The 7x200m incremental intermittent protocol for anaerobic threshold assessment in swimming. A physiological and biomechanical study.

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João Carlos Marujo Martins Pereira de Sousa

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Estudo, manjar d'alma

"Recomeça...

Se puderes,

Sem angústia e sem pressa.

E os passos que deres,

Nesse caminho duro

Do futuro,

Dá-os em liberdade

Enquanto não alcances

Não descanses

E nenhum fruto queiras só metade."

Miguel Torga, Diario XIII

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This Thesis is based on the following papers and abstracts, which are referred in the text by their Arabic and Roman numerals, respectively:

---Papers---

1. Sousa, J.C.; Vilas-Boas, J.P.; Fernandes, R.J. Individual Anaerobic Threshold Assessment in the four conventional swimming techniques. For submission to the International Journal of Sports Medicine.

2. Sousa, J.C.; Ribeiro, J.; Sousa, M.; Nazario, R.; Figueiredo, P.; Abraldes, A.; Vilas-Boas, J.P.; Fernandes, R.J. Biomechanical analysis of the 7x200m front crawl incremental intermittent protocol. For submission to the Journal of Applied Biomechanics.

--Abstracts--

I. Sousa, J.C.; Vilas-Boas, J.P.; Fernandes, R.J. (2010). Individual anaerobic threshold assessment in elite swimmers. Abstract book of the 4th Meeting of Young Researchers of University of Porto, pp. 432.

II. Sousa, J.C.; Ribeiro, J.; Vilas-Boas, J.P.; Fernandes, R.J. (2011). Individual anaerobic threshold assessment in front crawl swimmers. In: N.T. Cable; K. George (eds.), Abstract book of the 16th annual congress of the European College of Sports Science, Liverpool, UK, pp.567-568.

Table of Contents

Index of Tables

Index of Figures

Index of Equations

Abstract

Physiological and biomechanical factors have a direct influence in swimming performance, for that is essential to assess those several factors. In fact, for more specific and precise evaluation of those factors, the use of progressive incremental exercise tests may be one of the most precise methods to assess vital information for training process. The purpose of the study was, firstly used the 7x200m incremental intermittent protocol for physiological evaluation, assessing the individual anaerobic threshold in all conventional techniques and medley in elite swimmers due to the scarce literate using all techniques and medley; Secondarily, the protocol was used to evaluate and compare the stroking parameters (stroke rate, stroke length, stroke index), swim efficiency (intra-cyclic velocity variations and propelling efficiency), hydrodynamic body position (trunk incline) and arm coordination with (index of coordination) in swimmers of different levels, middle-distance and open water swimmers. The results obtained, shows values of IndAnT were lower than the standard 4 $mmol.l^{-1}$ value in all techniques, corroborating the literature for well aerobically trained front crawl swimmers. Throughout the 7x200m steps, Stroke rate and index of coordination increased, trunk incline and propelling efficiency decreased and stroke index and intra-cyclic velocity variations maintained stable. Differences were observed between individual anaerobic threshold and the standard 4 $mmol.l^{-1}$ value in front crawl and between steps in velocity, stroke rate, stroke index and index of coordination. The incremental protocol for used in the present study is specific and precise for physiological and biomechanical assessment, confirming that the 4 $mmol.l^{-1}$ and velocity at 4 $mmol.l^{-1}$ values do not represent the individualized lactate threshold and to understand the behaviour of biomechanical parameters during different intensities, with fatigue installation and before and after anaerobic threshold.

KEY-WORDS: SWIMMING, ANAEROBIC THRESHOLD, KINEMATICS, INCREMENTAL PROTOCOL

Resumo

Os factores fisiológicos e biomecânicos influenciam directamente na performance desportiva do nadador, como tal é necessário avaliar esses factores. Os testes incrementais e progressivos são dos métodos mais específicos para avaliação desses mesmos factores, que fornecem informação vital para o processo de treino. O objectivo deste estudo foi usar o teste de 7x200m incremental e progressivo, em primeiro para determinar o limiar anaeróbio individual nas quatro técnicas de nado e estilos individual em nadadores de elite; e em segundo lugar avaliar e comparar os parâmetros biomecânicos gerais (frequência gestual, distância ciclo e índice de braçada), eficiência de nado (eficiência propulsiva e variações intracíclicas da velocidade), posição hidrodinâmica (tronco inclinado) e coordenação (índice de coordenação) em nadadores de diferentes níveis competitivos, meio-fundo e de águas abertas. A análise dos resultados mostra que os valores de limiar anaeróbio individual foram inferiores ao valor standard de 4mmol.l-1 nas várias técnicas de nado e que vai de encontro com a literatura em nado crol sobre nadadores treinados. Ao longo do protocolo observou-se um aumento da frequência gestual e índice de coordenação, uma diminuição da eficiência propulsiva e tronco inclinado e uma estabilização das variações intracíclicas da velocidade e índice de braçada. Foram observadas diferenças entre o limiar anaeróbio individual e o valor standard de 4 mmol.l-1 na técnica de crol e ainda diferenças entre patamares na velocidade, frequência gestual, índice de braçada e índice de coordenação. O protocolo incremental de 7 patamares de 200m confirma-se como uma ferramenta específica e efectiva na avaliação fisiológica e biomecânica do treino, demonstrando que os valores das 4mmol.l-1 e da velocidade correspondente às 4mmol.l-1 não corresponde a um limiar anaeróbio individual do nadador, permitiu ainda compreender o comportamento dos parâmetros biomecânicos ao longo do protocolo em diferentes intensidades de nado, fadiga e no antes e depois do limiar anaeróbio.

PALAVRAS CHAVE: NATAÇÃO, LIMIAR ANAERÓBIO, CINEMÁTICA, PROTOCOLO INCREMENTAL

List of Abbreviations

%: percentage

η_P: propelling efficiency

[La$^-$]: blood lactate concentration values

AnT: anaerobic threshold

$AnT_{[La-]}$: blood lactate concentration corresponding to AnT

ATP: adenosine three phosphates

b/min: beats per minute

cf: confront

e.g.: example

h: hours

i.e.: this is

IdC: index of coordination

indAnT: individual AnT

IVV: intracyclic velocity variations

m/s: meters per second

MaxLass: maximal lactate steady state

min: minute

mmol/l: millimoles per litter

ºC: degree Celius

SD: standard deviation

SL: stroke length

SR: stroke rate

TI: Trunk incline

vAnT: swimming velocity corresponding to AnT

v4: swimming velocity corresponding to 4mmol/l

v3.5: swimming velocity corresponding to 3.5mmol/l

VO_2: volume of oxygen consumption

VO_{2max}: maximal volume of oxygen consumption

vs: versus

CHAPTER 1 - GENERAL INTRODUCTION

Competitive performance in swimming has reached a very high level of demand, becoming essential the training diagnosis and evaluation of competitive swimmers as part of training programs. According to Smith et al. (2002) the first-level evaluation should be the competitive performance itself, since it is at this moment that all elements interplay and provide the 'highest form' of assessment. Nevertheless, it became necessary to control the training process to optimize resources and results. Thus, accepting that swimming performance is influenced by several factors, the assessment of the bioenergetics and biomechanics parameters is essential (Fernandes et al., 2008).

More specific, the use progressive incremental exercise tests to evaluate aerobic performance capacity (Faude et al. 2009), has become an important factor to determine the success of the swimmer. Following Pyne et al. (2000) swim test sets are one method of analyzing the progress of swimming training and gather vital information to ensure training program and helping achieve goals, being the 7x200m protocol (Pyne et al., 2001 and Fernandes et al., 2003) a prime example. This protocol allows the coach and sport scientist to examine a number of variables and constructs (Smith et al, 2002).

Thus, the intermittent incremental protocol proposed by Fernandes et al. (2003), previously validated by Cardoso et al. (2003), was adapted and used in the present study for individual anaerobic threshold (IndAnT) assessment. The use of 200m step distance is, for several authors (Lavoie & Leone, 1988; Costill et al., 1992; Atkinson & Sweetenham, 1999; Gastin, 2001; Pyne et al., 2000; Pyne et al., 2001), the most adequate to assess swimmers AnT. However, Kuipers et al. (2003) stated that evaluations through incremental protocols with steps duration of 3 min or less may have failed to assess the adequate $[La^-]$ at a given exercise intensity and consequently assessed incorrect AnT values. In fact, some authors suspect that an accurate lactate evaluation in a given workload intensity, steps duration may take 3 min or more to a establishment of [La$^-$] occurs (Yoshida, 1984; McLellan, 1985; Orok et al., 1989; Anoula & Rusko 1992; Foxdal et al., 1995; Moreau et al., 1999; Rama, 2009). This is not our point of view once previous data of our group evidenced that 300 and 400m steps did not implied different [La$^-$] in an incremental protocol (Fernandes et al., 2011).

