U.PORTO
FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

Technical characterization of front crawl and backstroke swimmers of 11-13 years of age

Dissertação apresentada às provas de 2º Ciclo de Estudos em Desporto para Crianças e Jovens, orientada pelo Professor Doutor Ricardo Fernandes e co-orientada pela Professora Doutora Susana Soares, 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 Sport for Children and Youth, under the supervision of Professor Ricardo Fernandes and Professor Susana Soares, 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.

Ana Filipa Braga Barroso Campos Silva

Porto, Setembro de 2011

Silva, Ana (2011). Technical Characterization of front crawl and backstroke swimmers of 11-13 years of age. Dissertação apresentada às provas de 2º Ciclo de Estudos em Desporto para Crianças e Jovens, orientada pelo Professor Doutor Ricardo Fernandes e co-orientada pela Professora Doutora Susana Soares, ao abrigo do Decreto-lei nº74/ 2006 de 24 de Março.

KEY WORDS: KINEMATICS, SWIMMING, FRONT CRAWL, BACKSTROKE, AGE GROUP.

PALAVRAS-CHAVE: CINEMÁTICA, NATAÇÃO, CROL, COSTAS, INFANTIS.

Acknowledgments

I would like to take the opportunity to express my gratitude to all that have supported me on the process of elaboration of this thesis:

- Prof. Dr. Ricardo Fernandes, who gave me the honour of been my promoter, and also for his scientific expertise and for the availability provided.

- Prof. Dra Susana Soares for her professionalism, availability, and also her help in the statistical procedures.

- Prof. Dr. João Paulo Vilas-Boas, major european swimming personality, for his advising and support.

- MSc. Pedro Figueiredo for his cooperation in some experimental proceedings and suggestions and revising the text.

- MSc. João Ribeiro, MSc Ana Sousa, Dr. Paulo Renato, MSc. Ana Querido and Dr. Pedro Duarte for technical support and friendship.

- Special thanks to the swimmers and their coaches, as also the collaborators, who participated in these studies, for their time, commitment and enthusiasm.

- My sister, who always had patience and willingness to help me.

- My parents, for all the support.

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. Silva, A.; Figueiredo, P.; Soares, S.; Seifert, L.; Vilas-Boas, J.P.; Fernandes, R. J. Front crawl technical characterization of 11-13 years old swimmers. Submited to **Pediatr Exer Sci**.

2.Silva, A.; Soares, S.; Vilas-Boas, J.P.; Fernandes, R. J. Backstroke technical characterization of 11-13 years old swimmers. Submited to **J Sport Sci**.

---Abstracts---

I. Silva, A.; Figueiredo, P.; Renato, P.; Amaral, I.; Sousa, M.; Sampaio, A.; Soares, S.; Vilas Boas, J. P.; Fernandes, R. (2010). Avaliação da Coordenação entre Membros Superiores na Técnica de Crol em Nadadores Infantis. **AcQua – Revista Portuguesa de Natação**, pp. 36-43.

II. Silva, A.; Figueiredo, P.; Renato, P.; Abraldes, J.A.; Soares, S.; Fernandes, R.J. (2011). Sincronización entre membros seperiores en la técnica de crol en nadadores Jóvenes. Submited to **Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte.**

III. Silva, A.; Figueiredo, P.; Soares, S.; Vilas-Boas, J.P.; Fernandes, R. J. (2011). Arm Symmetry in 11-13 years old Front Crawl Swimmers in: S. Soares, F. Sousa, A. P. Veloso, J. P. Vilas-Boas (Eds.) **Programme and Book of Abstracts of International Society of Biomechanics in Sport**, pp. 120.

Table of Contents

Index of Tables

Appendix 4 Tabla 1: Valores medios ($\bar{x} \pm sd$) relativos a las principales características antropométricas y frecuencia de entrenamiento semanal de la muestra del estudio.

Tabla 2. Valores medios ($\bar{x} \pm sd$) de la velocidad, frecuencia gestual, distancia de ciclo, índice de coordinación, entrada y agarre, tracción, empuje, recuperación, suma de fases propulsivas y no propulsivas en relación al sexo, así como para la muestra total y el estudio de Chollet et al. (2000).

Tabla 3. Matriz de correlación entre los parámetros de velocidad, frecuencia gestual, distancia de ciclo, índice de coordinación y envergadura para la muestra total (n=60).

Index of Figures

Index of Equations

Appendix 3 [IdCleft – IdCright/ 0,5(IdCleft + IdCright)] x 100

Appendix 4

$$IdC_{izquierdo} = \frac{[(\text{Momento final del empuje}_{izquierdo} - \text{Momento inicial de tracción}_{derecho}) \cdot 100]}{\text{Duración de un ciclo completo}}$$

$$IdC_{derecho} = \frac{[(\text{Momento final del empuje}_{derecho} - \text{Momento inicial de tracción}_{izquierdo}) \cdot 100]}{\text{Duración de un ciclo completo}}$$

$$\textit{Duración ciclo completo} = \frac{(\text{Entrada y agarre} + \text{Tracción} + \text{Empuje} + \text{Recuperación})_{izquierdo} + (\text{Entrada y agarre} + \text{Tracción} + \text{Empuje} + \text{Recuperación})_{derecho}}{2}$$

$$IdC = \frac{IdC\ derecho\ +\ IdC\ izquierdo}{2}$$

Abstract

Swimming performance is influenced by the interaction of physiological, psychological and technical factors, based on individual genetic endowment, and continuously modulated by the training process. However, studies that evaluated the contribution of each influencing factor, and its relationship, in young swimmers are scarce. The aim of this Thesis was to characterize the general biomechanical parameters and the inter-arm coordination (through the Index of Coordination – IdC) of swimmers from the infant competitive swimming age-group (girls of 11-12 and boys of 12-13 years of age). 114 swimmers performed 2x25-m at 50-m pace in front crawl and backstroke, with 5 min rest. Two underwater cameras were used to assess general biomechanical parameters (velocity, stroke rate, stroke length and stroke index) and IdC. The data analysis was made taking into account the division of the sample in maturity stages and genders. In both swimming techniques, swimmers adopted the catch-up coordination (the lowest mean value was -7.19 ± 4.77 for post-pubertal girls and the highest -6.34 ± 4.82 for pubertal girls), which are in accordance with adult backstrokers, but in opposition for front crawlers (adults usually adopt superposition mode when performing at very high intensities). Young swimmers presented lower values than adults in all biomechanical parameters for pubertal and post-pubertal (respectively) the values were: 1.46 ± 0.12 and 1.55 ± 0.12 for boys and 1.37 ± 0.18 and 1.41 ± 0.13 $m.s^{-1}$ for girls; 52.17 ± 6.76 and 51.88 ± 5.18 for boys and 50.01 ± 5.63 and 48.16 ± 5.04 $cycles.min^{-1}$ for girls; 1.69 ± 0.23 and 1.81 ± 0.24 for boys and 1.66 ± 0.28 and 1.75 ± 0.20 $m.cycle^{-1}$ for girls; the post-pubertal group showed closest values to adult swimmers due to their higher anthropometric characteristics and more advanced maturational status. Some differences were also registered between genders, with boys presenting higher velocity, stroke index and stroke rate. These data increased the knowledge about young swimmers biomechanical and technical characteristics, and showed that the IdC is a useful tool possible to use for age-group swimmers performance diagnosis.

KEY WORDS: KINEMATICS, SWIMMING, FRONT CRAWL, BACKSTROKE, AGE-GROUP

Resumo

Na natação, a performance é determinada pela interacção de factores fisiológicos, psicológicos e técnicos, com base na herança genética individual, e continuamente desenvolvida pelo processo de treino. No entanto, estudos com nadadores jovens, com o objectivo de avaliar os fatores de desempenho que influenciam a performance e a sua independência são escassos. Neste sentido, é objectivo desta tese caracterizar os parâmetros biomecanicos gerais e a coordenação entre membros superiores (através do Índice de Coordenação – IdC) em nadadores jovens do escalão infantil (meninas de 11-12 e meninos de 12-13 anos de idade). 114 nadadores realizaram 2 x 25-m, à velocidade de 50-m na técnica de crol e costas, com um intervalo de 5 minutos. Duas câmaras subaquáticas foram utilizadas para avaliar os parâmetros biomecânicos gerais (velocidade, frequência de braçada, comprimento do braçada e índice de braçada) e IdC. A análise dos dados foi efectuada tendo em conta a divisão da amostra em estados maturacionais e géneros. Em ambas as técnicas de nado, os jovens nadadores adoptaram o modo de catch-up (o menor valor médio foi de -7.19 ± 4.77 para o grupo das meninas pós-pubere e o valor médio mais elevado de -6.34 ± 4.82 para meninas puberes). Estes resultados estão de acordo com atingidos pelos adultos na técnica de costas, mas são contrários aos obtidos na técnica de crol (adultos costumam adotar o modo de coordenação em superposição, a intensidade elevada). Os jovens nadadores apresentaram valores mais baixos em todos os parâmetros biomecânicos, para o grupo de púberes e pós-puberes (respectivamente) os valores foram: 1.46 ± 0.12 e 1.55 ± 0.12 para os rapazes e 1.37 ± 0.18 e 1.41 ± 0.13 m.s-1 para as meninas; 52.17 ± 6.76 e 51.88 ± 5.18 para os rapazes e 50.01 ± 5.63 e 48.16 ± 5.04 cycles.min-1 para as meninas; 1.69 ± 0.23 e 1.81 ± 0.24 e para os rapazes e 1.66 ± 0.28 e 1.75 ± 0.20 m.cycle-1 para as meninas; tendo o grupo de nadadores pós-púberes valores mais próximos aos apresentados por nadadores adultos. Este resultado deve-se ao facto destes nadadores apresentarem valores antropométricos e maturacionais superiores. Algumas diferenças foram registadas entre géneros, nomeadamente na velocidade, comprimento de braçada, o índice de braçada e frequência de braçada, onde os rapazes obtiveram resultados mais elevados comparativamente com as meninas. Concluindo, esses estudos permitiu aumentar o nosso conhecimento sobre a caracterização técnica e biomecânica dos jovens nadadores e mostrou que o IdC é uma ferramenta útil e possível de ser usada até mesmo durante as sessões de treino.

PALAVRAS-CHAVE: CINEMÁTICA, NATAÇÃO, CROL, COSTAS, INFANTIS.

Résumé

En natation, la performance est déterminée par l'interaction de facteurs physiologiques, psychologiques et techniques, basées sur le patrimoine génétique individuel, et constamment développé par le processus de formation (d'entraînement). Cependant, des études avec des jeunes nageurs, avec le but d'évaluer les facteurs de performance qui influencent le rendement et l'indépendance sont rares. En ce sens, l'objectif de cette thèse est de caractériser les paramètres biomécaniques et la coordination générale entre les membres (par le biais de l'indice de coordination - IDC) des jeunes nageurs de la catégorie cadets (filles entre 11-12 ans et garçons entre 12-13 ans). 114 nageurs ont effectué 2 x 25 m à une vitesse de 50 m en technique Crawl et dos, avec un intervalle de 5 minutes. Deux caméras sous-marines ont été utilisées pour évaluer les paramètres biomécaniques généraux (vitesse, fréquence, longueur et taux de brasse) et IDC. L'analyse des données a été réalisée en tenant compte de l'échantillon divisé en genres et les états de maturation. Dans les deux techniques de nage, les jeunes nageurs ont adopté le mode de rattrapage (la valeur moyenne la plus faible a été -7,19 ± 4,77 pour le groupe des filles post-pubères et la plus haute valeur moyenne a été de -6,34 ± 4,82 pour les filles pubères). Ces résultats sont cohérents avec ceux atteints par les adultes dans la technique du dos, mais ils sont contraires à ceux obtenus dans la technique de Crawl (les adultes ont tendance à adopter le mode de coordination de superposition, de haute intensité). Les jeunes nageurs présentent des valeurs inférieures dans tous les paramètres biomécaniques pour le groupe de pubères et post-pubères (respectivement). Les valeurs ont été: 1,46 ± 0,12 et 1,55 ± 0,12 pour les garçons et 1,37 ± 0,18 et 1,41 ± 0,13 ms-1 pour les filles, 52,17 ± 6,76 et 51,88 ± 5,18 pour les garçons et 50,01 ± 5,63 et 48,16 ± 05,04 cycles.min-1 pour les filles, 1,69 ± 1,81 et ± 0:23 et 0:24 pour les garçons et 1,66 ± 0,28 et 1,75 ± 0,20 m.cycle-1 pour les filles. Le groupe des nageurs post-pubères présente des valeurs plus proches de ceux rapportés par les nageurs adultes. Ce résultat est dû au fait que ces nageurs présentent des valeurs anthropométriques et de maturation supérieures. Certaines différences ont été enregistrées entre les sexes, notamment dans la vitesse, la longueur et le taux de fréquence de la brasse, où les garçons ont obtenu des résultats plus élevés par rapport aux filles.

En conclusion, ces études ont contribué à accroître notre connaissance de la technique de caractérisation et de la biomécanique des jeunes nageurs et ont montré que l'IPC est un outil utile et peut être utilisé même pendant les sessions d’entraînement.

MOTS CLÉS: CINEMATIQUE, NATATION, CRAWL, DOS, ENFANTS.

Abbreviations and Symbols

Abbreviation/Symbol - Term (unit)

% - percentage

* - significant difference

< - less than

> - higher than

± - more or less

IdC – Index of Coordination

IdCleft – Index of Coordination of the left arm

IdCright – Index of Coordination of the right arm

IdC1 – Index of Coordination 1

IdC2 – Index of Coordination 2

i.e. - this is

n - number of subjects

SD - standard deviation

SI - stroke índex

SL - stroke length

SPSS - statistical package for social sciences

SR – stroke rate

v – mean swimming velocity

Chapter 1

General Introduction

Swimming performance, as in other cycling and individual sports, has been strongly linked to physiological, technical and physical capacities (Figueiredo et al, 2010). Knowing that technique is one of the major factors influencing swimming performance (Sanders, 1999; Pendergast, 2006), swimmers usually start serious training before the onset of puberty and achieve international competitive level at a relatively early age (Lätt et al., 2009; Platonov et al., 1994).

Previous studies have shown that elite swimmers are distinguishable from novice swimmers through several kinematic differences. For example, elite swimmers are able to achieve longer stroke length (SL) while minimizing stroke rate (SR), resulting in a more economical stroke pattern (Pendergast et al., 2006), and the hips and shoulders of elite adults swimmers rotate more symmetrically and with greater amplitude than those of novice swimmers (Cappaert et al, 1995), resulting in major differences in body alignment and greater efficiency of propulsion (Kolmogorov, 1997). In addition, elite adult swimmers have lower active drag because they manage to decrease the drag force using propulsion forces in a more efficient way than young swimmers, although the net force applied by both is the same (Kolmogorov et al, 1992).

Swim performance has traditionally been analysed from the race components (start time, swim time, turn time and final time), particularly swim time (Seifert et al, 2008). During this period, changes in velocity, SR, SL and Stroke Index (SI) can be calculated (Costill et al, 1985a). The anthropometric properties are also relevant swimming performance determinants; for example, adult men could indirectly influence coordination because they have higher propulsive forces than adult women, a different fat distribution, and anthropometric values, which lead to higher SL, and different drag (Seifert et al, 2006). These parameters have greatly improved our understanding of what constitutes swimming skill, but less attention has been given to motor organization (Seifert et al, 2008).

Front crawl and backstroke are considered alternate swimming techniques because the inter-arm coordination is globally in anti-phase (Costill et al, 1985b), i.e., one arm propels underwater while the other recovers aerially. However, the hand velocity during an arm cycle is not constant because of the time spent catching the water forward and downward. Nevertheless, closer analysis of inter-arm coordination was conducted to determine more exactly the inter-arm coupling in front crawl (Seifert et al, 2008) and in backstroke (Lerda et al, 2003). In this sense, eleven years ago, Chollet et al. (2000) proposed a tool to determine the inter-arm coordination – the Index of Coordination (IdC). This index, initially used for crawl, is based on the measurement of the lag time between the propulsive phases of the two arms. Years later, Lerda and Cardelli (2003) adapted the same tool to backstroke technique. In both alternating swimming techniques, IdC can express three different synchronization modes: opposition (IdC = 0), providing continuous motor action, resulting in a smooth series of propulsive phases, without lag times; (ii) catch-up (IdC < 0), existing a lag time between propulsive phases of the two arms; and (iii) superposition (IdC > 0), which describes an overlap in the propulsive phases (Seifert et al, 2008). As the IdC gives temporal information about the management of propulsive actions (Schnitzler, 2007), its use for evaluating front crawl and backstroke swimming techniques is justified by the fact that, in both techniques, the main propulsion comes from the synchronization of the upper limbs (Seifert et al, 2008).

Coaches usually consider catch-up coordination as a mistake (Seifert et al., 2008). However, Seifert et al. (2006) showed that this mode is useful for front crawl slow paces once it favours the glide phase following propulsive actions. On the other hand, most of the technical analyses consider that the superposition mode is used only by very high skilled swimmers (Costill et al., 1992; Chollet et al., 2000; Seifert et al., 2004), showing that the swimmers who superposed their arm actions were the best of the group. Later, Seifert et al. (2008) added that the three coordination modes (catch-up, opposition and superposition) are regularly observed in relation to the individual profile (sprinter, mid or long distance). Comparisons between genders were also done:

women show more frequently an catch-up coordination than men because of their greater fat mass, a different distribution of this mass, lower arm strength, and greater difficulty in overcoming forward resistance (Seifert et al. 2003a; Seifert et al., 2008).

Contrary to front crawl, backstroke shows that a greater continuity of propulsive arm action is not an indicator of superior performance level (Seifert et al, 2004). Moreover, an increase in SR does not explain the change in coordination observed in the front crawl (Seifert et al, 2003b). Thus, SL could be the main variable responsible for the increasing velocity in the backstroke technique as it provides a means to compensate for the superposition mode, which is considered impossible in this specific swimming technique (Chollet et al, 1996); indeed, backstroke is characterized by a more marked discontinuity of the propulsive arm actions than front crawl (Querido et al, 2010). In backstroke technique, there are also some differences between genders to denote: although both genders exhibit catch-up coordination, women have a better continuity than men, which can be explained by the increase of entry and catch at the moment of clearing (Lerda et al, 2005). The better flotation of women can explain their greater aptitude to maintain a horizontal body position and consequently the lengthening of the entry and catch to reduce drag (Lerda et al, 2005).

Investigations in young competitive swimmers are much reduced comparing to those conducted with adult swimmers, mainly due to financial coasts but also to ethical issues (Garrido et al, 2010). The training control and evaluation of swimmers is considered a fundamental tool for increasing the efficiency of training processes (Maglischo, 2003) and to the prediction of performance (Wright and Smith, 1994). Therefore, as although children are not mini-adults (Armstrong and Welsman, 2002), it is important to conduct more studies with these age-goups to help coaches and swimmers to get better results. The main propose of this Thesis was to conduct a technical characterization of the alternated swimming technics in swimmers of 11-13 years old, contributing to its performance improvement. We will focus in the general biomechanical parameters and in the inter-arm coordination assessment.

In the **Appendix I** it was characterized the inter-arm coordination in front crawl technique performed at high velocity (at the 50-m race pace), through IdC. It was analysed a sample of forty swimmers, from both genders and from both maturity stages (pubertal and post-pubertal, following Tanner, 1989). Because breathing while swimming disturbs propulsive continuity, causing catch-up coordination (Chollet, 2000; Seifert et al, 2005), only non-inspiratory cycles were considered to better determine IdC values. General stroke parameters (velocity, SL and SR) were also assessed. Using a larger sample (sixty young swimmers: thirty males and thirty females), in **Appendix II**, it is presented a similar analysis, focused in a comparison between young and adult swimmers, based on a study conducted by Chollet et al. (2000), describing a detailed explanation of IdC.

To better characterize the biomechanical profile and temporal information about the management of propulsive actions of front crawl in age group swimmers, it was gathered a higher sample of young swimmers (n = 114), and added complementarily parameters in a full papper (**Chapter 2**). In this study, an analysis of motor behaviour at the 50-m front crawl race pace for these specific ages was conducted. As age-group studies are scarce, and, to our knowledge, no work has been done on arm coordination in this population, this approach is perfectly justified. With this sample it was used the same protocol described in Appendix above and stroke parameters, particularly velocity, SL and SR, were also calculated. Furthermore, SI (which relates the product of velocity and SL), and the ratio between SL and arm span, were also assessed.

