U.PORTO
FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

KINEMATICAL ANALYSIS DURING SWIMMING AT AND ABOVE THE MAXIMAL LACTATE STEADY STATE

Dissertação apresentada às provas de 2º Ciclo em Treino de Alto Rendimento Desportivo – Natação, orientada pelo Professor Doutor Ricardo Fernandes e co-orientada pelo Professor Doutor João Paulo Vilas-Boas, ao abrigo do Decreto-lei nº74/ 2006 de 24 de Março. Este trabalho insere-se no projecto PTDC/DES/101224/2008 (FCOMP-01-0124-FEDER-009577) na Fundação da Ciência e Tecnologia.

Presentation of Master Thesis in 2nd Cycle Studies in High Performance Sports Training – Swimming, under the supervision of Professor Ricardo Fernandes and Professor João Paulo Vilas-Boas, according to Decret-law nº 74/ 2006 of 24 March. This work is part of the project PTDC/DES/101224/2008 (FCOMP-01-0124-FEDER-009577) of Fundation for Science and Technology.

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Porto, Outubro de 2011

Nazario, Rafael (2011). Kinematical analysis during swimming at and above the maximal lactate steady state. Dissertação apresentada às provas de 2º Ciclo em Treino de Alto Rendimento Desportivo – Natação, orientada pelo Professor Doutor Ricardo Fernandes e co-orientada pelo Professor Doutor João Paulo Vilas-Boas, ao abrigo do Decreto-lei nº74/ 2006 de 24 de Março.

KEY WORDS: KINEMATICS, SWIMMING, AEROBIC CAPACITY.

PALAVRAS-CHAVE: CINEMÁTICA, NATAÇÃO, CAPACIDADE AERÓBIA

Acknowledgments

The preparation of this work was only possible due to collaboration and encouragement of a group of persons to which I am immensely grateful and don not even know how to thank.

- Prof. Dr. Ricardo Fernandes, for all the knowledge, patience, collaboration, and monitoring throughout the preparation of this thesis.

- Prof. Dr. João Paulo Vilas-Boas, also for the knowledge, support and collaboration in this work, and for agreeing to co-supervise it.

- Prof. Dr. Pedro Figueiredo for his support, patience and all information that gave to me, without which I could not have come to the end of this journey.

- MSc. João Ribeiro, MSc Jailton Gregorio for all the support, knowledge and all the time dedicated to help me.

- To all my friends, that even far away from me, always sent words of encouragement. To my friend Paulo Vaz, present during those two years of challenges in another country.

- To my family, for having supported me in this academic and life step. To my father who always listened when I had some doubt. To my mother who helped with everything, without measuring efforts, and to my sister for all the support.

- To Eliamara Fontoura, my girlfriend, who accepted and faced the challenge of being away from everything and everyone, and always helped me in time of weakness and indecisions.

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

--Papers--

1. Nazario, R.; Sousa, M.; Figueiredo, P.; Ribeiro, J.; Pelarigo, J.; Vilas-Boas, J.P.; Fernandes, R. J. Kinematical analysis during swimming at maximal lactate steady state. For submission to *International Journal of Sports Medicine.*

2. Nazario, R.; Sousa, M.; Figueiredo, P.; Ribeiro, J.; Pelarigo, J.; Vilas-Boas, J.P.; Fernandes, R. J. Comparison of kinematical parameters when swimming at and above the maximal lactate steady state. For submission to *Journal of Sports Science.*

---Abstract---

I. Nazario, R., Sousa, M., Figueiredo, P., Ribeiro, J., Pelarigo, J., Vilas-Boas, J.P., Fernandes, R. (2011). Kinematical analysis along a maximal lactate steady state swimming test. Book of Abstracts of the 16th Annual Congress of the European College of Sport Science, pp. 72. Liverpool, United Kingdom.

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Abstract

The purpose of this study was to verify how kinematical parameters react in relation time and intensity effects during the maximal lactate steady state ($MLSS_{100\%}$) test and above ($MLSS_{102.5\%}$). Thirteen long distance swimmers (28.9 ± 10.8 years, 1.75 ± 0.51 m, and 67.1 ± 5.7kg) performed in different days two to four 30-min constant speed bouts, to determine the $MLSS_{100\%}$ and above $MLSS_{102.5\%}$. The video analysis, using APAS System (Ariel Dynamics Inc., USA), allowed determining the stroke rate, stroke length, trunk incline, intracyclic velocity variation, propelling efficiency, index of coordination, propulsive impulse and stroke phases in five different moments of the test (0, 25, 50, 75 and 100%). A ANOVA for repeated measures was used to compare the mean values for each variable at each point of analysis. During the $MLSS_{100\%}$ there was a significant increase of the stroke rate [0.46 ± 0.06 – 0.50 ± 0.07 Hz] from the beginning of the test to the other moments, and phase propulsive C increase between the moments 0 and 50%, 0 and 100%. For the $MLSS_{102.5\%}$ test there was a significant increase of stroke rate [0.47 ± 0.07 - 0.53 ± 0.10 Hz] and decrease in the stroke length [2.19 ± 0.32 - 2.06 ± 0.35] and propulsive efficiency [0.37 ± 0.06 – 0.34 ± 0.05]. The other parameters showed a constant behavior along the intensities and did not show a different between protocols as well. Indeed, to maintain the highest intensity of exercise where there is a metabolic balance or not, it seems that swimmers need to make some adjustment in the kinematical parameters along the $MLSS_{100\%}$ and $MLSS_{102.5\%}$ test.

KEY WORDS: Kinematics, swimming, aerobic capacity.

Resumo

O presente estudo tem como objetivo a verificação de como os parâmetros cinemáticos reagem em relação efeito do tempo e da intensidade durante o teste de máxima fase estável de lactato sanguíneo ($MLSS_{100\%}$) e acima ($MLSS_{102,5\%}$). Treze nadadores de longa distância (28,9 ± 10,8 anos, 1,75 ± 0,51 m, e 67,1 ± 5,7 kg) realizaram, em diferentes dias, entre duas e quatro tentativas de 30 minutos, para determinar a $MLSS_{100\%}$ e $MLSS_{102,5\%}$. As análises de vídeo, utilizando APAS System (Ariel Dynamics Inc., EUA), permitiu a determinação da frequência gestual, distância de ciclo, tronco inclinado, variação intracíclica de velocidade, eficiência propulsiva, o índice de coordenação, o impulso propulsivo e as fases do nado em cinco momentos diferentes do teste (0, 25, 50, 75 e 100%). Uma *ANOVA* para medidas repetidas foi utilizada na comparação dos valores médios entre cada variável e ponto de análise. Durante a $MLSS_{100\%}$, houve um aumento significativo da frequência gestual [0,46 ± 0,06-0,50 ± 0,07 Hz] a partir do início do teste para os outros momentos; a fase propulsiva C mostra diferenças entre os momentos 0 e 50%, 0 e 100%. Para o teste de $MLSS_{102,5\%}$, houve um aumento significativo da frequencia gestual [0,47 ± 0,07-0,53 ± 0,10 Hz] e diminuição na distância de ciclo [2,19 ± 0,32-2,06 ± 0,35] e eficiência propulsiva [0,37 ± 0,06-0,34± 0,05]. Os restantes parâmetros apresentaram um comportamento constante ao longo das intensidades e não mostraram diferenças entre os protocolos. De fato, para manter a máxima intensidade de exercício onde há um equilíbrio metabólico, os nadadores precisam fazer alguns ajustes nos parâmetros da cinemática ao longo da $MLSS_{100\%}$ e $MLSS_{102,5\%}$.

PALAVRAS - CHAVES: Cinemática, natação, capacidade aeróbia.

List of Abbreviations

%: Percentage

(°): angle

(l): Shoulder-to-hand distance

(La): Lactate

AnT: anaerobic threshold

cm: centimeters

h: Hour

IdC: Index of Coordination

IVV: Intracyclic velocity variation

kg: kilograms

m/s: meter per second

m: Meters

min: Minutes

MLSS: Maximal Lactate Steady State

$MLSS_{102.5\%}$: *Above Maximal Lactate Steady State*

ηp: Propulsive Efficiency

s: seconds

SD: Standard deviation

SL: Stroke Length

SR: Stroke Rate

TI: Trunk Incline

v: Velocity

α : angle

Chapter 1

General Introduction

Swimming performance is influenced by several factors, particularly the bioenergetics, biomechanics, psychologics, contextual and genetic ones (Fernandes et al., 2008). Indeed, success in this sport is dependent on training monitoring, which will lead to stroke technique and physiological swimmers improvement. The kinematical aspects of stroke tend to be equally or more important than the physiological aspects. Increases velocities in swimming are usually generated by an increase in propulsive force and a reducing of the drag. Thus, the level of technical skill of the swimmer can reduce the hydrodynamic drag and increase propulsion (Kolmogorov et al., 1992). To achieve a certain velocity, he swimmer can take different combinations of stoke rate (SR) and stroke length (SL), depending on the level of technical skill (Dekerle et al., 2005). Generally, a higher velocity for the same SL is associated with greater technical skill, and also a better propulsive efficiency (Toussaint et al., 1992). The high intensity exercise causes a physiological stress that stimulates the production of lactic acid. However, the organism uses a physiological adjustment for this to be the most stable possible. During moderate exercise intensities, lactate is produced and removal at equal rates (Billat et al., 2003), resulting in a balance in the concentration. When the swimming intensities are above, there is an imbalance of these rates, which can result in increased blood lactate concentration (Beneke et al., 2003).