One of the most studied areas in swimming is the assessment of the anaerobic threshold (AnT), which could be defined as the break point on the curve of blood lactate concentrations ([La$^-$]) vs workload during incremental exercise (Mader & Heck, 1986), or by the moment when the lactate production exceeds its removal (Brooks, 2000). AnT has been reported has one of the most consistent predictor of performance in endurance events, being frequently assessed for training diagnosis in cyclic sports. Studies have repeatedly found high correlations between performance in endurance events such as running, cycling, and race-walking and the maximal steady-state workload at the AnT (McKardle et al., 1996). One of the most used methods for AnT assessment in running and swimming is based on the averaged value of 4 mmol.l^{-1} of [La-], proposed by Mader et al (1976). However, several authors (e.g. Setgman et al.,1981 and Fernandes et al., 2005) suggested an individualized approach rather than the use of a fixed [La-]. In fact, a fixed value of [La-] does not take into account considerable interindividual differences, and that value of 4mmol.l^{-1} may frequently underestimate or overestimate (in trained athletes) real aerobic capacity (Keul et al, 1979; Setgmann et al, 1981; Simon et al, 1981; Faude et al, 2009; Fernandes et al., 2011). Stegmann et al. (1981) defined the IndAnT as the metabolic rate where the elimination of [La-], during exercise is both maximal and equal to the rate of diffusion of lactate into the blood. The determination of IndAnT involves the measurement of [La-] during a progressive incremental exercise test and a subsequent recovery period (McLelan & Jacobs, 1993).

This thesis begins with a general introduction (**Chapter 1**), where all the chapters are approached and described. In the **Chapter 2**, the assessment of IndAnT in all conventional swimming techniques (front crawl, backstroke, breastroke, and butterfly) and in medley is determined using the 7x200m intermittent incremental protocol. These results were previously presented to academic community in form of abstract in the 4th meeting of young researchers of University of Porto (**Appendix I**). Most studies that assessed InAnT were conducted in front crawl (e.g. Fernandes et al., 2003; Fernandes et al., 2005; Anderson et al., 2006; Fernandes et al., 2010; Ribeiro et al., 2011a), in breaststroke (Thompson et al. 2006; Thompson & Garland, 2009), front crawl, backstroke and breastroke (Pyne et al., 2000; Pyne et al., 2001; Anderson et al.,2008). However, Pyne et al. (2000), Pyne et al. (2001) and Anderson et al. (2008) included swimmers for all techniques in their studies, but front crawl was the used stroke for butterfly and medley swimmers. The relevance of the present study, is justified because it is only method evaluated all conventional techniques and medley, revealing to scientists and coaches the effectiveness of using the 7x200m test intermittent incremental protocol in assessing IndAnT in the swimmer's best technique.

In spite of incremental testing protocols used as a standard procedure for swimming physiological assessment, it is widely accepted that the achievement and/or maintenance of a specific swimming velocity is not only related to bioenergetical factors but also with the biomechanical ones (Termin & Pendergast, 2000), once they are physiologically influenced (Dekerle et al., 2005; Barbosa et al. 2008). Some studies aimed to assess the biomechanical changes throughout incremental tests (eg. Keskinen & Komi, 1988; Dekerle et al., 2005), focusing mainly in the determination of the stroking parameters (stroke rate, SR, and stroke length, SL). The combination of increases or decreases in SR and SL establishes the increasing and decreasing of velocity (Craig et al., 1985; Tousaint et al., 2006; Kjendlie et al., 2006; Barbosa et al., 2011), and stroke mechanics is considered to reach an optimal balance between SR and SL when velocity values are at their highest level with a relatively low energy cost of swimming (Barbosa et al., 2008). Furthermore, Costill et al. (1985) proposed other variable to assess the stroke cycle kinematics, the stroke index (SI), which assumes that at a given velocity the swimmer who moves the greatest distance per stroke has the most effective swimming technique. Complementarily, to study the influence of hydrodynamic forces in swimming velocity, Zamparo et al. (2009) suggested the use of the Trunk Incline (TI) variable, concluding that the human body changes ‘‘configuration’’ with increasing speed; indeed, velocity of specific drag (D/v2) decreases as the velocity increases, so TI decreases with increasing velocity; Therefore, the changes in D/v2 are related to changes in TI. Zamparo et al. (2009) also indicate that TI is lower during passive drag measurements than while swimming, thus suggesting that active drag should be larger than passive drag.

In fact, the swimming velocity has different expressions on SR and SL depending on the swimmer’s ability to generate propulsive forces and overcome the resistive ones (Ribeiro et al., 2011b), which has a direct consequence on the velocity variations within a stroke cycle (intra-cycle velocity variations, IVV). The IVV is a recognized parameter used for the analysis of technical proficiency (Holmer, 1979; Craig et al., 2006; Tella et al., 2008), swimming efficiency (Alberty et al., 2005; Vilas-Boas et al., 2010), skill level (Seifert et al., 2010), motor organization (Schnitzler et al., 2010), and comparison between swimming intensities (Barbosa et al., 2008) and techniques (Maglischo et al., 1987; Craig et al., 2006). For Vilas-Boas et al. (2010) IVV represents the accelerations and decelerations of a swimmer’s fixed body point, or the body center of mass (CM), within a stroke cycle, and two methods are frequently used for its assessment: (i) the velocity measurement of a fixed point, usually the hip, using mechanical or image-based methods (Maglischo et al., 1987; Craig et al., 2006; Schnitzler et al., 2010), and (ii) the bi or three dimensional (2D and 3D, respectively) reconstruction of the movement of the CM through digitizing procedures. (Maglischo et al., 1987; Barbosa et al., 2008; Psycharakis et al., 2010). Complementarily, for evaluation of the efficiency of propulsion generation the index of propelling efficiency (η_P) (Zamparo et al.,2005) and the inter-arm coordination are accepted, in case of inter-arm coordination it is related to the ability to maintain propulsive continuity, presenting direct expression on SR and SL (Seifert et al., 2010). The index of coordination (IdC) proposed by Chollet et al. (2000) assess the modifications on temporal organization of arm stroke phases and arm coordination. The IdC in front crawl is based on the lag time between the propulsive phases of each arm, which quantifies three possible coordination modes (Chollet et al., 2000): opposition (continuity between two arm propulsions, IdC = 0%), catch-up (a time gap between the two arm propulsions, IdC < 0%) and super position (an overlap of the two arm propulsions, IdC > 0%). According to Seifert et al. (2007), the arm coordination in swimming is influenced by some constraints: environmental constraints (e.g. active drag and velocity), task constraints (pace imposed, goal, instructions or rule of the task) and organism constraints (the swimmer speciality, anthropometric characteristics and gender).

So, **Chapter 3** was designed to evaluate the stroking parameters, swim efficiency, hydrodynamic body position and arm coordination along the incremental and intermittent protocol with 200m step durations. It was also aimed to compare long distance and elite swimmers, trying to observe expected differences between groups due to training and competition characteristics.

Lastly, a General Discussion is presented, in which the results obtained from the 7x200m incremental intermittent protocol of the two independent studies will be confronted with the literature (**Chapter 4**). The final conclusions obtained by the analysis in the General Discussion of the present study are presented in the **Chapter 5**.

CHAPTER 2 – Individual Aerobic Assessment in all conventional swimming techniques

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Abstract

The individual anaerobic threshold (IndAnT) is defined as the highest metabolic rate where blood lactate concentrations ([La]) are maintained at a steady-state during prolonged exercise, and was reported to have great variability between swimmers. In fact, the standard 4 mmol/l value does not take into account considerable inter-individual differences, and may underestimate or overestimate real aerobic capacity. The purpose of this study was to assess the IndAnT in the four conventional swimming techniques and in medley. In a 50 m swimming-pool, 25 elite swimmers (20.1±2.2 yrs, 181.2±6.9 cm, 73.8±8.0 kg and n>8 training units per week) performed an nx200 m individualized intermittent protocol, with increments of 0.1 $m \cdot s^{-1}$ between each step, and 1 min intervals. Capillary blood samples, collected during the intervals, allowed assessing IndAnT through the [La-]/velocity curve modelling method. Velocity and [La] values corresponding to IndAnT averaged, respectively, 1.37±0.11 $m.s^{-1}$ and 2.31±0.67 $mmol.l^{-1}$ for front crawl (n=13), 1.33±0.35 $m.s^{-1}$ and 1.93±0.33 $mmol.l^{-1}$ for backstroke (n=2), 1.19 $m.s^{-1}$ and 1.36 $mmol.l^{-1}$ for breaststroke (n=1), 1.32±0.66 $m.s^{-1}$ and 4.30±0.55 $mmol.l^{-1}$ for butterfly (n=4), and 1.35±0.08 $m.s^{-1}$ and 3.68±1.31 $mmol.l^{-1}$ for medley (n=5). [La] corresponding to IndAnT values were lower than the standard 4 $mmol.l^{-1}$ value in all techniques, corroborating the literature for well aerobically trained front crawl swimmers. Concerning the swimming velocity at IndAnT, significant differences with velocity at 4 $mmol.l^{-1}$ were observed for front crawl, breaststroke and butterfly, and a tendency is also evident for backstroke. The incremental protocol for IndAnT assessment used in the present study is specific and precise for IndAnT assessment, confirming that the 4 $mmol.l^{-1}$ and velocity at 4 $mmol.l^{-1}$ values do not represent the individualized lactate threshold in trained swimmers performing the other conventional swimming techniques.

