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Arm-Leg Coordination in Breaststroke and Butterfly Swimming Techniques

A study conducted with young male and female swimmers

Dissertação apresentada à Faculdade de Desporto da Universidade do Porto, no âmbito do 2º Ciclo de Estudos conducente ao grau de Mestrado em Desporto para Crianças e Jovens, orientada pelo Professor Doutor Ricardo Fernandes e co-orientada pela Professor Doutor J. Paulo Vilas-Boas, de acordo com o Decreto-lei nº74/ 2006 de 24 de Março.

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KEY WORDS: SWIMMING, MOTOR CONTROL, BIOMECHANICS, YOUNG

PALAVRAS CHAVE: NATAÇÃO, CONTROLO MOTOR, BIOMECÂNICA, JOVENS

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---Papers--

1. Santos, P.R.; Soares, S.; Figueiredo, P.; Vilas Boas, J.P.; Fernandes, R.J. (2011) Assessment of the Arm-Leg Coordination in young Breaststroke Swimmers. Submitted to International Journal of Sports Medicine.

2. Santos, P.R.; Soares, S.; Figueiredo, P.; Vilas Boas, J.P.; Fernandes, R.J. (2011). Arm-Leg Coordination in Young Butterfly Swimmers. Submitted to Journal of Sports Science Medicine.

--Abstracts--

I.

Santos, P.R.; Figueiredo, P.; Silva, A.; Sousa, I.; Pereira, V.; Sousa, M.; Sampaio, A.; Soares, S.; Fernandes, R.J. Índice de coordenação na técnica Bruços. Um novo método de análise da técnica. Comunicação apresentada no XXXIII Congresso APTN.

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Chapter 2

Equation 1.

IFBP=leg propulsion + arm propulsion + elbow push + $\|(T2+T3)\|-T1a$

Equation 2.

IFBP = leg propulsion + arm propulsion + elbow push

Equation 3.

IBFP II = Leg Propulsion + Leg Insweep + Arm Propulsion + Elbow Push

Abstract

Coordination factors are decisive for achieving a good technical and competitive performance. Chollet and co-workers, at the beginning of this century, proposed the concept of index coordination for all swimming techniques. Regarding to breaststroke, it is identified as index of flat breaststroke propulsion (IFBP), and in the butterfly technique, as total time gaps (TTG), which allows analyzing the motor coordination of swimmers. Some studies with elite and non-elite adult swimmers were conducted, but few were oriented towards groups of children and young swimmers. The purpose of this Thesis is to characterize the IFBP and the TTG, in young swimmers, performing at velocity corresponding to 100m. 164 swimmers performed 25 m breaststroke (n=114) and 3x25 m butterfly (n=40) at 100m race pace; in the butterfly, for each 25 m, it was required an individually imposed breathing pattern: non inspiratory cycle, breathing every one complete arm cycle, and breathing every two arm cycles, in a randomized order. A digital camera (Sony DCR-HC42E®) placed inside a sealed box (SPK-HCB), on the sagittal plane of the swimmer, recorded the underwater images. For calibration of the registered plan, to allow the transformation of virtual coordinates in real coordinates, it was used a bi-dimensional structure (2.10m width x 3m height), and thirteen calibration points. Biomechanical analysis was performed with the software APASystem (Ariel Dynamics, Inc., USA), being digitized frame by frame (at 50 Hz), on the one arm-leg cycle and particularly the distal end of the middle finger, the wrist, the elbow, the shoulder, the hip (femoral condyle), the knee, the ankle and the foot of each swimmer. In breaststroke it was studied of the interaction between independent variables gender and maturation, and, in butterfly, between gender, maturation and breathing conditions. When interactions do not reveal significant values, were compared all independent variables. Significant interactions between gender and maturation were observed for stroke rate, stroke length, second half leg recovery, leg recovery, T3 and recovery effective in breaststroke. In butterfly it was not observed significant interactions for all independent variables, but significant differences were observed when comparing all variables. The arm-leg coordination presented by the young swimmers was in glide mode in the two swimming techniques.

