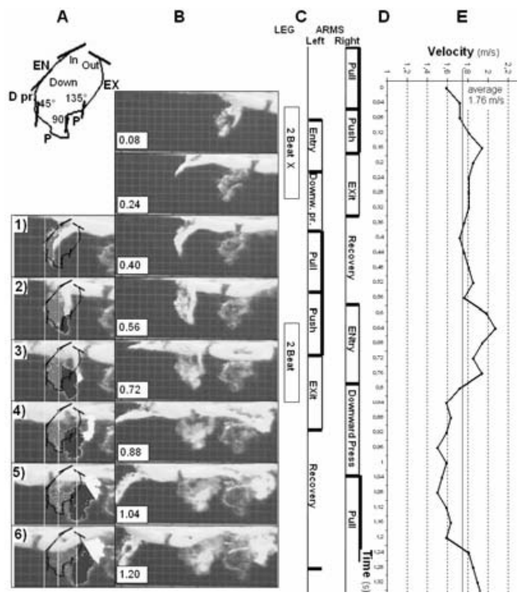

Figure 2: One cycle of a rotating arm action crawl of a leg-amputated competitor.
B: From a side view video recording, every 0.16 s a picture was taken.
D and C: Time line (s) and timing of the phases of:
- both arm actions: Entry, Downward press (to 45° in the angle hand-shoulder-horizontal), Pull (45° 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).

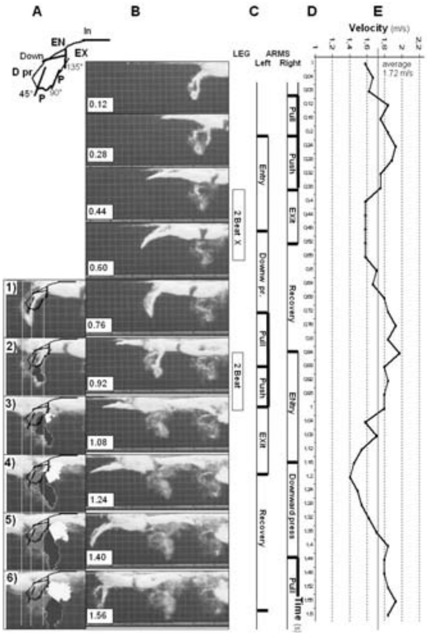

Figure 3. Glide stroke with high elbow: on each picture in A, the path of the midpoint of the flat part of the forearm (wrist) and the positions of the forearm at the phase delimiting instants. For explanation, see fig. 2.

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.

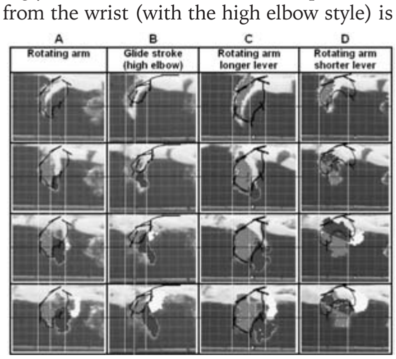

Figure 4. Movement path of the middle of the hand in three sprint styles (A, C, D) and of the forearm in a glide stroke with high elbow (B). For explanation, see fig. 2.

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.

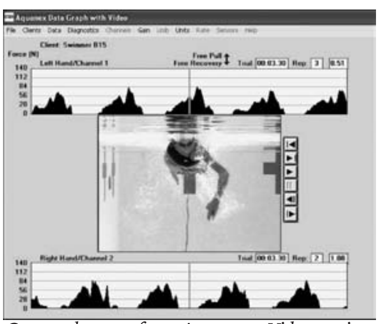

Figure 1. Captured screen from Aquanex+Video testing procedure shows synchronized underwater video image and hand force curves.

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.

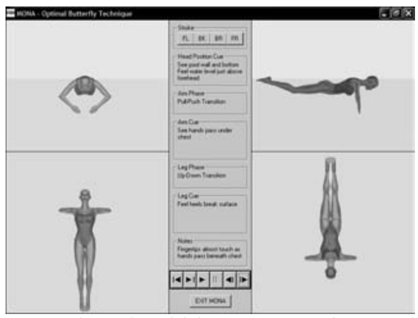

Figure 2. Biomechanical model for instructing subjects in the use of specific cues to monitor technique in butterfly.

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

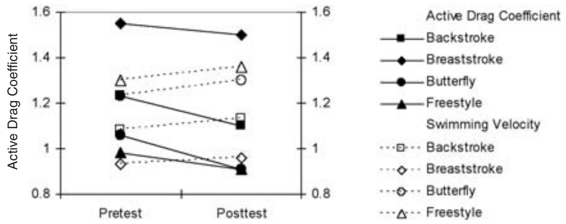

Figure 3. Changes in active drag coefficient and swimming velocity with instructional intervention.

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.

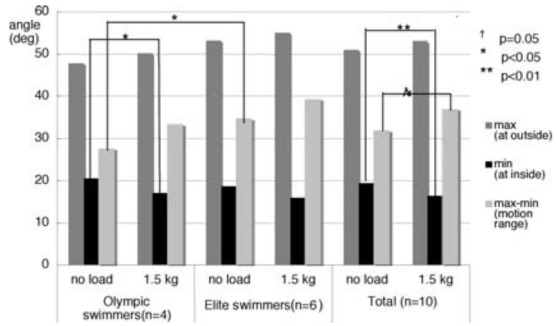

Figure 2: Maximum, minimum and motion range (max-min) of upper arm angles during one support scull for Olympic swimmers and Elite swimmers under no load and 1.5-kg load conditions.