Introduction

The key to success in swimming does not relies in voluminous and indiscriminate training, but in conducting a purpose and careful process, meaning that training should be well planned and monitored. Several studies highlight this point of view, evidencing the importance of training control and evaluation of swimmers (Costill et al., 1999; Olbrecht, 2000; Smith et al., 2002). From the complex group of swimming performance influencing factors, the physiological parameters seem to gain the attention of the technical and scientific community since long time. In fact, 20% of the 662 papers published in the Biomechanics and Medicine in Swimming books (a series of international symposia organized every four years between 1970 and 2010) had a physiological approach, and ~45% of the studies about swimming research available in the PubMed™ are related with the physiologic area of expertise (Vilas-Boas et al., 2010).

Among the different parameters possible to be determined in a swimming physiological evaluation, the assessment of the Anaerobic Threshold (AnT) is, probably, the most common. As the AnT is considered to be the break point on the curve of blood lactate vs workload during incremental exercise (Mader et al. 1978), it could be identified in the point when the lactate production exceeds its removal (Brooks, 2000). Occurring within the range of submaximal exercise intensities, AnT has been reported as one of the most consistent predictor of performance in cyclic sports with high aerobic participation, such as running, cycling, and race-walking (Mader et al., 1978; McKardle et al., 1996), and swimming (Mader et al., 1978; Olbrecht, 2000). Taking place, in general, between 50 and 80% of the maximal load, and at a blood lactate concentration ([La]) of 4 mmol/l (Mader et al., 1978), this last [La] value is being used widely for its determination in cyclic sports in general, and in swimming in particular. However, some authors keep suggesting an individualized approach rather than the use of a fixed [La] (e.g. Stegmann et al., 1981; Pyne et al., 2001; Fernandes et al., 2011). The standard 4 mmol.l-1 value does not take into account considerable inter-individual differences and may frequently underestimate (particularly in anaerobically trained subjects) or overestimate (in aerobically trained athletes) real aerobic capacity (Keul et al, 1979; Stegmann et al, 1981; Simon et al, 1982; Howat & Robson, 1990; Faude et al, 2009).

Thus, the concept of individual anaerobic threshold (IndAnT) has raised in the beginning of the 1980's (Stegmann et al., 1981), being accepted as the metabolic rate where the elimination of [La] during exercise is both maximal and equal to the rate of diffusion of lactate into the blood; its assessment implies the measurement of [La] during a progressive incremental exercise protocol and subsequent recovery period (McLelan & Jacobs, 1993). In swimming, graded incremental exercise tests are used to evaluate aerobic performance capacity (Faude et al. 2009), particularly the Australian 7x200 m (Pyne et al, 2001) and its subsequent adaptation by Fernandes and co-authors for children (Fernandes et al., 2010), and adult swimmers of both genders and proficiency levels (e.g. Fernandes et al., 2003; Fernandes et al., 2008). However, this intermittent incremental protocol for IndAnT assessment was conducted only for the front crawl technique, existing an absence of data regarding both [La] and velocities corresponding to IndAnT in the other conventional swimming techniques.

The aim of the current study was to assess the IndAnT in front crawl, breaststroke, backstroke and butterfly, as well as in medley, in highly trained swimmers performing their preferential technique. It was hypothesized that the [La] corresponding to IndAnT ([La$^-$]IndAnT) was lower than the standard 4 mmol.l-1 value, leading to corresponding relevant differences between the swimming velocities corresponding to IndAnT (vIndAnT) and 4 mmol.l^{-1} (v4). Complementarily, due to the existence of higher intracyclic velocity variations in the simultaneous techniques comparing to the alternated ones (Barbosa et al., 2010), it was hypothesized that the [La$^-$]IndAnT of the breaststroke and butterfly will be higher than those of front crawl and backstroke. As the assessment of IndAnt in all conventional swimming techniques was never assessed, the originality and pertinence of this study are clearly stated.

Material and Methods

Subjects

Twenty-five elite swimmers, specialists in front crawl (n=13), backstroke (n=2), breaststroke (n=1), butterfly (n=4) and medley (n=5) volunteered to participate in the present study, and signed written term consent form in which the protocol was explained; the local ethics committee approved the experiments. The swimmers' mean ± SD physical and competitive level characteristics were: 20.1±2.2 years old, 181.2±6.9 cm of height, 73.8±8.0 kg of body mass, 10.8±5.2 % of fat mass, 91.3±2.9% of world record in the 200m long course event of each swimmer best technique, and n>8 training units per week.

Testing procedure

In a 50 m indoor pool (water temperature at 27°C), and after a standardized warm-up consisting of 1500 m of aerobic swimming, each subject performed a nx200 m individualized intermittent incremental protocol, with increments of 0.1 m·s-1 each step, and 1 min rest intervals (adapted from Fernandes et al, 2003). Initial velocity was established according to the swimmers' individual 400 m performance in the moment of the test, and at least six steps until exhaustion should be accomplished. In water starts were used, and velocity was measured through a chronofrequencemeter, being controlled through auditory signals in each 50 m. Capillary blood samples for [La] analysis were collected from the earlobe at rest, in the rest intervals, immediately after the end of each exercise step, and at 3 min (and 5 min) during the recovery period, being analysed using an Lactate Pro analyzer (Lactate Pro, Arkay, Inc, Kyoto, Japan) that is considered an accurate device (Baldari et al., 2009). IndAnT was determined by [La]/velocity curve modeling method (least square method), being assumed to be the intersection point, at the maximal fit situation, of a combined pair of linear and exponential regressions (cf. Fernandes et al., 2011), and v4 was determined by linear inter or extrapolation of the [La-]/velocity curve. One example for each conventional swimming technique (and medley) of the IndAnT and v4 assessment methodologies are given in Figure 1.

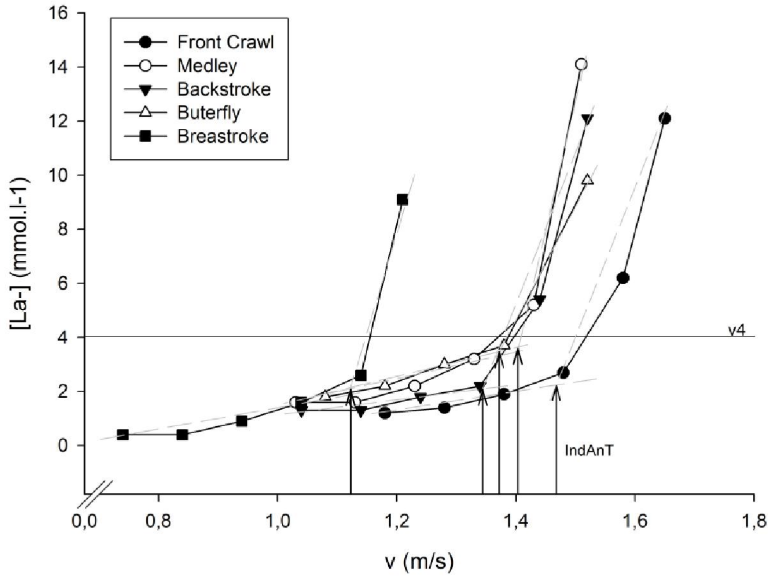

Figure 1. Examples of a blood lactate concentration to velocity curve in the nx200 m protocol for individual anaerobic threshold assessment, being represented by the interception of a linear and an exponential line (in each conventional swimming technique and in medley). v4 is also presented.

Statistical analyses

Mean and SD computations for descriptive analysis were obtained for all variables (all data were checked for distribution normality with the Shapiro-Wilk test). Paired samples Student's t-test were used for comparisons between vIndLan and v4 for n≥10, and Wilcoxon non parametric test of for n<10 and a significance level of 5% was accepted. All statistics were performed using SPSS (version 18.0 for Windows).

Results

In Table 1 it is possible to observe the mean and SD values corresponding to $[La^-]$IndAnT, vIndAnT and v4 in three conventional swimming techniques, and in medley; for breaststroke it is presented individual values. [La] corresponding to IndAnT values were lower than the standard 4 $mmol.l^{-1}$ value in all techniques, being closer for medley. vIndAnT was, in general, lower than v4 (with exception for medley); however, differences were only significant for front crawl.

Table 1. Mean ± SD values corresponding to [La-]IndAnT, vIndAnT and v4 obtained in the three conventional swimming techniques, and in medley. Individual values are displayed for breaststroke.

	front crawl (n=13)	backstroke (n=2)	breaststroke (n=1)	butterfly (n=4)	medley (n=5)
$[La^-]$IndAnT (mmol·l-1)	2.32±0.68	1.93±0.33	1.76	3.31±0.97	3.68±1.31
vIndAnT (m·s-1)	1.38±0.11*	1.33±0.04	1.12	1.24±0.15	1.35±0.08
v4 (m·s-1)	1.46±0.08*	1.41±0.01	1.16	1.28±0.10	1.36±0.04

* represents significant differences between vIndAnT, v4

When the conventional swimming techniques were grouped in simultaneous and alternated techniques, [La] corresponding to IndAnT values were lower than the averaged 4 mmol.l^{-1} value, and vIndAnT was lower than v4 in the alternated techniques group (Table 2).