Complementarily, it was made a study of the arm symmetry between left and right arm during front crawl swimming, in young swimmers (**Appendix III**), once this is an additional parameter that helps to better characterize the arm coordination in swimmers of these ages. To accomplish this aim, the IdC was calculated for both arms, and with these two IdC values (IdC_{left} and IdC_{rigth}), it was possible to determine the arm coordination symmetry. Thus, the arm symmetry was assed for both genders and from both maturity stages (pubertal and post-pubertal).

Due to the scarce number of studies that aims to assess IdC in backstroke, in **Chapter 3** it is presented a biomechanical profile and temporal information about the management of propulsive actions of backstroke technique, using a same sample of 114 young swimmers. Indeed, there are much less studies done in backstroke (the first study was made by Lerda and Cardelli, 2003) than in front crawl technique, and, to our knowledge, no work has been done on arm coordination assessment in age-group swimmers. An analysis of stroke parameters (velocity, SL, SR, SI) and the ratio between SL and arm span were also assessed at velocity corresponding to the 50m race pace.

In **Chapter 4** it is discussed the obtained biomechanical parameters with those reported in the literature, and given notions of motor behaviour and temporal information about age-group swimmers performing front crawl and backstroke at high intensity. In this sense, in this chapter, were made the general discussion about all the analysis done with this sample. Following the previous chapters, the main corresponding conclusions are presented on **Chapter 5**.

Front crawl technical characterization of 11-13 years old swimmers

Ana Silva[1], Pedro Figueiredo[1,3], Susana Soares[1], Ludovic Seifert[2], João Paulo Vilas-Boas[1,3], Ricardo J. Fernandes[1,3]

[1] University of Porto, Faculty of Sport, CIFI2D, Portugal

[2] University of Rouen, Faculty of Sport Sciences, France

[3] Porto Biomecanics Laboratory, University of Porto

Abstract

Our aim was to characterize the front crawl in young swimmers performing at very high intensity. 114 swimmers performed 25-m front crawl swimming at 50-m pace. Two underwater cameras was used to assess general biomechanical parameters (velocity, stroke rate, stroke length and stroke index) and inter-arm coordination (Index of Coordination), being also identified each stroke phase. Comparing to adults, young swimmers presented lower values in all biomechanical parameters, having the post-pubertal group closest values to adult swimmers due to their superior anthropometric and maturational characteristics. Boys showed higher velocity and stroke index as reported for elite, but higher stroke rate in opposition to adults. In addition, when considering the total sample, a higher relationship was observed between velocity and stroke length (than with stroke rate), indicating that improving stroke length is fundamental. Furthermore, only catch-up was adopted, and the catch presented the highest duration and the pull phase the smallest.

Keywords: Swimming, front crawl, age group, kinematics

Introdution

Technique is a major swimming performance influencing factor and a central concern of the training process in this sport (Millet et al, 2002). In fact, the success of competitive swimmers is mainly due to the ability to combine high propelling efficiency and minimal hydrodynamic resistance, which is achieved through technique improvement (Toussaint et al., 1992). The front crawl, an alternated swimming technique, is the fastest form of human aquatic locomotion, and is often used in training and competition. Knowing that the arms actions provide most of the total propulsion in front crawl (Beckett, 1985; Deschodt et al., 1999), the inter-arm coordination is decisive for the effective application of the propulsive forces. In fact, in front crawl, when one arm is propelling, the other is recovering (Nikodelis et al., 2005; Potdevin et al., 2004).

To characterize the front crawl technique, indicators of motor process, such as stroke rate (SR) and stroke length (SL), are widely used once their interaction determines swimming velocity (Barbosa et al., 2010; Potdevin et al., 2004; Seifert et al., 2006; Vorontsov et al., 2002). Furthermore, the Stroke Index (SI) is also frequently assessed once it reflects swimming efficiency (by relating the product of velocity and SL) (Costill et al., 1985). Studying young swimmers, Jürimãe et al. (2007) considered the SI a major indicator of swimming performance.

Eleven years ago, a new tool for technical evaluation of swimmers was proposed by Chollet et al. (2000) – the index of coordination (IdC). This index is based on the measurement of the lag time between the propulsive phases of the two arms, and was considered as an interesting tool to assess motor control and motor learning, even though the links between coordination, and propulsion and efficiency are not automatic. Indeed, as Potdevin et al. (2004) suggested, the arm coordination in front crawl swimming is one of the most important factors contributing to the generation of propulsive forces.

Several studies regarding the IdC assessment have been carried out in adult elite swimmers, analyzing front crawl performed from low to heavy swimming intensities (Chollet et al., 2000; Millet et al., 2006; Seifert et al., 2003a; Seifert et al., 2003b). In fact, the use of IdC for evaluating front crawl has been a topic of growing interest and is justified by the fact that the general coordination of front crawl depends mainly on the synchronization of the arms, as mentioned before (Potdevin et al., 2004). In this sense, it is possible to observe three different synchronization modes in front crawl (Chollet et al., 2000): (i) opposition (IdC = 0%), i.e., when one arm begins the propulsive phase and the other is finishing it, providing continuous motor action; (ii) catch-up (IdC < 0%), existing a lag time between propulsive phases of the two arms and (iii) superposition (IdC > 0%), which describes an overlap in the propulsive phases of both arms. Complementarily, the arm coordination is affected by several constraints (Newell, 1986; Seifert et al., 2008), particularly the swimmer's anthropometric characteristics, the environmental (e.g. water properties, temperature or length of the pool) and the task (i.e., the goal of the activity) constraints.

As children are involved in swimming training since early ages, their technical characterization is also required in order to assure a proper evolution in their sportive career. Moreover, they have specific characteristics, as well as their lower height, weight, endurance and strength, comparing to adults (Vorontsov et al., 2002). In this sense, according to Vorontsov (2010), training for younger age group swimmers should target the learning of motor skills, development of core, body strength and flexibility. However, studies in young competitive swimmers are scarce when compared to adults. In fact, the study of the general biomechanical parameters and the inter-arm coordination in children swimmers was not conducted yet. The aim of this study was to characterize the front crawl technique in 11-13 years old swimmers. For this purpose, it were assessed the general biomechanical parameters (velocity, SR, SL and SI), and the inter-arm coordination (using the IdC), when performing at very high intensity. It was hypothesized that children present lower velocity, SR, SL and SI than older swimmers; complementarily, since stroking characteristics of expert and less-skilled swimmers seems to be different when performing at very high swimming intensities (Chollet et al., 2000; Potdevin et al., 2004; Schnitzler et al., 2007; Seifert et al., 2007), it is hypothesized that children adopt a coordination mode similar to non-expert swimmers. Finally, as in competitive age-group swimming children are divided by gender and age categories, the assessed variables were studied according to swimmers' gender and maturation. This grouping is justified by the existing gap between boys and girls, as chronological age is one of the main predictors of performance (Saavedra et al., 2010), but also because children of the same chronological age can differ by several years in their biological maturation (Malina et al., 2004).

Methods

One hundred and fourteen age-group swimmers from the infant competitive swimming age group category (girls of 11-12 and boys of 12-13 years of age), were participating in a training campus, volunteered for this study. The mean ± SD values regarding their anthropometric, sexual maturation status and training frequency characteristics are described in Table 1. It is possible to observe that boys are older, heavier and taller, and have higher arm span than girls; however, both gender groups present an equal training frequency. Swimmers and respective coaches were informed about the details of the experimental protocol before beginning the measurement procedures. The experimental protocol was implemented in the preparatory period of the first macrocycle of the training season. The local Ethics Committee approved the experimental procedures, and the swimmer's parents signed a consent form in which the protocol was described.

Table 1. Mean ± SD values of the swimmers' anthropometric, sexual maturation status and training frequency characteristics.

	Boys (n = 56)	Girls (n = 58)
Age (years) *	12.7 ± 0.8	11.4 ± 0.5
Weight (kg) *	50.0 ± 7.8	44.4 ± 7.4
Height (cm) *	157.7 ± 8.4	152.3 ± 6.9
Arm Span (cm) *	160.6 ± 9.2	153.0 ± 8.1
Breast development (stage)	-	3.19 ± 0.80
Genital development (stage)	2.95 ± 0.88	-
Pubic hair (stage)	3.25 ± 1.12	3.59 ± 0.84
Training Frequency (training units/week)	5.5 ± 0.5	5.5 ± 0.5

* Statistically significant differences ($P \leq 0.05$).

Complementarily, it was made an evaluation of swimmer's maturation according to Tanner et al. (1982). Briefly, images relating to the development of secondary sex characteristics – genital (boys), breast (girls) and pubic hair (boys and girls) – were presented to the swimmers, and a self-evaluation rating (based in five stages) was carried on. Afterwards, the same images were presented to swimmers' parents and coaches separately. The final result was expressed as the mean value of these three evaluations as proposed before (e.g. Baxter-Jones et al., 2005).

For the technical evaluation, swimmers performed 25-m front crawl at 50-m race pace beginning with an in-water start. Each subject swam alone, without the pressure of opponents, in order to reduce the drafting or pacing effects (Barbosa et al., 2010). Two underwater video cameras (Sony® DCR-HC42E) placed in the sagital and in the frontal planes inside a sealed housing (SPK - HCB) recorded two complete underwater arm stroke cycles. To transform the virtual in real coordinates it was used a bi-dimensional structure (6.30-m^2, and thirteen calibration points). Biomechanical analysis was performed with the software APASystem (Ariel Dynamics, Inc., USA), being digitized frame by frame (at 50 Hz) two consecutive non-inspiratory cycles, particularly the hip (femoral condyle), and, on both sides of the body, the distal end of the middle finger, the wrist, the elbow and the shoulder. The digitise-redigitise reliability was very high (ICC = 0.996).

Following Chollet et al. (2000), the IdC corresponds to the time from the beginning of the propulsive phase of the left and right arm, corresponding to the time between the beginning of propulsion of the first right arm stroke and the end of propulsion of the first left arm stroke, and between the beginning of propulsion of the second left arm stroke and the end of propulsion of the first right arm stroke. IdC was calculated based on the division of the arms actions in four phases: (i) entry/catch, corresponding to the time since the entry of the hand in the water until it starts to make the backward movement; (ii) pull, since the end of the previous action until achieve the vertical alignment of the shoulder (first propulsive phase); (iii) push, since the end of the previous action to the exit the hand of the water (second propulsive phase) and (iv) recovery, covering the time from the exit of the hand until its new entry. The IdC and each stroke phase were expressed as the percentage of the duration of a complete arm stroke (Chollet et al., 2000). The sum of the pull and the push phases, and of the catch and the recovery phases, indicate the duration of the propulsive and non-propulsive phases, respectively. The duration of a complete arm stroke was the sum of the propulsive and non-propulsive phases.

The swimming velocity was assessed through the ratio of the displacement of the hip in a stroke cycle to its total duration. SL was determined by the horizontal distance traveled by the hip during a stroke cycle, and SR as the number of stroke cycles performed per min. The SI was achieved by the product of v and SL. It was also computed the ratio SL to arm span.

Data was tested for normality of distribution using the Skewness test. The statistical analysis performed was based on exploratory data analysis. Mean and SD were calculated for all measured parameters. To compare genders and maturation, it was applied the analysis of independent measures ANOVA. The statistical significance was set at $P \leq 0.05$ (SPSS Statistics version 18.0). This statistical analysis was applied for all subjects (independently of their maturation and gender), according to the maturation group (independently of their gender), and by gender (independently of maturation group). Finally, it was analyzed the relation between all parameters analyzed by determining the momentum Pearson correlation coefficient.

Results

Mean ± SD values regarding the general biomechanical parameters, as well as the IdC, are presented in Table 2 for both genders and maturation groups. The relative arm phases durations, and the sum of the propulsive and non-propulsive phases are also displayed.

Table 2. Mean ± SD values of the parameters related to velocity, stroke rate, stroke length, arms synchronization, entry and catch, pull, push and recovery phases, propulsive phases and non-propulsive phases, according to genders and maturation.

	Boys (n = 56)		Girls (n = 58)	
Parameters	Pubertal (n = 36)	Post-Pubertal (n = 20)	Pubertal (n = 24)	Post-Pubertal (n = 34)
Velocity ($m.s^{-1}$) [a, b]	1.46 ± 0.12	1.55 ± 0.12	1.37 ± 0.18	1.41 ± 0.13
Stroke Rate ($cycles.min^{-1}$) [a]	52.17 ± 6.76	51.88 ± 5.18	50.01 ± 5.63	48.16 ± 5.04
Stroke Length ($m.cycle^{-1}$) [b]	1.69 ± 0.23	1.81 ± 0.24	1.66 ± 0.28	1.75 ± 0.20
Stroke Length/ Arm Span	1.07 ± 0.13	1.09 ± 0.14	1.13 ± 0.2	1.13 ± 0.11
Stroke Index ($m^2.s^{-1}.cycle^{-1}$) [a, b]	2.48 ± 0.46	2.82 ± 0.52	2.32 ± 0.69	2.44 ± 0.42
Index of Coordination (%)	-6.79 ± 4.17	-7.00 ± 4.53	-6.34 ± 4.82	-7.19 ± 4.77
Entry/catch (%)	32.18 ± 4.66	32.54 ± 5.01	32.95 ± 4.39	33.47 ± 6.19
Pull (%) [c]	18.00 ± 2.43	16.50 ± 2.75	18.51 ± 3.17	19.06 ± 3.49
Push (%)	25.00 ± 3.18	25.78 ± 4.18	24.83 ± 3.13	24.77 ± 3.21
Recovery (%) [a]	24.83 ± 2.59	25.22 ± 3.67	23.42 ± 3.67	22.71 ± 3.67
Propulsive Phases (%)	43.00 ± 3.91	42.27 ± 5.13	43.16 ± 4.49	43.83 ± 5.07
Non-Propulsive Phases (%)	57.02 ± 3.91	57.75 ± 5.12	56.37 ± 4.69	56.18 ± 5.07

Legend: a (boys > girls), b (post-pubertal > pubertal), c (girls >boys) ($P \leq 0.05$)

When observing each parameter independently of swimmers maturation and gender, no significant differences were noticed. However, when comparing maturation states (independently of gender), post-pubertal group showed higher velocity, SL and SI than pubertal group; in addition, when comparing gender groups (independently of maturation state), boys exhibited greater velocity, SR and SI values, longer recovery phase, and shorter pull phase than girls. No significant differences were noticed between genders or maturation status regarding SL/arm span ratio, as well as in IdC, entry and catch, and push phases, and in propulsive and non-propulsive phases.

In addition, for all groups, the IdC values indicated an inter-arm coordination in catch-up mode. In fact, the sum of non-propulsive phases (entry/catch and recovery) was higher than the sum of propulsive phases (pull and push); the entry/catch phase had the higher percentage compared with the other three front crawl stroke phases (pull, push and recovery), and the pull phase had the lowest percentage.

Complementarily, some significant correlations have to be highlighted. Velocity had a rather low positive correlation with SR ($r = 0.22$, $p < 0.05$), and a moderate positive correlation with SL ($r = 0.53$, $p < 0.01$); as expected, a negative correlation between SR and SL was noticed ($r = -0.67$, $p < 0.01$). In addition, a high positive correlation was observed between velocity and SI ($r = 0.83$, $p < 0.01$), and between SI and SL ($r = 0.90$, $p < 0.01$). The IdC correlated directly with SR ($r = 0.38$, $p < 0.01$), and inversely with SL ($r = -0.41$, $p < 0.01$).

Discussion

The major finding of this study is that young swimmers used the catch-up arm coordination mode when performing front crawl at the 50-m pace, showing an evident lag time between propulsive arm phases. These results are not in accordance with the literature concerning adult elite swimmers since, at very high swimming intensities, the opposition and superposition arm coordination modes are usually adopted (Chollet et al., 2000; Millet et al., 2002; Potdevin et al., 2004; Seifret et al., 2003b); this topic will be deeply discussed afterwards.

Firstly, it was observed no statistical differences in the studied biomechanical and coordinative parameters independently of swimmers maturation and gender. This fact could be explained by the maturational perspective on motor development (Newell, 2986), once, nevertheless the organismic constraints (e.g. anthropometrical characteristics and maturation state) might imply some differences between swimmers, the task that they were involved was similar. In fact, despite of the observed age differences, these swimmers belong to the same competitive age-group, as well as to swimming clubs with the same planning and periodization strategies.

When comparing maturation groups (despite gender), velocity was higher in post-pubertal group (reaching values closer to adult swimmers: 1.81 ± 0.1 m.s^{1}, e.g. Beunen et al., 2008). Likewise, SL values were greater in post-pubertal comparing to pubertal swimmers, suggesting that older swimmers achieved high velocities through a more efficient technique or that they can produce more strength. In fact, the post-pubertal SL values are closer to those presented by elite swimmers performing at the same relative intensity (2.01 ± 0.1 m.cycles^{-1} (Beunen et al., 2008) and 2.23 ± 0.16 m.cycles^{-1} (Seifert et al., 2003b) than the values presented by their younger counterparts. Arellano et al. (1991) showed that an improved swimming technique results in a longer SL and, as an indicator of swimming efficiency, it is more related to performance than SR (Millet et al., 2002; Pelayo et al., 1996; Saavedra et al., 2010; Schnitzler et al., 2008; Seifert et al., 2006). When comparing our data with studies conducted with swimmers of similar age and anthropometric characteristics performing at high intensity, it was found similar SL values (1.64 ± 0.20 m) to our pubertal group (Zamparo et al., 2006). Vitor and Böhme (2010) also studied male young swimmers (although almost all of them classified as stage four of pilosity), observing SL values closest to our post-pubertal group: 1.85 ± 0.17 m. These authors observed a positive correlation between velocity and SL ($r = 0.53$, $p < 0.05$), referring the inexistence of relationship between velocity and SR, corroborating our data. In the present study, when SL was normalized to the arm span, no significant differences were observed between maturation groups, suggesting that the inter-maturational group difference in this variable was not only dependent on technical development but mainly on body growth.

Complementarily, SI was higher in post-pubertal group, which is explained by its dependence of velocity and SL; in fact, very high positive correlation values were observed between these variables as they are co-variants. The SI results of the pubertal swimmers were also similar to the studies previously mentioned: 2.42 ± 0.44 and 2.31 ± 0.34, for (Beckett, 1985) and (Vitor et al., 2010), respectively. This difference between groups suggests a better swimming technique of the post-pubertal group. In fact, it is known that more talented young swimmers are maturationally advanced compared to their swimming peers (Malina et al., 2004), and that there is a tendency for SL, SI and performance improvement with maturation in both genders (Lätt et al., 2009; Saavedra et al., 2010). Vorontsov et al. (2010) confirmed the impact of maturation upon physical development and strength both in girls and boys, and observed that more mature girls and boys have better physical development and higher levels of general and specific strength than their less mature counterparts.

When comparing genders (despite maturation groups), it was observed that boys had significantly greater velocity values than girls, which is in accordance with elite adult swimmers related studies (Chollet et al., 2000; Greco et al., 2007; Pelayo et al., 1996; Schnitzler et al., 2007; Seifert et al., 2003a; Seifert et al., 2007); this result can be explained by the different gender anthropometric characteristics, particularly by the observed higher males' height and arm span, corroborating the literature for older swimmers (Schnitzler et al., 2007; Seifert et al., 2003a; Seifert et al., 2007; Seifert et al., 2006); inclusively, arm span was previously identified as a good predictor of performance in young (10) and adult swimmers (Seifert et al., 2007). Hence, although girls are slightly younger, boys in every age are least 1.5 to 2 years less mature than girls of the same age, and keep a high rate of natural increase of muscle mass several years after they reach full maturity. Differences in SR and SI were also observed, presenting boys greater values than girls. However, regarding to elite swimmers, and whatever the competition distance, men and women had a similar SR (Pelayo et al., 1996; Schnitzler et al., 2007; Seifert et al., 2003a; Seifert et al., 2007; Seifert et al., 2006). Meanwhile, the observed gender differences in SI could be explained by its high dependence of velocity. Vitor and Böhme (2010) also observed a high positive correlation ($r = 0.79$, $p < 0.01$) between these variables, as they are co-variants. Conversely, no differences between genders were observed for SL. This is not in accordance to the studies conducted with adult swimmers (Saavedra et al., 2010; Schnitzler et al., 2007; Seifert et al., 2003a), suggesting that the differentiation between genders regarding SL only occurs when maturation is completed. Indeed, Zamparo (2006) noticed that the arm length increase as a function of age during childhood and, before puberty, is essentially the same for boys and girls.