KEY WORDS: Biomechanics, Motor Control, Swimming, Young

Resumo

Os factores de ordem coordenativa são determinantes para a obtenção de um bom desempenho técnico e desportivo. Chollet e colegas de trabalho, no início do século, criaram e desenvolveram o conceito de índice de coordenação (IdC) para todas a técnicas. Para o bruços é identificado como índice de propulsão do Bruços plano (IFBP), e para mariposa por totalidade dos intervalos de tempo (TTG), o que permite analisar a coordenação dos nadadores. Alguns estudos com atletas adultos de elite e não elite, foram realizados, no entanto poucos foram os orientados para grupos de crianças e jovens. Neste sentido, o propósito desta tese foi caracterizar o IFBP de bruços e o TTG de mariposa, em jovens nadadores usando a velocidade de competição de distância de 100m. 164 Jovens nadadores (sendo 114 em bruços e 50 nadadores em mariposa), realizaram os testes na distância de 25m. Na técnica de mariposa, foram realizados três testes, para cada percurso realizado foi escolhido aleatoriamente um padrão respiratório a utilizar, sendo (sem respiração; uma respiração para um ciclo completo de braços, e uma respiração para cada dois ciclos). Durante os testes, uma câmara digital (Sony DCR-HC42E®) foi colocada dentro de uma caixa selada (SPK - HCB®) e registou os nados subaquáticos, no plano sagital à faixa de nado. Para a calibração dos planos registados de forma a permitir a transformação de coordenadas virtuais em coordenadas reais, foi utilizada uma estrutura bidimensional (2,10 m de largura x 3m altura, e treze pontos de calibração). A análise biomecânica foi realizada com recurso ao software APASystem (Ariel Dynamics, Inc., EUA), sendo digitalizados quadro a quadro (a 50 Hz) em cada ciclo completo de braço e perna, a ponta do dedo maior da mão, punho, cotovelo e ombro, o quadril (condilo femoral), joelho, tornozelo e pé de cada nadador. Foi estudada a interação entre as variáveis independentes género e maturação, na técnica de bruços e entre o género, maturação e padrões respiratórios, na técnica de mariposa. Quando as interações não revelaram valores significativos, foram realizadas comparações em todas as variáveis independentes. No bruços, observaram-se interações significativas entre género e maturação, e os valores obtidos nas variáveis de estudo são diferentes das relatadas na literatura, no entanto, a tendência é idêntica à encontrada nesses estudos. Na técnica de mariposa, não se observaram interações significativas entre todas as variáveis independentes, mas foram observadas diferenças significativas quando se fizeram comparações em todas as variáveis independentes. Em conclusão, nas técnicas de bruços e mariposa, a tendência de nado é predominantemente de deslize.

Palavras Chave: Biomecânica, Controlo Motor, Natação, Jovens.