Table 2. Mean ± SD values corresponding to [La-]IndAnT, vIndAnT, and v4 obtained in the alternated and simultaneous swimming techniques.

	alternated techniques (n=15)	simultaneous techniques (n=10)
$[La^-]$IndAnT (mmol·l-1)	2.27 ± 0.65	3.34 ± 1.19
vIndAnT (m·s-1)	1.37 ± 0.10*	1.28 ± 0.13
v4 (m·s-1)	1.45 ± 0.07*	1.31 ± 0.09

* represents significant differences between vIndAnT and v4

Considering the total group of swimmers (n=25), $[La^-]$IndAnT ranged from 1.12 mmol.l^{-1} in one front crawler to 5.87 mmol.l^{-1} in one medley specialist; the averaged value of all conventional techniques plus medley was of 2.71±1.04 mmol.l-1, expressively lower than the standard 4 mmol.l-1 value.

Discussion

The main aim of the current study was to assess the AnT in the four swimming techniques that are used in training and competition. The AnT is frequently used on swimming diagnosis to evaluate the adequacy of the training exercises and programs directed to the development of the swimmer’s aerobic capacity, and corresponding training series intensity prescription. However, despite the existence of several tests to assess AnT, the majority reveals significant constraints that should prevent coaches and researchers in its use: (i) the 30 and 60 min (Olbrecht et al., 1985) and 2000 m tests (Touretski, 1993), although being non-invasive and simple to implement, are monotonous and little motivating that could lead to an underestimation of the final result; moreover, the typical mean velocities resulting from these tests are unlikely to be uniform, reflecting different levels of physiological intensity (Smith et al., 2002). The maximal lactate steady state protocol (Heck et al., 1985) is also a long distance test, having also the above-referred limitations, and is hard to implement once requires the repetition of prolonged test distances in, at least, three consecutive days; (ii) the critical velocity test (Wakayoshi et al., 1992), composed by, at least, two distances swam at maximal intensity or by two competition events, is simple, motivating and give individualized results; however, as it should not be suppressed a long test distance (of ~15 min duration), once it may lead to an overestimation of the final result (Wright & Smith, 1994), it is very hard to accomplish in the simultaneous swimming techniques, particularly in butterfly; (iii) the two speed test, based on 2 x 200 m and 2 x 400 m tests (Mader et al., 1978), is widely known and used, but it uses an averaged value (of 4 mmol.l-1 of [La]) to assess the IndAnT, which does not take into consideration the significant inter-individual variability (Kelly et al., 1992; Svedahl & MacIntosh, 2003; Fernandes et al., 2010; Fernandes et al., 2011).

Other more specific and individualized methodologies are reported in the literature but also have important restrictions that prevent its widespread use, particularly the bias of the personal observation of the [La]/velocity curve inflection point, and the requirement of very high [La] (15 mmol.l-1) that implies strenuous exercise intensities. Thus, in the current study, it was used an individualized methodology that allowed to determine the exact point for the beginning of an exponential rise in [La], which was used before both for adults (Fernandes et al., 2008; Fernandes et al., 2011) and children swimmers (Fernandes et al., 2010). It was observed that the [La]IndAnT values were lower than the fixed 4 $mmol.l^{-1}$ value in all swimming techniques, being closer for medley; this is in accordance with the literature for front crawl (Fernandes et al., 2005, Fernandes et al., 2010), confirming that the 4 $mmol.l^{-1}$ does not represent the individualized lactate threshold in aerobically trained swimmers. The data obtained for butterfly and medley are closer to the value of 3.5 $mmol.l^{-1}$ proposed by Heck et al. (1985) as a more adequate value for trained swimmers. The [La]IndAnT of alternated and simultaneous swimming techniques seems to be distinct, probably due to the kinematical characteristics of the breaststroke, butterfly and medley that could influence the physiological data. In fact, as swimming performance is dependent from the energetic profile, and this one from the biomechanical behavior (Barbosa et al., 2010), it was already expected that the higher intracyclic velocity variations of the simultaneous techniques could lead to higher $[La^-]$IndAnT values. Once intracyclic velocity variations results from the balance between propulsion and drag, which are determined by the stroke mechanics and segmental velocities, it is perfectly understandable that simultaneous techniques, due to their higher energy cost (Holmér et al., 1974; Barbosa et al., 2006), imply a higher [La]IndAnT, as the anaerobic contribution could be greater even at moderate intensities. As an example, it is known that the intracyclic velocity variations of butterfly are higher at lower velocities (de Jesus et al, 2010), imposing a high energy cost (Barbosa et al. 2005), since energy must be delivered to overcome inertial forces (Costill et al. 1987; Nigg 1983). However, at high velocities, it seems there is no difference at post race [La] (Bonifazi et al. 1993, Vescovi et al 2011); this might be due to the potential energy gains when a better coordination is applied at higher velocities, and higher potential and rotational energy kinetics from the upper body is transferred to the lower body (Sanders, 2011). These changes have an effect of efficiency, justifying that at the velocities correspondent to the [La]IndAnT simultaneous techniques present higher energy requirements, and so higher [La]. In addition, previous research have reported that [La] tends to be higher in medley events compared with other techniques (Bonifazi et al. 1993), as observed in this study.

The vIndAnT was, in tendency, lower than v4 (with exception for medley). Nevertheless these differences was only significant for front crawl, they correspond to [2.5 - 4.3 s] of time difference in a 100 m effort. Understanding that aerobic capacity should be trained using high volume, low intensities and little rest between repetitions (Olbrecht, 2000), it can be observed that ~4 s at each 100 m could impose more than 1 min difference in the final of a typical 16 x 100 m training series for aerobic capacity development. In addition, it is also important to highlight that although changes in v4 obtained for front crawl are roughly correlated with the changes in v4 in backstroke, breaststroke and butterfly, they cannot always be transferred to nor observed in the other techniques (Olbrecht, 2000). As expected, front crawl had the highest (and breaststroke the lowest) vIndAnT, in accordance with Kelly et al. (1992).

Conclusion

Once the enhancing of swimmer's performance can no longer be obtained only by the increasing of training volume and by the use of nonspecific methodologies (Costill, 1999; Olbrecht, 2000), more objective and specific training sets are required to improve the quality of the training process, aiming develop performance. The incremental protocol for IndAnT assessment used in the current study seems to allow specific and precise for IndAnT assessment, in detriment of the v4 value that do not represent the IndAnT in trained swimmers performing the alternated techniques. Conversely, the averaged 3.5 mmol.l-1 values closer to the IndAnT of butterfly and medley. Given that high percentage of the training volume in swimming is dedicated to the development of the swimmer's aerobic capacity (Maglischo, 2003), coaches are advised to use IndAnT to provide individualized objective data that allow them to better quantify the proper intensities to develop the aerobic performance.

CHAPTER 3 - Biomechanical analyses of competitive swimmers of different performance levels

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Abstract

Biomechanical factors play a very important role in swimming performance and the influence of stroking parameters, stroke rate (SR), stroke length (SL) and stroke index (SI) are well reported. The purpose of this study, that was to evaluate and compare the stroking parameters, swim efficiency with intra-cyclic velocity variations (IVV) and propelling efficiency (η_P), hydrodynamic body position with trunk incline (TI) and arm coordination with index of coordination (IdC) in swimmers of different levels using the 7x200m incremental intermittent protocol. In a 25m swimming pool, 6 middle-distance and 6 open water swimmers performed an 7x200 m individualized intermittent protocol, with increments of 0.05 $m \cdot s^{-1}$ between each step, and 1 min intervals. Swimming velocity (v) ranged from 1.24 to 1.48 and from 1.04 to 1.37$m.s^{-1}$ for middle-distance and open water swimmers. Concerning v, differences within-group were found in both groups ($p \leq 0.03$) and between groups were found from steps 1 to 7 ($p \leq 0.05$). Regarding stroking parameters, within-group differences were found in SR and between groups were found in SR from steps 1 to 6, SI from steps 1 to 7 and SL in step 7. Finally, IdC shows differences within middle-distance group and between groups difference were observed in IVV in step 1, η_P in step 6 and IdC in step 3. The results obtained indicates that the changes of the biomechanical parameters between steps of an incremental protocol and between swimmers of different levels could be an interesting means to assess the adequacy of the swimmers adaptation to training and different velocities and distances. This fact leads to coaches and scientists to use intermittent protocols as procedure for biomechanical performance assessment.

Keywords: stroking parameters, swim efficiency, hydrodynamic body position, arm coordination, 7x200m step protocol

Introduction

To achieve real training procedures in Swimming, coaches and swimmers need to track the changes and the influence of the determinant factors (Smith et al., 2002), that provide vital information to the training process. In fact, testing play a major role in assessing the likely outcome of a swimming competitive performance (Anderson et al., 2008), and also as a training prescription tool (Olbrecht, 2000; Fernandes et al., 2011). Although, it is important to questioned what factors contribute to peak performance from a biomechanical point of view (Toussaint & Truijens, 2005).

In swimming it is widely accepted that the achievement and/or maintenance of a specific velocity is not only related to bioenergetical factors but also with the biomechanical ones (Termin & Pendergast, 2000), since they are physiologically influenced (Dekerle et al., 2005, Barbosa et al. 2008). Among the biomechanical factors, the influence of the stroking parameters stroke rate (SR), stroke length (SL), and stroke index (SI) on swimming performance (Keskinen & Komi, 1993; Wakayoshi et al, 1995) and their changes throughout incremental tests (Keskinen & Komi, 1988, Dekerle et al., 2005) are well reported. In fact, swimming velocity has different expressions on SR and SL (Tousaint et al., 2006; Craig et al., 1985; Kjendlie et al., 2006), depending on the swimmer’s ability to generate propulsive forces and overcome the resistive ones. This fact has a direct consequence on the intra-cycle velocity variations (IVV), considered an inverse indicator of swimming efficiency (Vilas-Boas et al., 2010). Although the validity of the IVV from of a fixed body landmark has been questioned (Psycharakis & Sanders, 2009) its assessment (e.g. the hip) seems to be reliable (Costill et al., 1987), enabling the assessment of fatigue effects (Alberty et al., 2005). Despite possible minors associated errors, the information provide by this method seems far more adapted to field studies than the centre of mass 3-D reconstruction, which is very time consuming, and depends on the accuracy of the anthropometric biomechanical model used to compute the inter-limb inertial effects (Schnitzler et al., 2010).