As referred in the beginning of this section, our age-group swimmers, independently of gender and maturation, adopted the catch-up coordination mode to perform the 25-m front crawl at high intensity. It is well accepted (Vorontsov, 2010; Vorontsov et al., 2002) that the ability to produce strength reaches its peak of development at the end of puberty, evidencing that the current swimmers are do not have similar strength values than adults. This fact, along with a poorer technique, could lead the young swimmers to slip through the water during propulsion – shortening the propulsive phases – instead of using a long hand path and high propulsive surfaces. Zamparo (2006) observed differences among swimmers of different ages regarding the elbow angle, evidencing that children and adult recreational swimmers tended to maintain the arm in a straighter position rather than competitive swimmers who bended the elbow to a larger extent; any clear-cut difference between genders were not observed though.

The type of coordination mode adopted by young swimmers does not corroborate the literature conducted in elite male (Millet et al., 2002; Potdevin et al., 2004; Schnitzler et al., 2007; Seifert et al., 2006) and elite male and female swimmers (Beunen et al., 2008; Chollet et al., 2000; Seifert et al., 2003b) performing at very high velocities; in fact, those studies refer that at 50- and 100-m paces, swimmers usually adopt at an opposition or superposition inter-arm coordination, expressing IdC values closer (or even higher) to zero. This later coordination mode, which is considered the most efficient (Chollet et al., 2000; Seifert, 2010; Seifert et al., 2003b), and is associated with high intensity efforts and skill levels (Beunen et al., 2008; Chollet et al., 2000; Potdevin et al., 2004; Schnitzler et al., 2007; Seifert et al., 2003b; Seifert et al., 2007), seems to reflect the ability to accelerate and maintain a long hand trajectory at high SR (Seifert et al., 2003a). In fact, Seifert (2010) showed that high IdC values do not guarantee *per si* high velocities, which is corroborated by the absence of relationship between IdC and velocity in the present study. Indeed, Potdevin et al. (2004), evidenced that the superposition coordination mode is only achieved when performing at SR higher than 55 cycles/min^{-1}, being SR considered the best predictor of IdC (Seifert et al., 2006); in the present study it was also observed a moderate direct relationship between IdC and SR ($r = 0.38$, $p < 0.01$).

In addition, it seems important to refer that the present age-group swimmers spent more time in entry/catch phase than that reported for adults: ~20% (Chollet et al., 2000; Millet et al., 2002; Schnitzler et al., 2007; Seifert et al., 2003a; Seifert et al., 2003b). Our particular sense indicates that, in the base training period, swimmers tend to spend longer time during catch phase (as they are not confortable to put head in water), implying a more downward than backward movement, causing an evident time gap between propulsion phases of the arms. The maturational status of young swimmers could explain their lack of backward strength, leading to a more discontinuous arm synchronization.

When comparing genders, the highest IdC value was observed in the literature was found for elite women (29%, (Schnitzler et al., 2007)), being justified by their worst anthropometric characteristics (particularly the lower height and arm span) that could explain the higher duration of the entry/catch phase (Schnitzler et al., 2007; Seifert et al., 2003a). However, the girls evaluated in this study did not showed higher values of entry/catch phase comparing to boys. Complementarily, our young swimmers present a relative duration of the push phase comprehended in the interval values of experts swimmers (20 to 24%, (Seifert et al., 2003a)). Moreover, it was observed a higher relative duration of the recovery phase in boys, and of the pull phase in girls; however, these results had no influence in the sum of propulsive and non-propulsive phases, and consequently in IdC values. It is well accepted that from childhood until adolescence strength values do not differ between genders, but that after puberty gender differences are evident as strength is closely related to body size and muscle mass (Beunen et al., 2008); thus, there exists a clear advantage in boys, as it occurs in elite men swimmers, allowing them to have a greater propulsive power (Pelayo et al., 1996, Schnitzler et al., 2007; Seifert et al., 2003a). Indeed, this could lead boys to apply two peak forces during the arm path, instead of one as it happens in elite women, explaining why boys presented a shorter pull phase comparatively to girls (Seifert et al., 2003a). These authors observed that, in a sprint race, only one peak force was observed in females (resulting from the local fatigue), which lead them to applied shorter propulsive actions.

The above mentioned results imply that the tested age-group swimmers spent lower relative duration in the overall propulsive phases (~43%, pull plus push phases), rather than elite swimmers (>50%, at very high intensity, cf. Chollet et al., 2000; Millet et al., 2002; Schnitzler et al., 2007; Seifert et al., 2003a; Seifert et al., 2003b). Conversely, our swimmers presented values of non-propulsive phases of ~57% (entry/catch plus recovery phases) which is the highest value reported in the literature.

Conclusion

The main highlight of this study was that young swimmers adopted a catch-up inter-arm coordination mode when swimming front crawl at very high intensity, which does not corroborate our hypothesis and the common knowledge regarding elite swimmers data. The observed lower relative duration of the propulsive phases was due to the higher time spent during the entry/catch phase rather than in the pull phase. Complementarily, our age-group swimmers presented lower values of velocity, SR, SL and SI comparing to adults, but the post-pubertal group presented closest values to elite swimmers due to their superior anthropometric and maturational characteristics. In addition, it was observed higher velocity, SR and SI values in boys than in girls, as reported in their elite counterparts; nevertheless, no differences between genders were noticed for SL. However, when considering the total sample, a higher relationship was observed between velocity and SL, than between velocity and SR, indicating that to improve swimming velocity young swimmers should increase SL (more than SR). The general biomechanical parameters and the inter-arm coordination are easy to assess variables, particularly if it is used a qualitative approach to assess IdC. These parameters have an ecological meaning to design, control and evaluate the training process. Thus, new studies in young swimmers are welcome, mainly in the other conventional techniques (backstroke, butterfly and breaststroke) and in other swimming intensities.

Acknowledgment

This study was supported by grant: PTDC/DES/101224/2008

Chapter 3

Backstroke technical characterization of 11-13 years old swimmers

Ana Silva[1], Pedro Figueiredo[1,2], Susana Soares[1], João Paulo Vilas-Boas[1,2], Ricardo J. Fernandes[1,2]

1 University of Porto, Faculty of Sport, CIFI2D, Portugal

2 Porto Biomecanics Laboratory, University of Porto

Abstract

The purpose of this study was to characterize the backstroke technique in 11-13 years old swimmers, at very high intensity. 114 swimmers performed 25-m backstroke swimming at 50-m pace. The general biomechanical parameters (velocity, stroke rate, stroke length and stroke index) were assessed, as well as the two Index of Coordination, being identified each stroke phase. Index of Coordination 1 characterizes the continuity between propulsive phases of each arm and Index of Coordination 2, the simultaneity between the beginning of the pull of one arm and of the recovery of the other arm. Comparing to pubertal swimmers, post-pubertal achieved values of velocity and stroke length closer to those showed by adults. Comparing genders, only in velocity values were registered differences, where boys are faster than girls. Moreover, a similar Index of Coordination 1 and Index of Coordination 2 were registered comparing young swimmers to adults. In opposition to what was expected, no hand lag time was noticed in young swimmers.

Keywords: Swimming, backstroke, age group, kinematics.

Introdution

Swimming velocity results from the interaction between propulsive and resistive forces. In fact, to achieve better results, swimmers need to increase propulsion and decrease hydrodynamic drag by perfecting their technique. Many studies demonstrated the importance of technical ability in stroke organization, which has traditionally been evaluated through changes in velocity, stroke rate (SR) and stroke length (SL) (Girold, Chatard, Cossor, & Mason, 2001; Pelayo, Sidney, Kherif, Chollet, & Tourny, 1996; Seifert, Toussaint, Alberty, Schnitzler, & Chollet, 2010). Further, Maglischo (2003) noticed that the ideal coordination in high-level front crawl and backstroke swimmers should conform to the opposite coordination model, which provides continuous propulsion, once when one arm begins the pull phase the other is finishing the push phase.

In the last decade special attention has been given to the modifications in the temporal organization of arm stroke phases in front crawl and backstroke swimming techniques. Firstly for front crawl, Chollet, Charlies, & Chatard (2000) proposed the Index of Coordination (IdC) that quantifies the lag time between the propulsive phases of each arm, expressing three different synchronization modes: (i) opposition (IdC = 0), evidencing continuous motor action through a smooth series of propulsive phases without lag time; (ii) catch-up (IdC < 0), existing a lag time between propulsive phases of the two arms; and (iii) superposition (IdC > 0), which describes an overlap of the propulsive phases. Several studies were conducted trying to characterize the IdC in front crawl for different velocities and swimmers of distinct levels and genders (for a detailed review see Seifert, Chollet, & Rouard, 2006).

The IdC was posteriorly adapted for backstroke technique by Lerda and Cardelli, (2003a), quantifying the continuity between the motor phases of each arm. It was observed that it presented negative values (varying from -25% to -5%) whatever the swimming pace and the swimmers level and gender, indicating that backstrokers always assume a catch-up coordination mode (Chollet, Seifert, & Carter, 2008; Lerda and Cardelli, 2003a; Lerda Cradelli, & Coudereau, 2005; Seifert, Chollet, & Rouard, 2006). This fact is a result of anatomical characteristics and can be more pronounced due to the limited shoulder flexibility and an incorrect alternating body-roll movement (Maglischo, 2003; Psycharakis, & Sanders, 2010). As Chollet, Seifert, & Carter (2008) suggested, this limitation could lead to an additional phase, the hand lag time at the thigh, leading to a discontinuity between the propulsive actions of the two arms, and to significant intracycle speed fluctuations. Barbosa et al. (2008) evidenced that higher intracycle speed fluctuations lead to superior energy cost, suggesting that even if catch-up coordination is the only mode possible in backstroke technique, swimmers should minimize the lag time. However, in studies conducted by Lerda & Cadelli (2003a) and Lerda, Cardelli, & Coudereau (2005), this phase was not noticed. In addition, a third propulsive arm phase could be related, the clearing phase (between the push phase and the above-water recovery), which farther impose a particular inter-arm coordination. Schleihauf et al. (1988) reported that this phase could be used by swimmers with particular anatomical characteristics (hyperlaxity of the shoulder) as a second upsweep (Alves, 1996), increasing propulsion and diminishing intracycle speed fluctuation; however, following Maglischo (2003), the “three-peak stroke pattern” is not usual.

Literature about inter-arm coordination assessment in backstroke is scarce, and if age-group swimmers are considered, no study is available. Considering that age-group swimmers have different physical and biological characteristics, which influence swimming performance (Fernandes, Sousa, Pinheiro, Vilar, Colaço, & Vilas-Boas, 2010; Nikodelis, Kollias, & Hatzitaki, 2005) and a naturally reduced history of training, seems very important to analyze their supposed to be a specific stroke-technique parameters and inter-arm coordination. The aim of this study was to characterize the backstroke swimming technique, in 11-13 years old swimmers, when performing at very high intensity. It were analyzed the general biomechanical parameters (velocity, SR, SL and Stroke Index – SI), as well as the inter-arm coordination (through the IdC). It was hypothesized that age-group swimmers show a catch-up inter-arm coordination mode in backstroke, as it was noticed before in elite swimmers, and is questioned if exist a lag time phase in the thigh between the end of the push phase and the beginning of the clearing phase. In addiction, a comparison between maturation status and genders was conducted. It was hypothesized that post-pubertal swimmers showed kinematic and coordinative values closer to adults than pubertal ones.

Methods

One hundred and fourteen age-group swimmers, from the infant competitive swimming age group category (girls of 11-12 and boys of 12-13 years of age), volunteered for this study; their mean physical and functional characteristics are described in Table 1. It is possible to observe that boys are older, taller and heavier, and have higher arm span than girls; however, both gender groups present an equal weekly training frequency. Before beginning the measurement procedures, the protocol was fully explained to the participants and their respective coaches, being approved by the local Ethics Committee. It was implemented in the preparatory period of the first microcycle of the training season.

Table 1. Mean ± SD values of the swimmers'anthropometric, sexual maturation status and training frequency characteristics.

	Girls (n = 58)	Boys (n = 56)
Age (years) *	11.4 ± 0.5	12.7 ± 0.8
Body Mass (N) *	435.4 ± 72.6	490.3 ± 76.5
Height (cm) *	152.3 ± 6.9	157.7 ± 8.4
Arm Span (cm) *	153.0 ± 8.1	160.6 ± 9.2
Breast development (stage)	3.19 ± 0.80	-
Genital development (stage)	-	2.95 ± 0.88
Pubic hair (stage)	3.59 ± 0.84	3.25 ± 1.12
Training Frequency (training units/week)	5.5 ± 0.5	5.5 ± 0.5

* Statistically significant differences between genders ($P \leq 0.05$).

Complementarily, a swimmer's maturation evaluation was made (Tanner, & Whitehouse, 1982) by presenting to the swimmers images related to the development of secondary sexual characteristics – genital (boys), breast (girls) and pubic hair (boys and girls) and a self-evaluation rating (based in five stages) was carried on. The images were also presented to swimmer's parents and coaches. The final result was expressed as the mean value of these three evaluations.

For the kinematical evaluation, all swimmers performed 25-m backstroke at the 50-m race pace. Each subject swam alone, without the pressure of opponents, in order to reduce the drafting or pacing effects (Barbosa et al., 2010) and in-water starts were used. Two underwater video cameras (Sony® DCR-HC42E, 1/250 digital shutter, Nagoya, Japan), placed in the sagital and in the frontal planes inside a sealed housing (SPK – HCB waterproof box, Tokyo, Japan), recorded two complete underwater arm stroke cycles. It was used a bi-dimensional images calibration structure (6.30m^2, and thirteen calibration points) to transform the virtual in real coordinates. Kinematical analysis was performed with the software APASystem (Ariel Dynamics, San Diego, USA), being digitized frame by frame (at 50 Hz). The hip (femoral condyle) and, on both sides of the body, the distal end of the middle finger, the wrist, the elbow, the shoulder and the ankle were digitized; the digitise-redigitise reliability was very high (ICC = 0.982).

The backstroke arm movements was divided into six phases (Chollet, Seifert, & Carter, 2008): (i) entry and catch, from the entry of the hand into the water to the beginning of its backward movement; (ii) pull, starting when the hand begins the backward movement to its arrival in a vertical plane to the shoulder (the first part of propulsive phase); (iii) push, from the position of the hand below the shoulder to the end of the hand's backward movement (the second propulsive phase); (iv) hand lag time, corresponding to the time when hand stops at the thigh after the push phase and before the clearing; (v) clearing, from the hand release upward to the beginning of the exit from the water; and (vi) recovery, from the point of water release to the water re-entry of the arm. Each phase was expressed as a percentage of the duration of a total arm stroke. The duration of the propulsive phases was usually defined as a sum of the pull and push phases, and the duration of the non-propulsive phases the sum of the entry and catch, hand lag time, clearing and recovery phases. However, the clearing phase could be also considered as a propulsive phase (Chollet, Seifert, &

Carter, 2008; Alves, 1996; Schleihauf et al. 1988; Maglischo, 2003) if the swimmer sweeps his hand up, back, and in to his thigh, pushing water back with the palm of his hand and the underside of his forearm. In this sense, the IdC was assessed by determining IdC1 and IdC2, being quantified the lag time between the propulsive movements of the left arm and the right arm (Lerda and Cardelli, 2003a): to assess IdC1, the time recorded at the beginning of the pull of one arm was subtracted from the end of the push of the other arm, and to obtain IdC2, the time recorded at the beginning of the pull of one arm was subtracted from the end of the clearing of the other arm. These lag times were expressed as percentages of the mean duration of a stroke cycle, corresponding to the average between the lag time of left arm and right arm. The IdC1 measured the continuity in propulsive action coordination of the two arms, and the IdC2 measured the degree of simultaneity between the beginning of the pull of one arm and the recovery of the other arm (nearer to zero values corresponded to a greater simultaneity). The velocity values were achieved through the ratio between the displacement of the hip in an arm cycle and its total duration. SL and SR were determined by the horizontal distance traveled by the hip during a cycle of arms, and as is the number of arms cycles performed per min and SI was achieved through the product of velocity and SL (Costill et al., 1985).

An exploratory data analysis was conducted, being the distributions normality tested using the Kolmogorov-Smirnov ($n>50$) and the Shapiro Wilk ($n<50$) tests. Mean and SD were calculated for all measured parameters. To compare genders and maturation, it was applied the ANOVA independent measurments. The statistical significance was set at $P \leq 0.05$ (SPSS Inc., Chicago, USA, version 18.0). This statistical analysis was applied for all subjects (independently of their maturation and gender), according to the maturation group (independently of their gender), and by gender (independently of maturation group). When interaction was found, a t-test for independent variables was applied to compare results by gender and maturation. When interaction was not present, comparisons were performed between genders, without considering the effect of maturation, and by maturation, without considering the effect of gender. The comparisons were made using a Bonferroni adjustment. Finally, it was calculated correlation between all parameters analyzed by determining a Pearson correlation coefficient.

Results

Mean ± SD values regarding the general biomechanical parameters (velocity, SR, SL and SI), the two Indexes of Coordination (IdC1 and IdC2), as well as the relative arm phases durations and the sum of propulsive and non-propulsive phases, are presented in Table 2. The values are displayed for boys and girls regarding their maturational group.

Table 2. Mean ± SD values of velocity, Stroke Rate, Stroke Length, Stroke Length/ Armspan, Index of Coordination 1, Index of Coordination 2, Entry and catch, Pull, Push, Hand Lag Time, Clear, Recovery, Propulsive Phases and Non Propulsive Phases for the entire sample, according to genders and maturation.

	Girls (n = 58)		Boys (n = 56)	
Parameters	Pubertal (n = 36)	Post-Pubertal (n = 20)	Pubertal (n = 24)	Post-Pubertal (n = 34)
Velocity ($m.s^{-1}$) [a, b]	1.06 ± 0.14	1.13 ± 0.14	1.18 ± 0.14	1.24 ± 0.12
Stroke Rate (cycle/min^{-1})[a]	39.50 ± 5.88	38.43 ± 5.92	42.65 ± 5.46	43.35 ± 5.80
Stroke Length ($m.cycle^{-1}$)[b]	1.64 ± 0.26	1.79 ± 0.22	1.68 ± 0.25	1.75 ± 0.27
Stroke Length/ Arm Span [c]	1.10 ± 0.16	1.15 ± 0.13	1.07 ± 0.15	1.05 ± 0.16
Stroke Index ($m^2.s^{-1}.cycle^{-1}$) [a, b]	1.76 ± 0.43	2.03 ± 0.37	2.01 ± 0.45	2.20 ± 0.46
Index of Coordination 1 (%)	-9.89 ± 3.16	-9.77 ± 2.93	-10.16 ± 3.60	-10.39 ± 2.44
Index of Coordination 2 (%)	1.86 ± 4.39	1.72 ± 2.62	2.25 ± 2.25	1.95 ± 2.95
Entry and catch (%)	14.68 ± 4.42	17.04 ± 4.63	17.39 ± 7.21	15.87 ± 4.55
Pull (%)	14.35 ± 2.22	13.37 ± 2.39	12.76 ± 7.34	14.82 ± 3.47
Push (%)	21.06 ± 4.95	21.79 ± 4.00	22.43 ± 4.08	20.52 ± 3.51
Hand Lag Time (%)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Clearing (%)	18.69 ± 3.76	17.53 ± 3.59	17.91 ± 3.24	18.35 ± 2.87
Recovery (%)	31.23 ± 4.45	31.35 ± 6.97	29.52 ± 4.13	30.44 ± 2.87
Propulsive Phase (%)	36.70 ± 7.89	35.16 ± 4.12	36.33 ± 4.20	35.34 ± 4.33
Non Propulsive Phase (%)	62.01 ± 10.71	64.84 ± 4.12	63.67 ± 4.20	64.66 ± 4.33

Legend: a (boys > girls), b (post-pubertal > pubertal), c (girls >boys) (P ≤ 0.05)

When comparing maturation states (independently of gender), it was possible to observe that post-pubertal group showed higher values of velocity, SL and, consequently, SI values. Complementarily, boys presented higher velocity, SR and SI values, in opposition to the SL values, which was higher in girls.