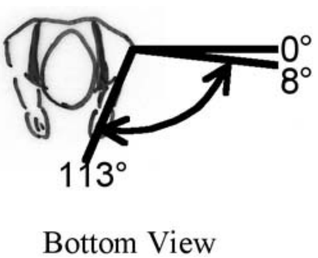

Figure 3: Scull range during support scull. The mean range for 10 swimmers with no load was approximately 105°, from 8° outside to 113° inside.

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.

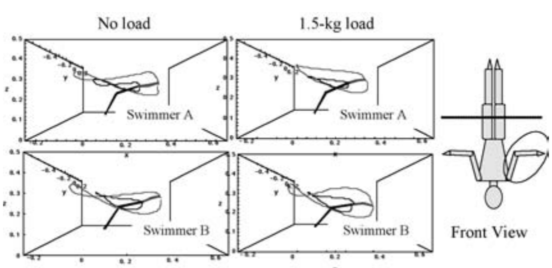

Figure 4: Front view sculling patterns of right middle fingertip and right wrist for Olympic swimmers under no load and 1.5-kg load conditions. Sculling pattern with no load is a slanting sideways figure-of-eight. Sculling pattern with a 1.5-kg weight is a slanting sharp-pointed ellipse for Swimmer A, 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

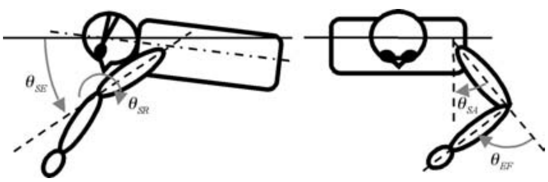

Figure 1. Definitions of the arm joint angles, the shoulder extension (SE), abduction (SA), rotation (SR), and the elbow flexion (EF) in frontcrawl swimming.

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

$$\theta_{SE}(t) = 180^{\circ}/(1+e^{-kSE(t-tSE)}) \qquad \text{(Eq. 1)}$$

$$\theta_{EF}(t) = \theta_{EF\,\max}\, e^{-kEF(t-tEF)^2} \qquad \text{(Eq. 2)},$$

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.

$$\theta_{SA}(t) = 0^{\circ} \qquad \text{(Eq. 3)}$$

$$\theta_{SR}(t) = 90^{\circ}-80^{\circ}e^{-20(t-t_{SR})^2} \qquad \text{(Eq. 4)}.$$

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.

$$\boldsymbol{A}_{wrist} = \frac{d^2\,\mathbf{P}_{wrist}(\theta_{SE}, \theta_{EF}, \theta_{SA}, \theta_{SR})}{dt^2} \qquad \text{(Eq. 5)}$$

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

$$a = (\boldsymbol{A}_{wrist} + \mathbf{g}).\mathbf{j} \qquad \text{(Eq. 6)}$$

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.

$$I = \sum_{i=0}^{n} \{a(i) - a_{\text{measured}}(i)\}^2 \qquad \text{(Eq. 7)}$$

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.

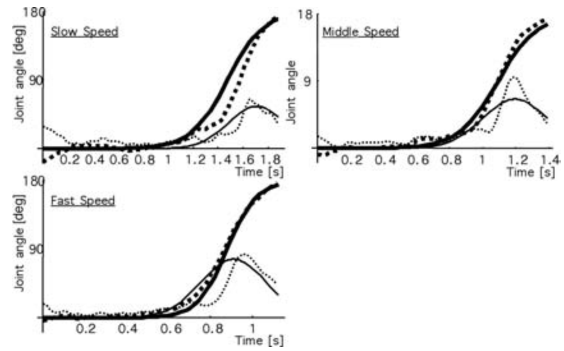

Figure 2. Comparison of the angular displacement between that estimated from the acceleration (solid) and that measured using videography (dotted) of the shoulder extension (thick) and the elbow flexion (thin).

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).

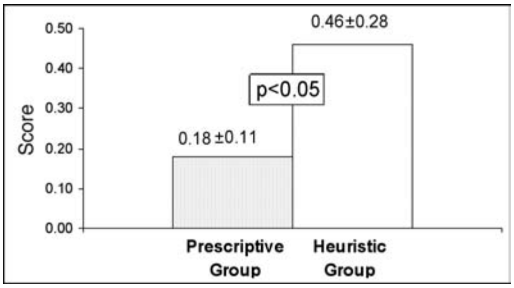

Figure 1. Results after the teaching period (Mean and SD).

No differences were found in the summative tests (fig. 2).

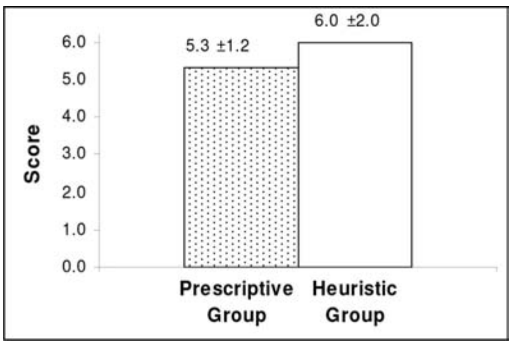

Figure 2. Results of the summative tests after the teaching period (Mean and SD).

In the group learned by the prescriptive method no differences were found between pre-post results in any test performed (fig. 3).