The fatigue is one of the factors which is usually associated with reduced ability to maintain a given exercise intensity. In situation of fatigue, swimmers tend to adopt strategies of movements in order to maintain the exercise intensity. In swimming, it is known that the kinematical aspects can be compromised by physiological mechanisms associated with fatigue, particularly the SR and SL (Zamparo et al., 2006).

There are some protocols used to assess the physiological factors, usually used to assess aerobic capacity. The “gold – standard” to assess anaerobic threshold is the maximal lactate steady state (MLSS) test (Heck et al., 1985; Beneke & Von Dullivard, 1996). There are described several protocols to the MLSS assessment, being the most usual the proposed by Heck et al. (1985). According to these authors, MLSS is attained when lactate varies by less than 1 mmol/l during the final 20 min of a constant workload of 30 min duration; however, submaximal loads are up to 30 min in duration, then tests should be performed on different days and the individual recovered from the previous load (Heck et al., 1985; Beneke, 1995; Beneke & Von Duvillard, 1996; Beneke et al., 1996). The pioneer MLSS assessment method was previously proposed by Margaria et al. (1963) using five to eight exercise tests of independent constant load. However, Mclellan & Jacobs (1993) proposed the MLSS assessment using three steps of 30 min duration with 1 hour rest. Afterward, Billat et al. (1994) validated a protocol that allows an immediate estimation of the exercise intensity corresponding to $MLSS_{100\%}$, by using only two 20 min submaximal intensities in long distance athletes. Later, Beneke et al. (2003) stated that the $MLSS_{100\%}$ assessment require three to five submaximal tests at constant workload performed at different intensities. The $MLSS_{100\%}$ test is considered to be a gold-standard to aerobic capacity evaluation, being used to prescribe individualized aerobic training in cyclic and individuals sports. The $MLSS_{100\%}$ corresponds to the highest workload that can be maintained over time without a continuous blood lactate accumulation (Heck et al., 1985) and its physiological background is comparable with the theory of the anaerobic threshold (AnT) concept. In fact, the workload corresponding to $MLSS_{100\%}$ is used as the criterion an evaluation method in the assessment of an athlete´s aerobic capacity (Billat, 1996; Billat et al., 2003). Moreover, since it was observed that AnT assessed by $MLSS_{100\%}$ method is highly related to competition performance in aerobic events (Haverty et al., 1988; Harnish et al., 2001), the workload corresponding to $MLSS_{100\%}$ can be used to aerobic training prescription.

Therefore, the decline of the SL along the different intensities ($MLSS_{100\%}$ and $MLSS_{102.5\%}$) could be explained by the progressive fatigue accumulation, it seems that the long distance swimmers used a freely preferred SR. In fact, the combination of SR and SL in producing swimming velocity has a large variability that implies a highly individual process (Keskinen & Komi, 1993; Pelayo et al., 1996). The $MLSS_{100\%}$ intensity has been strongly correlated with performance in endurance sports (Billat et al., 2003) and can be used to evaluate the aerobic capacity of athletes and also as one of the main parameters for the prescription of the aerobic training (Beneke & Duvillard, 1996; Billat et al., 2003).

This thesis wants to investigate the kinematical factors at $_{MLSS100\%}$ and $MLSS_{102.5\%}$ swimming intensity. It were evaluated: (i) the stroking parameters (SR and SL); (ii) trunk incline (TI) that has an important influence in the drag, which is a major determinant of the energy cost of swimming at a specific velocity (Zamparo et al., 2006); (iii) the intracyclic velocity variation (IVV), a parameter to characterize swimming technique, representing the fluctuations of the instantaneous velocity during a stroke cycle in the resistive and propulsive acting on the swimmer (Alberty et al., 2005); (iv) the propelling efficiency (Ƞp) that give the information of how much energy the swimmer needs spent to cover a given distance or increase the speed, which means that contracting muscles is needed to accelerate water backwards and increases the expenses of useful energy (Zamparo et al., 2006); (v) the index of coordination (IdC) that represents how the swimmers organize the propulsive and non-propulsive phases of right and left arms (Chollet et al., 2000); and (vi) propulsive impulse (Tprop) calculated through the time required by the swimmer to propulsion per lap and (vii) stroke phases suggested by Chollet et al. (2000). Therefore, the analysis of these parameters might help to understand the main factors that influence the maintenance intensity of swimming at MLSS, where it is possible to find balance between production and removal of blood lactate and the possible changes that occur when swimming in intensity above the MLSS.

Thus, in **Appendix I,** it was analyzed how one long distance swimmer reacts along the MLSS test. A case study in order to define the five moments to be analyzing with APAS System (Ariel Dynamics Inc., USA) allowed determining the kinematical parameters. However, to be able to answer the doubts, the thesis was divided into two articles in order to realize the effect of MLSS during the time and intensity.

This thesis begins by a general introduction **(Chapter 1),** in which all chapters are described. In the **Chapter 2** it is present a study which aimed assessing the kinematical parameters (SR, SL, TI, IVV, ∏p, IdC, Tprop and stroke phases) during the $MLSS_{100\%}$ test. **Chapter 3** aimed to observe if intensity higher than $MLSS_{100\%}$ implies technical changes during the $MLSS_{102.5\%}$ for the referred parameters and compare these values. **Chapter 4** shows a general discussion of the $MLSS_{100\%}$ and $MLSS_{102.5\%}$ results. The final conclusions of the present study are present in the **Chapter 5**.

Chapter 2

KINEMATICAL ANALYSIS DURING SWIMMING AT MAXIMAL LACTATE STEADY STATE.

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Abstract

The purpose of this study was to conduct a kinematical analysis during swimming at maximal lactate steady state. Thirteen long distance swimmers voluntary participated in the present study, and performed, in different days two to four 30-min submaximal constant speed bouts, to determine the maximal lactate steady state (MLSS). The video analysis, using APAS System (Ariel Dynamics Inc., USA), allowed determining the stroke rate, stroke length, trunk incline, intracyclic velocity variation, propelling efficiency, index of coordination, propulsive impulse and stroke phases in five different moments of the test (0, 25, 50, 75 and 100%). An ANOVA for repeated measures was used to compare the mean values for each variable at each point of analysis. There was a significant increase of the stroke rate [0.46 ± 0.06 – 0.50 ± 0.07 Hz] from the beginning of the test to the other moments, but the stroke length [2.21m ± 0.30 – 2.13m ± 0.31], trunk Incline [10.77 ± 3.77 – 10.08 ± 3.84], intracyclic velocity variation [0.24 ± 0.05 – 0.21 ± 0.06], propulsive efficiency [0.35 ± 0.05 – 0.34 ± 0.05], index of coordination [-16.9 ±5.78 to -15.2 ±4.99] and propulsive impulse [16.72 ± 4.41–16.67 ± 3.25] did not showed a significant differences during the protocol. Phase non-propulsive A [40.8±7.18 - 39.9 ±7.65], phase propulsive B [15.6% ± 2.91 – 15.0% ± 3.85] and phase non propulsive D did not showed differences along the test. Phase propulsive C shows differences between the moments 0 and 50%, 0 and 100%. Indeed, to maintain the highest swimming intensity where there is a metabolic balance, swimmers need to make adjustments in the kinematical parameters along the test, even if they not show to have statistical significance.

KEY WORDS: Kinematics, swimming, Aerobic capacity.

INTRODUCTION

Swimming performance is influenced by several factors, having the biomechanical and bioenergetic ones great importance (Fernandes et al., 2008). The biomechanical factors refers to the technique and how swimmers can maintain or change velocity, and the bioenergetical parameters refers to the energy supply system, from which the aerobic pathway seems to present great relevance in swimming (Smith et al., 2002).These parameters should be frequently monitored, aiming to biomechanical and physiological improvements. Indeed, tests are used as part of an elite training program to assess the likely outcome of the swimmers competitive performance (Anderson et al., 2008).The increases in velocity usually are show by the increase of the propelling efficiency and decrease in drag. Indeed, the swimmer technique can reduce the hydrodynamic drag (Kolmogorov et al., 1992), and swimmers adopt an optimal compromise between stroke rate (SR) and stroke length (SL) to attain and maintain the velocity required during a test or race (Arellano et al., 1994; Chollet et al., 1997; Craig et al., 1979).

The Maximal Lactate Steady State (MLSS) test is considered as a gold-standard to aerobic capacity evaluation, being used to prescribe individualized aerobic training in cyclic and individuals sports. Corresponding to the highest workload that can be maintained over time without a continuous blood lactate accumulation (Heck et al., 1985), the MLSS physiological background is comparable with the theory of the anaerobic threshold (AnT) concept. Determination of the AnT usually requires an incremental load test that is a generally accepted and a standardized basic procedure of exercise testing (Beneke, 1995; Heck et al., 1985). However, various concepts of the AnT do not necessarily provide identical levels of blood lactate concentration and workloads at MLSS (Beneke, 1995; Heck et al., 1985). Consequently, the determination of MLSS requires several subsequent constant submaximal load tests performed on separate days (Beneke, 1995; Beneke and Von Dullivard, 1996; Beneke et al., 1996). It is assumed that MLSS can be used to detect the highest workload that can be maintained over time without continuous blood lactate accumulation, when blood lactate concentration increased by no more than 1.0 mmol during the final 20 min of the test (Beneke, 1995; Heck et al., 1985).