Résumé

Les facteurs d'ordre de la coordenation sont déterminants pour l'obtention d'une bonne performance technique et sportive. Chollet et ses collègue équipe, dans le début de ce siècle, ont créé et ont développé le concept de l'indice de coordination (IdC) pour toutes les techniques. Pour la Brasse, est identifié comme un indice de propulsion brasse plate (IFBP), et pour le Papillon, comme tous les intervalles de temps (TTG), qui permet d'analyser la coordination des nageurs. Certaines études avec des athlètes d'élite et l'adulte non-élite, ont été effectuées, bien peu étaient destinées à des groupes d'enfants et de jeunes. À ce temps-là, des études réalisées avec des athlètes adultes d'élite et non élite sont apparues, mais les études se penchant sur les groupes d'enfants et de jeunes ont été peu nombreuses. En ce sens, l'intention de cette thèse est de caractériser l'IFBP de Brasse et le TTG du Papillon, dans de jeunes nageurs utilisant la vitesse de la compétition de 100m. 164 jeunes nageurs, (soit 114 nageurs de brasse et 50 nageurs dans le Papillon), à effectué les teste a une distance de 25m. Dans la technique de Papillon, trois essais ont été effectués pour chaque trajet entrepris a été choisi au hasard en utilisant un modèle de respiration, et (sans respirer, une respiration pour un cycle complet d'armes, et un souffle tous les deux cycles).Pendant les essais, une chambre digitale (Sony DCR-HC42E®) a été placée dans une boîte estampillée (SPK - HCB) et a enregistré les mouvements de nage subaquatiques, dans le plan sagittal à la bande de nage. Pour le calibrage des plans enregistrés, afin de permettre la transformation des coordonnées virtuels dans des coordonnées réelles, a été utilisée une structure bidimensionnelle (2,10m de large x 3m de haut, et treize points de calibrage). L'analyse biomécanique a été réalisée en utilisant l'APASystem (Dynamique Ariel, Inc, Etats-Unis) et chaque tableau (50 Hz) dans chaque cycle complet du bras et de jambe, le bout du doigt le plus grand de la main, le poing, le coude et de l'épaule, la hanche (condilo fémoral), le genou, la cheville et le pied de chaque nageur. Nous avons étudié l'interaction entre le sexe et la maturation des variables indépendantes, dans la technique de la Brasse, et entre les sexes, la maturation et la respiration, dans la technique le Papillon. Lorsque les interactions n'ont révélé aucune des valeurs significatives, les comparaisons ont été faites dans toutes les variables indépendantes. Dans le Brasse, se sont observées des interactions significatives entre les sexes et de la maturation, et les valeurs obtenues dans les variables de l'étude sont différentes de ceux rapportés dans la littérature, néanmoins, la tendance est identique trouvée dans ces études. Dans la technique Papillon, ne se sont pas observées des interactions significatives entre toutes les variables indépendantes. Néanmoins, ont été observées des différences significatives quand se sont faites des comparaisons dans toutes les variables indépendantes. En conclusion, dans les techniques de Brasse et de Papillon, la tendance de je nage est majoritairement de glissement.

Mots-Clés : Contrôle Moteur, Biomécanique, Natation, Jeunes, La Maturation.

Abbreviations and Symbols

Abbreviation/Symbol - Term (unit)

cycle.min^{-1} - number of arm-leg cycles performed per min.

cm - centimeter

Frequency breathing ratio 1:1 - one breathing with one completed arm stroke

Frequency breathing ratio 1:2 - one breathing with two completed arm strokes

IFBP - index of coordination in flat breaststroke

Hz – Hertz

i.e. - this is

m.cycle^{-1} – horizontal distance traveled by the hip during an arm-leg cycle

m.s^{-1} – meter per second n - number of subjects

s – seconds

SD - standard deviation

SI - stroke index

Sig. - significance

SL - stroke length

SPSS - statistical package for social sciences

SR - stroke rate

T1 - time gap associated to the glide and is divided in T1a and T1b (breaststroke technique)

T1 - the time between the entry of the hands in the water and the high break-even point of the first kick (butterfly technique)

T1a - the time between the end of the leg propulsion and the beginning of the arm propulsion

T1b – the time between the end of the leg insweep and the beginning of the arm propulsion

T2 - the time between the beginning of the arm recovery and the beginning of the leg recovery (breaststroke)

T2 - the time between the beginning of the hands backward movement and the low break-even point of the first kick (butterfly)

T3 - the time between the end of arm recovery and the end of the leg recovery (Breaststroke)

T3 - the time between the hands arrival in a vertical plane to the shoulders and the high break-even point of the second kick (butterfly)

T4 - the time between the flexion of 90º during the arm recovery and the flexion of 90º during the leg recovery (breaststroke)

T4 - the time between the hands release from the water and the low break-even point of the second kick (butterfly)

training units/week - training frequency

TTG - total time gap

v - velocity

* - significant difference

ºC - degree centigrade

% - percentage

= - equality

< - less than

> - higher than

≤ - less or equality than

± - more or less

Abreviaturas e Símbolos

Abreviaturas/Símbolos - Termos (unit)