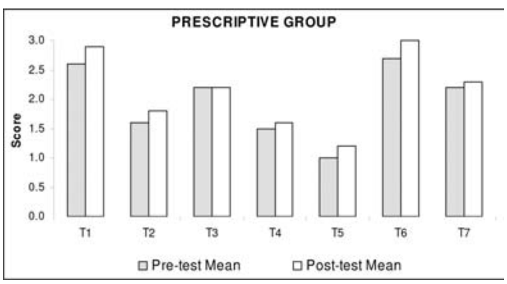

Figure 3. Comparison between pre-tests and post-tests scores obtained by subjects of group learned by the prescriptive method.

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 ($p<0.01$).

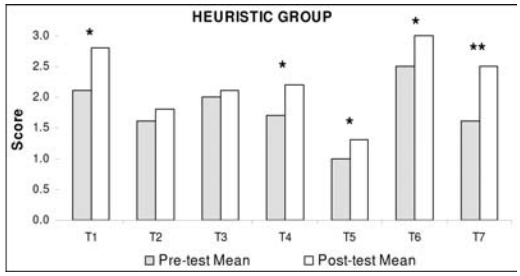

Figure 4. Comparison between pre-tests and post-tests scores obtained by subjects of group learned by the heuristic method. Significant differences are shown: (*) when $p<0.05$, (**) when $p<0.01$.

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≤ 0.01);*
** - significant difference between swimming with and without RV (p≤ 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≤ 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.

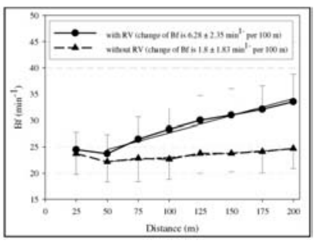

Figure 1. Comparisons of Bf during submaximal 200-m front crawl swim between swimming with RV and swimming without RV.

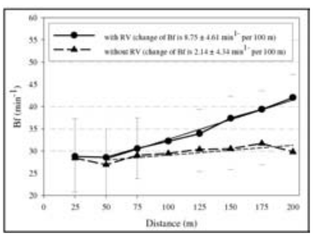

Figure 2. Comparisons of Bf during maximal 200-m front crawl swim between swimming with RV and swimming without RV.

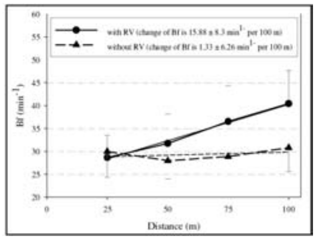

Figure 3. Comparisons of Bf during front crawl swimming to exhaustion between swimming with RV and swimming without RV.

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

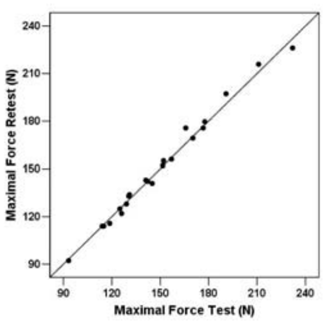

Figure 1. Maximal tethered force test and retest for familiarised swimmers (r=0.995).

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).

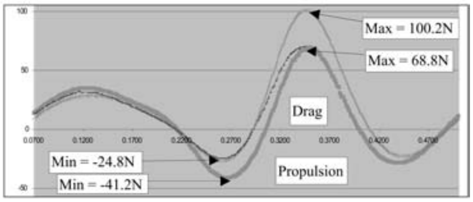

Figure 2. Net thrust graph highlighting the effects of ankle flexibility on propulsion.

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.

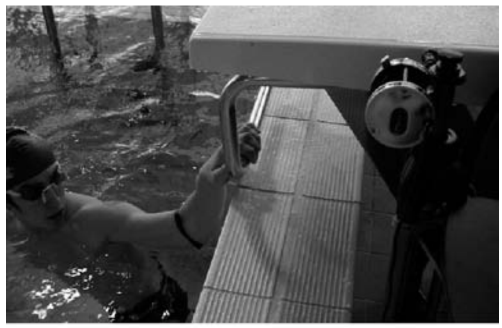

Figure 1. The speedometer

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.

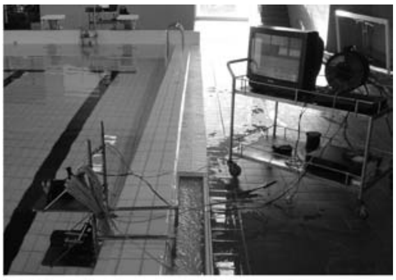

Figure 3. The dual-media image capture and mixing mechanism

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.

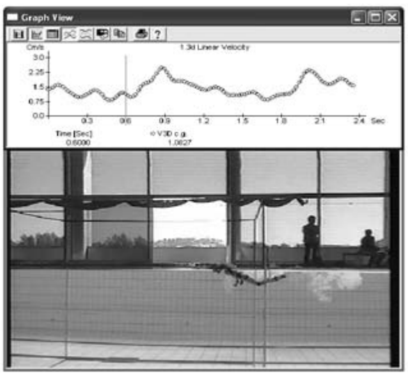

Figure 4. Data analysis

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.

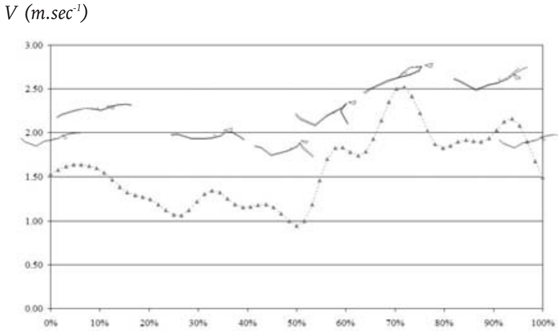

Figure 5. Butterfly intra-cycle velocity variation profiles of v_{CM} from a swimmer during a stroke cycle.