The purpose of this study was to conduct a kinematical analysis during swimming at MLSS. It were evaluated: (i) the stroking parameters (SR and SL); (ii) trunk incline (TI) that has an important influence in the drag, which is a major determinant of the energy cost of swimming at a specific velocity (Zamparo et al., 2006); (iii) the intracyclic velocity variation (IVV), a parameter to characterize swimming technique, representing the fluctuations of the instantaneous velocity during a stroke cycle in the resistive and propulsive acting on the swimmer (Alberty et al., 2005); (iv) the propelling efficiency (ηp) that give the information of how much energy the swimmer needs spent to cover a given distance or increase the speed, which means that contracting muscles is needed to accelerate water backwards and increases the expenses of useful energy (Zamparo et al., 2006); (v) the index of coordination (IdC) that represents how the swimmers organize the propulsive and non-propulsive phases of right and left arms (Chollet et al., 2000) and (vi) propulsive impulse (Tprop) calculated through the time required by the swimmer to propulsion per lap. The analysis of these parameters along a constant pace, corresponding to AnT might help to understand the main factors that influence the maintenance of the maximal aerobic swimming intensity, where it is possible to find balance between production and removal of blood lactate.

METHODS

Subjects

Thirteen long distance swimmers voluntary participated in the present study. Their main physical and training background characteristics were: 28.9±10.8 years of age, 1.75±0.51 m of height, 1.78±0.58 m of arm span, 67.1±5.7 kg of body mass, 21.89±1.61 of body mass index, and 6.3±3.1 years of swimming experience. The criterion for swimmer's participation was a performance time of 360 s (or less) in the 400 m freestyle event. The local ethics committee approved the experimental procedures, and all swimmers signed a consent form in which the protocol was explained. Additionally, this study has been performed in accordance with the ethical standards proposed by Harriss and Atkinson (2009).

Testing procedure

All test sessions took place in a 25 m indoor pool, 1.90 m deep, with a water temperature of 27.5ºC. The subjects performed an intermittent incremental protocol of 7 x 200 m until exhaustion with increments of 0.05 $m.s^{-1}$ between steps, and 30s rest intervals to assess the swimming velocity corresponding to individual anaerobic threshold. The individual AnT was determined by [La-]/velocity curve modeling method (least square method; cf. Fernandes et al, 2005; Machado et al, 2006). The AnT was assumed to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential). After 48h rest interval, the MLSS, a continuous test proposed by Heck et al. (1985) was conducted. For the MLSS determination, each swimmer performed two to four 30 min constant load steps at different workloads, with 24 h rest, being the intensity increments or decreases of 2.5% of the initial velocity (Pelarigo et al., 2011). The velocity corresponding to MLSS was defined at the highest swimming velocity during which the blood lactate concentrations [La^-] increased no more than 1 mmol/l during the final 20 min of the test (Heck et al., 1985). The swimming velocity was controlled by a visual pacer (TAR. 1.1, GBK – electronics, Aveiro, Portugal), with flashing lights on the bottom of the pool, helping swimmers to keep up the predetermined velocity. Swimmers were videotaped with two digital cameras (Sony® DCR-HC42E), inserted into a sealed housing (SPK-HCB), that recorded two completed arm underwater stroke cycles in the sagital plane, cameras were placed 0.30 m above the water at the lateral wall of the pool, 6.78 m from the plane of movement, and 12.5 m from the starting wall. For a higher precision, SR and SL were determined using the Ariel Performance Analysis System software (Ariel Dynamics, USA), digitizing manually and frame by frame at a frequency of 50 Hz, nine anatomical points: the right rip (femoral condyle) and both sides finger tips, fist, elbow and shoulder of each swimmer. After a bi-dimensional reconstruction using DLT procedure (Abel-Aziz and Karara,1971), a low pass filter of 5Hz was used, as suggested by Winter(1990). The video recordings were used to compute the kinematical parameters, being SL determined through the horizontal displacement of the hip during a stroke cycle, and SR was from the time needed to complete a stroke cycle.

The TI (also defined as the angle of attack) 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. The IVV was calculated on the basis of the equation (Alberty et al., 2005; Schnitzler et al., 2008).

$$IVV = (SD/\ Mean) \times 100$$

Where SD is the standard deviation of velocity, divided by the hip´s mean velocity.

The Ƞp 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 model proposed by Zamparo et al. (2005):

$$Ƞp = (v.\ 0,9/\ 2\pi\ .\ SR.\ l).\ 2\ /\ \pi$$

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*).

Arm Coordination was assessed using the IdC, which is based on the lag time between the propulsive phases of each arm, and quantifies three possible coordination modes (Chollet et al., 2000). Each arm movement was divided into four distinct phases: (i) phase A (glide+catch), corresponding to the time from the hand´s entry into the water to the beginning of its backwards movement; (ii) phase B (pull), corresponding to the time from the beginning of the hand´s backward movement and ends at the hand´s arrival in the vertical plane to the shoulder; (iii) phase C (push), corresponding to the time from the hand´s position below the shoulder and ends with the release of the hand from the water; and (iv) phase D (recovery), corresponding to the time from the hand´s release from the water and ends with a new entry of the hand into the water. The duration of a complete stroke was the sum of the propulsive (B+C) and non-propulsive phases (A+D). The lag time between the beginning of propulsion in the first right arm stroke and the end of propulsion in the first left arm stroke defined IdC1. The lag time between the beginning of propulsion in the second left arm stroke and the end propulsion in the first right arm stroke defined IdC2. IdC was then the mean of IdC1 + IdC2 (Chollet et al., 2000).

The Tprop can be calculated as a model proposed by Alberty et al. (2009).

$$\text{Tprop/distance} = \text{Tcycle}.(100\% + 2.\text{IdC})\text{D/SL}$$

Where D/SL corresponds to the number of stroke cycles needed to cover the distance. What is calculated is the total time to propulsion per stroke cycle multiplied by the number of stroke lap. (Alberty et al., 2009).

To analyze the above referred kinematical parameters along the MLSS test, it were defined five different moments: 0, 25, 50, 75 and 100% of the total test duration.

Statistical Analysis.

All statistics were performed using SPSS (version 18.0 for Windows). Mean ± SD were used to represent the average of the studied variables. The normal distribution of the data was verified by the Shapiro – Wilk’s test. An ANOVA for repeated measures was used to compare the mean values for each variable at each point of analysis (0, 25, 50, 75 and 100%), and to detect significant differences, post hoc bonferroni tests were used. A significance level of 5% was accepted ($p<0.05$).

RESULTS

Mean and SD values for the kinematical parameters along the MLSS test are reported in Table 1.The SR values showed an increase from the first moment of the protocol to the other four moments. The SL appears with a tendency to decrease along the test without a statistical significance. The values obtained for IVV, Ƞp, TI, IdC and Tprop seems to be constant along the protocol.

Table 1: Mean ± SD values of the SR, SL, TI, IVV, Ƞp, IdC and Tprop in each moment of the MLSS test.

	0%	25%	50%	75%	100%
SR(Hz)	0.46± 0.06	0.48*± 0.06	0.49*± 0.06	0.49*± 0.07	0.50*± 0.07
SL(m)	2.21±0.30	2.16±0.26	2.18±0.24	2.15±0.28	2.13±0.31
TI (°)	10.77±3.77	10.46±3.86	10.31±3.4	10.00±3.98	10.08±3.84
IVV	0.24±0.05	0.23±0.04	0.25±0.05	0.23±0.04	0.21±0.06
Ƞp	0.35±0.05	0.36±0.04	0.36±0.04	0.34±0.04	0.34±0.05
IdC (%)	-16.9 ±5.78	-15.9 ±4.66	-16.0 ±5.17	-15.6 ±5.84	-15.2 ±4.99
Tprop(s)	16.72±4.41	17.00±4.34	16.67±4.26	16.78±4.04	16.67±3.25

* Significantly different from 0 % ($p<0.05$)

The mean values for stoke phases are shown in Figure 1. It can be observed that stroke phases A, B and D were maintained constant along the protocol, and that phase C augmented significantly from the beginning to 50 and 100% of the test.

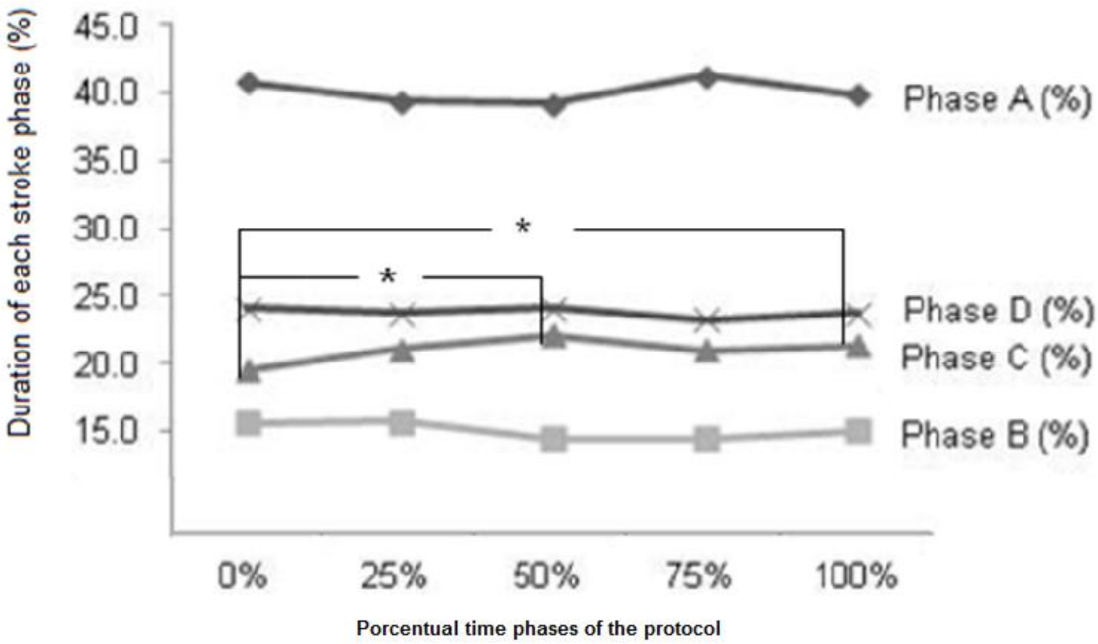

Figure 1: Mean values of phases A, B, C and D along the protocol.
* Significant difference from 0 % ($p < 0.05$)

DISCUSSION

The aim of this study was to analyze the behavior of the kinematical parameters, SR, SL, TI, IVV, ηp, IdC, Tprop and stroke phases along the MLSS, which is considered the gold standard protocol for AnT assessment.