Regarding to IdC and stroke phases values, there were no significant differences between maturation and gender groups to be noticed. The IdC1 was negative, which means that age-group swimmers adopt a catch-up coordination when performing backstroke at high intensity, in both maturity states and genders, being observed a discontinuity of propulsive phases between arms. The IdC2, which was positive, showed simultaneity of the beginning of pull phase in one arm and the recovery in the other arm, being observed a trend to boys to achieve higher values than girls. Complementarily, there was supremacy of non-propulsive phases (reaching values of ~64%) comparing to the propulsive phases, justifying the type of coordination adopted by young swimmers; the longest phase was the recovery (a non propulsive phase) and the smaller was the pull phase (a propulsive phase). No hand lag time was noticed in any swimmer.

In addition, direct moderate to high relationships were observed between velocity and SR ($r = 0.45$), SL ($r = 0.38$) and SI ($r = 0.82$) (all for $p < 0.01$), suggesting that young swimmers obtained high velocity, through SR increasing and others through SL rising.

Discussion

An important finding of the present study is that, in opposition to which was noticed before for elite backstrokers (Chollet, Seifert, & Carter, 2008), age-group swimmers performing backstroke at high intensity, did not present a hand lag time after the clearing phase and before the recovery. Similar values to those obtained by the above referenced authors (1.8 ± 0.4), or even higher, were expected, once our sample was composed by young swimmers. In fact, no hand lag time was noticed, suggesting that this technical error might have been a constant concern of these age-group swimmers'coaches. Relatively to inter-arm coordination (IdC1), it was observed that as adults, these age-group swimmers adopted a catch-up coordination mode for swimming backstroke.

The inexistence of statistical differences for all subjects, independently of their maturation and gender, could be explained through the maturational perspective on motor development of Newell (1986). This author proposed three categories of constraints that interact to determine the optimal pattern of coordination and control for any activity: organismic, environmental and task constraints. Thus, although organismic constraints could exhibit some differences (e.g. anthropometrical characteristics and maturity state), the task for these swimmers were similar, i.e., inspite of their significantly age differences, all these swimmers belong to the same competitive level, and their training frequency is equal or similar in both maturational groups. In this sense, it is not possible to compare the values independently of gender and maturity; so the analysis should be between gender and between maturity states.

The analysis of maturity groups showed that post-pubertal swimmers had higher values of velocity, SL and SI. In fact, although they showed lower velocity and SL values than those reported by elite adults (Chollet, Seifert, & Carter, 2008; Lerda & Cardelli, 2003a), post-pubertal group reach closer values to elite than pubertal swimmers, as it was hypothesized above. Therefore, as SI depends on velocity and SL values, the post-pubertal group presented higher SI values. These could be explained by the anthropometric and strength differences, but most probably by a better technique, once these parameters are correlated to higher performances. Andrews, Bakewell, & Scurr (2011) noticed that elite swimmers showed a greater entry angle'shoulder than non-elite swimmers and closer to the suggested optimum (180º). This capacity (higher SI values), which is considered an indicator of swimming economy, since it describes the swimmer's ability to move at a given velocity with the fewest number of strokes (Costill et al., 1985), may also traduce a decrease in hydrodynamic drag. Indeed, reduction in the shoulder angle entry – which was considered a major fault in backstroke swimming – leads to increases in form and wave drag, reducing performance (Maglischo, 2003). Moreover, these observed differences in SL do not seem to be related with growth because the ratio between SL and arm span was not statistically significant between this two maturity stages. Thus, these higher SL values showed by post-pubertal swimmers suggest higher swimming efficiency (Lerda et al., 2005). Furthermore, Chollet, Pelayo, Tournay, & Sidney (1996) showed that the higher velocity of male swimmers in 100-200m events is due to a greater distance per stroke. Futhermore, and according to Malina (1984), in both genders, the more talented young swimmers are maturationally advanced compared to their swimming peers. Regarding SR values, it was observed that boys achieved closer values to elite men at the same distance – 44.3 ± 5.1 (Chollet, Seifert, & Carter, 2008). However, in the study of Lerda, Cardelli, & Coudereau (2005) centered on elite swimmers performing 100-m backstroke, there was no significant differences between genders in this parameter.

Regarding gender, differences in velocity, SR, SI and the ratio between SL and arm span were noticed. The observed higher results for boys could be linked to the fact that they appear to be more competitive, being more concerned with winning and with a trend to comparing their performance with their swimming peers, than girls. However, as Chollet, Seifert, & Carter (2008) observed when the imposed swim speeds increased, velocity and SR increased. Thus, as boys reached higher velocity values than girls, they needed to increase SR. This was the reason why a high positive correlation was noticed between velocity and SR ($r = 0.45$, $p < 0.01$). On the other hand, because of their higher velocity, boys used higher SI than girls, showing that they swim more efficiently. As Jürimãe et al. (2007) stated, performance in swimming has been related to different anthropometrical, physiological and biomechanical parameters. Therefore, although girls showed lower arm span than boys, the higher values in the ratio between SL and arm span in girls are able of a better use of their arms than boys. Indeed, girl also showed lower SR values suggesting that girls tried to increase velocity with an increase in SL as these parameters showed a positive correlation ($r = 0.32$, $p < 0.01$) each other. In the backstroke technique, SR was lower than in the butterfly, front crawl and breastroke, and SL was higher in backstroke and front crawl techniques, suggesting that it is one of the most relevant performance determinant variables (Chollet, Seifert, & Carter, 2008).

This technical adjustment – increased SL – could translate into a longer propulsive force application and for less drag, thus reducing energy cost. Comparing to a study of Lerda, Cardelli, & Coudereau (2005), SR values in fastest women (38.1 ± 5.4) are similar to our results in girls, but in males there is a difference of almost 7 cycles per minute for faster men (34.9 ± 5.8) and about 11 cycles per minute for slower men (31.1 ± 4.9), with boys showing higher SR values. These differences are probably related to the anthropometric characteristics, being adult swimmers taller and with arm span higher than young swimmers. In this sense, according to Lerda and colleagues (Lerda, Cardelli, & Coudereau, 2005), higher velocity of the faster swimmers can be explained by variations in SL for men and in SR for women.

Even at high intensity, age-group swimmers also showed catch-up coordination mode in backstroke. These results are according to other studies (Chollet, Seifert, & Carter, 2008; Lerda & Cardelli, 2003a; Lerda, Cardelli, & Coudereau, 2005), which stated that backstroke inter-arm coordination is necessarily in catch-up mode and an increase in SR does not imply a change in coordination, as observed in the front crawl technique (Barbosa et al., 2010; Millet, Chollet, Charlies, & Chatard, 2002). In the present study, boys noticed an IdC1 similar to faster adult men (-10.1 ± 3.9), but girls showed a different result than faster women (-3.4 ± 3.7). However, girls showed a tendency to have IdC1 slightly higher than boys, although not statistically different. Similar results were noticed for adult swimmers (Lerda & Cardelli, 2003a).

Similarly, there were no differences between genders and between maturity states for the IdC2. However, it is possible to observe a trend similar to the results obtained by adults, namely, post-pubertal group showing slightly lower values in IdC2 than pubertal group. In adult swimmers, this index – which quantifies simultaneity between the beginning of the pull of one arm and the beginning of the aerial recovery of the other arm – was lower than young swimmers, being related to an increase of clearing phase duration ($r = 0.86$, $p < 0.05$) and was negatively correlated with durations of entry and catch ($r = -0.66$, $p < 0.05$), pull ($r = 0.50$, $p < 0.05$) and recovery ($r = -0.67$, $p < 0.05$) (Lerda & Cardelli, 2003a). Furthermore, it was indicated that increase in skill is characterized by a shorter duration between the beginning of pull of one arm and that of the recovery of the other arm – IdC2 (Lerda & Cardelli, 2003a; Lerda, Cardelli, & Coudereau, 2005). Likewise, young swimmers showed positive correlation between IdC2 and clearing phase duration ($r = 0.40$, $p < 0.01$) and a negative correlation with the duration of the entry and catch phase ($r = -0.41$, $p < 0.01$). No significant correlation was noticed between IdC2 and pull duration, but with the push phase duration this correlation occurred ($r = 0.25$, $p < 0.01$).

Catch-up appears to be the exclusive coordination mode in this technique due to anthropometrical actions at the shoulder level of constraining flexibility (Richardson, Jobe, & Collins, 1980). The alternating body-roll seems to playable a relevant part in this stroke characteristic (Maglischo, 2003; Richardson, Jobe, & Collins, 1980). These two technical aspects of the backstroke impose a particular coordination between the two arms, and an additional phase in the arm stroke, the clearing phase (Lerda & Cardelli, 2003a). This phase is shortly in women (20.0 ± 4.6%) than in adult men swimmers (27.1 ± 9.0%), in opposite on to what happens with the entry and catch phase duration (8.3 ± 8.5% and 4.5 ± 3.7% for women and men, respectively). However, in this study there were no differences between genders in the duration time of these two phases, as it was described to adult swimmers by Lerda, Cardelli, & Coudereau (2005). Following these authors, in adult swimmers, the differences between genders in these two phases, was related to the effect of flotation, and that is higher in women than in men. The better flotation of women can explain their greater aptitude to maintain a horizontal body position and consequently the lengthening of the entry and catch to reduce drag (Chatard, Bourgoi, & Lacour, 1990). This observation confirms that the durations of stroke phases are not due to chance but related to anthropometric criteria, as Chatard and colleagues stated (Chatard, Bourgoin, & Lacour, 1990). However, this explanation is true when reporting to the static position, which could not be related with movement, when swimming. As the state of maturation shows, the age-group swimmers whom participate in this study are still growing. So, these results suggest that the differentiation between genders occurs only when maturation is fully complete. However, the differences in anthropometric characteristics between genders seem to be decisive to reach higher performances (Lerda, Cardelli, & Coudereau, 2005).

According to Lerda and colleagues (Lerda, Cardelli, & Coudereau, 2005) a longer entry and catch phase in adults can streamline the body and limit imbalances, thus reducing drag. This characteristic was considered as the best predictor of the performance in both genders. However, when comparing age-group to adult swimmers, it is possible to observe that although age-group had a longer entry and catch phase, this could be more related to a lower level of coordination, due to the maturity stage that they across, and not to reduce drag. Furthermore, these swimmers can increase the effectiveness of stroke by increasing the pull phase duration, that is lower than adult faster swimmers (19.07 ± 3.93%), and is a characteristic of slower swimmers (16.13 ± 2.47%) as Lerda and Cardelli (2003a) noticed. These results lead to a lower sum of propulsive phases duration in young swimmers, comparing to adult results obtained in previous published papers (40.0 ± 3.9%) and a longer sum of non propulsive phases than adults (60.0 ± 3.9%) (Chollet, Seifert, & Carter, 2008).

Conclusion

In conclusion, in age-group swimmers, at high intensity, no hand lag time phase was noticed. In the backstroke technique, as opposed to front crawl, a higher continuity of the propulsive arm action was not an indicator of superior performance level, which could explain why age-group swimmers showed similar IdC1 to adults. Relatively to biomechanical parameters it was observed differences between age-groups, with post-pubertal group showing higher values of velocity, SL and SI than pubertal peers, and also between young and adult swimmers, namely in velocity and SL, in which young swimmers achieved lower results. However, these differences are related to growth and mainly to maturation. Until the end of puberty, no differences between genders were observed, except in the velocity values, where boys are faster than girls. Indeed, anthropometric properties as propulsive forces, fat distribution, anthropometric values and drag contribute to different IdC values and the differences in body composition only really appears at the end of maturation process.

Acknowledgment

This study was supported by grant: PTDC/DES/101224/2008.

Chapter 4

General Discussion

From all the swimming performance influencing factors, technique seems to be universally considered as one of the most important, being a central concern of the training process of this sport (Saavedra et al., 2010; Vilas-Boas, 1998). Thus, considering that most of the authors agree that the period of learning the swimming techniques should occur between seven and twelve year of age, it is important to conduct studies in swimmers of these ages. Recently, attention has been given to the modifications in the temporal organizations of arm stroke phases using the IdC, a tool that allow to better characterize the swimming technique. However, this tool has only been used for adult swimmers.

In **Appendix I**, based on the methodology proposed by Chollet el al. (2000), it was found that young swimmers (20 boys and 20 girls) performing at high velocity only adopted a catch-up coordination mode. This occur because young swimmers performed a longer entry and catch phase rather than pull phase, leading to a larger sum of non-propulsive phases, and resulting in a negative IdC. These results were in opposition to studies previously done with elite adult swimmers (e.g. Chollet et al., 2000; Seifert et al., 2004). Complementarily, an analysis of the general biomechanical parameters was made and, as it was expected, lower values of velocity, SR and SL in young swimmers comparing to adults were registed. Comparing genders, boys showed higher values of velocity and SR than girls, but similar SL, which seems to suggest an optimization of the arm span by girls.

In **Appendix II,** using a larger sample, it was concluded that young swimmers only adopt catch-up coordination mode, in opposition from what was noticed in a study conducted with adults (Chollet et al., 2000), whom adopt superposition coordination mode when swimming at high intensity. In this sense, it seems to be important to emphase the coordinative training in this age-group, looking for exercises that promote greater continuity of propulsion, and, thus, a more efficient swimming technique at high velocities (which will be applied in a competitive situation). Additionally, it was made a detailed comparison between young and adult swimmers, being shown that young swimmers achieved lower velocity, SR and SL values comparing to adults. The two studies above referenced, which compared young swimmers of different genders and maturity stages (pubertal and post-pubertal), allowed us to confirm that the process of growth and maturation seems to interfere decisively in young swimmers coordination.

However, these findings have raised doubts if this behaviour is adopted by the generality of young swimmers. Thus, it seemed to be pertinent to study a larger sample, to better characterize the temporal stroke organization in these ages. Then, in **Chapter 2**, a detailed analysis was made with 114 young swimmers (56 boys and 58 girls). The results showed that, following the previous studies, only catch-up coordination was observed in swimmers of 11-13 years old. These values were the result of a higher entry and catch phase rather than in the pull phase, which led to a lower relative duration of the sum of propulsive phases. Moreover, some differences were also denoted in biomechanical parameters between our sample and the literature studies conducted with adult swimmers, as well as the lower velocity, SR, SL and SI. However, it was observed that the post-pubertal group obtained closest values to adults due to their superior anthropometric and maturational characteristics (relatively to pubertal ones). In addition, it was observed, as it was in **Appendix I** and **Appendix II**, that boys reached higher velocity, SR and also SI values than girls, as it was reported for elite swimmers (Potdevin et al., 2004; Seifert et al., 2007). Nevertheless, once again, no differences were noticed in SL between genders, in opposition to studies with adult swimmers (Fernandes et al., 2006; Seifert et al., 2007). However, when considering all the sample (without subdividing by gender or maturity), it was noticed a higher relationship between velocity and SL than between velocity and SR, indicating that to improve swimming velocity young swimmers should increase SL (more than SR).

Complementarily, in **Appendix III**, it was made an analysis of arm symmetry, in sequence of the analysis of IdC, once it uses its values for both arms. In fact, the IdC was the mean between IdC for the left arm (IdC_{left}) and for the right arm (IdC_{rigth}). It was found that young swimmers showed arm asymmetry. However, independently of their maturity stage, boys registed an asymmetry to the right and girls to the left side, which could be the result of the unilateral breathing usually reinforced by swimming learning and training process (as noticed before by Nikodelis et al. 2005; Tourny-Chollet et al., 2009), but also due to the fact that young swimmers are in the middle of their maturational development.

Knowing that the number of studies that aims to assess IdC in backstroke is scarce, a study in backstroke was conducted in young swimmers (**Chapter 3**). It was noticed no hand lag time in age-group swimmers performing at high intensity, which is in accordance with Lerda and Cardelli (2003) and Lerda et al. (2005). However, as the sample was composed by young swimmers, it was expected similar or even higher values for this phase (as proposed by Chollet et al., 2008). These results suggest that this technical error, pointed out by Colwin (2002) and Maglischo (2003), should be a constant concern of young swimmers'coaches.

In front crawl, the wide range of race events (from 50m to the 1500m) suggests that several coordination modes are possible. Conversely, in backstroke, the range of events is smaller (from 50 to 200m) and, in any case, the organismic constraints greatly limit the choice of coordination mode (Seifert et al., 2008). In fact, a greater continuity of propulsive arm action in backstroke was not an indicator of superior performance level (Chollet et al., 2008; Lerda et al., 2005; Lerda et al., 2003; Querido et al., 2010). Therefore, in backstroke, catch-up mode appears to be the exclusive coordination mode in both young and adult swimmers due to anthropometrical actions at the shoulder level of constraining flexibility (Richardson et al., 1980). The alternating body-roll seems to play a relevant part in this stroke characteristic (Maglischo, 2003; Richardson et al., 1980). These two technical aspects of the backstroke impose a particular coordination between the two arms, and an additional phase in the arm stroke the clearing phase (Lerda & Cardelli, 2003). According to Lerda et al. (2005) a longer entry and catch phase in adults can streamline the body and limit imbalances, reducing drag, being considered as the best predictor of the performance in both genders. However, when comparing age-group to adult swimmers, it is possible to observe that although young swimmers had a longer entry and catch phase, this adaptation could be more related to a lower coordination due to the development period that they were, and not to create a better propulsion. The lower percentage of propulsive phases showed by young swimmers, comparing to adults (Chollet et al., 2008) is a result of a lower pull phase, which is a characteristic of slower swimmers (Lerda et al., 2003). Comparing to adults, boys showed similar IdC1 values, but girls showed a different result than women. However, girls showed a tendence to had a IdC1 higher than boys as it was noticed in adult swimmers (Lerda et al., 2003). Similarly, in IdC2, there were no differences between genders regardless to maturity states. However, it is possible to observe a trend similar to the results of adults, namely, post-pubertal group showed slightly lower values in IdC2. Although age-group swimmers showed lower velocity and SL values than those reported by adults, post-pubertal group reach values nearest to elite than pubertal swimmers. Regarding genders, differences in velocity, SR, SI and the ratio between SL and arm span were noticed in opposition to which was described in adults. Moreover, although girls showed lower arm span than boys, the higher values in ratio between SL and arm span in girls, seems to suggest that girls tried to increase velocity with an increase in SL.

It is important to emphasize that the process of growth and maturation seems to interfere decisively in the coordination, particularly in inter arm coordination. However, our above mentioned studies also suggesting that, in general, the differentiation between genders only occurs when maturation is completed. Thus, the IdC, is characterized as a tool which helps coach to evaluate the technical progress, being a complement of biomechanical parameters, which it is possible to use with a direct observation of swimmers. Indeed, with these studies, it was expected that coordinative training in this age group is further stimulated, looking for exercises that promote greater continuity of propulsive actions and thus, a more efficient technique for high-speed swimming.

Chapter 5

Conclusions

The present study pretended to increase the knowledge concerning the technical characteristics, through the characterization of biomechanical profile and temporal information about the management of propulsive actions in alternate techniques of the 11-13 years old swimmers. Indeed, these studies seem to contribute to a better understanding the characterization in young swimmers technique. Through the IdC it was concluded that only catch up coordination mode was observed in young swimmers, even at high intensity, in both alternated techniques, with no differences in genders and maturity states. Additionally, young swimmers presented lower values of biomechanical parameters, namely velocity, SL and SI comparing to adults. It was also observed that, until the end of puberty, there were no differences between genders, except in velocity values, where boys are faster than girls, which seems to suggest that the differences between genders only occur after puberty due to the differences in anthropometric properties as propulsive forces, fat distribution, anthropometric values and drag and differences in body composition that only really appears at the end of maturation process.