ALI_{efect} – acção lateral interior efectiva

cm - centímetro

DC – distância de ciclo

Des_{efect} – deslize efectivo

FG – frequência gestual

Hz – Hertz

IdC – índice de coordenação

kg – kilograma

MI – membros inferiores

MS – membros superiores

$Prop_{efect}$ – propulsão efectiva

Rec_{efect} – recuperação efectiva

SD – desvio padrão

T1 - representa o intervalo de tempo de deslize, e divide-se em T1a e T1b

T1a – intervalo de tempo entre fim da acção descendente dos membros inferiores e o inicio do movimento propulsivo dos membros superiores

T1b – intervalo de tempo entre o final da acção lateral interior dos membros inferiores e o início da fase propulsiva dos membros superiores

T2 – intervalo de tempo entre o início da 1ª parte da recuperação dos membros superiores e o início da 1ª parte da recuperação dos membros inferiores

T3 – intervalo de tempo entre o final da 1ª parte da recuperação dos membros superiores e o final da 1ª recuperação dos membros inferiores

T4 – intervalo de tempo entre o início da 2ª parte da recuperação dos membros superiores e o início da 2ª parte da recuperação dos membros inferiores

* - diferenças significativas entre géneros

% - percentagem

± - mais ou menos

ºC – graus centígrados

= - igualdade

< - menor que

> - maior que

Chapter 1

General Introduction

Swimming is a cyclic form of locomotion in the aquatic environment, where propulsion is generated to overcome forces of resistance (Seifert et al., 2010). The human locomotion in water poses the challenge of optimizing movement coordination in order to exploit aquatic resistance and, thus, to maximize propulsion while minimizing active drag (David et al., 2009). Therefore, the goal for competitive swimmers is to maximize propulsion while minimizing drags (Seifert et al., 2010). In fact, the aquatic environment naturally imposes forward resistance (Toussaint et al., 1988) and requires propulsive forces (Bergeret al., 1999; Schleihauf, 1979), to overcome this resistance.

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), by analyzing of the general biomechanic parameters namely velocity, stroke rate and stroke length (Craig et al., 1979; Hay, 2002). During this period, changes in velocity, SR and SL can be calculated (Costill et al., 1985). The Improvements in swimming performance has been explained in terms of better control of stroke rate and stroke length, in particular with regard to race paces (Craig & Pendergast, 1979), skill due to age (Arellano et al., 2003), and gender (Grimston & Hay, 1986; Pai, et al., 1984). However, 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).

Breaststroke and butterfly are considered simultaneous swimming techniques, because the rules requires that the actions of the two arms and the actions of the two legs, are simultaneous, each other, which dictates that the arms actions alternate with the legs movements. In breaststroke, the arms and legs also are alternately propulsive, as well as alternately opposed to the forward hydrodynamic drag (Seifert & Chollet, 2005), and, thus, it is very difficult to control the discontinuous propulsive action of the arms and legs, and to their complex time synchronization (Soares, et al., 1999). More than in any other stroke, the breaststroke undergoes wide variations in velocity, because of the greater drag components of the forward movement (Kolmogorov et al., 1997), during underwater recovery of both arms and legs (Holmer, 1979). So, from a technical point of view, another factor should be considered: the arm-leg coordination (Cappaert et al., 1996; Chollet et al., 2004).The swimmers have to manage the transition of underwater and aerial movements, showing a variety of strategies in response to the FINA rules (e.g. as the elbows and wrist remain underwater, while the shoulders and hands can break the surface of the water at each cycle, some elite breaststroke swimmers make an aerial recovery of the hands to minimize the aquatic resistance (Colman et al., 1998). In butterfly, this alternation does not favour a propulsive continuity, leading to strong resisting phases, particularly during the arm recovery phase (Sanders, et al., 1995). In this sense the body undulation and kick seems to facilitate the aerial recovery of the arms; nevertheless, to be effective, it should indeed resemble a wave motion (Sanders et al., 1995), and, therefore, the arm and leg actions need to be highly coordinated (Costill, et al., 1992; Kolmogorov et al., 1997). Nowadays, inter-limb and arm-leg coordination are also important in order to assess motor organization. Chollet et al. (2001) proposed the Index of Coordination for butterfly, in Leblanc et al. (2005) implemented this concept for breaststroke. The key points defining the beginning and end of the stroke phases were analyzed and the arm-leg coordination was assessed by four time gaps (T1, T2, T3, T4), which measure the synchronization of these key points; the time gaps between key points decreased with increases in stroke rate and/or velocity, indicating better propulsive continuity (Chollet et al., 2006; Chollet et al., 2004), particularly pointed out that elite swimmers show low propulsive discontinuities and a relatively short glide with the arms extended forward. In the breaststroke arm-leg coordination was determined by measurement of the five time gaps (T1a, T1b, T2, T3 and T4) between the different stroke phases of each pair of motor limbs and this in turn enabled us to analyze the body acceleration-deceleration. The IFBP corresponds to total propulsion duration, and was considered as the sum of leg propulsion, arm propulsion and elbow push, except if T1a>0, or when T2 and T3 were <0. In the butterfly, the total time gap