Concerning the stroking parameters, the SR and the SL values presented stability (with the exception of the SR first moment) during the test. These results are in agreement with the study of Dekerle et al. (2005) which also reported a stability in SR (0.48± 0.04 to 0.50± 0.05) and SL (2.55± 0.38 to 2.46±0.44) at MLSS for all athletes. This fact suggests that observed the condition of [La]) stability might be relevant for the maintenance of the stroke parameters behaviour. The higher SR values observed just after the first moment of evaluation could be explained by the fact that when swimmers are required to swim for a long period of time, they use the beginning of the test to adjust the right velocity and made some adjustment to maintain the velocity constant.

Since the velocity is constant along the test, the TI values remain similar in the five moments of evaluation. According to Zamparo et al. (2009) the TI and hence projected frontal area decreases as a function of speed during free swimming. Since the TI remains constant along the MLSS effort this might indicate that the swimmers are able to maintain their swimming technique not experiencing additional drag form, since the frontal area is expect to do not change along the effort.

In addition, the IVV also presented a constant behavior along the test. The uniform distribution of the propulsive actions during the stroke cycles represents a fundamental aspect of efficiency in swimming, depending not only on the establishment of propulsive force, but also on global motor synchronization and the ability of the swimmer to maintain a low level of drag during non-propulsive phases of the stroke cycle (Craig et al. 1988)

The efficiency maintenance level could also be observed by the constant ηp values presented along the test. These results suggested that the swimmers could maintain high values of propelling efficiency for long periods of time as long as a physiological stability is preserved, not evidencing a real appearance of fatigue.

Analyzing the IdC is possible to observe a standard pattern during the test. Pelarigo et al. (2011) also reported that the IdC was not altered along the time at MLSS (- 4.68% ± 6.6 and – 3.84%± 6.1).

As known, a constant velocity was imposed on the swimmer, enforcing that a constancy of the required Tprop to overcome the corresponding drag impulse was observed during the test. Alberty et al. (2009) showed that swimmers had some freedom of choosing the combination of SR and IdC, showing values for Tprop between 17 to18s along the test with a velocity corresponding to 100% of the mean speed attained in a 400 m race (V_{400}). The swimmer could reduce the lag time between the left and the right arm propulsion with the option to overlap these impulses. The analysis of this variable could be useful to better understand chances in the SR and SL values along the test.

The stroke phases showed a constant behavior during the protocol, phase A, phase B and phase D seems constant, but phase C increase along the time. The chances in phase C might help understanding the adjustment in SR made by the swimmers to maintain the right pace. Chollet et al. (2000) showed that changes in arm coordination and stroke phases as a function of velocity were further reinforced by the performance level. Therefore, at least for more experienced swimmers, MLSS represents an upper limit for maintenance of the kinematical parameters and physiological responses during the lasting 30-min. Pelarigo et al. (2010) showed that during the MLSS intensity the stroke phases were constant.

The analysis of the kinematical parameters evidences that each swimmer kept a continual technique to achieve physiological stability and then swim during the protocol, and this way assist the prescription of aerobic training and what possible changes along MLSS test. Indeed, MLSS can be defined as the maximal velocity that can be maintained over a long period of time with no accumulation of blood lactate concentration and also represent a kinematical stability in the main parameters. This particular speed could represent an interesting intensity to control and improve the swimming technique during aerobic training.

Chapter 3

COMPARISON OF KINEMATICAL PARAMETERS WHEN SWIMMING AT AND ABOVE THE MAXIMAL LACTATE STEADY STATE

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Abstract

The purpose of this study was to compare the kinematical parameters obtained at and above maximal lactate steady state (MLSS) in front crawl. Thirteen long distance swimmers (28.9 ± 10.8 years old, 1.75 ± 0.51 m, and 67.1 ± 5.7 kg) performed, in different days, two to four 30-min constant speed bouts to determine the velocity at MLSS ($MLSS_{100\%}$) and above MLSS ($MLSS_{102.5\%}$). The video analysis, using APAS System (Ariel Dynamics Inc., USA), allowed determining the stroke rate, stroke length, trunk incline, intracyclic velocity variation, propelling efficiency, index of coordination, propulsive impulse and stroke phases in five different moments of the test (0, 25, 50, 75 and 100%). An ANOVA for repeated measures was used to compare the mean values for each variable at each point of analysis between the two tested intensities. The values were not significant different in relation of the intensity. Therefore, the effect of time in $MLSS_{100\%,}$ showed a significant increase of the stroke rate [0.46 ± 0.06 - 0.50 ± 0.07 Hz], standard behavior in the stroke length [2.21 ± 0.30 - 2.13 ± 0.31] and increase in phase C along the test. The $MLSS_{102.5\%}$ showed an increase in stroke rate [0.47 ± 0.07 - 0.53 ± 0.10 Hz] and decreases in stroke length [2.19 ± 0.32 - 2.06 ± 0.35] and propulsive efficiency [0.37 ± 0.06 – 0.34 ± 0.05]. Indeed, it seems that the major differences between kinematical parameters occurred along the time, since we did not find among intensities, which might explain the specificity of the long distance swimmers training, requiring adjustments in the intensity of the highest workload without a blood lactate accumulation and the intensity above, to the effect of time and for the maintenance of the intensity.

KEY WORDS: Kinematics, swimming, Aerobic capacity.

INTRODUCTION

Nowadays, performance tests are used as part of an elite training program to access the best performance that each subject can achieve. According to Fernandes et al. (2008) swimming performance is influenced by several factors, particularly bioenergetics, biomechanics, psychologies, contextual and genetic. The Maximal Lactate Steady State (MLSS) test is considered to be the gold-standard for aerobic capacity evaluation, being used to prescribe individualized aerobic training in cyclic and individuals sports. The MLSS corresponds to the highest workload that can be maintained over time without a continuous blood lactate accumulation (Heck et al., 1985), and its physiological background is comparable with the theory of the anaerobic threshold concept. To help understand swimming performance, changes in stroke technique during competitive events or exhaustive exercise have been studied extensively (Alberty et al., 2009), being frequently assessed using the biomechanical parameters (stroke rate – SR and stroke length – SL). Craig et al. (1979) showed, 30 years ago, that the evolution of the SR depend on the velocity, were the swimmers had to perform a constant velocity using the minimal SR and trying to achieve the maximal SL. Literature (e.g. Dekerle et al., 2005) also suggests that the stroking parameters are physiologically attached, particularly, to the local muscle fatigue. Therefore a SL decrease is also reported for exercise intensities higher than the blood lactate threshold during incremental test and throughout several submaximal constant load tests. This data suggest that the changes in technique could be related to simultaneous changes in metabolic variables (Keskinen et al., 1988; Wakayoshi et al., 1996). Dekerle et al. (2005) found significant changes in SR and SL when swimming above the MLSS test. During imposed paced, the swimmer can increase the time relative to the whole stroke cycle over which forces are applied to obtain the propulsive impulse necessary to maintain the velocity constant, as fatigue develops (Sander et al., 2002). That information suggests a possible relationship between the development of fatigue and the degradation in swimming technique (Keskinen et al., 1993).

The purpose of this study was to conduct a kinematical analysis comparing two swimming intensities, 100% and 102,5% of the velocity corresponding to MLSS, being evaluated: (i) the stroking parameters (SR and SL); (ii) trunk incline (TI) that has an important influence in drag, which is a major determinant of the energy cost of swimming at a specific velocity (Zamparo et al., 2006); (iii) the intracyclic velocity variation (IVV), a parameter to characterize swimming technique, representing the fluctuations of the instantaneous velocity during a stroke cycle. (Alberty et al., 2005); (iv) the propelling efficiency (Ƞp) that give the information of how much energy the swimmer needs to spent to cover a given distance or increase the speed, which means that contracting muscles is needed to accelerate water backwards and increases the expenses of useful energy (Zamparo et al., 2006); (v) the index of coordination (IdC) that represents how the swimmers organize the propulsive and non-propulsive phases of right and left arms (Chollet et al., 2000) and (vi) propulsive impulse (Tprop) calculated through the time required by the swimmer to propulsion per lap and (vii) the stroke phases suggested by Chollet et al. (2000). The analysis of these parameters along the $MLSS_{100\%}$ and $MLSS_{102.5\%}$ test might help to understand the main factors that influence the maintenance of swimming intensity, where it is possible to find balance between production and removal of blood lactate, and what happens with the kinematical parameters when swimming at the $MLSS_{102.5\%}$.