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.

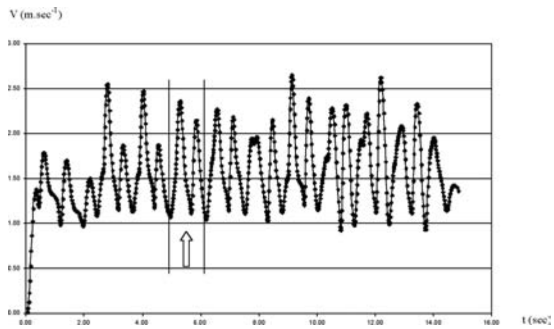

Figure 6. Speed profiles of v_{hip2} from a swimmer during a 25 meter Butterfly set.

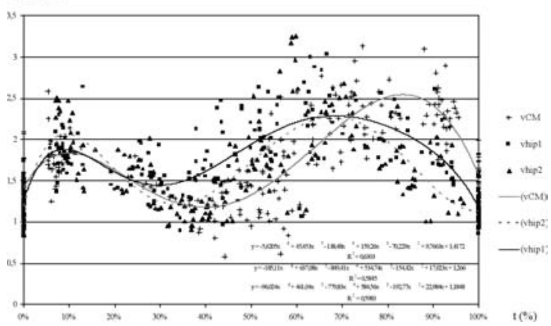

Figure 7. Velocity profiles obtained for the pooled data for v_{hip1}, v_{hip2} and v_{CM} during a stroke cycle.

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 ($p \leq 0,01$). 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.

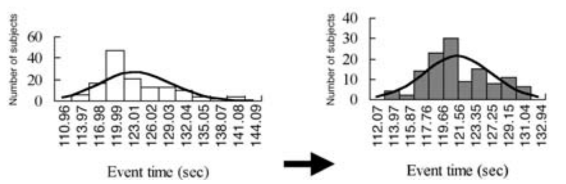

Figure1. Sample selected for the normal distribution by D'Agostino-Pearson test.

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).

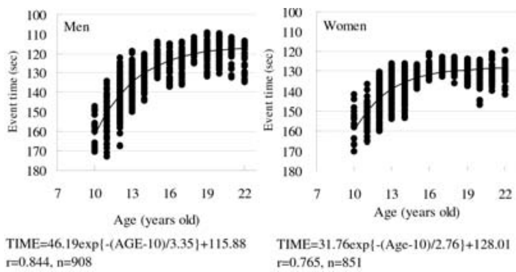

Figure 2. Development tendency of 200m freestyle event time.

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:

$$LAP=\left(a_1AGE^3+a_2AGE^2+a_3AGE+c_1\right)TIME+\left(b_1AGE^3+b_2AGE^2+b_3AGE+c_2\right)$$

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.

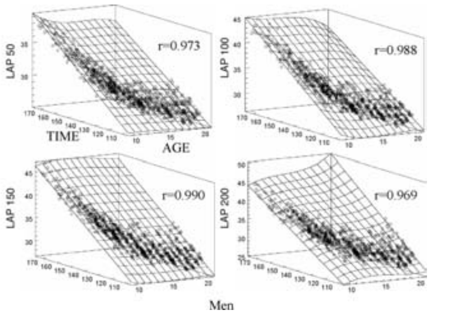

Figure 3. Three dimensional relationships among LAP, TIME and AGE for men.

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.

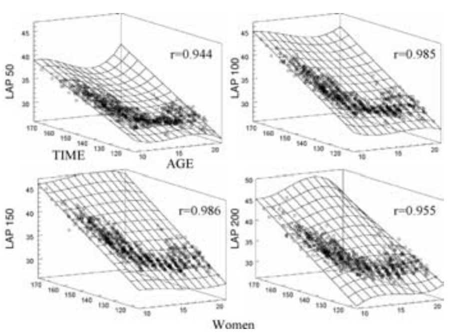

Figure 4. Three dimensional relationships among LAP, TIME and AGE for women.

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).

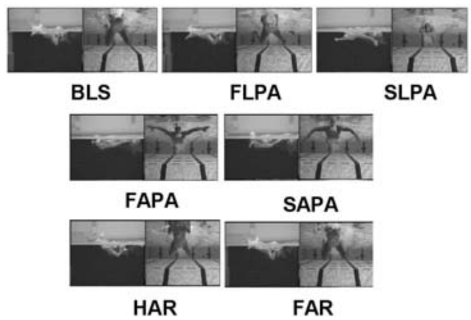


Figure 1. Image used under Colman authorization. The figure focused the criteria point used to separate the critical behaviour developed in the field format criteria.

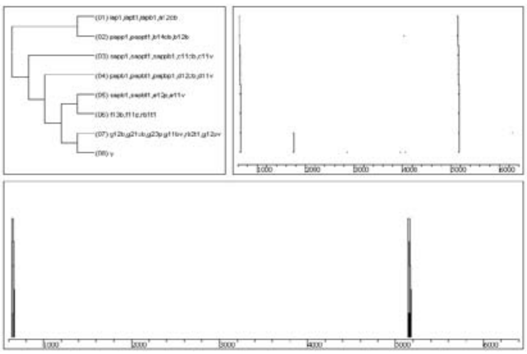
Each criterion included, as behaviour unities, the most relevant segment relation occurrences between trunk, head, arms and legs positions, hand trajectories and acceleration. For each criterion and for each unity the correspondent code was defined. The code definition was followed by the coding process 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.