Appendix 1

Avaliação da Coordenação entre Membros Superiores na técnica de crol em nadadores infantis

Ana Silva[1,2], Pedro Figueiredo[1], Paulo Renato[1,3], Inês Amaral[1], Marisa Sousa[1], António Sampaio[1,4], Susana Soares[1], J. Paulo Vilas-Boas[1], Ricardo J. Fernandes[1]

[1] Faculdade de Desporto, CIFI2D, Universidade do Porto
[2] Grupo Desportivo de Natação Vila Nova Famalicão
[3] Sporting Clube de Braga
[4] Instituto Superior da Maia

Resumo

O presente estudo teve como objectivo a caracterização da coordenação entre membros superiores na técnica de crol a velocidade elevada, em nadadores infantis. Quarenta nadadores, 20 raparigas (11.50 ± 0.5 anos) e 20 rapazes (12.40 ± 0.7 anos) realizaram 25 m crol à velocidade máxima. Através da análise das imagens de ciclos não inspiratórios captadas por duas câmaras subaquáticas (colocadas nos planos frontal e sagital) foram identificadas as fases de um ciclo dos membros superiores, sendo determinado o índice de coordenação. Os parâmetros biomecânicos gerais velocidade, frequência gestual e distância de ciclo também foram calculados.

Verificou-se que os nadadores infantis coordenam a sua acção dos membros superiores na técnica de crol segundo o modelo descontínuo, existindo um momento do ciclo onde não existe propulsão por parte dos membros superiores. Observou-se, também, que os nadadores despendem mais tempo na fase de entrada e agarre, e têm uma menor duração na fase de tracção, relativamente ao que está descrito na literatura para nadadores de elite. Adicionalmente, os nadadores infantis mais velozes apresentam maior frequência gestual e amplitude de ciclo. No entanto, como estes dois parâmetros se correlacionam negativamente, e como a frequência gestual se relaciona directamente com o índice de coordenação, o aumento das fases propulsivas (maior eficiência de braçada) nesta população deverá ser conseguido através do aumento da frequência gestual.

Palavras-Chave: Infantis, índice de coordenação, crol, parâmetros biomecânicos gerais

Abstract

The aim of this study was to characterize the arm coordination and the general biomechanical parameters (velocity, stroke length and stroke rate) in young swimmers performing front crawl at high intensity. Forty young swimmers performed a 25 m crawl at maximum intensity. Stroke phases (entry and catch, push, pull and recovery) were identified by video analysis (through two underwater cameras in sagital and frontal planes), being assessed the Index of Coordination. The velocity, stroke rate and stroke length were also calculated.

It was observed that, in front crawl swimming technique performed at high intensity, only catch-up coordination was noticed in this specific population. In fact, young swimmers spend more time in catch/entry phase rather than in the pull phase. Further, fastest swimmers displayed higher stroke rate and stroke length. However, stroke rate and stroke length are negatively correlated, and because stroke rate have a direct relation with the index of coordination, the increase of propulsive phases (leading to a more efficient stroke) should be done by increasing the stroke rate.

Keywords – Age-group swimmers, index of coordination, front crawl, general biomechanical parameters

Introdução

Dos factores que influenciam o rendimento desportivo de um nadador, a técnica parece ser unanimemente considerada um dos mais importantes, sendo uma das preocupações centrais no processo de formação desportiva (Vilas-Boas, 1998). A técnica de crol, por ser ventral, por implicar menor arrasto hidrodinâmico, e pelo facto da acção alternada dos membros superiores (MS) permitir uma propulsão mais contínua, é a mais rápida das quatro técnicas, sendo a mais frequentemente utilizada no treino e em competição (Tourny-Chollet et al., 2009). Nesta técnica de nado, sendo os MS responsáveis por parte significativa da propulsão (Alberty et al., 2008), a coordenação entre MS tem uma importância decisiva para a aplicação eficaz das forças propulsivas.

Para melhor caracterizar a técnica de nado é frequente utilizarem-se a frequência gestual (FG), a distância de ciclo (DC), o índice de ciclo e a razão entre FG e a DC, pois a sua interacção determina a velocidade de nado (Alberty et al., 2008; Seifert et al., 2005). Recentemente, Chollet et al. (2000) propuseram um novo instrumento para determinar a sincronização entre MS na técnica de crol - o Índice de Coordenação (IdC) - sendo a sua determinação baseada no intervalo temporal existente entre as fases propulsivas da acção dos MS. Segundo os referidos autores, o IdC na técnica de crol pode expressar três tipos de coordenação: catch-up (quando existe um desfasamento temporal entre o final da fase propulsiva de um MS e o inicio da propulsão do outro MS), oposição (sem intervalo entre as fases propulsivas dos MS) e sobreposição (existindo uma sobreposição nas fases propulsivas dos MS).

Tendo em consideração que a maior parte dos estudos relativos à determinação do IdC têm sido realizados com nadadores de elite (e.g. Chollet et al., 2000; Seifert et al., 2004), afigura-se-nos fundamental estudar os nadadores em processo de formação, pois esta é a etapa base de desenvolvimento coordenativo. Assim, o objectivo do presente estudo foi caracterizar a coordenação entre MS na técnica de crol realizada a velocidade elevada, em nadadores infantis, através da determinação do IdC.

Métodos

Quarenta nadadores do escalão Infantil voluntariaram-se para participar no presente estudo. As suas principais características antropométricas e o número de unidades de treinos semanais que realizam em média estão descritos na Tabela 1.

Numa piscina de 25 m coberta e aquecida, cada nadador realizou 25 m crol à velocidade máxima. Para a determinação do IdC foram recolhidas imagens através de duas câmaras de vídeo (Sony DCR-HC42E®) em imersão, uma colocada no plano sagital e a outra no plano frontal. Para permitir a transformação das coordenadas virtuais em coordenadas reais, foi colocada uma estrutura de calibração bidimensional com dimensões de 2.10 m de largura e 3 m de altura.

Tabela 1. Valores médios e respectivos desvios-padrão relativos às principais características antropométricas e de unidades de treino semanais dos nadadores em estudo.

	Raparigas (n=20)	Rapazes (n=20)
Idade (anos)	11.50 ± 0.5	12.40 ± 0.7
Peso (kg) *	43.26 ± 5.5	49.84 ± 7.6
Altura (cm) *	153.80 ± 7.2	158.74 ± 7.8
Envergadura (cm) *	153.70 ± 10.1	161.50 ± 9.8
Unidades de Treino (treinos/semana)	5.5 ± 0.5	5.5 ± 0.5

* Diferenças estatisticamente significativas ($P \leq 0.05$).

A avaliação biomecânica foi realizada com o software APASystem, tendo-se procedido à digitalização frame a frame de dois ciclos não inspiratórios consecutivos. Foram digitalizados treze pontos: anca, extremidade distal dos dedos médios, pulsos, cotovelos, ombros, joelhos e tornozelos.

O cálculo do IdC teve por base a divisão da acção dos MS nas quatro fases (Chollet et al., 2000): (i) entrada e agarre, correspondendo ao tempo desde a entrada da mão entra na água até que começa a efectuar o movimento ântero-posterior; (ii) tracção, desde o final da acção anterior até atingir o alinhamento vertical do ombro, sendo a primeira fase propulsiva; (iii) empurre, desde o final da acção anterior até à saída da mão da água, sendo a segunda fase propulsiva; (iv) recuperação, abrangendo o tempo desde que a mão emerge até que volta a entrar na água. O IdC foi expresso em percentagem do tempo total do ciclo de MS.

O cálculo da velocidade (v) foi efectuado através da razão entre o deslocamento da anca num ciclo de MS e a sua duração total. A DC foi determinada através da distância horizontal percorrida pela anca durante um ciclo de MS e a FG corresponde ao número de ciclos de MS efectuados por minuto.

O tratamento estatístico realizado baseou-se na análise exploratória dos dados, assim como no cálculo das médias e respectivos desvios-padrão para todas as variáveis em estudo. Para a comparação entre géneros aplicou-se um *t-test* de medidas independentes (software SPSS Statistics versão 17.0). A significância estatística foi considerada para $P < 0.05$.

Resultados

A tabela 2 sintetiza os principais resultados obtidos no presente estudo, assim como o estudo pioneiro de Chollet et al. (2000). Pode-se observar que os nadadores apresentaram valores mais elevados de v e FG comparativamente com as nadadoras, sendo os valores de DC muito semelhantes entre si. Relativamente à coordenação entre MS, observaram-se valores semelhantes de IdC entre subgrupos sexuais, enquanto, no que se refere aos valores percentuais das quatro fases, se destaca o menor valor da fase de recuperação nas raparigas comparativamente com os rapazes.

Complementarmente, na tabela 3 podem-se observar os valores de correlação obtidos entre as principais variáveis em estudo para o grupo total, tendo-se verificado alguns resultados significativos, nomeadamente as relações directas entre a v, a FG e a DC e relações inversas entre a FG e a DC, assim como entre o IdC e a DC.

Tabela 2. Valores médios e respectivos desvio-padrão dos parâmetros relativos à velocidade, frequência gestual, distância de ciclo, coordenação entre MS, entrada e agarre, tracção, empurre, recuperação, soma das fases propulsivas e soma das fases não propulsivas de acordo com os géneros e para a amostra total, assim como para Chollet et al. (2000).

Parâmetros	Raparigas (n = 20)	Rapazes (n = 20)	Total (n = 40)	Chollet et al. (2000)
Velocidade (m/s) *	1.37 ± 0.2	1.52 ± 0.1	1.45 ± 0.2	1.81 ± 0.1
Frequência gestual (ciclo/min)*	47.16 ± 7.1	52.07 ± 5.6	49.62 ± 6.8	54.00 ± 4.0
Distância ciclo (m/ ciclo)	1.77 ± 0.3	1.78 ± 0.3	1.77 ± 0.3	2.01 ± 0.1
Índice de coordenação (%)	-9.30 ± 4.6	-9.33 ± 3.9	-9.31 ± 4.2	2.53 ± 4.4
Entrada e agarre (%)	36.54 ± 5.1	34.67 ± 5.7	35.60 ± 5.4	22.10 ± 3.9
Tracção (%)	16.29 ± 3.8	15.77 ± 3.4	16.03 ± 3.5	26.70 ± 3.7
Empurre (%)	25.34 ± 3.3	23.87 ± 3.0	24.60 ± 3.2	26.30 ± 2.7
Recuperação (%)*	22.00 ± 3.8	25.64 ± 3.2	23.82 ± 3.9	24.90 ± 2.6
Fases propulsivas (%)	41.63 ± 3.76	39.64 ± 4.31	40.63 ± 4.11	53.00 ± 3.5
Fases não propulsivas (%)	58.50 ± 3.94	59.42 ± 4.12	59.42 ± 4.17	47.00 ± 3.2

* Diferenças estatisticamente significativas entre géneros ($P \leq 0.05$).

Tabela 3. Matriz de correlação entre os parâmetros velocidade (v), frequência gestual (FG), distância de ciclo (DC) e sincronização entre MS (IdC), para a amostra total (n = 40).

	Velocidade	Frequência gestual	Distância de ciclo	Índice de coordenação
Velocidade	1			
Frequência gestual	0.31*	1		
Distância ciclo	0.46**	-0.68**	1	
Índice de coordenação	-0.08	0.29	-0.31*	1

* $P \leq 0.05$ e ** $P < 0.01$

Discussão

Os valores de IdC obtidos evidenciam que os nadadores infantis testados organizam a sua coordenação entre MS na técnica de crol em catch-up. Estes resultados, obtidos à velocidade correspondente à prova de 50 m, estão em oposição aos descritos na literatura para nadadores de idades e níveis desportivos superiores quando efectuam esforços à mesma intensidade relativa, os quais atingem modos coordenativos de oposição e até de sobreposição (cf. Chollet et al., 2000; Seifert et al., 2004). De facto, os nadadores do presente estudo apresentam uma maior duração relativa na fase de entrada e agarre e uma menor duração na tracção relativamente ao descrito na literatura. Do mesmo modo, os resultados descrevem uma superioridade no somatório das fases propulsivas no grupo de elite (Chollet et al., 2000), ocorrendo o inverso (maior percentagem das fases não propulsivas) no grupo de Infantis. Este facto sugere que o nosso entendimento da coordenação motora em adultos não pode ser directamente aplicado em crianças. Neste sentido, o processo de crescimento e maturação parece interferir decisivamente na coordenação entre MS na técnica de crol.

Quando comparados os géneros verificaram-se diferenças estatisticamente significativas, com valores superiores para os rapazes nas variáveis v e FG, o que poderá ser explicado pela diferença (embora não estatisticamente significativa) de idades. Complementarmente, apesar de se ter verificado diferenças na altura e envergadura entre géneros, os valores de DC foram idênticos entre esses subgrupos. Este facto parece indicar um subaproveitamento da amplitude da acção dos MS pelo grupo masculino. Efectivamente, quando nos reportamos a nadadores de nível desportivo nacional e internacional, está descrito que os nadadores apresentam valores de DC significativamente superiores às nadadoras (Fernandes et al., 2006; Seifert et al., 2007). Complementarmente, pôde-se observar uma menor duração relativa da fase de recuperação nas raparigas comparativamente com os rapazes. No entanto, essa diferença parece não ter grande significado na coordenação entre MS pois, quando comparadas as fases propulsivas e as fases não propulsivas, não foram observadas diferenças entre subgrupos sexuais.

As relações directas entre a v, a FG e a DC parecem evidenciar que os nadadores Infantis mais rápidos são-no porque conseguem maiores frequências das acções motoras dos MS, mas também porque mantêm maiores amplitudes. A relação inversa entre a FG e a DC está de acordo com a literatura (e.g. Seifert et al., 2010), evidenciando que para se atingir uma determinada velocidade existem diversas combinações destes parâmetros (nomeadamente quando a FG aumenta a DC diminui e vice-versa), não podendo aumentar em simultâneo (cf. Seifert et al., 2006). O facto dos nadadores com coordenação entre MS mais optimizada serem os que têm menor DC, corroborando o estudo de Potdevin et al. (2004), parece evidenciar a importância da diminuição relativa das fases não propulsivas e aumento relativo das fases propulsivas, pelo aumento da FG, uma vez que este parâmetro se relaciona positivamente com o IdC (apenas para $p < 0.10$).

Com este estudo espera-se que o treino coordenativo neste escalão etário seja ainda mais estimulado, procurando exercícios que promovam uma maior continuidade das acções propulsivas e, desta forma, uma técnica mais eficiente para velocidades de nado elevadas.

Conclusões

Os nadadores infantis quando nadam crol a velocidade elevada utilizam uma coordenação entre MS em catch-up, aproximando-se do modo coordenativo de oposição, mas ficando longe do modo de sobreposição característico dos nadadores mais velhos e de nível desportivo mais elevado. Estes resultados sugerem que, muito embora o processo de maturação pareça interferir na coordenação entre MS na técnica de crol, o treino técnico neste escalão etário deve ser realizado também a intensidades de nado altas para promover adaptações coordenativas a velocidades utilizadas em situação de competição.

Sincronización entre miembros superiores en la técnica de crol en nadadores jóvenes

Arm Sincronization in age group front crawl swimmers

Silva, A.[1], Figueiredo, P.[1], Renato, P.[1], Abraldes, J. A.[2], Soares, S.[1], Fernandes, R.J.[1]

[1] Faculdade de Desporto. Universidade do Porto

[2] Facultad de Ciencias del Deporte. Universidad de Murcia

Resumen

El índice de coordinación (IdC) es utilizado para determinar la sincronización entre los miembros superiores en la técnica de crol a través del tiempo existente entre las respectivas fases propulsivas. El objetivo de este estudio fue determinar el IdC en nadadores jóvenes. La muestra fue de 60 nadadores infantiles, que realizaron una prueba de 25m a crol a velocidad elevada. Se registraron imágenes subacuáticas con dos cámaras (plano sagital y frontal) y se digitalizaron (APASystem®) los correspondientes a dos ciclos de nado. Se realizó un estudio descriptivo, correlación entre variables e inferencial en función del sexo ($p \leq 0.05$). Se comprobó como la técnica de crol en nadadores jóvenes presenta una coordinación catch-up, diferente a la de nadadores mayores. Estos nadadores presentan mayor tiempo en la fase de entrada y agarre y una menor duración en la tracción, en relación con lo que manifiesta la bibliografía específica. El análisis del sexo nos indica mayores valores en niños en relación a la velocidad y la frecuencia gestual de nado.

PALABRAS CLAVE: Cinemática, natación, crol, nadadores jóvenes

Abstract

The Index of Coordination (IdC) is used to determine the inter arm coordination and their propulsive arm phases. The aim of this study was to characterize the front crawl technique of young swimmers. 60 age group swimmers performed 25m in apnea in front crawl at high velocity. Two underwater cameras (sagital and front plan) were used to digitize (APASystem®) two stroke cycles. Statistical analysis was based on the measurement of means and standard deviations, as well as a t-test for independent measures and the correlation coefficient ($P < 0.05$). This study showed that, in crawl, only catch-up coordination was observed in young swimmers. These swimmers spend more time in entry and catch phase rather than pull phase, which is in opposition to what is described in the literature for adult swimmers.

KEY WORDS: Kinematics, swimming, front crawl, age group

Introducción

De los factores influenciadores del rendimiento deportivo en natación, la técnica parece ser, unánimemente, considerada una de las más importantes, siendo ésta, una de las preocupaciones centrales en el proceso de formación deportiva (Saavedra y Escalante, 2010). La técnica de crol, por ser ventral, por implicar menor arrastre hidrodinámico y, por el hecho de que la acción alternativa de los miembros superiores permiten una propulsión más continua, es, además, la más rápida de las cuatro técnicas de nado, siendo la más usada frecuentemente en los entrenamientos y en la competición. En esta técnica de nado, sabiendo que los miembros superiores son responsables significativos de la propulsión, su sincronización tiene una importancia decisiva para la aplicación eficaz de fuerzas propulsivas (Maglischo, 2003; Deschodt, Arsac, Rouard, 1999).

Para caracterizar mejor la técnica de nado es frecuente utilizar parámetros biomecánicos generales. Así, la frecuencia gestual (en adelante FG) representa el número total de ciclos de brazadas realizadas por minuto, la distancia de ciclo (en adelante DC) expresa la distancia total recorrida en un ciclo de brazada, siendo importante la relación entre FG y DC, pues su interacción determina la velocidad de nado. La evaluación de los parámetros biomecánicos generales se viene estudiando desde los años setenta. Sin embargo, las críticas a sus limitaciones, propició un desarrollo de instrumentos biomecánicos y métodos analíticos, más allá de la cuantificación, que habitualmente se realiza de otros parámetros cinemáticos, relacionados con el rendimiento en natación (Alberty, Sidney, Huot-Marchand, Hespel y Pelayo, 2005).

Además, Chollet, Charlies y Chatard (2000) propusieron un nuevo instrumento para determinar la sincronización entre los miembros superiores en la técnica de crol – el índice de coordinación – determinándose su resultado en función del intervalo temporal existente entre las fases propulsivas de la acción de los miembros superiores. Según estos autores, el índice de coordinación (en adelante IdC) en la técnica de crol se puede expresar de tres formas diferentes (Figura 1): *catch-up* (cuando existe un desfase temporal entre el final de la fase propulsiva de un miembro superior y el inicio de la propulsión del otro miembro); *oposición* (sin intervalo entre las fases propulsivas de los miembros superiores) y *superposición* (existiendo una superposición en las fases propulsivas de los miembros superiores). Esta temática viene siendo motivo de interés por la comunidad científica específica en natación, encontrándose frecuentes estudios en los últimos años, sirva como ejemplo los siete trabajos publicados en el último *International Symposium for Biomechanics and Medicine in Swimming* (2010), referentes a esta temática. Sin embargo, la determinación del IdC se ha estudiado con nadadores adultos, ya sean de recreo o de élite (Chollet et al., 2000; Seifert, Boulesteix, Carter, Chollet, 2004; Schnitzler, Seifert, Ernwein, Chollet, 2008, Seifert, Toussant, Alberty, Schnitzler y Chollet, 2010), por ello, parece fundamental estudiar este índice en nadadores en proceso de formación, pues esta etapa es la base del desarrollo coordinativo, en la cual se sustentará la especialización posterior.

Objetivos

El objetivo del presente estudio fue caracterizar los parámetros biomecánicos generales y la sincronización de los miembros superiores en la técnica de crol realizada a velocidad alta, en nadadores jóvenes, a través de la determinación del índice de coordinación. Complementariamente, se intentó verificar la eventual existencia de diferencias entre sexos.