METHODS

Subjects

Thirteen long distance swimmers voluntary participated in the present study. Their main physical and training background characteristics were: 28.9±10.8 years of age, 1.75±0.51 m of height, 1.78±0.58 m of arm span, 67.1±5.7 kg of body mass, 21.89±1.61 of body mass index, and 6.3±3.1 years of swimming experience. The criterion for swimmer’s participation was a performance time of 360 s (or less) in the 400 m freestyle event. The local ethics committee approved the experimental procedures, and all swimmers signed a consent form in which the protocol was explained. Additionally, this study has been performed in accordance with the ethical standards proposed by Harriss and Atkinson (2009).

Testing procedure

All test sessions took place in a 25 m indoor pool, 1.90 m deep, with a water temperature of 27.5ºC. The subjects performed an intermittent incremental protocol of 7 x 200 m until exhaustion with increments of 0.05 $m.s^{-1}$ between steps, and 30 s rest intervals to assess the swimming velocity corresponding to individual anaerobic threshold. The individual AnT was determined by [La-]/velocity curve modeling method (least square method; cf. Fernandes et al, 2005; Machado et al, 2006). The AnT was assumed to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential). After 48h rest interval, the MLSS, a continuous test proposed by Heck et al. (1985), was conducted: each swimmer performed two to four 30 min constant load steps at different workloads, with 24 h rest, being the intensity increments or decreases of 2.5% of the initial velocity (Pelarigo et al., 2011). The velocity corresponding to MLSS was defined at the highest swimming velocity during which the blood lactate concentrations (La^-) increased no more than 1 mmol/l during the final 20 min of the test (Heck et al., 1985). After 24h, each swimmer performed at least one more test with an increment of 2.5% of the velocity corresponding to MLSS. The swimming velocity was controlled by a visual pacer (TAR. 1.1, GBK – electronics, Aveiro, Portugal), with flashing lights on the bottom of the pool, helping swimmers to keep up the predetermined velocity.

Swimmers were videotaped with two digital cameras (Sony® DCR-HC42E), inserted into a sealed housing (SPK-HCB), that recorded two completed arm underwater stroke cycles in the sagital plane; cameras were placed 0.30 m above the water at the lateral wall of the pool, 6.78 m from the plane of movement, and 12.5 m from the starting wall. For a higher precision, SR and SL were determined using the Ariel Performance Analysis System software (Ariel Dynamics, USA), digitizing manually and frame by frame at a frequency of 50 Hz, nine anatomical points: the right hip (femoral condyle) and both sides finger tips, wrist, elbow and shoulder of each swimmer. After a bi-dimensional reconstruction using DLT procedure (Abel-Aziz and Karara, 1971), a low pass filter of 5Hz was used, as suggested by Winter (1990). The video recordings were used to compute the kinematical parameters, being SL determined through the horizontal displacement of the hip during a stroke cycle, and SR assessed from the time needed to complete a stroke cycle. TI (also known as the angle of attack) 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. The IVV was calculated on the basis of the equation (Alberty et al., 2005; Schnitzler et al., 2008).

$$IVV = (SD/ Mean) \times 100$$

Where SD is the standard deviation of velocity, divided by the hip´s mean velocity.
The Ŋp of the arm stroke was calculated with the values of velocity, SR and the shoulder to hand distance (calculated from measures of arm length and elbow angle), following a recent model proposed by Zamparo et al. (2005):

$$Ŋp = (v.\ 0,9/ 2\pi\ .\ SR.\ l).\ 2 / \pi$$

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*).
Arm Coordination was assessed using the IdC, which is based on the lag time between the propulsive phases of each arm, and quantifies three possible coordination modes (Chollet et al., 2000). Each arm movement was divided into four distinct phases: (i) phase A (glide+catch), corresponding to the time from the hand´s entry into the water to the beginning of its backwards movement; (ii) phase B (pull), corresponding to the time from the beginning of the hand´s backward movement ending at the hand´s arrival in the vertical plane to the shoulder; (iii) phase C (push), corresponding to the time from the hand´s position below the

shoulder ending with the release of the hand from the water; and (iv) phase D (recovery), corresponding to the time from the hand´s release from the water ending with a new entry of the hand into the water. The duration of a complete stroke was the sum of the propulsive (B+C) and non-propulsive phases (A+D). The lag time between the beginning of propulsion in the first right arm stroke and the end of propulsion in the first left arm stroke defined IdC1. The lag time between the beginning of propulsion in the second left arm stroke and the end propulsion in the first right arm stroke defined IdC2. IdC was then the mean of IdC1 + IdC2 (Chollet et al., 2000).

The Tprop can be calculated as a model proposed by Alberty et al. (2009).

$$Tprop/distance = Tcycle.(100\% + 2.IdC)D/SL$$

Where D/SL corresponds to the number of stroke cycles needed to cover the distance, and then calculate the total time for propulsion per stroke cycle multiplied by the number of the strokes per lap (Alberty et al., 2009). To analyze the above referred kinematical parameters along the MLSS test, it were defined five different moments: 0, 25, 50, 75 and 100% of the total test duration.

Statistical Analysis.

All statistics were performed using SPSS (version 18.0 for Windows). Mean ± SD were used to represent the average of the studied variables. The normal distribution of the data was verified by the Shapiro – Wilk's test. An ANOVA for repeated measures was used to compare the mean values for each variable at each point of analysis (0, 25, 50, 75 and 100%), and to detect significant differences, post hoc bonferroni tests were used. A significance level of 5% was accepted ($p<0.05$).

RESULTS

Mean values obtained for the kinematical parameters during $MLSS_{100\%}$ and $MLSS_{102.5\%}$ are reported in the figures 1 to 5. None statistical significant difference was assessed between swimming intensities ($MLSS_{100\%}$ vs. $MLSS_{102.5\%}$) in any at the kinematical parameters. The SR values showed an increase while SL decreases along the $MLSS_{102.5\%}$, with a statistical significance, between 0 to 75 and 0 to 100% phases of the test. The ꓵp also showed a significant decrease along the $MLSS_{102.5\%}$, 0 to 50% and 0 to100%. The values obtained for IVV, TI, IdC, Tprop and stroke phases seem to be constant along the $MLSS_{102.5\%}$ protocol.

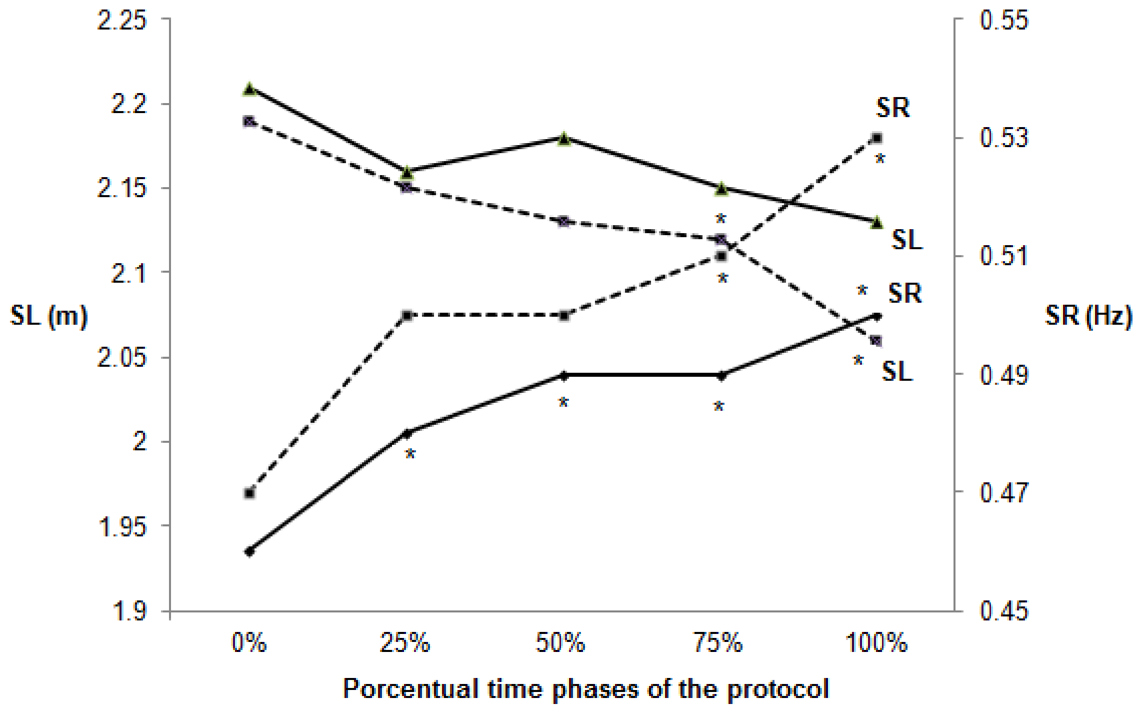

Figure 1: The Mean values for stroke rate (SR) and stroke length (SL) for $MLSS_{100\%}$ (full line) and $MLSS_{102.5\%}$ (dotted line) without significant differences between protocols. The SR at $MLSS_{100\%}$ showed significant differences from 0 to 25, 50, 75, and 100% of the protocol. During $MLSS_{102.5\%}$ showed differences from 0 to 50% and 0 to 100%. The SL values showed significant differences only at $MLSS_{102.5\%}$, from 0 to75% and 0 to 100%.

* Significant difference from 0 % ($p < 0.05$).