Complementarily, the arm coordination is also accepted as an indicator of swimming efficiency, since it is related to the ability to maintain propulsive continuity, presenting direct expression on SR and SL (Seifert et al., 2010). Inter- arm coordination represents one of the most important factors contributing to the generation of propulsive forces (Potdevin et al., 2006), being a way to minimize IVV; moreover, the propulsive continuity allow the swimmer to minimize the deceleration between two propulsions, increasing swimming efficiency (Seifert et al., 2010). Chollet et al. (2000) proposed the Index of Coordination (IdC) to assess those modifications on temporal organization of front crawl arm stroke phases and arm coordination. Following these authors, the three major patterns of arm coordination are the catch up, the superposition and the opposition modes, being the coordination employed by the swimmer determined by the relative contributions of each phase (entry/catch, pull, push and recovery) to the total duration of the arm stroke cycle. In addition, the hydrodynamic drag assumes a relevant role in technical adaptations, and, therefore, in the arm coordination and IVV (Seifert et al., 2007), being the contribution of the drag and lift forces to overall propulsion one of the most discussed issues in swimming research (Barbosa et al., 2011).

In this sense, the question to be addressed now is whether the biomechanical parameters, and its changes as v increases, distinguish swimmers of different performance levels. The purpose of this study was to evaluate and compare the stroking parameters, swim efficiency, hydrodynamic body position and arm coordination in swimmers of different levels when performing an incremental and intermittent protocol with 200m step durations.

Methods

In this study different groups of swimmers (middle-distance and open water swimmers) were tested. Twelve swimmers, middle-distance (n=6) and open water (n=6) specialists volunteered to participate in the present study, and signed written term consent form in which the protocol was explained; the local ethics committee approved the experiments. The swimmers' mean ± SD physical and competitive level characteristics were for middle-distance: 17.33±1.21 years old, 172.67±6.86 cm of height, 65.21±8.42 kg of body mass, 12.50±7.18 % of fat mass and n>8 training units per week; Open water: 18.33±1.75 years old, 179.17±3.97 cm of height, 66.27±4.05 kg of body mass, 10.20±9.08 % of fat mass and n>8 training units per week

As proposed by Pyne et al. (2000) a standardized warm-up, consisting primarily of aerobic swimming of low-to-moderate intensity, was conducted before the testing protocol. All tests were conducted in a 25 m indoor swimming pool, 1.90 m deep, with a water temperature of 27.5ºC. In water starts and rollover turns were used. All equipment was calibrated prior to each experiment.

Each participant performed, in randomized order, an intermittent incremental protocol until exhaustion with: (i) step duration of 7x200m, (ii) increments of 0.05 m/s each step, (iii) 30s rest interval (adapted from Fernandes et al., 2008). Researchers and coaches determined the velocity of the last step based on the best hypothetical time in the 400m front crawl event that the swimmers were able to accomplish at that time. Successive 0.05 m/s was subtracted from the swimming velocity corresponding to the referred hypothetical time, allowing the determination of the mean target velocity for each step (cf. Fernandes et al., 2008). Throughout the protocol, the swimming velocity was controlled using an underwater visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal), with flashing lights on the bottom of the pool. This device was used to help the swimmers to keep the predetermined swimming v. The subjects were videotaped in the sagittal plane using a double camera set-up (Sony® DCR-HC42E, 1/250 digital shutter), being one camera placed above the water surface and the other was kept underwater (Sony SPK-HCB waterproof box) exactly below the surface camera. Two complete arm stroke cycles of the last 50 m lap of each step were analysed, and nine anatomical landmarks (right femoral condoyle and both sides finger tips, wrist, elbow, and shoulder) were digitized at a frequency of 50 Hz (APASystem, Ariel Dynamics, USA). The 2D reconstruction was accomplished using DLT algorithm and a low pass digital filter of 5 Hz. The mean swimming velocity and SL were calculated using the fixed right hip point, and SR was determined as the number of cycles per min (Craig & Pendergast, 1979). In the intermittent incremental protocol, SR and SL were calculated in each step, being assessed through images visualization and APAS system analysis. In addition, SI was calculated by the product of swimming v by SL, assuming that at a given v, the swimmer who moves the greatest distance per stroke has the most effective swimming technique (Costill et al., 1985).

Trunk Incline (TI) was defined by the angle (α) between the shoulder (acromion process) and the hip (great trochanter) segment and the horizontal. This measurement was taken at the end of the insweep, where the hand is directly below the shoulder (Zamparo et al., 2009). The IVV was quantified by the determination of the coefficient of variation of the hip´s instantaneous velocity (cf. Alberty et al., 2005; Schnitzler et al., 2008)

The η_P of the arm stroke was calculated with the values of velocity (v), SR and the shoulder to hand distance (calculated from measures of arm length and elbow angle), following a recently proposed model by Zamparo et al. (2005).

$$\eta_P = ((v*0.9)/(2\pi*SR*L))(2/\pi) \qquad (2)$$

where the v is the average velocity of the swimmer, multiplied by 0.9 because in the frontal crawl about 10% of forward propulsion is produced by the legs, SR, and the average calculated from shoulder-to-hand distance (*l)*.

Finally, the arm stroking coordination was obtained through the Index of Coordination (IdC) (Chollet et al., 2000), being each arm stroke broken down into four phases: (i) entry and catch (corresponding to the time between the entry of the hand into the water and the beginning of its backward movement); (ii) pull (corresponding to the time between the beginning of the hand 's backward movement and its arrival in a vertical plane to the shoulder); (iii) push (corresponding to the time from the position of the hand below the shoulder to its release from the water) and (iv) recovery (corresponding to the point of water release to water reentry of the arm, i.e., the above water phase). The duration of each phase was measured for each arm-stroke cycle with a precision of 0.02s. The duration of the propulsive phases was the addition of the pull and the push phases durations, and the duration of the non-propulsive phases was obtained by the he catch and the recovery phases (the duration of a complete arm-stroke was the sum of the propulsive and non-propulsive phases). The IdC was calculated as the time gap between the propulsion of the two arms as a percentage of the duration of the complete arm stroke cycle. Higher negative percentage values expressed an evident discontinuity in the inter-arm propulsion, tending to IdC=0% as the time gap was diminishing.

Results

The mean ± SD values of the assessed stroking parameters for middle-distance and open water swimmers are presented on Figure 1. Swimming v ranged from 1.24 to 1.48 and from 1.04 to 1.37$m.s^{-1}$ for middle-distance and open water swimmers, respectively. Regarding v within-group, significant differences where found between steps in open water and middle-distance swimmers ($p<0.03$ and $p\leq0.05$, respectively). The analyses of v evidenced significant differences ($p<0.05$) between groups in all steps of the protocol. It is possible to observe that SR increased (B panel) and SL slightly decreased (C panel) throughout the incremental tests. When comparing groups, significant highest SR values were observed for middle-distance swimmers in all steps of the protocol;

Concerning SL, only in the 7th step were observed differences between-groups, with lower values for open water swimmers. The ANOVA repeated measures test did not show significant differences within-group (Figure 1).