(TTG) is defined as the sum of the absolute values of T1, T2, T3 and T4, and is used to assess the effectiveness of the global arm-leg coordination (Seifert et al., 2005). Although a profile of expert coordination in butterfly has emerged from these studies, little is known about the coordination used by less-skilled swimmers, who, because of their poorer technique and smaller forces due to younger age, lack the experience of the elite swimmers. It would indeed be interesting to investigate how these less-skilled swimmers organize their arm-leg coordination in high swimming intensity (Seifert et al., 2008).

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). 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). When studying the performance of young swimmers in particular, organismic constraints may include gender, expertise, anthropometry, and the swimmer’s discipline. Of those organismic constraints, the anthropometric characteristics like arm span, arm size, hand area, foot size, leg length and height, especially, are likely to influence arm coordination (Seifert et al., 2007). Clarys (1979) and Kolmogorov & Duplischeva (1992) suggested that active drag, velocity and the ratio of stroke rate to stroke length were more dependent on the swimming technique and much less on the anthropometry. Malina (1994) proposed that factors predicting age-group swimming performance may change much during their physical maturation. In addition, there could be a wide variation in the biological or physical ages of children of the same chronological age, being necessary to consider the effects of growth and development when analyzing the performance of young swimmers (Latt et al., 2010). 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). Therefore, as although children are not mini-adults (Armstrong & Welsman, 2002), it is important to conduct more studies with these age-groups to help coaches and swimmers to get better results.

Considering the previously mentioned, the main propose of this Thesis was to conduct a technical characterization of the simultaneous swimming technics in swimmers of 11-13 years old, contributing to its performance improvement and athletic achievement. We will focus in the general biomechanical parameters and in the arm-leg coordination assessment.

In the **Appendix I**, it was characterized the arm-leg coordination in breaststroke technique performed at high velocity (at the 50-m race pace), through IFBP. It was analysed a sample of sixty nine swimmers, from both genders and from both maturity stages (pubertal and post-pubertal, following Tanner, 1989). General stroke parameters (velocity, SL and SR) were also assessed. With study, we realized a preliminary pilot study of the Breaststroke technique and, thus, we conducted a revision of the bibliography and obtained a first set of specific results in this field of study. As there are no studies with samples of young swimmers, we established some degree of comparison with the results obtained with samples of elite and non-elite adults in other studies. To better characterize the biomechanical profile and temporal structuration about the management of arm-leg actions of breaststroke in age group swimmers, it was gathered a higher sample of young swimmers (n = 114), and added complementarily parameters in a full paper in the **Chapter 2**. In this study, an analysis of motor behaviour at the 100-m breaststroke 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 I** With this sample it was used the same protocol described in Appendix I above, and it was analysed the interaction between independent variables, gender and maturation, assessing the dependent variables biomechanical parameters, arm and leg phases, temporal gaps and effective phases.