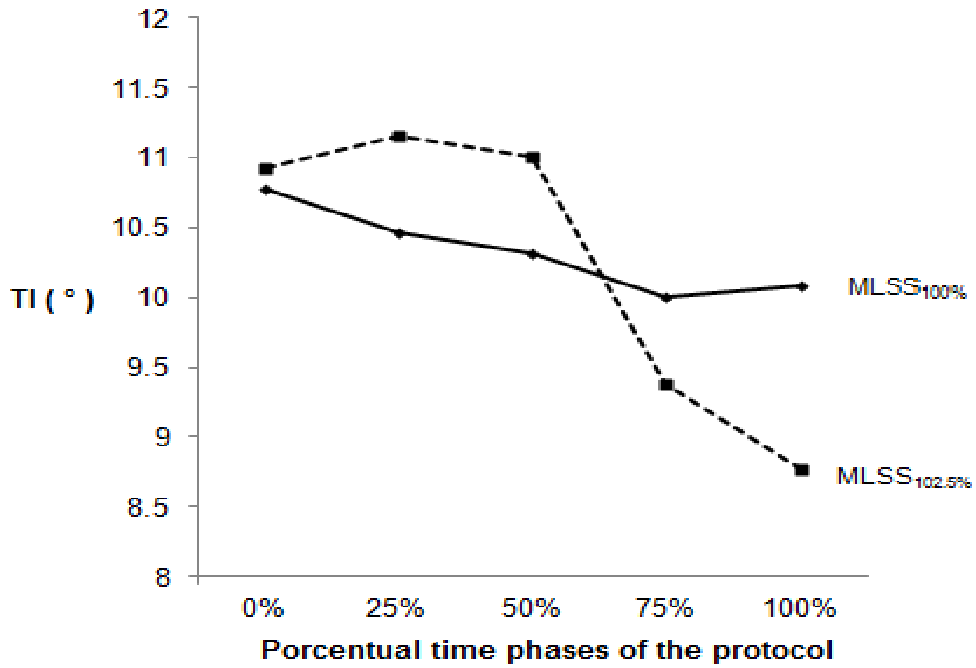

Figure 2: Evolution through $MLSS_{100\%}$ (full line) and $MLSS_{102.5\%}$ (dotted line) for the mean values of trunk incline (TI). The values did not show a significant difference along and between the protocols.

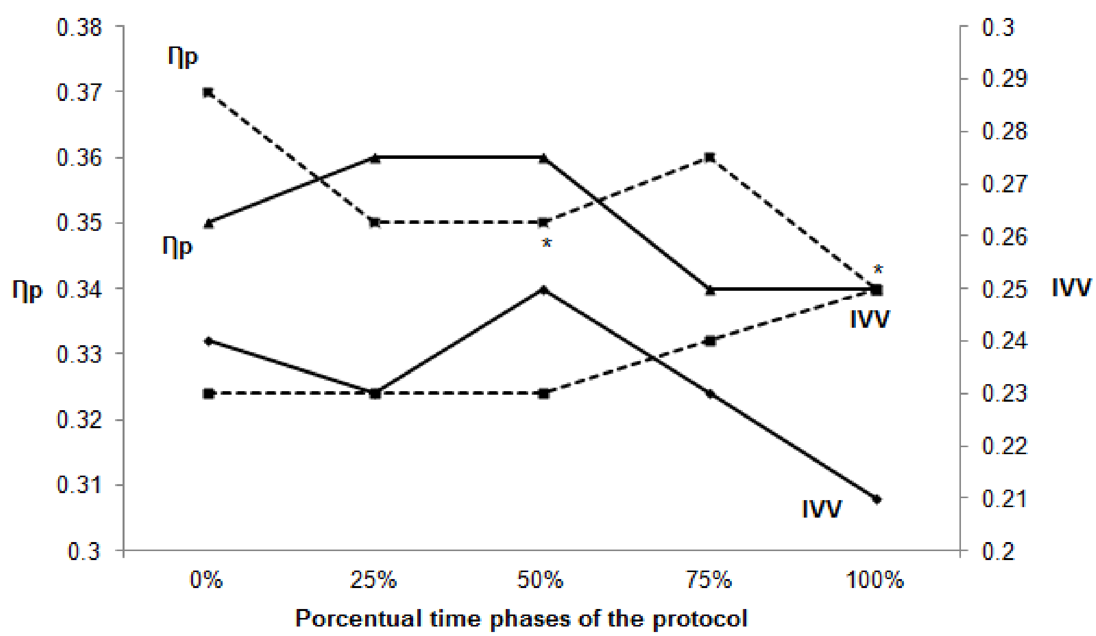

Figure 3: The mean values for propelling efficiency (ηp) and intra cyclic velocity variation (IVV) during the $MLSS_{100\%}$ (full line) and $MLSS_{102.5\%}$ (dotted line) protocols. Significant differences were found for ηp at $MLSS_{102.5\%}$, from 0 to 50% and 0 to 100%. The other values remained constant during the protocols.
* Significant difference from 0 % ($p < 0.05$).

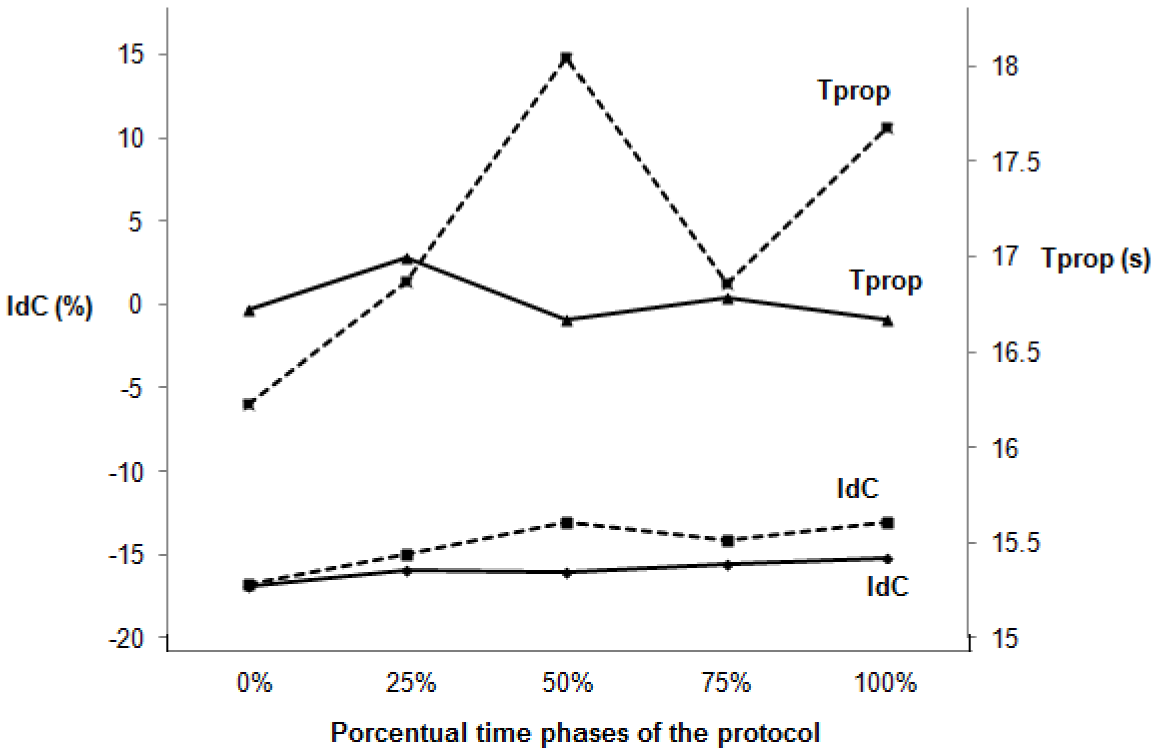

Figure 4: The mean values for index of coordination (IdC) and propulsive impulse (Tprop) along the $MLSS_{100\%}$ (full line) and $MLSS_{102.5\%}$ (dotted line) protocols did not show any significant differences.

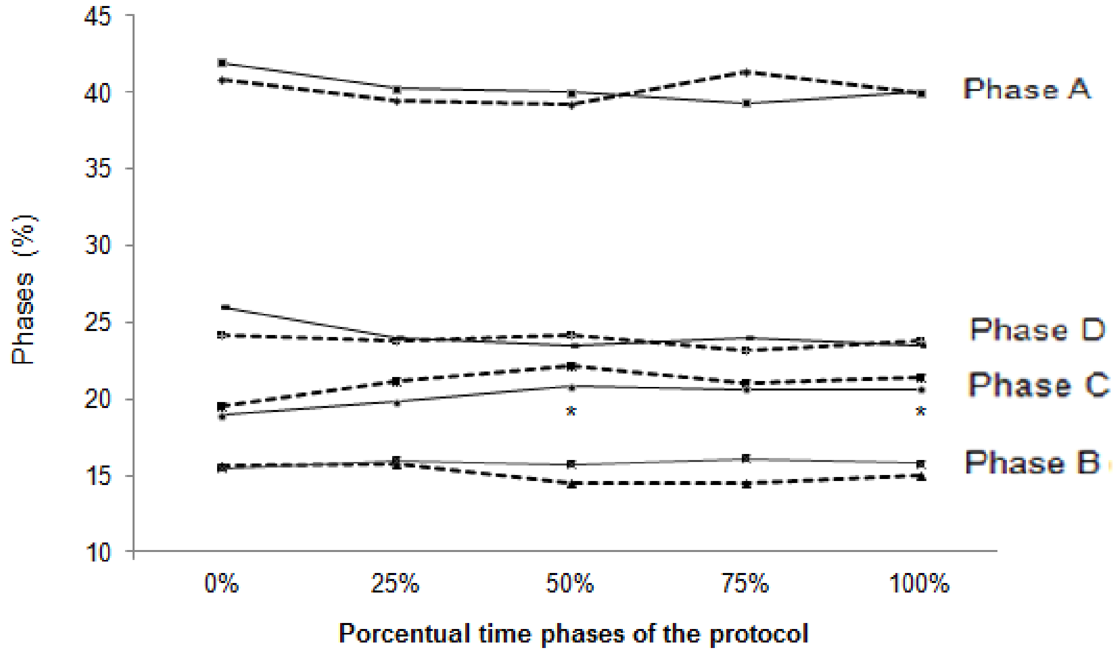

Figure 5: The mean values for stoke phases during the intensities of $MLSS_{100\%}$ (full line) and $MLSS_{102.5\%}$ (dotted line). It can be observed that stroke phases were maintained constant between the protocol intensities. Indeed, phase C of $MLSS_{100\%}$ presented a significant differences from 0 to 50% and 0 to 100%.
* Significant difference from 0 % ($p < 0.05$).