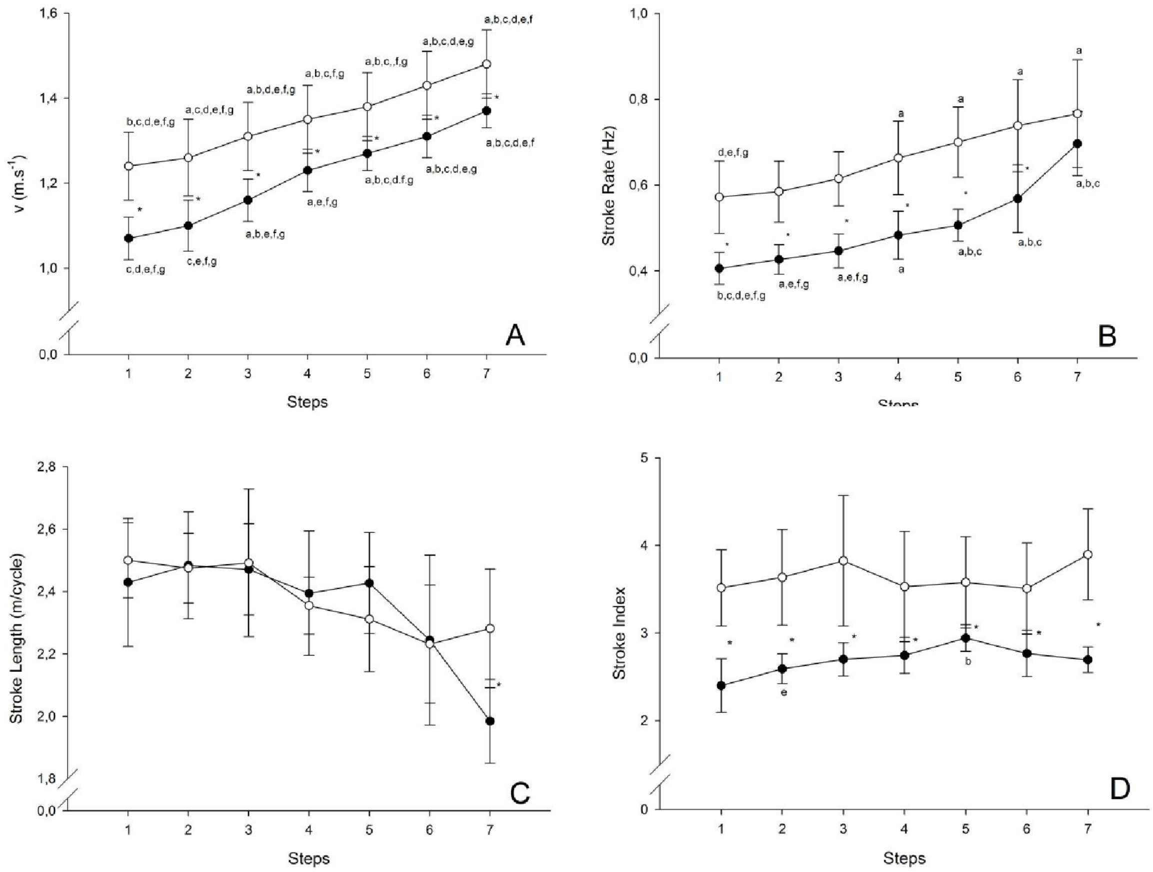

Figure 1. Values of velocity (v) (A panel), stroke rate (SR) (B panel), stroke length (SL) (C panel) and stroke index (SI) (D panel) in the 7x200m test. *, significant differences between open water (solid dot) and middle-distance (open dot) swimmers, *p<.05*. [a,b,c,d,e,f,g], significant differences between steps 1,2,3,4,5,6 and 7, *p<.05*.

Within-group significant differences where found between step 2 and 5 (p=0.01). Significant differences between groups were observed in the SI values for all the steps (p≤0.01).

In figure 2 it is possible to observe the mean ± SD values of the IVV, η_P, TI and IdC for the 7 steps of the 200m front crawl test for the middle-distance and open water swimmers. The IVV seems to present an almost constant behavior along the steps, not being observable a defined tendency in any of the groups. When comparing groups, lower values of IVV in open water swimmers were observed.

Respectively, η_P values were higher in middle-distance than in open water swimmers, presenting no differences within-groups. Concerning both groups, significant differences were found in step 4 between the two groups. The

Analysis of the SL, IVV and η_P showed that both groups studied decrease from the 1 to the 7 step. Although, no significant differences were found between and within groups.

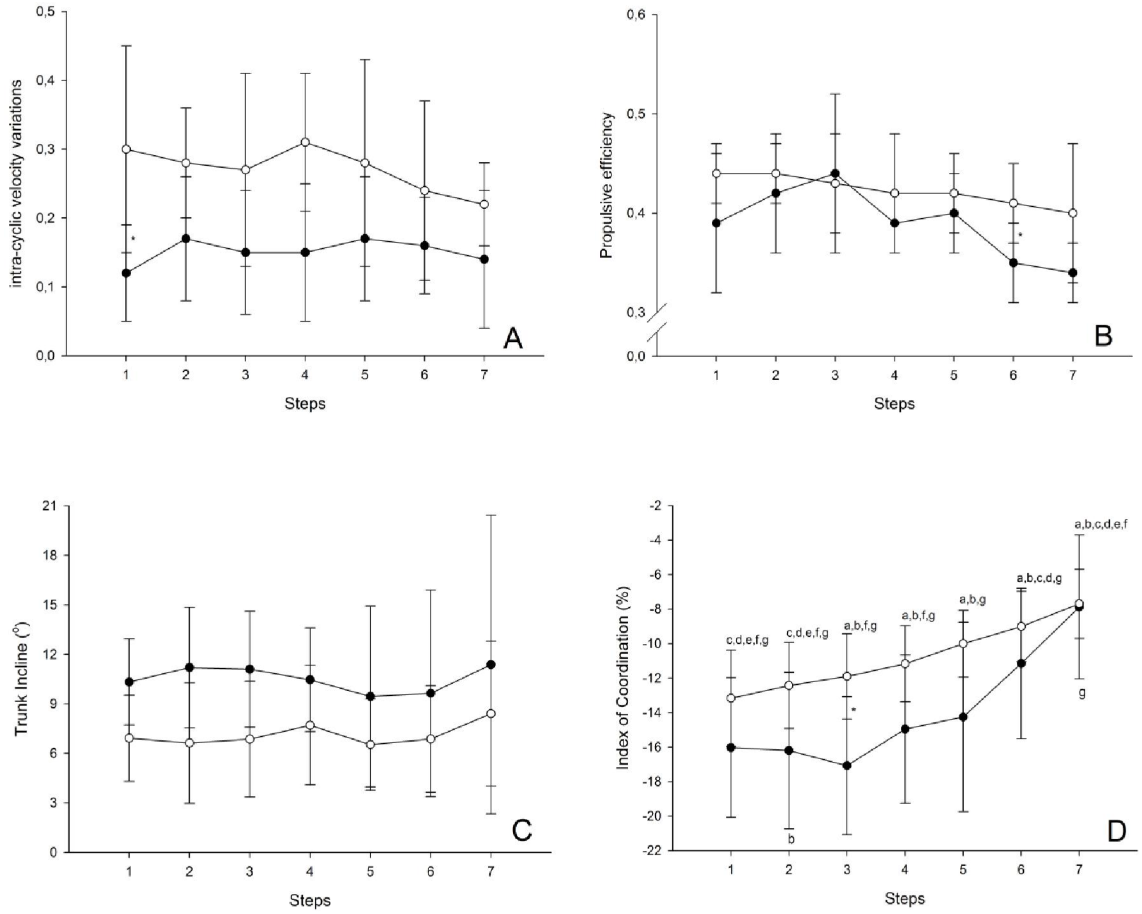

Figure 2. Step values for intra-cycle velocity variations (IVV), propulsive efficiency (η_P), trunk incline (TI) and index of coordination (IdC) in the incremental protocol for middle-distance and open water swimmers. *, significant differences between long distance (solid dot) and elite (open dot) swimmers, *p<.05.* ^{a,b,c,d,e,f,g}, significant differences between steps 1,2,3,4,5,6 and 7, *p<.05.*

Finally, for both groups IdC was negative (corresponding to a catch up coordination) with an increase at higher swimming intensities. Significant differences were presented in step 3 (P=0.03) between groups. In addition, the IdC values obtained by the open water group revealed a slight tendency to be more negative than values obtained by the middle-distance group.

Discussion

The aim of this study was to observe the behaviour of kinematical parameters along a 7x200m intermittent incremental protocol comparing different competitive levels of swimmers.

It was possible to observe that swimmers reach higher velocities by increasing SR and decreasing SL, a stroking pattern in agreement with the previous literature dedicated to the adult (Pyne et al., 2001; Dekerle et al., 2005; Psycharakis et al., 2008) and children (Fernandes et al, 2010) swimmers.Nevertheless, it should be emphasized that the combination of SL and SR has a large variability, which implies a highly individual process (Keskinnen & Komi, 1993; Pelayo et al., 1996; Baron et al., 2005) that might be explained by differences between swimmers in anthropometric characteristics, stroking technique, flexibility, and coordination (Pelayo et al., 1996; Psycharakis et al., 2008). The decline of the SL observed along the incremental protocol might be explained by the increasing velocity, achieved through the increment of SR (Dekerle et al., 2005, Ribeiro et al., 2011) and, eventually, by the progressive fatigue installation (Keskinnen & Komi, 1993). Although, open water swimmers presented SL values similar to middle-distance swimmers, but those values were obtained with lower velocities. In fact, the data suggested that, to achieve higher velocities, middle-distance swimmers adopted a more efficient SR and SL combination, as observed by the higher SI and η_P values, indicating that greater skill and technique could lead to higher efficiency of propulsion generation.