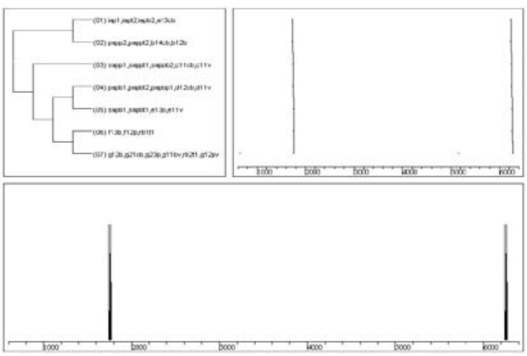
The video recorded swim sessions were coded by ThemeCoder, which enables detailed transcription of digitized video files. It included 55 events composed by 28 event type. The quality of data is dependent of the observation capacity, specific swimming knowledge and practice of the observer. To test its 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

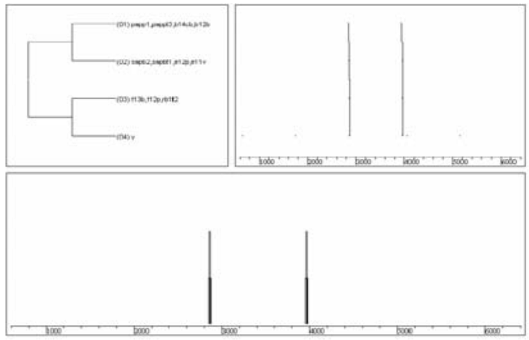
integrate all seven phases of the cycle described above; incomplete are those patterns that only present some of the phases.
The software displays a Three-box T-Pattern diagram as shown in figures 2, 3, 4 and 5 were we can visualize the structure and details of patterns and the way in which particular 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.

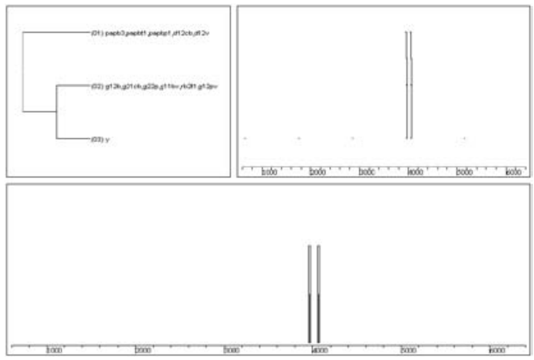




Figures 2 and 3. Description of all details of cycle pattern. Each branch includes simultaneous occurrence of leg, trunk, arms and head codes (01) beginning of leg support phase; (02) first leg propulsion action; (03) second leg propulsion action; (04) first arm propulsion action; (05) second arm propulsion 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".

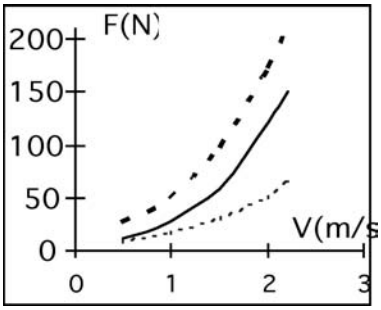

Figure 2. The force-velocity characteristics of the swimming simulator «ART» (real swimming mode by Clarys - continues line; power mode – bold dotted line; speed mode – weak dotted line).

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.

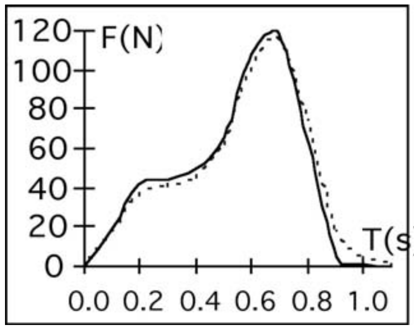

Figure 3. The dynamic force characteristics in typical cyclic swimming movements on the exerciser "ART" (simulating butterfly style).

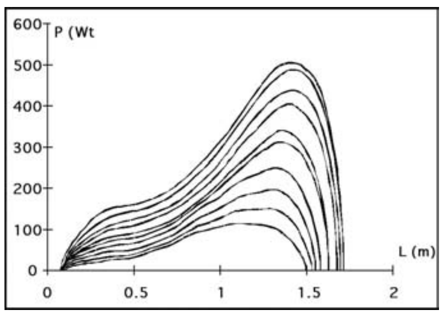

Figure 4. Change of stroke dynamical structure in ST-10 (simulating butterfly style).

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).

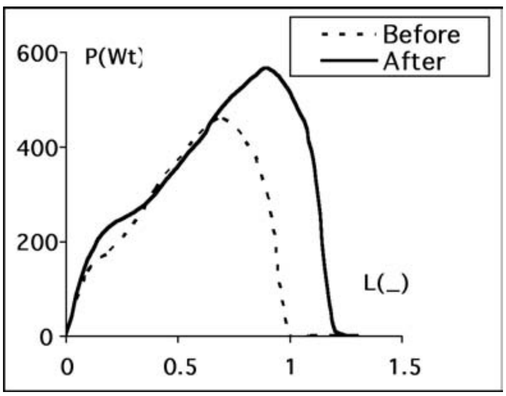

Figure 5. Change of dynamical structure after a "power mode" training program (simulating butterfly style).

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).