DISCUSSION

The aim of this study was to analyze the behavior of the kinematical parameters, SR, SL, TI, IVV, Ƞp, IdC, Tprop and stroke phases along the velocity above of the $MLSS_{102.5\%}$ and then compare the related parameters between $MLSS_{102.5\%}$ and $MLSS_{100\%}$, which is considered the gold standard protocol for AnT assessment.
The SR and SL showed a significant increase and decrease, respectively, along the $MLSS_{102.5\%}$, but between the two protocols we did not find significant differences. The values found for the $MLSS_{102.5\%}$ are higher than $MLSS_{100\%}$, which shows a tendency to increase the SR and decrease the SL to swim 2.5% above MLSS. However, Dekerle et al. (2005) showed values of SR (0.49±3.1 to 0.54±2.4) significantly different along the $MLSS_{102.5\%}$ protocol, in agreement with the present

study values. When swimmers are required to swim faster than $MLSS_{100\%}$ and for a long period, they have a tendency to shorten the SL and increase the SR. Swimmers can keep a high level of SL values throughout exercises performed at a slow and aerobic velocity, which correspond to a moderate and submaximal intensities. However, when the intensity increases to $MLSS_{102.5\%}$, the reduction in SL becomes progressively greater. This can be related with the energy required, which seem to influence the kinematical characteristics of stroking, while swimming as $MLSS_{102.5\%}$ (Keskinen et al., 1988; Keskinen et al., 1993; Toussaint et al., 1992). Besides, as fatigue developed throughout exercises swum at $MLSS_{102.5\%}$, SL tends to decrease progressively (Dekerle et al., 2005). Pelarigo et al. (2011) showed an increase in SR and decrease in the SL during the exercise when swimming at $MLSS_{102.5\%}$. Also found that between two exercises intensities there were no significant differences on SR and SL, corroborating with our values.

The TI had a constant behavior along the $MLSS_{102.5\%}$. The differences between the intensities of $MLSS_{100\%}$ and $MLSS_{102.5\%}$ are not significant during the five moments of the protocol, indeed showed a slight tendency to decrease. Zamparo et al. (2009) found values of TI as a function of the velocity during the drag measurements and during the free swimming. The values (15±3 - 10±2) showed by Zamparo et al. (2009) corroborate with ours, where a tendency to decrease in the TI values with the increasing velocity was observed between the protocols.

Furthermore, constant values of IVV were observed and the values between $MLSS_{100\%}$ and $MLSS_{102.5\%}$ did not showed significantly different as well. Generally, high IVV has been positively correlated with an increased rate of energy expenditure in front crawl. Indeed, Alberty et al. (2005) found that IVV were not modified under fatigue condition even despite the modification of arm coordination, if there is an increase in IdC values, a better chain of the propulsive actions happens, and it was expected that IVV would decrease. Swimming fast depends on several factors, these include the ability to produce high mechanical power, to reduce drag while keeping power losses from pushing water, and to adopt a greater continuity in propulsion (Chollet et al., 2000; Seifert et al., 2004). Schnitzler et al. (2008) showed that a poor motor organization could be related with an increase in propulsive and drag forces and led to an increase in IVV.

The Ƞp presented a significant decrease during the $MLSS_{102.5\%}$, and did not show differences between the protocols. Studies showed values for Ƞp from 0.42 to 0.47 for competitive US swimmers (Zamparo et al., 2005). Toussaint et al. (1990) report data of 0.44±0.03 and 0.61±0.06 for highly triathletes and competitive swimmers. Pendergast et al. (2003) reported a Ƞp of 0.37 in front crawl with a speed range from 1.0m/s to 1.4m/s. Thus, studies analyzing distance with imposed pace have found decreases in SL and increases in SR, which may result from a reduced capacity to generate force to overcome drag (Alberty et al., 2009). The efficiency 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 higher velocity. However, maximal swimming velocity can be achieved by a swimming technique where optimal propelling force is obtained with an optimal Ƞp and a minimal body drags (Toussaint et al., 2000).

Analyzing the IdC it is possible to observe a constant behavior along the protocol. In the present study, the exercise intensity $MLSS_{100\%}$ and $MLSS_{102.5\%}$ were important to determine different responses, but with no significant differences. IdC represents the average lag time between two consecutives arm propulsive phases relative to the stroke cycle duration. Pelarigo et al. (2011) showed that the values for IdC (−3.85±6.2% and−3.15±6.1%) were not modified, independently of the swimming intensity ($MLSS_{100\%}$ and $MLSS_{102.5\%}$) analyzed. Therefore, the maintenance or not of the IdC during imposed pace cannot be explained only by the kinematical and metabolic condition, but mainly by the differences of the exercise intensity between studies. The swimmer has freedom to reduce the lag time between the left and the right arm propulsion with the option to overlap these impulses (Alberty et al., 2009). However, a small increment in the velocity requires a much greater metabolic energy turnover, and probably different stroke strategies to maintain the pace. In the study conducted by Alberty et al. (2009), with the development of fatigue, the swimmers had less freedom to change the distribution of the propulsive force within the stroke cycle, leading to an increase in the IdC to maintain the imposed pace. Thus, corroborating this analysis Seifert et al. (2004) presented IdC increased throughout the imposed pace from V3000 to V200 (from -10.9±5.4% to – 7.24±5.4).

Furthermore, the Tprop presents a constant behavior during the $MLSS_{102.5\%}$, and without significant differences between $MLSS_{100\%}$ and $MLSS_{102.5\%}$. Alberty et al. (2009) showed an increased for Tprop with an increasing velocity, which can be explain by the good relation from the swimmers with a constant and long period of the protocols.

Finally the stroke phases showed a constant behavior along the protocol, and did not showed differences between $MLSS_{100\%}$ and $MLSS_{102.5\%}$. Indeed, non-propulsive phases showed a tendency to increase and propulsive phases a tendency to decrease with higher intensity. Pelarigo et al. (2010) showed that the intensity $MLSS_{100\%}$ and $MLSS_{102.5\%}$, consequently, the metabolic condition, were important to determine different responses only in phase propulsive B. The analysis of other studies (Alberty et al., 2005; Alberty et al., 2009) showed differences during the phases and it can be verified that the fatigue determines an increase in the participation of the propulsive phases aiming to maintain the propulsive impulse. The effect of fatigue on the stroke phases and arm coordination has been analyzed during distance trials and imposed pace. Analyzing swim conditions of imposed pace and lower exercise intensity performed until exhaustion (95% to 110% of V400) Alberty et al. (2005) verified a decrease in the duration of non-propulsive phases and maintenance of the propulsive phases with fatigue development. Chollet et al. (2000) referred for high level swimmers a reduction of the non-propulsive phase of entry and catch during sprints, and relative increase of the propulsive phases (pull and push). The duration of the catch phase decrease with velocity between 1.1m/s and 1.8m/s, whereas, simultaneously, the pull and push phases increased. High level swimmers are thus characterized by a greater capacity to modify the differences phases of the arm stroke.

The changes observed in the swimming technique and kinematical parameters to maintain the constant velocity in the $MLSS_{102.5\%}$, might show that swimmer needs to adjust the stroke cycles to compensate fatigue, allowing the completion of the $MLSS_{102.5\%}$ protocol.

The changes in swimming technique (i.e., reduction in SL and ηp, increase in SR) of long distance swimmers during imposed velocity at heavy intensity domain, occurs in the condition of non-metabolic equilibrium. Therefore, during the $MLSS_{100\%}$ the change in SR and push phase seems to determine the upper boundary beyond which an increase in those parameters might be necessary to maintain the swim velocity for a longer period.

Chapter 4

General Discussion

Swimming success is dependent on training monitoring, which will lead to technique and physiological improvement. There are some protocols used to assess the physiological factors, usually used to determine swimmers' aerobic capacity. The "gold–standard" procedure to assess anaerobic threshold is the Maximal Lactate Steady State (MLSS) test (Heck et al., 1985; Beneke & Von Dullivard, 1996). Therefore, the methods of training control, which are in continuous actualization, allow coach to assess direct and precisely the swimmers physiological and kinematical characteristics.