Material y Métodos

Muestra

La muestra del estudio estuvo compuesta por sesenta nadadores pertenecientes a la categoría infantil. Los valores medios de las principales características físicas y frecuencia de entrenamiento semanal en función del sexo y para la totalidad de la muestra pueden observarse en la Tabla 1.

Tabla 1: Valores medios ($\bar{x} \pm sd$) relativos a las principales características antropométricas y frecuencia de entrenamiento semanal de la muestra del estudio.

Parámetros	Niñas (n=30)	Niños (n=30)	Total (n=60)
Edad (años)*	11.5 ± 0.5	12.4 ± 0.7	11.9 ± 0.7
Peso (kg)*	43.2 ± 6.4	51.1 ± 7.8	47.2 ± 8.1
Altura (cm)*	152.0 ± 7.2	159.4 ± 7.5	155.7 ± 8.2
Envergadura (cm)*	152.6 ± 8.6	162.4 ± 9.2	157.5 ± 10.1
Entrenamientos semanales	5.5 ± 0.5	5.5 ± 0.5	5.5 ± 0.5

* Diferencias estadísticamente significativas entre sexo ($p \leq 0.05$).

Procedimiento

Antes de la realización de la prueba fueron informados los entrenadores, nadadores, familiares y tutores del deportista conforme al procedimiento desarrollado en la investigación. Todos los deportistas se sometieron voluntariamente al estudio y con consentimiento de sus entrenadores, familiares o tutores legales. El estudio cuenta con el aval y reconocimiento del comité de ética de la Faculdade de Desporto da Universidade do Porto. Portugal.

El estudio se llevó a cabo en una piscina cubierta de 25 m de longitud. La temperatura del agua para la prueba era de 27,5º C. Cada nadador realizó 25 m de nado crol a la velocidad correspondiente a una prueba de 50 m de la misma técnica. Esta velocidad fue controlada por los respectivos entrenadores de los deportistas en relación al tiempo final de la prueba. Los nadadores que no realizaron la prueba a la velocidad designada tuvieron que repetir nuevamente el test.

Instrumental

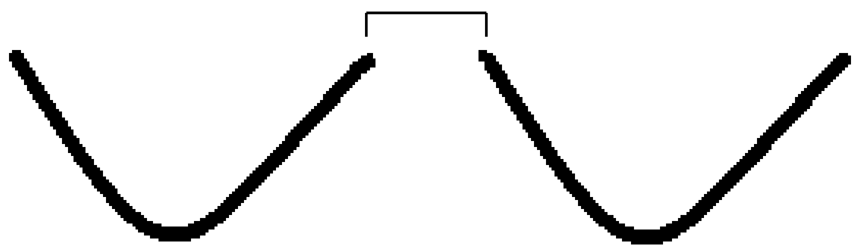
Para la determinación del IdC se recogieron imágenes a través de dos cámaras de video (Sony DCR-HC42E®), colocadas bajo el agua, una en plano sagital y la otra en el plano frontal. Ambas cámaras registraron a una velocidad de 50 fotogramas por segundo. Para la transformación de las coordinadas virtuales en coordenadas reales, se utilizó una estructura bidimensional (210 cm x 300 cm). La evaluación biomecánica fue realizada con el Software APASystem® bajo Microsoft Windows XP® v.2003. Se procedió a la digitalización *frame* a *frame* de dos ciclos no inspiratorios consecutivos en los siguientes puntos anatómicos: extremidad distal de los dedos, muñeca, codos, hombros (para ambos lados) y la cadera (derecha). El protocolo desarrollado siguió el modelo publicado por Querido, Marques-Aleixo, Figueiredo, Seifert, Chollet, Vilas-Boas et al. (2010), para el proceso de digitalización.

Protocolo

El cálculo del IdC se basó en la división de cuatro fases de la acción de los miembros superiores de la técnica de crol (Chollet et al., 2000): 1) entrada y agarre, correspondientes al tiempo empleado desde la entrada de la mano en el agua hasta que se comienza a efectuar el movimiento antero-posterior, 2) tracción, desde el final de la acción anterior hasta que la mano está alineada verticalmente con el hombro (siendo ésta la primera fase propulsiva); 3) empuje, desde el final de la acción anterior hasta la salida de la mano del agua (siendo ésta la segunda fase propulsiva); 4) recuperación, abarcando el tiempo que va desde la salida de la mano hasta que ésta vuelve entrar en el agua. A través de la Figura 1 es posible comprender los tres tipos de coordinación posibles en la técnica de crol (1a, 1b y 1c,).

1a) Catch-up: IdC<0%.

Intervalo de tiempo no propulsivo



Fase propulsiva del brazo izquierdo   Fase propulsiva del brazo derecho

1b) Oposición: IdC=0%.

Intervalo de tiempo no propulsivo

Fase propulsiva del brazo izquierdo   Fase propulsiva del brazo derecho

1c) Superposición: IdC>0%.

Superposición de las fases propulsivas

Fase propulsiva del brazo izquierdo   Fase propulsiva del brazo derecho

Figura 1. Representación gráfica de los tres tipos de coordinación posibles en la técnica de crol.

Las fases de brazada y, posteriormente, el IdC fueron expresados en porcentaje del tiempo total del ciclo de los miembros superiores. El cálculo de las fases de brazada fue obtenido a través del número de *frame* (cada *frame* corresponde a 0.02 s) durante dos ciclos de brazada (desde la primera entrada de la mano izquierda hasta la segunda entrada de la mano derecha). El IdC fue obtenido a través de la determinación del intervalo de tiempo existente entre las fases propulsivas del miembro superior izquierdo y derecho. Es decir, estos intervalos corresponden al tiempo entre el inicio de la fase propulsiva de la primera brazada del miembro superior derecho y el fin de la primera brazada del miembro superior izquierdo y el intervalo entre el inicio de la fase propulsiva de la segunda brazada del miembro superior izquierdo y el final de la fase propulsiva de la brazada del miembro superior derecho (Chollet et al, 2000; Seifert, Chollet y Rouard, 2006):

1a)

$$IdC_{\text{izquierdo}} = \frac{[(\text{Momento final del empuje}_{\text{izquierdo}} - \text{Momento inicial de tracción}_{\text{derecho}}) \cdot 100]}{\text{Duración de un ciclo completo}}$$

1b)

$$IdC_{\text{derecho}} = \frac{[(\text{Momento final del empuje}_{\text{derecho}} - \text{Momento inicial de tracción}_{\text{izquierdo}}) \cdot 100]}{\text{Duración de un ciclo completo}}$$

1c)

$$\text{Duración ciclo completo} = \frac{(\text{Entrada y agarre} + \text{Tracción} + \text{Empuje} + \text{Recuperación})_{\text{izquierdo}} + (\text{Entrada y agarre} + \text{Tracción} + \text{Empuje} + \text{Recuperación})_{\text{derecho}}}{2}$$

1d)

$$IdC = \frac{IdC_{\text{derecho}} + IdC_{\text{izquierdo}}}{2}$$

El cálculo de la velocidad fue efectuado a través de la distancia recorrida por la cadera en un ciclo de miembros superiores y en función de la duración total de éste. La DC fue determinada a través de la distancia horizontal recorrida por la cadera durante un ciclo de miembros superiores y la FG corresponde al número de ciclos de miembros superiores efectuados por minuto (Figueiredo, Vilas-Boas, Seifert, Chollet y Fernandes, 2010).

Análisis estadístico

El análisis estadístico realizado se centró en un análisis exploratorio de los datos, así como en el cálculo de medias y desviaciones típicas para todas las variables de estudio. Para verificar las diferencias en función del sexo se llevó a cabo un *t-test* de medidas independientes. También se utilizó el coeficiente de correlación de Pearson para verificar la relación entre las variables. Para todo el tratamiento estadístico se utilizó el paquete estadístico SPSS, v.17.0, bajo el entorno Microsoft Windows 7. Se asumió un error estadístico del 5%, para todas las variables de estudio, considerándose una significación estadística para $p \leq 0.05$.

Resultados

La Tabla 2 sintetiza los principales resultados obtenidos en el presente estudio. Además, se incluyen los datos del estudio de Chollet et al. (2000) para su comparación. Se puede observar que los niños presentaron valores más altos de velocidad y de FG en comparación con las niñas, encontrando valores de DC iguales. En relación a la sincronización entre los miembros superiores, se observan valores similares en el IdC entre sexos. Sin embargo, referente a los valores porcentuales de las cuatro fases, se destaca el menor valor de la fase de recuperación en la niñas en relación a los niños. Comparando los datos de los nadadores con los obtenidos por Chollet et al. (2000) en un estudio con adultos, comprobamos que los resultados referidos a los parámetros biomecánicos son mayores en los adultos en que los jóvenes nadadores. Sin embargo, es en los valores del IdC donde se registran mayores diferencias. Así, los adultos adoptan una coordinación en *superposición* y los jóvenes en *catch-up*. Los resultados obtenidos en las fases no propulsivas y las propulsivas puede ser explicados por mostrar una fase más larga de la entrada y agarre en los jóvenes y una mayor fase de tracción por los adultos.

Tabla 2. Valores medios ($\bar{x} \pm sd$) de la velocidad, frecuencia gestual, distancia de ciclo, índice de coordinación, entrada y agarre, tracción, empuje, recuperación, suma de fases propulsivas y no propulsivas en relación al sexo, así como para la muestra total y el estudio de Chollet et al. (2000).

Parámetros	Niñas (n=30)	Niños (n=30)	Total (n = 60)	Chollet et al. (2000)
Velocidad (m/s)*	1.38 ± 0.2	1.49 ± 0.2	1.44 ± 0.2	1.81 ± 0.1
Frecuencia gestual (ciclo/ min)*	48.38 ± 6.3	52.32 ± 5.9	50.36 ± 6.4	54.00 ± 4.0
Distancia de ciclo (m/ciclo)	1.73 ± 0.3	1.73 ± 0.3	1.73 ± 0.3	2.01 ± 0.1
Índice de Coordinación (%)	-9.23 ± 3.8	-8.31 ± 5.3	-8.77 ± 4.6	2.53 ± 4.4
Entrada y agarre (%)	36.81 ± 4.7	35.18 ± 4.7	36.00 ± 4.8	22.10 ± 3.9
Tracción (%)	16.06 ± 3.2	15.30 ± 2.9	15.68 ± 3.1	26.70 ± 3.7
Empuje (%)	24.77 ± 3.0	24.27 ± 2.8	24.52 ± 2.9	26.30 ± 2.7
Recuperación (%)*	22.36 ± 3.5	25.26 ± 3.0	23.81 ± 3.6	24.90 ± 2.6
Fases Propulsivas (%)	40.83 ± 3.4	39.57 ± 3.9	40.20 ± 3.7	53.00 ± 3.5
Fases no Propulsivas (%)	59.17 ± 3.4	60.44 ± 3.8	59.81 ± 3.7	47.00 ± 3.2

* Diferencias estadísticamente significativas entre sexos ($p \leq 0.05$).

Complementariamente, en la Tabla 3 se pueden observar los valores de correlación obtenidos entre las principales variables del estudio para el grupo total de la muestra. Se observaron algunos resultados significativos, principalmente relaciones directas entre la velocidad y la DC, entre la velocidad y la envergadura, y entre la DC y la envergadura. También se observaron relaciones inversas entre la FG y la DC, así como entre la envergadura, velocidad y DC.

Tabla 3. Matriz de correlación entre los parámetros de velocidad, frecuencia gestual, distancia de ciclo, índice de coordinación y envergadura para la muestra total (n=60).

	Velocidad	Frecuencia gestual	Distancia de ciclo	Índice de coordinación	Envergadura
Velocidad	-				
Frecuencia gestual	0.19	-			
Distancia de ciclo	0.58**	-0.67**	-		
Índice de coordinación	0.07	0.09	-0.01	-	
Envergadura	0.34**	-0.06	0.30*	0.20	-

* y ** Diferencias significativas para $p \leq 0.05$ y $p \leq 0.001$, respectivamente.

Discusión

Los valores del IdC obtenido evidencian que los nadadores estudiados organizan su sincronización entre miembros superiores en relación a la técnica de crol en *catch-up*. Estos resultados, obtenidos en la velocidad correspondiente a la prueba de 50 m, están en oposición a los descritos en la literatura para nadadores de edades y niveles deportivos superiores cuando efectúan esfuerzos a la misma intensidad relativa, los cuales presentan modelos coordinativos más próximos al crol de oposición y hasta de superposición (Schnitzler, Seifert, Alberty, Chollet, 2010; Seifert et al., 2010; Schnitzler et al., 2008; Seifert, Boulesteix, Chollet, 2004; Chollet et al., 2000). De hecho, los nadadores del presente estudio presentan una mayor duración relativa en la fase de entrada y agarre, y una menor duración en la tracción con respecto a lo descrito en la literatura. Del mismo modo, los resultados describen una superioridad en el sumatorio de las fases propulsivas en el grupo de elite (Chollet et al., 2000), o por lo menos una igualdad porcentual (Schnitzler et al., 2008), ocurriendo lo contario (mayor porcentaje de las fases no propulsivas) en nuestro grupo de nadadores jóvenes. De hecho, los nadadores del presente estudio presentan una mayor duración relativa en la fase de entrada y agarre, y una menor duración en la tracción relativamente a lo descrito en la literatura. Este hecho sugiere que el desarrollo de la coordinación motora en adultos no puede ser el mismo aplicado en niños, particularmente en natación (Malina, 1996). En este sentido, el proceso de crecimiento y maduración parece interferir decisivamente en la sincronización entre miembros superiores en la técnica de crol. Del mismo modo, estos valores parecen indicar que, tal y como referencia Vorontsov (2005), es en la fase de la pubertad donde la cinemática y la estructura dinámica de la técnica se establecen, tanto en niñas como en niños. Así, hasta esta edad, el entrenamiento de los jóvenes nadadores debía orientarse hacia el aprendizaje de habilidades motoras, desarrollando la fuerza corporal y la flexibilidad.

Cuando comparamos la muestra en función del sexo se verifican valores superiores para los niños en las variables de velocidad y FG, lo que podría ser explicado por la diferencia en los parámetros de envergadura, donde el sexo masculino presenta valores más elevados. Sin embargo, a pesar de tenerse observado diferencias en la altura y envergadura entre sexos, los valores de distancia de ciclo fueron idénticos entre estos grupos. Este hecho parece indicar un bajo aprovechamiento de la amplitud de las acciones de los miembros superiores en los niños. Por otro lado, el hecho de que las niñas desarrollan su crecimiento antes y ganan peso, por término medio dos años antes que nos niños, podría ser otro factor determinante para esta diferencia, demostrando un mayor control por parte de las niñas en esta edad (Vorontsov, 2010). Efectivamente, cuando nosotros estudiamos a nadadores de nivel deportivo nacional o internacional, se demuestra que los nadadores presentan valores de DC significativamente superiores a las nadadoras (Arellano, Brown, Cappaert, Nelson, 1994; Fernandes, Marinho, Barbosa y Vilas-Boas, 2006; Seifert, Chollet, Chatard, 2007). Además, se puede observar una mejor duración relativa de la fase de recuperación en las mujeres en relación a los hombres. Sin embargo, esa diferencia no parece tener un gran significado en la coordinación entre los miembros superiores pues, cuando se compararon las fases propulsivas y no propulsivas, no fueron observadas diferencias significativas entre los subgrupos sexuales.

Las relaciones directas entre la velocidad y la distancia de ciclo parecen evidenciar que los nadadores jóvenes son más rápidos por mantener mayores amplitudes. También se comprueba que, los nadadores que presentan mayores registros en la envergadura parecen ser los que tendrán mejores resultados, pues su DC y, consecuentemente, la velocidad son mayores. La relación inversa entre la FG y la DC está de acuerdo con la literatura (Alberty et al., 2005; Schnitzler et al., 2010), evidenciando que, para llegar a una cierta velocidad existen diversas combinaciones de estos parámetros, cuando la FG aumenta, la DC desminuye, y viceversa, sin poder aumentar simultáneamente (Seifert et al., 2006).

Cnclusiones

Teniendo como objetivo el estudio del IdC en la categoría infantil, a velocidad elevada de nado, podemos afirmar que existen diferencias entre los grupos de élite y de formación. El tipo de coordinación realizada por los nadadores infantiles es en catch-up (IdC<0).

También podemos comprobar que los niños son más veloces que las niñas. Sin embargo, no se observaron diferencias en la DC entre sexo como ocurre en nadadores de elite.

De este modo, sugerimos que el entrenamiento coordinativo en esta etapa formativa sea todavía más estimulado, proponiendo ejercicios que promuevan una mayor continuidad de las acciones propulsivas y, de esta forma, una técnica de nado más eficiente para velocidades elevadas (las cuales serán aplicadas en situación competitiva).

Appendix 3

Arm Symmetry in 11-13 years old Front Crawl Swimmers

Ana Silva[1], Pedro Figueiredo[1,2], Susana Soares[1], João Paulo Vilas-Boas[1,2], Ricardo J. Fernandes[1,2]

[1] CIFI2D, Faculty of Sport, University of Porto, Porto, Portugal
[2]Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Porto, Portugal

Abstract

The purpose of this study was to analyse the arm symmetry in age-group swimmers performing front crawl at very high intensity. Eighty trained swimmers of 11-13 years of age performed 25-m front crawl at 50-m pace. Two underwater cameras were used to assess the Index of Coordination (identifying each stroke phase) and the Symmetry Index. It was observed an asymmetry, which is in accordance with the results obtained for adult swimmers. It was also observed that only catch up mode was adopted by these young swimmers to achieve the swimming intensities corresponding to 50-m front crawl pace. Complementarily, the observed lower relative duration of the propulsive phases seems to be explained by the higher time spent during the entry/catch phase.

KEY WORDS: swimming, front crawl, arm symmetry, age group, kinematics

Introduction

The front crawl technique, which is the fastest form of human aquatic locomotion, is often used in training and competition (Tourny-Chollet et al., 2009). This swimming technique is described as alternated, once when one arm is propelling, the other is recovering. However, this alternated action of the arms seems not to guarantee propulsion symmetry (Tourny-Chollet et al., 2009). In fact, as Seifert et al (2005) noticed, most of the front crawl swimmers adopt asymmetric arm coordination, which is characterized by a propulsive discontinuity of one arm action and propulsive superposition of the other arm.

To assess the arm symmetry in swimming, it was recently proposed the Symmetry Index (cf. Tourny-Chollet et al., 2009) that was adapted from Robinson's Symmetry Index (1987) applied to walking. However, to assess the Symmetry Index (SId) it has to be previously calculated the Index of Coordination (IdC). This last index, proposed by Chollet et al (2000), is based on the measurement of the lag time between the propulsive phases of the two arms. In addition, nevertheless it has been recently shown that it might not exist a common optimal movement pattern in high performance sports, common coordination patterns have been reported (Seifert et al, 2003), enabling, for instance, the distinction between skilled and less skilled performers.

The aim of this study was to characterize the SId (and the IdC) in 11-13 years old swimmers performing front crawl at very high intensity. For a more detailed, subjects were also studied by gender and maturation.

Methods

Eighty swimmers (forty boys and forty girls) from the infant competitive swimming age group competitive category (girls of 11-12 and boys of 12-13 years of age) volunteered for this study. According to Tanner [27], images relating to the development of secondary sex characteristics were presented to the swimmers, and a self-evaluation rating (based in five stages) was carried on. Afterwards, the same images were presented to swimmer's parents and coaches separately. The final result was expressed as the mean value of these three evaluations.

All swimmers performed 25-m front crawl at 50-m race pace (controlled by their respective coach). In-water starts were used, and each subject swam alone. Two underwater video cameras (Sony® DCR-HC42E) recording the sagital and the transverse planes, and placed inside a sealed housing (SPK - HCB) recorded two complete underwater arm stroke cycles. To transform the virtual in real coordinates it was used a bidimensional structure (6.30-m^2, and thirteen calibration points). Biomechanical analysis was performed with the software APASystem (Ariel Dynamics, Inc., USA), being digitized frame by frame (at 50 Hz), two consecutive non-inspiratory cycles, particularly the hip (femoral condyle), and, on both sides of the body, the distal end of the middle finger, the wrist, the elbow, the shoulder, the knee and the ankle.