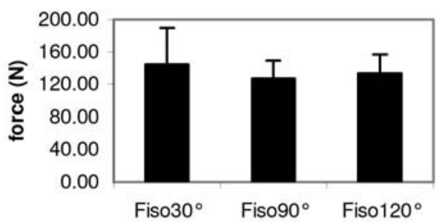

Figure 1. Maximal isometric forces for 3 arm-trunk angles (30°, 90°, 120°).

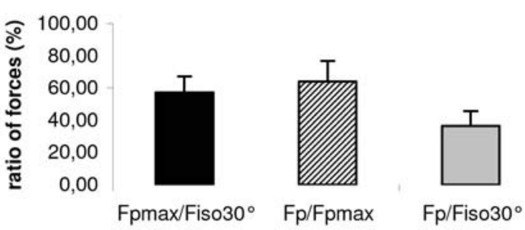

Figure 2. Ratios Fpmax/Fiso30º, Fp/Fpmax, Fp/Fiso30°.

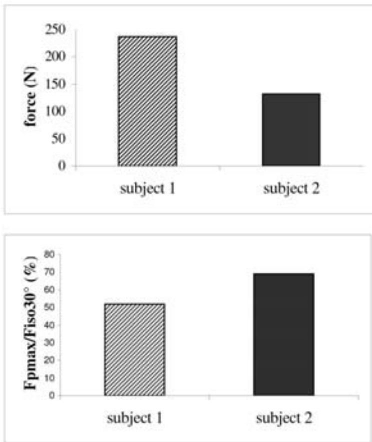

Figure 3. Fiso30° and Fpmax/Fiso30° for 2 subjects.

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

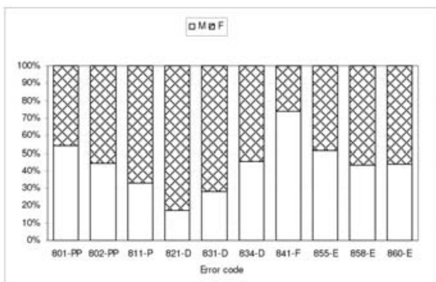

Figure 1. Errors frequency in male and female groups.

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.

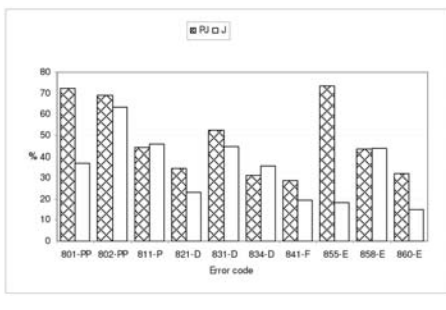

Figure 2. Errors frequency in junior and pre-junior swimmers groups.

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

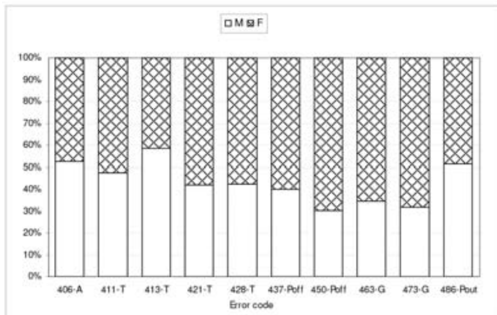

Figure 1. Crawl turns errors frequency in male and females groups.

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.

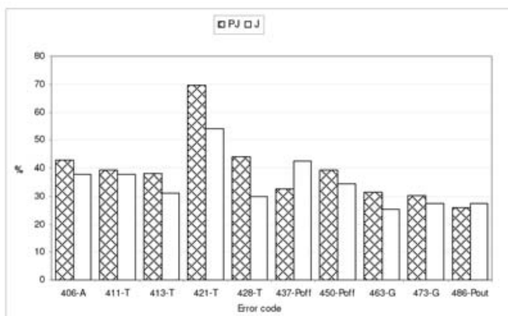

Figure 2. Crawl turns errors frequency in junior and pre-junior swimmers groups.

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

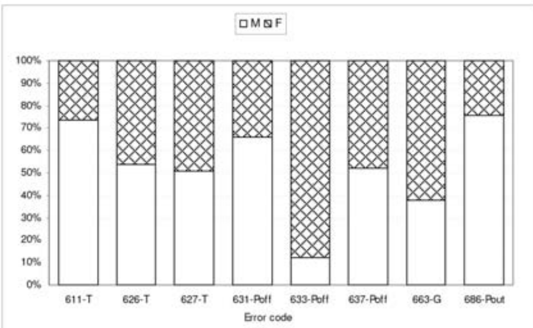

Figure 3. Back crawl turns errors frequency in male and females groups.

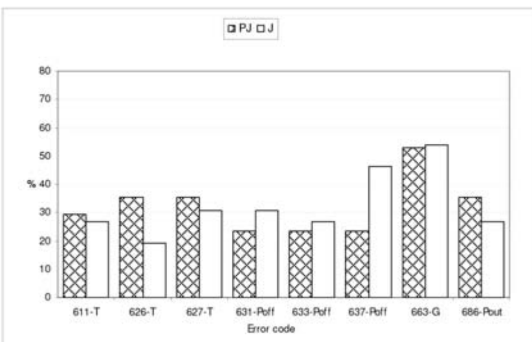

Figure 4. Back crawl turn errors frequency in junior and pre-junior swimmers groups.

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 ($9.1 \pm 3.7\%$ vs. $-3.2 \pm 3.6\%$; $F_{1,14}=10.37$; $p<0.05$). 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.