In the present Thesis, the kinematical parameters were assessed through video analysis and digitizing with the Ariel Performance Analysis system software, and the main findings were that the SR increased and SL showed a standard behavior throughout swimming at the $MLSS_{100\%}$; during swimming at $MLSS_{102.5\%}$, SR increased and SL decrease. Dekerle et al. (2005) also showed values of SR (0.49±3.1 to 0.54±2.4) significantly different along the $MLSS_{102.5\%}$ protocol, evidencing that when swimmers are required to swim faster than MLSS for a long period, they will have a tendency to shorten the SL and increase the SR. So, swimmers are able to keep high SL throughout exercises performed at moderate and submaximal intensities, but, when the intensity increases to $MLSS_{102.5\%}$, the reduction in SL is progressively evident, which could be explained by fatigue development (Dekerle et al., 2005). This can be related with the energy required, which seem to influence the kinematical characteristics of stroking while swimming at $MLSS_{102.5\%}$ (Keskinen et al., 1988; Keskinen et al., 1993; Toussaint et al., 1992). Pelarigo et al. (2011) showed an increase in SR and decrease in the SL during the exercise when swimming above MLSS. When $MLSS_{100}$ and $MLSS_{102.5\%}$ were compared, no relevant differences in SR and SL were found, as reported before by Pelarigo et al. (2011) but only comparing two percentage time phases of the effort (10^{th} and 30^{th} minutes).

The TI had a constant behaviour along the MLSS tests, but with a tendency to decrease at $MLSS_{102.5\%}$; this means that swimmers adopted a more horizontal position when swimming at higher velocities, offering lower resistance to progression. No differences exist between $MLSS_{100\%}$ and $MLSS_{102.5\%}$ during the five moments of the protocol. Zamparo et al. (2009) found similar values of TI as a function of the velocity during the free swimming that might indicate that swimmers are able to maintain their technique and not experiencing additional drag since the cross sectional area is expected to remain constant.

Swimming fast depends on several factors, including the ability to produce high mechanical power, to reduce drag while keeping power losses from pushing water, and to adopt a greater continuity in propulsion (Chollet et al., 2000; Seifert et al., 2004). Schnitzler et al. (2008) showed that a poor motor organization could be related with an increase in propulsive and drag forces and led to an increase in IVV. However, along the MLSS protocols, constant values of IVV were observed at both intensities, non-existing significance differences between them. Generally, high IVV values are positively correlated with an increased rate of energy expenditure in front crawl. Indeed, Alberty et al. (2005) found that IVV were not modified under fatigue conditions even despite the modification of arm coordination (if there is an increase in IdC values, a better chain of the propulsive actions happens, and it was expected that IVV would decrease).

The ηp presented a constant behavior along the $MLSS_{100\%}$ and a significant decrease during the $MLSS_{102.5\%}$, but not showing significant differences between the protocols. Toussaint et al. (1990) report ηp values of 0.44±0.03 and 0.61±0.06 for highly trained triathletes and competitive swimmers. Pendergast et al. (2003) reported a ηp of 0.37 in front crawl swimming from 1.0 to 1.4m/s. However, maximal swimming velocity can be achieved by a swimming technique where optimal propelling force is obtained with an optimal ηp and a minimal body drags (Toussaint et al., 2000).

Analyzing the IdC, it is possible to observe its constant behavior along the $MLSS_{100\%}$ and $MLSS_{102.5\%}$ protocols, meaning that the average lag time between two consecutives arm propulsive phases relative to the stroke cycle duration was maintained constant independently of the swimming intensity. Pelarigo et al. (2011) also showed that the values for IdC [−3.85±6.2 and −3.15±6.1] did not modified in a MLSS test independently of the swim intensity analysed. In the present study, the IdC values presented a tendency to be higher at $MLSS_{102.5\%}$ than $MLSS_{100\%}$, but without a statistical significance. It seems that the maintenance of the IdC during imposed pace cannot be explained only by kinematical and metabolic parameters, but mainly by the differences in the exercise intensity between studies. In the study conducted by Alberty et al. (2009), with the development of fatigue, the swimmers had less freedom to change the distribution of the propulsive force within the stroke cycle, leading to an increase in the IdC to maintain the imposed pace.

Well related with the IdC, the Tprop presented a constant behavior during the $MLSS_{100\%}$ and $MLSS_{102.5\%}$, without significance differences among the intensities. Alberty et al. (2009) showed an increase in Tprop with an increasing velocity during the 400-m event corresponding to 95%, 100% and 110% of the mean velocity attained.

Finally, the stroke phase C showed an increase along $MLSS_{100\%}$, rather than the other phases that stayed constant along the protocol. During the $MLSS_{125\%}$ all phases maintained constant. In addition, when $MLSS_{100\%}$ and $MLSS_{105\%}$ were compared, non-propulsive phases showed a tendency to increase, and propulsive phases a tendency to decrease at the higher intensity. Pelarigo et al. (2010) showed that the different intensities ($MLSS_{100\%}$ vs. $MLSS_{125\%}$) and, consequently, the metabolic conditions, were determinant for obtaining diferent phase propulsive B values. The analyzing of other studies (Alberty et al., 2005; Alberty et al., 2009) showed differences during the phases and that the fatigue determines an increase in the participation of the propulsive phases aiming to maintain the propulsive impulse, but in this case with a higher velocity and different distances.

The changes observed in the swimming technique and kinematical parameters to maintain the constant velocity during the $MLSS_{102.5\%}$, might show that swimmer needs to adjust his technique to compensate the physiological changes and then swim during the protocol. Based on the current results, it seems that the use of different intensities influence the kinematical parameters during each protocol, but without relevant kinematical differences between $MLSS_{100\%}$ and $MLSS_{102.5\%}$. However, and despite MLSS being the "gold – standard to the AnT assessment, it is truly important to refer that when coach prescribes the intensity of the swimming aerobic training, based in the $MLSS_{100\%}$ results, it is necessary to adjust the swimming velocity obtained (Maglischo, 1993). This adjustment will depend on the series duration and the relationship break-effort, since changes in distances and recovery intervals used in training series, could modify the stimulus given to swimmer. The long distance swimmers showed along the effort a good relation between the kinematical parameters and the maintenance of the imposed pacer, which could demonstrated that the adjustment made by the swimmer, might shown that they can swim on the effect of fatigue for longer without compromising the kinematic parameters.

Chapter 5

Conclusions

The results of the present study contribute to the improvement of swimming knowledge and to the methods to analyze the kinematical parameters and how they can influence the swimmers technique.

- Swimming at the $MLSS_{100\%}$ showed only some significant differences along the protocol. SR values were lower in the first moment of the protocol, comparing with the remaining moments of the test and phase C showed an increase, which might help understanding the adjustment in SR made by the swimmers to maintain the right pace.
- Swimming at $MLSS_{102.5\%}$ showed a SR increase and SL decrease along the protocol according with the literature. Indeed, also showed a decrease in the Ƞp, which depends essentially on the distance per stroke, which makes increase the SR to keep the velocity constant, and consequently cause chances in the SL.
- Finally, we could not find differences between the intensities of $MLSS_{100\%\ and}$ $MLSS_{102.5\%}$ when comparing the values. Other studies also showed that the comparison between the protocols did not suggested changes along the efforts.

Appendix I

KINEMATICAL ANALISYS ALONG THE MAXIMAL LACTATE STEADY STATE SWIMMING TEST

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Introduction:

The gold-standard methodology used to assess the athlete´s aerobic capacity is the Maximal Lactate Steady State (MLSS) test. In fact, once it determines the highest workload that can be maintained over time without a continual blood lactate accumulation, it can be used to prescribe individualized aerobic training. However, even knowing that swimming performance is influenced both by bioenergetic and biomechanical factors, studies that analyzed eventual kinematical changes during the MLSS test are scarce. We aimed to assess the stroking parameters, intracyclic velocity variation (IVV), propelling efficiency, trunk incline (TI) and index of coordination (IdC) along the MLSS test.

Key words: Aerobic capacity, aerobic training, Biomechanics Parameters, swimming.

Methods:

A triathlete participant in the World Junior Championship (19yr, 69kg and 1.75m) performed, in subsequent days, 2-4 30min sub-maximal continuous tests at imposed swim pace, with 2.5% differences between trials, to assess the velocity corresponding to MLSS. The test was recorded with two cameras (one under and other above water). Kinematic analysis was made using digitization (APAS) for the trial corresponding to MLSS, being divided in five different points (0, 25, 50, 75 and 100% of the test). Stroke length and stroke rate were computed; swimming efficiency was obtained through IVV that was calculated by the coefficient of variation of the hip´s instantaneous velocity (Alberty et al, 2005) and propelling efficiency values (Zamparo et al., 2005); TI was defined by the angle between the shoulder and the hip segment and the horizontal (Zamparo et al., 2009); inter-arm coordination was assessed using the IdC (Chollet et al., 2000).

Results:

Stroke rate increased (0.50-0.53Hz) and stroke length decreased (2.32-2.21m) along the MLSS test. Propelling efficiency decreased (0.45-0.42) and inter-arm coordination was adapted towards an increased along the 30min with a variation of the values between -19.5 and -13.8%. The TI, as the IVV, presented a constant behavior along the test (~11° and ~0.26, respectively).

Discussion:

The inter-cycle changes occurred show the interplay between the variables studied, being self-optimized in a compensatory mechanism to maintain, not only the velocity constant throughout the test, but also the physiological parameters (blood lactate). The only parameters that did not change were the trunk incline, as expected, once it has a good relation with drag, changes on it for the same mean velocity would increase the effort, and probably imbalance the production and removal of blood lactate; and the IVV, since it was suggested that IdC change in order to maintained them (Alberty et al., 2005).

Chapter 6

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