Following Chollet et al. (2000), the IdC corresponds to the time from the beginning of the propulsive phase of one arm to the end of the propulsive phase of the other arm. IdC was calculated based on the division of the arm's actions in four phases: (i) entry/catch, corresponding to the time since the entry of the hand in the water until it starts to make the backward movement; (ii) pull, since the end of the previous action until achieve the vertical alignment of the shoulder (first propulsive phase); (iii) push, since the end of the previous action to the exit the hand of the water (second propulsive phase) and (iv) recovery, covering the time from the exit of the hand until its new emersion. The duration of a complete arm stroke was the sum of the propulsive and non propulsive phases.

The IdC was calculated for both arms, being defined as the time gap between the beginning of pull in the first right arm stroke and the end of the push in the first left arm stroke (IdC_{left}), and as the time gap between the beginning of pull in the second left arm stroke and the end of the push in the first right arm stroke (IdC_{rigth}) (Chollet et al., 2000). Following these authors, the IdC, and each stroke phases, were expressed as the percentage of the duration of a total arm stroke. The sum of the pull and the push phases, and of the catch and the recovery phases, gave the duration of the propulsive and non propulsive phases, respectively. With these two IdC values (IdC_{left} and IdC_{rigth}) it was possible to determine the arm coordination symmetry, which was calculated as following (cf. Tourny-Chollet et al., 2009):

$$[IdC_{left} – IdC_{right}/ 0,5(IdC_{left} + IdC_{right})] \times 100$$

Accordingly with the above referred authors, it is observed symmetry between left and right IdC when -10% < SId < 10%, and it is observed asymmetry when SId is above 10% (asymmetry to the right side) or below -10% (asymmetry to the left side) (Herzog et al., 1989).
Normal distribution of data and the interaction between gender and maturation were verified before statistical analysis. Comparisons of means between maturational groups were performed through an ANOVA test for independent groups, followed by a Bonferroni post-hoc test. Gender comparisons were performed using a t-test for independent groups. Significance level was 5%.

Results

It was observed mean ± SD values for IdC of -7.94 ± 4.42 (%), evidencing that only the catch up coordination mode was adopted by these young swimmers when performing front crawl at very high intensity; this data and the IdC values by maturation and gender groups are shown in Figure 1 (not existing any statically differences between groups). The sum of the propulsive and of the non propulsive phases for all the sample (independently of swimming maturation or gender) was of, approximately, 42 and 57% (respectively).

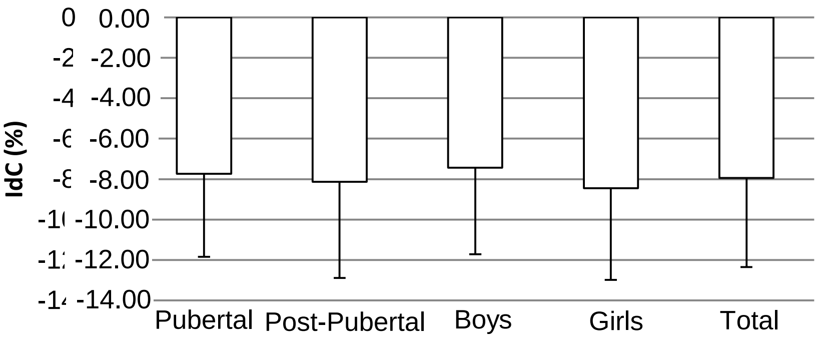


Figure 1. Mean and standard deviation IdC values (%) for maturation and gender groups, and for the total sample.

Regarding the main aim of this study, it seems that swimmers, as a group, presented a symmetric arm action, with a tendency to an asymmetry to the right side (SId = 4.24 ± 115.47, being -300 the minimum and 370 de maximum registed). Likewise, when comparing maturation groups, it was registered symmetric values for pubertal (the mean was 0.92 ± 127.58, the minimum registed was – 300 and the maximum was 333) and post-pubertal (7.55 ± 103.49 ranging between the values of -169 and 370) swimmers, with no differences observed between groups. However, analyzing the SD values, this symmetry was not so clear, showing that the sample is very heterogeneous. Conversely, when a comparison by gender was made, it were observed asymmetric values to the right side for boys (28.19 ± 117.23) and to the left side for girls (-19.71 ± 109.96) (but without differences between groups). However, IdC_{left} (-7.46 ± 5.78 and -7.94 ± 5.93 for boys and girls, respectively) and IdC_{right} (-7.28 ± 5.85 for boys and -9.28 ± 5.36 for girls) were observed and, when compared, did not show any statistical differences between them. Relatively to the arm phases for the left and right arm, only the push phase to the left side showed statistical differences, which is longer for boys (25.90 ± 3.51 for boys and 24.30 ± 2.84 for girls). The entry/catch phase was the longer phase (~33%). The pull phase was the smallest phase (~18%) and the recovery phase showed values of ~24%.

Discussion

As it was highlight above, independently of their gender and maturation, young swimmers adopted the catch-up coordination mode to perform the front crawl at high intensity, i.e., at velocities corresponding to their 50-m race pace. Although the post-pubertal and girls groups showed a tendency to exhibit lower values than pubertal and boys groups, respectively, there were no statistical differences between them. This fact is not coincident with the specialized literature conducted in older swimmers which evidenced that, at very high velocities, elite male (Millet et al, 2002; Schnitzler et al, 2007; Seifert et al, 2006) and elite swimmers from both genders (Chollet et al, 2000; Seifert et al, 2003b) always exhibited superposition coordination (expressing IdC values higher than zero).

As referred above, no statistical differences were noticed in IdC independently of swimmers maturation and gender. These results could be explained by the maturational perspective of motor development (Tourny-Chollet et al, 2009) since, nevertheless the organismic constraints (e.g. anthropometrical characteristics and maturation state) might imply some differences between swimmers, the task in which they were involved was similar. In fact, despite of the age differences, these swimmers belong to the same competitive age-group, and to swimming clubs with the presumably similar planning and periodization strategies since the respective coaches had also similar academic education. In addition, their competition is organized in groups where girls are younger than boys. According to Vorontsov (2010), girls begin their maturation earlier than boys, which can justify why the entire sample shows similar values. In fact, towards the age of 11-12 years, the adult kinematics and dynamic structure of swimming technique establishes both in girls and boys (Vorontsov, 2010), suggesting that the differentiation between genders only occurs when maturation is completed.

Complementarily, our age group swimmers spent lower relative duration in the overall propulsive phases rather than elite swimmers performing at very high intensity (>50%) (Chollet et al, 2000; Millet et al, 2002; Schnitzler et al, 2007; Seifert et al, 2003; Seifert et al, 2003b). Conversely, the values of non propulsive phases obtained by our swimmers is, to the best of our knowledge, the highest value of the literature, being the result of a longer entry/catch phase; the present age group swimmers spent more time in entry/catch phase than adults (~20%) (Chollet et al, 2000; Schnitzler et al, 2007; Seifert et al, 2003; Seifert et al, 2003b).

The mean values – indicating symmetry – obtained for the entire sample seems to be justified because after dividing the sample it was observed that boys adopted asymmetry to the right side and girls to the left side, which leads the mean to be closer to zero. This fact also leads the pubertal and post-pubertal groups to exhibited symmetrical mean values. When comparing genders (despite maturation groups), although girls showed a smaller values both genders exhibited asymmetry, but boys had asymmetry to the right side and girls to the left side. These results related to asymmetry are in accordance to Seifert et al (2005), whom noticed that the most of the front crawl adult swimmers adopted asymmetric arm coordination suggested that asymmetry may thus be a true coordination mode and not just a functional error (Tourny-Chollet et al, 2009). According to these authors (Seifert et al, 2005; Tourny-Chollet et al, 2009) this asymmetry could be as a result of the unilateral breathing usually reinforced by learning and training.

Regarding to the arm left and right phases, the difference between genders in left push phase could explain this asymmetry. This longer phase showed by boys lead them to exhibited slightly high values (although not statistical significant) of IdC_{right} compared with girls. In this sense, boys try to maximize the strength of the right arm, which could be their dominant arm, to increase propulsion.

Conclusion

Only catch up mode was resisted in young swimmers when swimming front crawl at very high intensity. The observed lower relative duration of the propulsive phases was due to the higher time spent during the entry/catch phase. An asymmetry to the right side for boys and to the left side for girls were registered, which could be the result of the unilateral breathing usually reinforced by learning and training (as noticed before by Nikodelis et al., 2005 and Tourny-Chollet et al., 2009), but also due to the fact that young swimmers are in the middle of their maturational development.

Chapter 6

References

Chapter 1

Armstrong, L.; Welsman, J. (2002). Young people and physical activity. Oxford: Oxford University Press.

Cappaert J. M.; Pease D.; Troup J. P. (1995) Threedimentsional analysis of the men's 100-m Freestyle during the 1992 Olympic games. Journal Applied Biomechanics, 11, 103 – 112.

Chollet D.; Charlies S.; Chatard C. (2000) A New Index of Coordination for the Crawl Description and Usefulness. International Journal of Sports Medicine, 21, 54 – 59.

Chollet D.; Pelayo P.; Tournay C.; Sidney M. (1996) Comparative analysis of 100 m and 200 m events in the four strokes in top level swimmers. Journal of Human Movement Studies, 31, 25 – 37.

Costill D. L.; Kovaleski J.; Porter D.; Kirwan J.; Fielding R.; King D. (1985) Energy expenditure during Front Crawl Swimming: predicting success in middle-distance events. International Journal of Sports Medicine, 6, 266 – 270.

Costill D. L.; Maglischo B. W.; Richardson A. B. (1992) Swimming. Oxford: Blackwell Scientific Publications.

Figueiredo P.; Sousa A.; Gonçalves P.; Pereira S. M.; Soares S.; Vilas-Boas J. P.; Fernandes R. J. (2010) Biophysical Analysis of the 200m Front Crawl Swimming: a Case Study. In P. L. Kjendlie, R. K. Stallman & J. Cabri (Eds.), *XIth International Symposium for Biomechanics and Medicine in Swimming* (pp. *79-81).* Oslo: Norwegian School of Sport Science.

Garrido N.; Marinho D. A.; Reis V. M.; Roland T.; Costa A. M.; Silva A. J.; Marques M. C. (2010) Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers?. Journal of Sports Science and Medicine, 9, 300 – 310.

Kolmogorov S. V.; Dublishcheva O. A. (1992) Active drag, useful mechanical power output and hydrodinamic force coefficient in different swimming strokes at maximal velocity. Journal of Biomechanics, 25, 311 – 318.

Kolmogorov S. V.; Rumyantseva O. A.; Gordon B. J.; Cappaert J. M. (1997) Hydrodinamic characteristics of competitive swimmers of different genders and performance levels. Journal of Applied Biomechanics, 13, 88 – 97.

Lätt E.; Jürimãe J.; Haljaste K.(2009) Longitudinal Development of Physical and Performance Parameters During Biological Maturation of Young Male Swimmers. Perceptual and Motor Skills, 108, 297 – 307.

Lerda R.; Cardelli C. (2003) Analysis of Stroke Organization in the Backstroke as a Function of SkilI. Research Quarterly for Exercise Sport, 74, 215 – 219.

Lerda R.; Cardelli C.; Coudereau J. P. (2005) Backstroke organization in Physical Education Students as a Function of Skill and Sex. Perceptual and Motor Skills, 100, 779 – 790.

Maglischo E.W. (2003). Swimming fastest. Human Kinetics.

Pendergast, D. R., Capelli, C., Craig Jr., A. B., di Prampero, P. E., Minetti, A. E., Mollendorf, J., Termin, A., Zamparo, P. (2006). In J. P. Vilas-Boas, F. Alves, A. Marques (Eds.), *Xth International Symposium for Biomechanics and Medicine in Swimming* (pp. 185-198). Porto: Revista Portuguesa de Ciências do Desporto.

Plantonov, V. N.; Fessenko, S. L. (1994). Los sistemas de entrenamiento de los mejores nadadores del mundo – Volume I. Editorial Paidotribo.

Sanders, R. S. (1999). Hydrodinamic characteristics of a swimmer's hand. Journal of Applied Biomechanics, 15, 3 – 26.

Querido A.; Marques-Aleixo I.; Figueiredo P.; Seifert L.; Chollet D.; Vilas-Boas J. P.; Daly D. J.; Corredeira R.; Fernades R. J. (2010) Front Crawl and Backstroke Arm Coordination in Swimmers with Down Syndrome. In P. L. Kjendlie, R. K. Stallman & J. Cabri (Eds.), XIth International Symposium for Biomechanics and Medicine in Swimming (pp. 157-159). Oslo: Norwegian School of Sport Science.

Schnitzler C.; Seifert L.; Ernwein V.; Chollet D. (2007) Arm Coordination Adaptation Assessment in Swimming. International Journal of Sports Medicine, 28, 1 – 7.

Seifert L.; Boulesteix L.; Carter M.; Chollet D. (2004) The spatial-temporal and coordinative structures in Elite Male 100-m Front Crawl Swimmers. International Journal of Sports Medicine, 26, 286 – 293.

Seifert L.; Boulesteix L.; Chollet D. (2003a) Effect of Gender on the Adaptation of Arm Coordination in Front Crawl. International Journal of Sports Medicine, 25, 217 – 223.

Seifert, L.; Chollet, D. (2008) Inter-limb Coordination and Constraints in Swimming: A Review. Nova Science Publishers, Inc., 3, 1 – 28.

Seifert L.; Chollet D.; Allard P. (2005) Arm Coordination Symmetry and breathing effect in front crawl. Human Movement Science, 24, 234 – 256.

Seifert L.; Chollet D.; Bardy B. G. (2003b) Effect of swimming velocity on arm coordination in the front crawl: a dynamic analysis. Journal of Sports Science, 22, 651 – 660.

Seifert L.; Chollet D.; Rouard, A. (2006) Swimming constraints and arm coordination. Human Movement Science, 26, 68 – 86.

Tanner, J. M. (1989). Foetus into Man. Physical Growth from conception maturity. Second Edition. Castlemead Publications.

Wright, B.; Smith, D. J. (1994). A protocol for the determination of critical speed as an índex of swimming endurance performance. In M. Miyashita, Y. Mutoh, A. B. Richardson (Eds.), *Medicine and Science in Aquatic Sports* (pp. 55-59). Basel: Medicine Sport Science.

Chapter 2

Arellano R.; Pardollp S. (1991) An evaluation of changes in the crawl-stroke techniques during training periods in a swimming season. In D. Mac Laren, T. Reilly, A. Lees (Eds.), *Swimming Science VI*, (pp. 143-149). Illions: Human Kinetics Publisher.

Barbosa, T.; Costa, M. (2010). Modeling the links between Young Swimmers'Performance: Energetic and Biomechanic Profiles. Pediatric Exercise Science, 22, 379 – 391.

Baxter-Jones, A. D. G.; Eisenmann, J.C.; Sherar, L.B. (2005). Controlling for Maturation. Pediatric Exercise Science, 17, 18 – 30.

Beckett K. D. (1985). Pulling a Fast One – A Double-arm pull off the wall may make your swimmers' flip turns faster. Swim Tech, 21, 27 – 29.

Beunen G.; Malina R. M. (2008) Growth and Biologic Maturation: Relevance to Athletic Performance. Malden: Blackwell Publishing, 1, 3 – 17.

Chollet D.; Charlies S.; Chatard C. (2000) A New Index of Coordination for the Crawl Description and Usefulness. International Journal of Sports Medicine, 21, 54.

Costill D. L.; Kovaleski J.; Porter D.; Kirwan J.; Fielding R.; King D. (1985) Energy expenditure during Front Crawl Swimming: predicting success in middle-distance events. International Journal of Sports Medicine, 6, 266 – 270.

Deschodt, V.J.; Arsac, L. M.; Rouard, A.H. (1999) Relative contribution of arms and legs in humans to propulsion in 25-m sprint front-crawl swimming. European Journal of Applied Physiology, 80, 192 – 199.

Greco C. C.; Pelarigo J. G.; Figueira T. R.; Denadai B. S. (2007) Critical Speed and Endurance Capacity in Young Swimmers: Effects of Gender and Age. Journal of Sport Science and Medicine, 6, 441 – 447.

Jürimãe J.; Haljaste K.; Cicchella A.; Lätt E.; Purge P.; Leppik A.; Jürimãe T. (2007) Analysis of Swimming Performance From Physical, Physiological, and Biomechanical Parameters in Young Swimmers. Human Kinetics, 19, 70 – 81.

Lätt E.; Jürimãe J.; Haljaste K. (2009) Longitudinal Development of Physical and Performance Parameters During Biological Maturation of Young Male Swimmers. Perceptive Motor Skills, 108, 297 – 307.

Malina R. M. (1984) Young Athletes: Biological, Psychological, and Educational Perspectives. Illinois: Human Kinetics.

Malina R. M.; Bouchard C.; Bar-Or O. (2004) Growth, maturation, and physical activity. (second edition). Illinois: Human Kinetics.

Millet G. P.; Chollet D.; Chalies S.; Chatard J. C. (2002) Coordination in Front Crawl in Elite Triathletes and Elite Swimmers. International Journal of Sports Medicine, 23, 99 – 104.

Newell, K. (1986). Motor Development in Children. Aspects of Coorfination and Control. Dordrecht: Martinus Nijhoff Publishers, 34, 341 – 360.

Nikodelis, T,; Kollias, I.; Hatzitaki, V. (2005). Bilateral inter-arm coordination in freestyle swimming: Effect of skill level and swimming speed, 23, 737 – 745.

Pelayo P.; Sidney M.; Kherif T.; Chollet D.; Tourny C. (1996) Stroking Characteristics in Freestyle Swimming and Relationship With Anthropometric Characteristics. Journal of Applied Biomechanics, 12, 197 – 206.

Potdevin F.; Brill B.; Sidney M.; Pelayo P. (2004) Stroke Frequency and Arm Coordination in Front Crawl Swwiming. International Journal of Sports Medicine, 27, 193 – 198.

Saavedra, J. M.; Escalante, Y. (2010) A Multivariate Analysis of Performance in Young Swimmers. Pediatric Exercise Science, 22, 135 – 151.

Schnitzler C.; Ernwein, V.; Seifert, L.; Chollet, D. (2006). Intracyclic velocity signal as tool to evaluate propulsive phase duration. In J. P. Vilas-Boas, F. Alves, A. Marques (Eds.) In *Xth International Symposium Biomechanics and Medicine in Swimming* (pp. 88-90) Porto: Revista Portuguesa de Ciencias do Desporto.

Schnitzler C.; Seifert L.; Chollet D. (2008) Variability of coordination parameters at 400-m front crawl swimming pace. Journal of Sport Science Medicine, 8, 203 – 210.

Schnitzler C.; Seifert L.; Ernwein V.; Chollet D. (2007) Arm Coordination Adaptation Assessment in Swimming. International Journal of Sports Medicine, 28, 1 – 7.

Seifert L. (2010) Inter-Limb Coordination in Swimming. Biomechanics and Medicine in In P. L. Kjendlie, R. K. Stallman & J. Cabri (Eds.), *XIth International Symposium for Biomechanics and Medicine in Swimming* (pp. *35-38).* Oslo: Norwegian School of Sport Science.

Seifert, L.; Boulesteix, L.; Chollet, D. (2003a). Effect of Gender on the Adaptation of Arm Coordination in Front Crawl. International Journal of Sports Medicine, 25, 217 – 223.

Seifert, L.; Boulesteix, L.; Chollet, D.; Vilas-Boas, J. P. (2008) Differences in spatial-temporal parameters and arm–leg coordination in butterfly stroke as a function of race pace, skill and gender. Human Movement Science, 27, 96 – 111.

Seifert L.; Chollet D.; Bardy B. G. (2003b) Effect of swimming velocity on arm coordination in the front crawl: a dynamic analysis. Journal of Sports Science, 22, 651 – 660.

Seifert, L.; Chollet, D.; Chatard, J. C. (2007) Kinematic Changes during a 100-m Front Crawl: Effects of Performance Level and Gender. Medicine Science Sports Exercise, 39, 1784 – 1792.

Seifert, L.; Chollet, D.; Rouard, A. (2006). Swimming constraints and arm coordination. Human Movement Science, 26, 68 – 86.