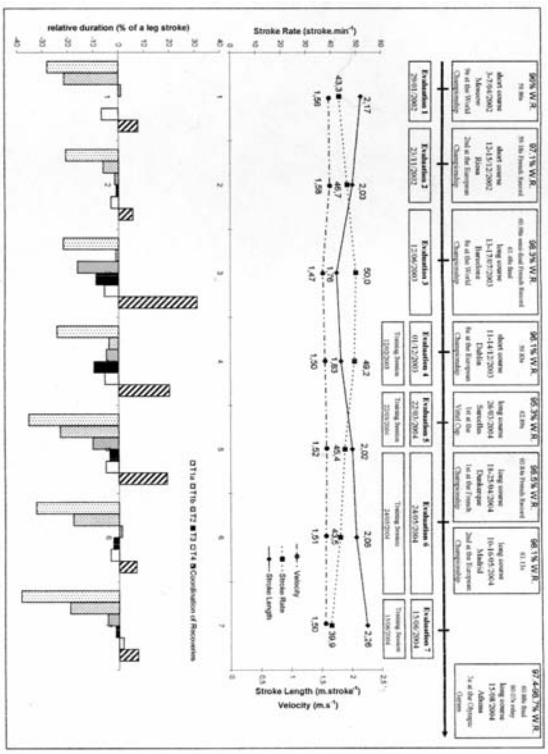

Figure 1. Relationships among performance, spatial-temporal parameters and coordination across seven evaluations.

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

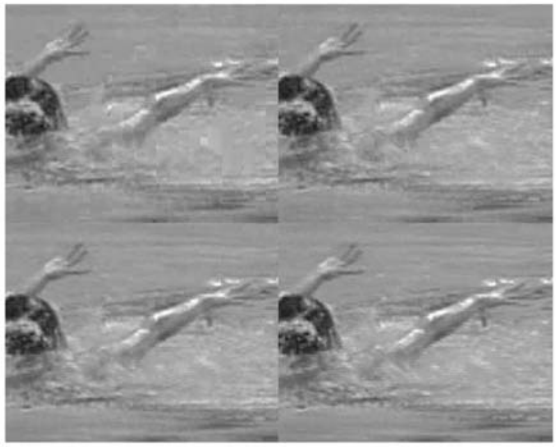

Figure 2. Differences of movie quality resulting from different bit rates. Upper left: 1Mbps, upper right: 2Mbps, lower left: 3Mbps, lower right: 6Mbps.

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.

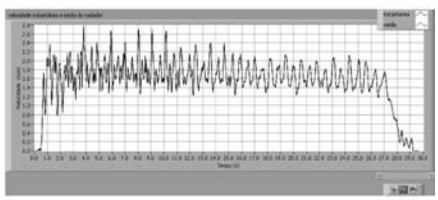

Figure 1. Instantaneous velocity curve of a 30 sec maximal swimming test obtained with speedometer.

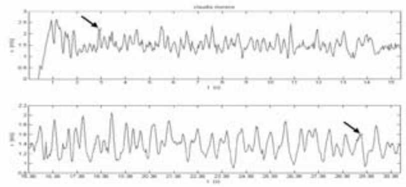

Figure 2. Cut off (→) of instantaneous velocities correspondent to start, glide and wall arrival.

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".

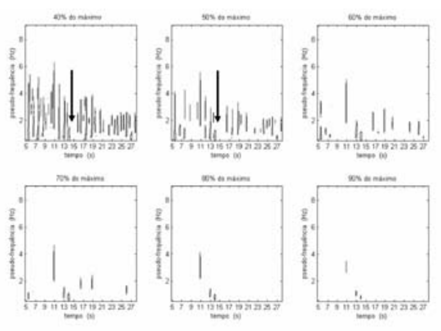

Figure 3. Contour plots from the wavelet analysis of the velocity curve of Fig. 1. It's possible to observe, in the first diagram, two distinct zones of frequency behaviour, with a separation around 14 sec (arrows). This behaviour change is confirmed on the sequential diagrams.

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.

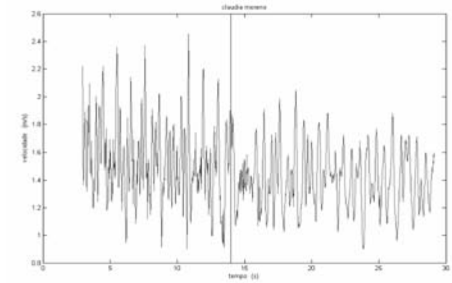

Figure 4. Velocimeter curve presented on Fig. 1 with the selected time point signed on.

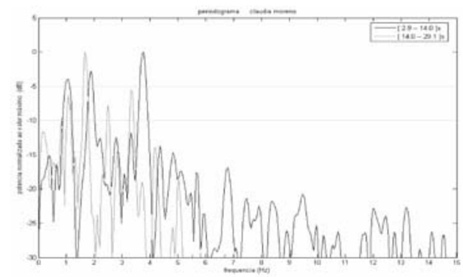

Figure 5. Periodograms for the two time intervals defined by the fatigue threshold point. The attenuations of 5 and 10dB from maximum amplitude are signed by the horizontal lines.

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.

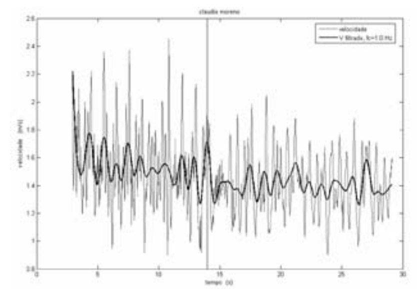

Figure 6. Instantaneous velocity in the considered time range, with the velocity filtered at 1.0Hz plotted over, and the fatigue threshold signed on.