Few studies have analyzed the effect of breathing on propulsion, kinematics, instantaneous velocity fluctuations or coordination in butterfly (Alves et al., 1999; Barbosa et al., 2003; Barbosa et al., 1999). Alves et al. (1999) studied the effect of frontal breathing on kinematics; notably they noted greater trunk inclination with frontal breathing as compared to breath-holding, for the less experienced swimmers (Alves et al., 1999). Usually, swimmers use one breath for every two arm strokes or they breathe for every stroke. In fact, several breathing patterns (breath-holding, frontal breathing, lateral breathing), with different ratios of breaths to arm strokes, have at times been adopted (Seifert et al., 2010). The inexistence of research on the approach of respiration in young swimmers led us to include the study of the respiratory frequency as one of the key factors of analysis which is presented in **Chapter 3**. Young butterfly swimmers see the butterfly technique as difficult to perform because of the arm strength that it requires. In fact, the fear of being unable to bring the arms forward leads initiates to focus almost exclusively on the aerial recovery, with far less attention given to their legs (Seifert and Chollet, 2008). Conversely, efficient arm-leg coordination requires one arm cycle for two leg cycles or a ratio of 1:2, with the upward and downward phases of the leg kicks synchronized (Chollet et al., 2006; Sidney et al., 2001). Chollet et al. (2006) and Seifert et al. (2008) demonstrated the need for a high coupling between the arms and legs in butterfly.

So, in **Chapter 3**, we follow the proposal presented by Seifert et al. (2008), and with a sample of 50 young (girls of 11-12, and boys of 12-13 years of age) swimmers of both sexes, with whom we carried out the characterization of their biological maturation (puberty and post-puberty, after Tanner, 1989) and the anthropometric aspects. Using the methodology of study developed by Chollet et al. (2000) the arm-leg coordination in butterfly technique, performed at high velocity (at the 100 m race pace), through TTG, was characterized. Keeping the same study protocol described in Appendix I, for each trial, it was required an individually imposed swimming breathing patterns: non inspiratory cycle; one breathing with one completed arm cycle (frequency ratio of 1:1); and one breathing with two arm cycles (frequency ratio of 1:2), in a randomized order. In each trial, were recorded on the sagital plane, two complete underwater butterfly cycles. In this study, we analysed the general biomechanical parameters, the arm and legs cycle phases and the temporal gaps and it was studied the interaction between the independent variables (gender, maturation and breathing). When interaction was not present, comparisons were performed between gender, without considering the effect of maturation and breathing; by maturation, without considering the effect of gender and breathing; and by breathing, without considering the effect of gender and maturation. In fact, the swimmer has to organize the transition between the underwater and the above-water phases of the cycle, and the time devoted to propulsion and glide during the underwater part of the cycle. Thus, arm-leg coordination may not automatically serve only to propel the body forward, since part of the motor organization may be dedicated to floating and breathing (Seifert, 2010).

Chapter 2

ASSESSMENT OF THE ARM-LEG COORDINATION IN YOUNG BREASTSTROKE SWIMMERS

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ABSTRACT

The purpose of this study was to assess the general biomechanics parameters and to characterize the arm-leg coordination in age-group breaststrokers performing at high intensity. 114 young swimmers (11-13 years of age) performed 25m breaststroke at 100m race pace. An underwater camera was used to assess velocity, stroke rate and stroke length, and the arm-leg coordination (through the index of flat breaststroke propulsion), being also indentified every cycle phases. Through the analysis of the interaction between gender and maturational groups, it was possible to observe significant differences in the stroke rate (F=6.077, p=0.015), stroke length (F=5.899, p=0.017), second half leg recovery (F=5.511, p=0.021), leg recovery (F=7.069, p=0.014), T3 (F=4.393, p=0.058) and recovery effective. (F=7.556, p=0.007), which being to be justified by anthropometric differences, maturational characteristics, and a different interpretation of the coordination of the breaststroke technique. When compared with other studies, performed with elite and non-elite adult athletes, it was verified that the current sample exhibits higher values in (almost) all of the assessed parameters.