Tanner J. M.; Whitehouse R. H. (1982) Atlas of Children's Growth Normal Variation and Growth Disorders. London: Academic Press.

Toussaint, H. B.; Beek, P. J. (1992). Biomechanics of Competitive Front Crawl Swimming. Sports Medicine, 13: 8 – 24.

Vitor, F. M.; Böhme, M. T. (2010). Performance of Young Male Swimmers in the 100-Meters Front Crawl. Pediatric Exercise Science, 22, 278 – 287.

Vorontsov, A. (2010). Strength and Power Training in Swimming. Nova Science Publishers, Inc.,16, 1 – 31.

Vorontsov, A. R.; Binevsky, D. A.; Filonov, A. Y.; Korobova, E. A. (2002). The Impact of Individual's Maturity up on Strength in Young Swimmers. Russian State Academy of Physical Education, 11, 321 – 326.

Zamparo, P. (2006). Efect of age and gender on the propelling efficiency of the arm stroke. European Journal Applied Physiology, 97, 52 – 58.

Chapter 3

Alves, E. (1996). Average Resuitant Impulse per Phase in Swimming: A Tool for Technicai Analysis. In L. Abrantes (Eds.). *Proceedings of the XIV Symposium on Biomechanics in Sports* (pp. 281-284). Lisboa: Edições FMH.

Andrews, C.; Bakewell, J.; Scurr, J. C. (2011). Comparison of advanced and intermediate 200-m backstroke swimmers' dominant and non-dominant shoulder entry angles across various swimming speeds. Journal of Sports Sciences, 29, 743 – 748.

Barbosa, T.; Costa, M.; Marinho, D. A.; Coelho, J.; Moreira, M.; Silva, A. J. (2010). Modeling the Links Between Young Swimmers'Performance: Energetic and Biomechanic Profiles. Pediatric Exercise Science, 22, 379 – 391.

Barbosa, T.; Fernandes, R. J.; Morouco, P.; Vilas-Boas, J. P. (2008). Predicting the intra-cyclic variation of the velocity of the centre of mass from segmental velocities in butterfly stroke: A pilot study. Journal of Sports Science and Medicine, 7, 201-209.

Chatard, J. C.; Bourgoin, B.; Lacour, J. R. (1990). Passive drag is still a good evaluator of swimming aptitude. European Journal of Applied Physiology, 59, 399 – 404.

Chollet, D.; Charlies, S.; Chatard, C. (2000). A New Index of Coordination for the Crawl Description and Usefulness. International Journal of Sports Medicine, 21, 54 – 59.

Chollet, D.; Pelayo, P.; Tournay. C.; Sidney, M. (1996). Comparative analysis of 100 m and 200 m events in the four strokes in top level swimmers. Journal Human Movement Studies, 31, 25 – 37.

Chollet, D.; Seifert, L. M.; Carter, M. (2008). Arm coordination in elite backstroke swimmers. Journal of Sports Sciences, 26, 675 – 682.

Costill, D. L.; Kovaleski, J.; Porter, D.; Kirwan, J.; Fielding, R.; King. D. (1985). Energy Expenditure During Front CrawlSwimming: Preddicting Sucess in Middle-Distance Events. International Journal of Sports Medicine, 6, 266 – 270.

Fernandes, R. J.; Sousa, M.; Pinheiro, A.; Vilar, S.; Colaço, P.; Vilas-Boas, J. P. (2010). Assessment of individual anaerobic threshold and stroking parameters in swimmers aged 10-11 years. European Journal of Sport Science, 10, 311 – 317.

Girold, S.; Chatard, J. C.; Cossor, J.; Mason, B. (2001). Specific strategy for the medalists versus finalists and semi-finalists in the men's 200m backstroke at the Sydney Olympic Games. In J. P. Vilas-Boas, F. Alves, A. Marques (Eds.), *Xth International Symposium for Biomechanics and Medicine in Swimming* (pp. 27-29). Porto: Revista Portuguesa de Ciências do Desporto.

Jürimãe, J.; Haljaste, K.; Cicchella, A.; Lätt, E.; Purge, P.; Leppik, A.; Jürimãe, T. (2007). Analysis of Swimming Performance from Physical, Physiological, and Biomechanical Parameters in Young Swimmers. Pediatric Exercise Science, 19, 70 – 81.

Lerda, R.; Cardelli, C. (2003a). Analysis of Stroke Organization in the Backstroke as a Function of SkiII. Research Quarterly for Exercise and Sport, 74, 215 – 219.

Lerda, R.; Cardelli, C. (2003b). Breathing an Propelling in Crawl as a Function of Skill and Swim Velocity. International Journal of Sports Medicine, 24, 75 – 80.

Lerda, R.; Cardelli, C.; Coudereau, J. P. (2005). Backstroke organization in Physical Education Students as a Function of Skill and Sex. Perceptual and Motor Skills, 100, 779 – 790.

Maglischo E.W. (2003). Swimming fastest. Human Kinetics.

Malina, R. (1984). Young Athletes: Biological, Psychological, and Educational Perspectives. Illinois: Human Kinetics.

Millet, G. P.; Chollet, D.; Chalies, S.; Chatard, J. C. (2002). Coordination in Front Crawl in Elite Triathletes and Elite Swimmers. International Journal of Sports Medicine, 23, 99 – 104.

Medic, N.; Young, B. W.; Starkes, J. L.; Weir, P. L.; Grove, J. R. (2009). Gender, age, and sport diferences in relative age effects among US Masters swimming and track and field athletes. Journal of Sports Sciences, 27, 1535 – 1544.

Newell, K. (1986) Motor Development in Children. Aspects of Coorfination and Control. Dordrecht: Martinus Nijhoff Publishers, 34, 341 – 360.

Nikodelis, T.; Kollias, I.; Hatzitaki, V. (2005). Bilateral inter-arm coordination in freestyle swimming: Effect of skill level and swimming speed. Journal of Sport Science, 23, 737 – 745.

Pelayo, P.; Sidney, M.; Kherif, T.; Chollet, D.; Tourny, C. (1996) Stroking Characteristics in Freestyle Swimming and Relationship with Anthropometric Characteristics. Journal of Applied Biomechanic, 12, 197 – 206.

Poujade, B.; Hautier, C. A.; Rouard, A. (2002). Determinants of the energy cost of front crawl swimming in children. European Journal of Applied Physiology, 87, 1 – 6.

Psycharakisi, S. G.; Sanders, R. H. (2010). Body roll in swimming: a review. Journal of Sports Sciences, 28, 229 – 236.

Schleihauf, R. E.; Higgings, J. R.; Hinrichs, R.; Luedtke, D.; Maglischo, C.; Maglischo, E. W.; Thayer, A. (1988). Propulsive Techniques: Front Crawl Stroke, Butterfly, Backstroke, and Breaststroke. *Swimming Science V*. Illions: Human Kinetics Publisher.

Schnitzler, C.; Seifert, L.; Ernwein, V.; Chollet, D. (2007). Arm Coordination Adaptation Assessment in Swimming. International Journal of Sports Medicine, 28, 1 – 7.

Seifert, L.; Boulesteix, L.; & Chollet, D. (2003). Effect of Gender on the Adaptation of Arm Coordination in Front Crawl. International Journal of Sports Medicine, 25, 217 – 223.

Seifert, L.; Boulesteix, L.; Carter, M.; Chollet, D. (2004). The spatial-temporal and coordinative structures in Elite Male 100-m Front Crawl Swimmers. International Journal of Sports Medicine, 26, 286 – 293.

Seifert, L.; Chollet, D.; Rouard, A. (2006). Swimming constraints and arm coordination. Human Movement Science, 26, 68 – 86.

Seifert, L.; Toussaint, M. H.; Alberty, M.; Schnitzler, C.; Chollet, D. (2010). Arm coordination, power, and swim efficiency in national and regional front crawl swimmers. Human Movement Science, 29, 426 – 439.

Tanner, J. M.; Whitehouse R. H. (1982). Atlas of Children's Growth Normal Variation and Growth Disorders. London: Academic Press.

Chapter 4

Chollet, D.; Charlies, S.; Chatard C. (2000). A New Index of Coordination for the Crawl Description and Usefulness. International Journal of Sports Medicine, 21, 54 – 59.

Chollet, D.; Seifert, L. M.; Carter, M. (2008). Arm coordination in elite backstroke swimmers. Journal of Sports Science, 26, 675 – 682.

Colwin C. M. (2002). Breakthrough swimming. Champaign: Human Kinetics.

Fernandes, R. J.; Marinho, D. A.; Barbosa, T. M.; Vilas-Boas, J. P. (2006) Is time limit at the minimum swimming velocity of VO2max influenced by stroking parameters?. Perceptive Motor Skills, 1, 67 – 75.

Lerda, R.; Cardelli, C. (2003). Analysis of Stroke Organization in the Backstroke as a Function of SkilI. Research Quarterly for Exercise and Sport, 74, 215 – 219.

Lerda, R.; Cardelli, C.; Coudereau, J. P. (2005). Backstroke organization in Physical Education Students as a Function of Skill and Sex. Perceptuel and Motor Skills, 100, 779 – 790.

Maglischo, E. W. (2003) Swimming fastest. Human Kinetics.

Nikodelis, T.; Kollias, I.; Hatzitaki, V. (2005). Bilateral inter-arm coordination in Freestyle swimming: Effect of skill leveland swimming speed. Journal of Sports Science, 23, 737 – 745.

Potdevin, F.; Brill, B.; Sidney, M.; Pelayo, P. (2004) Stroke Frequency and Arm Coordination in Front Crawl Swwiming. International Journal of Sports Medicine, 27, 193 – 198.

Querido A.; Marques-Aleixo I.; Figueiredo P.; Seifert L.; Chollet D.; Vilas-Boas J. P.; Daly D. J.; Corredeira R.; Fernades R. J. (2010) Front Crawl and Backstroke Arm Coordination in Swimmers with Down Syndrome. In P. L. Kjendlie, R. K. Stallman & J. Cabri (Eds.), XIth International Symposium for Biomechanics and Medicine in Swimming (pp. 157-159). Oslo: Norwegian School of Sport Science.

Richardson, A. B.; Jobe, F. W.; Collins, H. R. (1980). The shoulder in competitive swimming. American Journal of Sports Medicine, 8, 159 – 163.

Saavedra J. M.; Escalante, Y.; Rodriguez, F. A. (2010). A Multivariate Analysis of Performance in Young Swimmers. Pediatric Exercise Science, 22: 135-151.

Seifert, L.; Boulesteix,; L.; Carter, M.; Chollet, D. (2004). The spatial-temporal and coordinative structures in Elite Male 100-m Front Crawl Swimmers. International Journal of Sports Medicine, 26, 286 – 293.

Seifert, L.; Chollet, D. (2008). Inter-limb Coordination and Constraints in Swimming: A Review. Nova Science Publishers, Inc. 3, 1 – 28.

Seifert, L.; Chollet, D.; Chatard, J. C. (2007). Kinematic Changes during a 100-m Front Crawl: Effects of Performance Level and Gender. Medicine Science Sports Exercice, 39, 1784 – 1792.

Tourny-Chollet, C.; Seifert, L.; Chollet, D. (2009). Effect of Force Symmetry on Coordination in Crawl. International Journal of Sports Medicine, 30, 182 – 187.

Vilas-Boas, J. P. (1998). A avaliação objectiva dos factores de rendimento em nadadores: contributo para o desenvolvimento da natação em Portugal. Documento de apoio à disciplina Metodologia I - Natação. FCDEF-UP, Porto.

Appendix 1

Alberty, M.; Potdevin, F.; Dekerle, J.; Pelayo, P.; Gorce, P.; Sidney, M. (2008). Changes in swimming technique during time to exhaustion at freely chosen and controlled stroke rates. Journal of Sports Sciences, 26, 1191 – 1200.

Chollet, D.; Charlies, S.; Chatard, C. (2000). A New Index of Coordination for the Crawl Description and Usefulness. Sports Medicine, 21, 54 – 59.

Fernandes, R. J.; Marinho, D. A.; Barbosa, T. M.; Vilas-Boas, J. P. (2006). Is time limit at the minimum swimming velocity of VO2max influenced by stroking parameters?. Perceptive Motor Skills, 1, 67 – 75.

Potdevin, F.; Brill, B.; Sidney, M.; Pelayo, P. (2004) Stroke Frequency and Arm Coordination in Front Crawl Swwiming. International Journal of Sports Medicine, 27, 193 – 198.

Seifert, L.; Boulesteix, L.; Carter, M.; Chollet, D. (2004). The spatial-temporal and coordinative structures in Elite Male 100-m Front Crawl Swimmers. Sports Medicine, 286 – 293.

Seifert, L.; Chollet, D.; Allard, P. (2005). Arm Coordination Symmetry and breathing effect in front crawl. Human Movement Science, 24, 234 – 256.

Seifert, L.; Chollet, D.; Chatard, J. C. (2007). Kinematic Changes during a 100-m Front Crawl: Effects of Performance Level and Gender. Medicine Science Sports Exercise, 39, 1784 – 1792.

Seifert, L.; Chollet, D.; Rouard, A. (2006). Swimming constraints and arm coordination. Human Movement Science, 26, 68 – 86.

Seifert, L. ; Leblanc, H.; Chollet, D.; Delignières, D. (2010). Inter-limb coordination in swimming: Effect of speed and skill level/ Human Movement. Human Movement Science, 29, 103 – 113.

Tourny-Chollet, C.; Seifert, L.; Chollet, D. (2009). Effect of Force Symmetry on Coordination in Crawl. International Journal of Sports Medicine, 30, 182 – 187.

Vilas-Boas, J. P. (1998). A avaliação objectiva dos factores de rendimento em nadadores: contributo para o desenvolvimento da natação em Portugal. In: Documento de apoio à disciplina Metodologia I - Natação. Porto: FCDEF-UP.

Appendix 2

Alberty, M.; Sidney, M.; Huot-Marchand, F.; Hespel, J. M.; Pelayo, P. (2005). Intracyclic velocity variations and arm coordination during exhaustive exercise in front crawl stroke. International Journal of Sports Medicine, 471 – 475.

Arellano, R.; Brown, P.; Cappaert, J.; Nelson, R. C. (1994). Analysis of 50-, 100-, and 200-m freestyle swimmers at the 1992 Olympic games. Journal of Biomechanics, 10, 189 – 199.

Biomechanics and Medicine in Swimming XI (2010). Nordbergtrykk: Norwegian School of Sport Science.

Chollet, D.; Charlies, S.; Chatard, C. (2000). A New Index of Coordination for the Crawl Description and Usefulness. Sports Medicine, 54 – 59.

Deschodt, V. J.; Arsac, L. M.; Rouard, A. H. (1999). Relative Contribution of arms and legs in humans to propulsion in 25-m sprint front-crawl swimming. European Journal of Apllied Physiology, 80, 192 – 199.

Fernandes, R. J.; Marinho, D. A.; Barbosa, T. M.; Vilas-Boas, J. P. (2006). Is time limit at the minimum swimming velocity of VO2max influenced by stroking parameters?. Perceptual Motor Skills, 103: 67 – 75.

Figueiredo, P.; Vilas-Boas, J. P.; Seifert, L.; Chollet, D.; Fernandes, R. J. (2010). Inter-Limb Coordinative Structure in a 200 m Front Crawl Event. The Open Sports Science Journal, 25 – 27.

Maglischo, E. W. (2003). Swimming Fastest. Champaign, Illinois: Human Kinetics.

Malina, R. M. (1996). The young athlete: biological growth and maturation in a biocultural context. In: F. L. Smoll, R. E. Smith (eds.), Children and youth in sport. A biopsychosocial perspective, pp. 161 – 186. WCB/McGraw-Hill, USA.

Querido A.; Marques-Aleixo I.; Figueiredo P.; Seifert L.; Chollet D.; Vilas-Boas J. P.; Daly D. J.; Corredeira R.; Fernades R. J. (2010) Front Crawl and Backstroke Arm Coordination in Swimmers with Down Syndrome. In P. L. Kjendlie, R. K. Stallman & J. Cabri (Eds.), XIth International Symposium for Biomechanics and Medicine in Swimming (pp. 157-159). Oslo: Norwegian School of Sport Science.

Saavedra J. M.; Esclante, Y. (2010). A Multivariate Analysis of Performance in Young Swimmers. Pediatric Exercise Science, 22, 135 – 151.

Schnitzler, C.; Seifert, L.; Alberty, M.; Chollet, D. (2010). Hip Velocity and Arm Coordination in Front Crawl Swimming. International Journal of Sports Medicine, 31, 875 – 881.

Schnitzler, C.; Seifert, L.; Ernwein, V.; Chollet, D. (2008). Arm coordination adaptations assessment in swimming. International Journal of Sports Medicine, 29, 480 – 486.

Seifert, L.; Boulesteix, L.; Carter, M.; Chollet, D. (2004). The spatial-temporal and coordinative structures in Elite Male 100-m Front Crawl Swimmers. International Journal of Sports Medicine, 286 – 293.

Seifert, L.; Chollet, D.; Chatard, J. C. (2007). Kinematic Changes during a 100-m Front Crawl: Effects of Performance Level and Gender. American College of Sports Medicine, 1784 – 1792.

Seifert, L.; Chollet, D.; Rouard, A. (2006). Swimming constraints and arm coordination. Human Movement Science, 68 – 86.

Seifert, L.; Toussant, H. M.; Alberty, M.; Schnitzler, C.; Chollet, D. (2010). Arm coordination, power, and swim efficiency in national and regional front crawl swimmers. Human Movement Science, 29, 426 – 439.

Vorontsov, A. (2005). Periodisation of multi-year preparation of young swimmers. – Programme of Long Term Athletic Development. In A. Petriaev (Td.), Swimming III: Research, training, hydro-rehabilitation (pp. 194 – 207), St.-Petersburg, Science Resarch Institute for Physical Culture and Sport.

Vorontsov, A. (2010). Strength and Power Training in Swimming. Nova Science Publishers, 16, 1 – 31.

Appendix 3

Chollet, D.; Charlies, S.; Chatard, C. (2000). A New Index of Coordination for the Crawl Description and Usefulness. International Journal of Sports Medicine, 21, 54 – 59.

Herzog, W.; Nig, B. M.; Read, L. J.; Olsson, E. (1989). Asymmetries in ground reaction force patterns in normal human gait. Medicine Science Sports Exercice, 21, 110 – 114.

Millet, G. P.; Chollet, D.; Chalies, S.; Chatard, J. C. (2002). Coordination in Front Crawl in Elite Triathletes and Elite Swimmers. International Journal of Sports Medicine, 23, 99 – 104.

Nikodelis, T.; Kollias, I.; Hatzitaki, V. (2005). Bilateral inter-arm coordination in Freestyle swimming: Effect of skill leveland swimming speed. Journal of Sports Science, 23, 737 – 745.

Robinson, R. O.; Herzog, W.; Nigg, B. M. (1987). Use of force platsform variables to quantify the effects of chiropractic manipulation on gait symmetry. Journal Manipulation Physical Therapy, 10, 172 – 176.

Schnitzler, C.; Seifert, L.; Ernwein, V.; Chollet, D. (2007). Arm Coordination Adaptation Assessment in Swimming. International Journal of Sports Medicine, 28, 1 – 7.

Seifert, L.; Boulesteix, L.; Chollet, D. (2003). Effect of Gender on the Adaptation of Arm Coordination in Front Crawl. International Journal of Sports Medicine, 25, 217 – 223.

Seifert, L.; Chollet, D.; Allard, P. (2005). Arm Coordination Symmetry and breathing effect in front crawl. Human Movement Science, 24, 234 – 256.

Seifert, L.; Chollet, D.; Bardy, B. G. (2003b). Effect of swimming velocity on arm coordination in the front crawl: a dynamic analysis. Journal of Sports Science, 22, 651 – 660.

Tourny-Chollet, C.; Seifert, L.; Chollet, D. (2009). Effect of Force Symmetry on Coordination in Crawl. International Journal of Sports Medicine, 30, 182 – 187.

Seifert, L.; Chollet, D.; Rouard, A. (2006). Swimming constraints and arm coordination. Human Movement Science, 26, 68 – 86.

Vorontsov, A. (2010). Strength and Power Training in Swimming. Nova Science Publishers, Inc., 16, 1 – 31.