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.

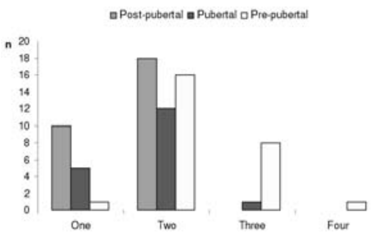

Figure 7. Absolute frequency of velocity curves with 1, 2, 3 or 4 fatigue thresholds by maturational groups.

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).

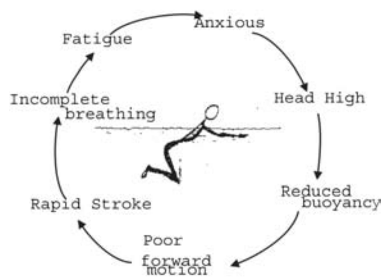

Fig. 1. The anxious child - a vicious circle

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		Male	
	Students	Swimmers	Students	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.

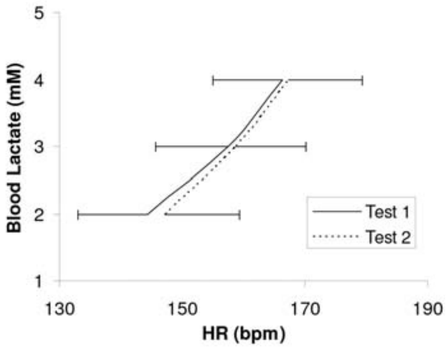

Figure 1. Mean HR (error bars are SD) for blood lactate concentrations of 2.0, 3.0, and 4.0 mM T_1 and T_2.

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:
$WC_L = 332.5 \text{ x } n$,
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.

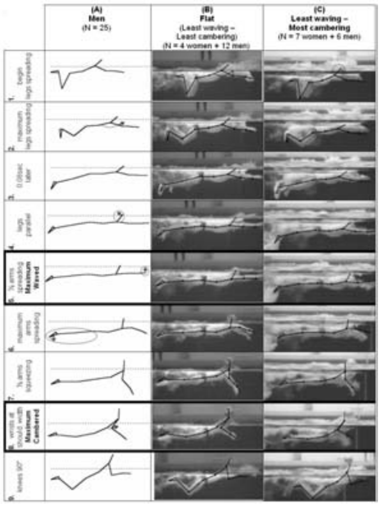

Figure 1a. Overview in average stick figures of nine selected instants for the men, the flat and the least waving-most cambering styles. Performance relevant angles, amplitudes,… are specified by an arrow; the direction shows the variation in technique corresponding to better performance. Movement deviations 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.

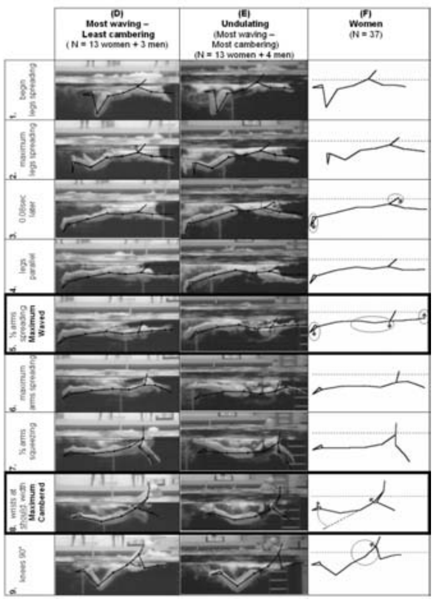

Figure 1b. Overview in average stick figures of nine selected instants for the most waving-least cambering style, the undulating style and the women. Performance relevant angles, amplitudes,… are specified by an arrow; the direction shows the variation in technique corresponding to better performance. 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.

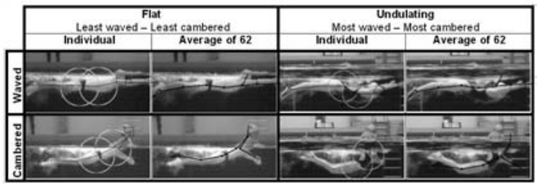

Figure 2. To classify the style in 50% most or 50% least waving and cambering, a digitizing procedure on PC is being developed, allowing to reconstruct in the maximum cambered and waved positions the body parts below and above the water surface. The two stick figures of the individual obtained are compared 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):

$$e_p = \frac{P_d}{P_o} = \frac{P_d}{P_d + P_k} \tag{1}$$

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•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

$$P_d = K \bullet v^3 \tag{2}$$

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:

$$e_p = \frac{P_d}{P_o} = \frac{K \bullet v_{free}^3}{K \bullet v_{M.A.D.}^3} = \frac{v_{free}^3}{v_{M.A.D.}^3} \tag{3}$$

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:

$$D = A \bullet v^n \tag{4}$$

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:

$$e_p' = e_p \cdot \frac{v_{free}^{n-2}}{v_{M.A.D.}^{n-2}} \tag{5}$$

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•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 $m \bullet s^{-1}$). The average v swimming arms only in the free-swimming condition was with 1.64 $m \bullet s^{-1}$ clearly slower (T-value 16.3, 12 degrees of freedom, $p<0.0001$) than the average v (1.81 $m \bullet s^{-1}$) 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 ($D = A \bullet v^n$). 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 $m \bullet s^{-1}$ 27% higher than the 1.29 $m \bullet s^{-1}$ 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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