Throughout the incremental protocol middle-distance group presented sustained values of IVV, increased of IdC and decreased of η_P, which where in accordance to (Zamparo et al., 2005; Schnitzler et al., 2008; Seifert el al., 2010), Despite the n_P decreased, these findings might point out that the swimmers were able to adapt their stroke technique to maintain IVV, while reaching higher swimming intensities (Schnitzler et al., 2010). In fact, for

Schnitzler et al. (2010) the changes in the IdC and IVV (determined from the hip) could be interesting means to assess the adequacy of the swimmer's adaptation to different velocities. Nevertheless, the values obtained by middle-distance swimmers were higher than those presented by Schnitzler et al. (2010). This difference may be explained by the distance (25m) of testing protocol used by the authors. Indeed, for different 25m repetitions at different intensities, the swimming v is necessarily determined by other factors (external pace) then the specific fatigue. On the other hand, open water swimmers presented lower and stable values of IVV. This fact suggests the inability to generate higher maximal impulse, due to lower η_P, presenting lower IVV. The maintenance of IVV values is in accordance to with Psycharakis et al. (2010) and Alberty et al. (2005). The attained IVV is justified by a coordinative adaptation of the upper limbs, bringing the propulsive actions closer together when velocity increases or fatigue occurs (Alberty et al., 2005; Figueiredo et al., 2010; Schnitzler et al., 2010)

Complementary, middle-distance group performance can be explained by a high IdC and not by the high IVV values obtained. Seifert et al. (2011) comparing national and regional level swimmers, revealed that if the propulsive surface and orientation are correct, a greater IdC could be associated with higher mechanical power output, in spite of similar low IVV values between groups. In case of open water swimmers, IdC increased in the final steps of the protocol. However, the increased IdC does not automatically ensure efficiency of propulsion generation and high swimming v (Seifert et al., 2011), because swimmers can slip their propulsive segments through the water (Counsilman, 1981) or spend a long time in the propulsive phase due to a slow hand speed (Alberty et al., 2005; Aujouannet et al., 2006; Seifert et al., 2007). The improvement of IdC in both groups is justified due to greater fatigue in the muscular groups responsible for traction and that IVV were not modified under fatigue condition even despite the modification of arm coordination (Alberty et al., 2005). Despite the improvement of the propulsive actions in both groups, the non reduction of IVV at the end of an exhaustive exercise might be explained by the inability of the swimmer to minimize the resistive impulse (Alberty et al., 2005).

Complementarily, the higher TI values in open water swimmers reflects a lack of skill and technique to adopt a better streamlined position, leading to a greater hydrodynamic resistance (Zamparo et al., 2009). In fact, TI values of this study are not in agreement with Zamparo et al. (2009) since the authors stated that increasing v implies a TI decreases. On the other hand, Craig et al. (1985) stated that, under fatigue, the swimmer may pay less attention to the body alignment, which induces a less streamlined position. This may explained the maintenance of the TI values by middle-distance swimmers in the last steps of the protocol and not its diminution as expected, base on previous results (Zamparo et al. 2009). The maintenance of TI values may reflect the need of both groups to compensate the installation of the fatigue.

Concluding, the results of the present study shows middle-distance swimmers were more efficient comparing with open water swimmers. The middle-distance swimmers can adapt better to higher velocities and fatigue accumulation, justified by an improved technique. The results indicate that analyzing the changes of the biomechanical parameters between steps of an incremental protocol and between swimmers of different levels could be an interesting mean to assess the adequacy of the swimmers adaptation to training and different velocities and distances. This fact, leads to coaches and scientists to understand that the use incremental protocols, as procedure for biomechanical performance assessment, can give viable information how biomechanical parameters behave, before and after AnT, to different intensities and different steps length (cf. Fernandes et al, 2011).

CHAPTER 4 – GENERAL DISCUSSION

Swimming performance is one of the main aims of swimming "science" community. Biomechanics, Physiology/Energetics, Biophysics, EMG, Anthropometry, Psychology, Medicine, Instruments, Evaluation, Education, Training and other factors are the main scientific approaches that are used to understand swimming (Vilas-Boas, 2010). It has been proposed that of these factors, biomechanics and physiology/energetic are the areas with greatest potential to assist swimmers to enhance their performance and achieve high-levels in competitive swimming (Toussaint & Hollander, 1994; Fernandes et al., 2009; Barbosa et al., 2010; Zamparo et al., 2011). In fact, the challenge of the current study was to assess the physiological and biomechanical behavior of competitive swimmers, in order to close the gap between theory and practice.

To assess the chosen physiological and biomechanical parameters, the intermittent incremental protocol was the prime tool used in the present study. This protocol was adapted from the 7x200 m front crawl protocol previous validated by Cardoso et al. (2003) and applied to competitive swimmers by Fernandes et al. (2003). Initially, this protocol was used to assess the maximal oxygen consumption (VO2max) and corresponding swimming velocities (Fernandes et al., 2003), being considered to be reached according to primary and secondary traditional physiological criteria (cf. Adams,1998; Howley et al., 1995), particularly the occurrence of a plateau in oxygen uptake despite an increase in swimming velocity and high levels of blood lactic acid concentrations ([La-]≥8 mmol/l), elevated respiratory exchange ratio (R≥ 1.0), elevated heart rate (>90% of [220-age]) and exhaustive perceived exertion.

However, the main objective was not to assess VO2max but to use the 7x200m intermittent incremental protocol to assess AnT. In fact, AnT assessment is one of the most used parameters determined by the 7x200m protocol (Pyne et al., 2000, 2001; Fernandes et al., 2005, 2008, 2010). This protocol enables the assessment of [La-] at different intensities in a fast, easy and accurate way, with immediate results (Madsen & Lohberg, 1987). Moreover, its main advantage is the individualized assessement of AnT (Pyne et al., 2001; Fernandes et al., 2008, 2010; Kilding et al., 2010).

Complementarily, the 7x200m protocol for AnT assessment allows the swimmer to begin the test with low velocity, existing a balance between the lactate production and its removal. After the AnT has been reached, the anaerobic contribution is truly significant, being the exponential growth of [La-] clearly observed in the following steps. Coen et al. (2001) stated that the increments between steps are one factor of variability to which the AnT assessment is insensitive. The 30 s intervals between steps were proved to be accurate for v at AnT assessment (Wakayoshi et al. 1993). In the current study the swimming v in all protocols was controlled by underwater pace-markers lights on the bottom of the 25 m pool, also used to help the swimmers to keep the pre-derminated pace along each step, being in accordance with the guidelines to control the workload of swimmers testing (Simon & Thiesmann, 1986).

Since Pyne et al. (2000) proposed the 7x200m protocol, several studies where conducted to assess the IndAnT using intermittent incremental protocols with 200m step lengths (Pyne et al., 2001; Fernandes et al., 2005; Fernandes et al., 2008; Fernandes et al., 2011; Thompson et al., 2006; Anderson et al., 2006, 2008; Psicharakis et al., 2008). However, none of these studies assess IndAnT in all conventional techniques and medley. To really understand the effectiveness of the 7x200m intermittent incremental protocol, it is important to approach to competitive level. Although Pyne et al. (2001), Anderson et al. (2006) and Anderson et al. (2008) used front crawl as a substitute of medley and butterfly, swimmers do not swim in their best technique. To predict with higher accuracy the swimming performance, tests should be more specific and might help finding realistic goals and training procedures for coaches and swimmers.

The AnT assessment reveals, using the 7x200m intermittent incremental protocol, different values between IndAnT and v4 were found (**chapter 2, Appendix 1**). Those findings are in accordance to Fernandes et al. (2010). Concerning front crawl, backstroke, and breaststroke values of IndAnT were lower than v4, showing that v4 does not represent the individualized lactate threshold in aerobically trained swimmers (Fernandes et al., 2010). In addition, values of IndAnt of butterfly and medley were closest to 3.5mmol.l-1, a value proposed by Heck et al. (1985) for swimmers with good aerobic performance. The results revealed an obvious dissimilarity between alternated and simultaneous techniques. In fact, as Barbosa et al. (2010) referred swimming performance is dependent from the energetic profile, and this one from the biomechanical behavior; thus, was already expected that the higher IVV in the simultaneous techniques leaded to higher $[La^-]$IndAnT values. Once IVV results from the balance between propulsion and drag (Vilas-Boas et al, 2010), which are determined by the stroke mechanics and segmental velocities, it is perfectly understandable that simultaneous techniques, present higher energy cost (Holmér et al., 1974; Barbosa et al., 2006), will imply a higher $[La^-]$IndAnT. However, breaststroke IndAnT value was relatively low, which may be justified by the fact that only one breaststroker was tested. In this, case $[La^-]$ peak at final step has 9.6mmol.l-1, much lower from the obtained values by Thompson et al. (2006) of 16.5mmol.l-1 with an elite breaststroke swimmer. Therefore, the present results highlight that, in accordance with several authors (Stegmann et al., 1981; Jacobs, 1986; Kelly et al., 1992; Simon, 1997; Ribeiro et al., 2003; Fernandes et al., 2005, 2010), v4 does not represent the individualized AnT in aerobically fit swimmers, and limits the use of the traditional v4 value as specific training intensity to the aerobic capacity development. Nonetheless, the data analyzed reveals that 7x200m intermittent incremental protocol is a specific and precise tool of major importance in the assessing of individualized lactate threshold, as proposed before for front crawl swimming (cf. Fernandes et al, 2010).

A combined physiological and biomechanical diagnosis of swimming performance seems to be one of today's major areas of interest, due to the fact that swimmer's performance is strongly influenced by his/her physiological profile and swimming technique (Weiss et al., 1988; Keskinen & Komi, 1993; Pyne et al., 2001; Psycharakis et al., 2008). So, for a combined study of biomechanical and physiological parameters, in **Chapter 3** some biomechanical parameters were studied during the 7x200m intermittent incremental protocol. Regarding the stroking parameters, our results are in accordance with the literature once it was shown that the SR and SL combinations change with increasing v (Keskinen & Komi, 1993). Indeed, it was reported that swimmers reach maximum v by increasing SR and decreasing SL (Pyne et al., 2001; Dekerle et al., 2005; Psycharakis et al., 2008; Fernandes et al, 2010), while [La-] increased (Keskinen & Komi, 1993). In **Chapter 3** results revealed differences in v and SR throughout the different steps, being v influenced by SR increase (Potdevin et al., 2004). In fact, the use of incremental protocol enables a better understanding of the behavior of kinematics in different swimming intensities as well as of the fatigue instalation during the steps (e.g. decreased of SL). Dekerle et al. (2005) observed in indAnT and stroking parameters the existence of a biomechanical boundary well related to the intensity corresponding to the AnT beyond which SL becomes compromised. Regarding SI, while in middle-distance swimmers this parameter tend to decline slightly, in open water swimmers it tend to raise, after step 3, wich is in accordance with Fernandes et al. (2010), this, suggest that swimmers are able to increase their v in incremental protocol without losing their effective swimming technique, and evidences different behaviors before and after AnT.