Key words

Swimming, Biomechanics, Motor control, Young, Maturation

INTRODUCTION

Breaststroke is a complex cyclic swimming technique, in which it is fundamental to tightly organize the inter-limb coupling to overcome the environmental constraints [27]. One breaststroke cycle is composed of three arm and three leg phases (18) that are embodied in propulsion, recovery, and glide moments (22). Complementary, three general variants of arm-leg coordination are described (according to the glide time): (i) glide, when the body stays fully extended and streamlined before the arm catch; (ii) continuous, when the arm catch takes over just as the leg actions are completed; and (iii) overlapped, when the arms start the catch before the completion of the leg action. In this swimming technique, the arms and legs are alternately propulsive, and alternately opposed to the forward hydrodynamic drag (21), being very difficult to control their discontinuous propulsive action due their complex time synchronization (23).

Breaststroke performance has traditionally been assessed by using the general biomechanical parameters (velocity, stroke rate and stroke lenght), as well as by the intra cycle velocity variation (29). However, for a more complete technical characterization, the arm-leg coordination should also be considered (6). However, for a more complete technical characterization, the arm-leg coordination should also be considered [5,6,15]. The four time gaps can measure either the lag time, the continuity or the superposition between the stroke phases of each pair of motor limbs (7). The lag time between the leg and the arm propulsive actions was found to be inversely related to increases in the stroke rate and swimming velocity. In fact, elite adult swimmers tend to exhibit a longer lag phase as the race distance increases, and, consequently, the velocity decreases (6,8,23,26). Thus, the relative continuity of the arm and leg propulsion contributes for the maintenance of a high velocity (19). When elite and non-elite swimmers were compared, it was noted that elite swimmers spent more time in propulsive actions, and had a more continuous propulsion due to reduced lag times within their stroke cycle (15); in addition, when the swimming race pace increased, both elite and non-elite swimmers showed a decrease in the relative duration of the leg-arm lag phase, and an increase in the propulsive phases.

So, the coordination patterns of competitive breaststrokers can provide knowledgeable information to the swimming coaches and researchers. Moreover, no hints regarding the coordination of beginners are available in the literature. In fact, research in young competitive swimmers is scarce compared to the one conducted with adult swimmers (1). This is odd, once coaches often observe an excessive flexion of the hip during leg recovery, a too fast arm recovery with a poorly streamlined position, and breathing occurring too early in young swimmers (15). In this since, the training process of age group swimmers, demand a special interest, particularly due to the huge variations in physical growth and maturational development in these developmental stages. In fact, some boys and girls may begin their adolescence period at this time, while others are still in their childhood, and differences in height and body proportions may occur suddenly (2,4).

The aim of this study was to characterize the breaststroke technique of young swimmers, performing at very high intensities using the general biomechanical parameters (velocity, stroke rate and stroke length), as well as the arm-leg coordination. The arm and leg phases relative durations in the breaststroke cycle were also determined. For a more detailed analysis, these evaluations were conducted according to swimmers' gender and maturation.

MATERIAL AND METHODS

Subjects

One hundred and fourteen age-group competitive swimmers (girls of 11-12 and boys of 12-13 years of age) volunteered for this study. The mean and SD values regarding their anthropometric characteristics, sexual maturation status, training frequency and best time in 100m breaststroke in short course are described in Table 1. Swimmers and respective coaches were informed about the details of the experimental protocol before beginning the measurement procedures. The local Ethics Committee approved the experimental procedures and the swimmers' parents signed a consent form in which the protocol was explained. These tests were implemented in the preparatory period of the first macro-cycle of the training season.

Table 1. Mean (±SD) values of the anthropometric characteristics, sexual maturation status, training frequency and best performance time at the short course 100m breaststroke.