In **Chapter 3** it is also presented that sustained values of IVV, increasing values of IdC and decreasing of η_P occurs, which are according to the literature (Zamparo et al., 2005; Schnitzler et al., 2008; Seifert el al., 2010), Despite the n_P decreased, these findings might point out that the swimmers were able to adapt their stroke technique to maintain IVV, while reaching higher swimming intensities, as proposed by Schnitzler et al. (2010).. Despite the modification of arm coordination, IVV maintenance can be explained by the inability of the swimmer to minimize the resistive impulse (Alberty et al., 2005). This fact justifie the improvement of IdC throughout the 7x200m protocol, in both swimmers groups. Analyzing the IdC, only catch up coordination mode was observed, even in high velocities. In addition, IdC has influence in biomechanical parameters (Chollet et al., 2000; Seifert et al., 2004a; Seifert et al., 2004b; Seifert et al., 2007; Alberty et al., 2005; Alberty et al.2009) and physiological ones, particularly energy cost and the AnT. Complementarily, this study also allowed to comprehending how the swimmers body position behaved in different velocities. For that purpose, TI was assessed, which may reflect the skill and technique of the swimmers to adopt a better streamlined position (cf. Zamparo et al., 2009); therefore, high values of TI leads to a higher hydrodynamic resistance and vice-versa. It was observed that TI was maintained constant throughout the 7x200m protocol, which is not in accordance with Zamparo et al. (2009). For the authors, with the increasing of v, TI tends to decrease. Nevertheless, under fatigue the swimmer may pay less attention to body alignment, which induces a less streamlined position (Craig et al., 1985).

In summary, the 7x200m intermittent incremental protocol should be considered as a precise tool to assess individual biomechanical and physiological parameters and their interaction should be taken in account. Although, future research should focus in understanding the behavior before and after AnT.

Chapter 5 – Conclusions

The results of the present study contribute to the improvement of swimming coach's knowledge concerning the adequacy of the 7x200m incremental intermittent protocol to assess biomechanical and physiological parameters. Indeed, these studies will allow a better understanding of the valuable 7x200m incremental intermittent protocol. Additionally, this study exposes methods that will provide vital information for coaches and scientists in training and competition context. Finally the main conclusions were:

(i) The 7x200m incremental intermittent protocol allowed the assessment of the IndAnT in all conventional techniques;

(ii) v4 does not represented the individualized AnT, in alternated techniques;

(iii) vIndAnT is close to the average v3.5 value in simultaneous techniques;

(iv) SR increase and SL decrease progressively along the 7x200m intermittent incremental protocols according with the literature;

(v) SI, IVV and η_P proved to be good indicators of swimming efficiency;

(vi) IVV maintained throughout the 7x200m intermittent incremental protocol according with the literature;

(vii) TI maintained throughout the 7x200m intermittent incremental protocol and not in accordance with the literature.

(viii) For IdC, swimmers maintain a "catch-up" coordination during the 7x200m intermittent incremental protocol, presenting a more continuous inter-arm coordination visible at the end of the effort.

APPENDIX 1

Individual anaerobic threshold assessment in elite swimmers

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Introduction

One of the most used methods for anaerobic threshold assessment is based on the averaged value of 4 $mmol.l^{-1}$ of blood lactate concentration ([La]). However, an individualized approach was suggested before [1], rather than the use of a fixed [La]. In fact, a fixed value of [La] does not take into account considerable inter-individual differences and may frequently underestimate or overestimate real endurance capacity [2]. The purpose of this study was to assess the individual anaerobic threshold (IndAnT) in national level swimmers performing in their best swimming technique.

Methods

Twenty-five elite swimmers (20.1±2.2 years old, 181.2±6.9 cm, 73.8±8.0 kg and n>8 training units per week) performed n x 200 m individualized intermittent incremental protocol, with increments of 0.1 $m \cdot s^{-1}$ for each 200 m step, and 1 min rest intervals [adapted from 1]. Initial velocity was established according to the individual level of fitness. IndAnT was determined by [La-]/velocity curve modelling method and assumed to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential) [3], as observable in Figure 1.

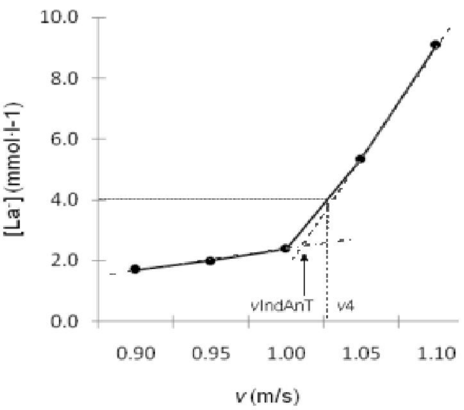

Figure 1. Example of an individual [La-] /v curve for IndAnT assessment represented by the interception of a linear and an exponential line (v4 is also shown).

Results

Velocity and [La] values corresponding to IndAnT averaged, respectively, 1.38±0.11 $m.s^{-1}$ and 2.32±0.68 $mmol.l^{-1}$ for front crawl (n=13), 1.33±0.04 $m.s^{-1}$ and 1.93±0.33 $mmol.l^{-1}$ for backstroke (n=2), 1.12 $m.s^{-1}$ and 1.76 $mmol.l^{-1}$ for breastroke (n=1), 1.24±0.15 $m.s^{-1}$ and 3.31±0.97 $mmol.l^{-1}$ for butterfly (n=4), and 1.35±0.08 $m.s^{-1}$ and 3.68±1.31 $mmol.l^{-1}$ for medley (n=5). [La] corresponding to IndAnT values where lower than the 4 $mmol.l^{-1}$ value in all the techniques. Concerning the swimming velocity at IndAnT, differences were only observed in front crawl, but its difference for v4 values is evident for training proposes.

Conclusion

The incremental protocol for IndAnT assessment used in the present study is specific for IndAnT assessment. The results seem to confirm the fact that the 4 $mmol.l^{-1}$ and v4 values do not represent the individualized lactate threshold in trained swimmers.

APPENDIX 2

Individual anaerobic threshold assessment in front crawl swimmers

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Introduction

One of the most used methods for anaerobic threshold assessment is based on the fixed reference value of 4 mmol/l of blood lactate concentration ([La^-]). However, since 30 years ago, the anaerobic threshold has been reported to have great variability between athletes, particularly swimmers (Stegmann et al, 1981; Fernandes et al, 2008). In fact, a fixed value of [La^-] does not take into account considerable inter-individual differences and may frequently underestimate or overestimate real aerobic capacity. Thus, conversely to the use of an averaged [La^-] value, an individualized approach was suggested before, both for adult (Fernandes et al., 2008) and children swimmers (Fernandes et al., 2010). The purpose of the study was to assess the individual anaerobic threshold in front crawl swimming.

Methods

In a 50 m swimming-pool, 13 international level swimmers (20.7 ± 2.7 years old, 182.8 ± 6.0 cm, 74.6 ± 5.2 kg and n>8 training units per week) performed a 7x200 m individualized intermittent incremental protocol, with increments of 0.1 m/s for each 200 m step (1 min rest intervals), being the initial velocity established according to the individual level of performance on the 400 m front crawl (adapted from Fernandes et al., 2008). Capillary blood samples, collected during the intervals (Lactate Pro, Arkay Inc), allowed assessing individual anaerobic threshold through the [La^-]/velocity curve modeling method (assumed to be the interception point of a combined pair of regressions used to determine the exact point for the beginning of an exponential rise in [La], as proposed by Machado et al. (2006).

Results

[La^-] and velocity values corresponding to individual anaerobic threshold averaged, respectively, 2.32 ± 0.68 mmol/l and 1.38 ± 0.11 $m.s^{-1}$, being both significantly lower than the averaged 4 mmol/l of [La$^-$] and corresponding velocity values.

Discussion

Our results corroborate those previously observed for well aerobically trained swimmers (cf. Stegmann et al., 1981; Martin & White, 2000; Fernandes et al., 2008). These authors observed that the [La$^-$] corresponding to anaerobic threshold in groups of untrained subjects or athletes not especially aerobically trained was found near 4 mmol/l, but in aerobically trained subjects (especially in highly trained long-distance runners, triathletes and swimmers), it was found to be distinctively lower. Therefore, we confirm the fact that the 4 mmol/l and its corresponding velocity values do not represent the individualized lactate threshold in trained swimmers.

KEY WORDS: front crawl, anaerobic threshold, curve modeling

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CHAPTER 6 - REFERENCES

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Appendix 1

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