	Boys		Girls	
	Pubertal (n=35)	Post-pubertal (n=22)	Pubertal (n=26)	Post-pubertal (n=31)
Body mass (kg)	50.1±7.2	49.0±8.1	41.8±7.4	48.6±6.9
Height (cm)	156.7±7.6[a]	158.1±9.6[ab]	149.0±5.2	155.4±6.4
Arm Span (cm)	159.6±8.5[b]	161.3±10.3	149.5±7.0	155.8±7.3
Age (years old)	11.9±0.[b]	12.1±0.7	10.8±0.5[b]	11.4±0.6
Maturation (stage)	2	3	2	3
Breast development (stage)	-	-	2.41±0.5	3.73±0.4
Genital development (stage)	2.4±0.5	3.9±0.4	-	-
Pubic hair (stage)	2.5±0.5	4.5±0.5	2.8±0.5	4.1±0.5
Training Frequency (training units/week)	5.8±0.4	5.9±0.4	5.8±0.3	5.9±0.2
Training experience (year)	3.4±0.8	4.5±0.6	3.2±0.7	3.6±0.8
Best time 100m breaststroke (s)	97.1±18.2	94.2±8.2	106.4±8.7	102.2±9.9

Legend: Significatively different, for p≤0.05, from: [a] pubertal girls, [b] post-pubertal girls.

Maturational Lever Assessment

Knowing that children of the same chronological age can differ significantly by several years in their biological maturity, it was conducted an evaluation of the swimmers' maturation. According to Tanner and Whitehouse (25), it was made an identification of the swimmers maturation stadium using images relating to the development of secondary sex characteristics – genital (boys), breast (girls) and pubic hair (boys and girls). After parent's authorization, images were presented to the swimmers and a self-evaluation rating was carried; afterwards, those images were presented to swimmers parents, and the final result was the mean value of these two evaluations. According to Tanner and Whitehouse (25), during the process of sexual maturation it is possible to identify until six stages in the evolution of gender according to the secondary sexual characteristics mentioned above, allowing to identify the developmental stage of subject.

Experimental Procedure

In a 25m pool, 1.90m deep, with a water temperature of 27.5ºC, swimmers performed 25m breaststroke at the velocity corresponding to the 100m race pace. Trials started in the water, without diving. A digital camera (Sony® DCR-HC42E, 1/250 digital shutter, Nagoya, Japan), placed inside a sealed housing (Sony® SPK-HCB, waterproof box, Tokyo, Japan), recorded one complete underwater breaststroke cycle, on the sagital plane. The digital camera was placed 1m depth and at 11.5m perpendicular distance from the swimming lane. For calibration of the registered plan, to allow the transformation of virtual coordinates in real coordinates, it was used a bi-dimensional structure (2.10m width x 3m height, and thirteen calibration points). Biomechanical analysis was performed with the software APASystem (Ariel Dynamics, Inc., USA), being digitized frame by frame (at 50 Hz), on the one arm-leg cycle and particularly the distal end of the middle finger, the wrist, the elbow, the shoulder, the hip (femoral condyle), the knee, the ankle and the foot of each swimmer. The digitize-redigitize reliability was very high (ICC = 0.992). The average of swimming velocity was assessed through the ratio of the displacement of the hip in an arm-leg cycle to its total duration. Stroke length was determined by the average of the horizontal distance traveled by the hip during an arm-leg cycle, and stroke rate as the number of arm-leg cycles performed per min.

Coordination Assessment

For assessment of arm-leg coordination, the breaststroke arm cycle was divided in five phases (6, 20): arm glide, arm propulsion, elbow push, first half of the recovery, and second half of the recovery. Following these authors, the propulsion of the upper limbs was the sum of arm propulsion and elbow push, and the arm recovery was considered the sum of the first and second parts of the recovery; the different phase’s duration was expressed in percentage of the complete cycle arm duration. Complementarily, the leg cycle was divided in five phases: leg propulsion, leg insweep, leg glide, first half of the recovery, and second half of the recovery. The leg recovery was the sum of the two parts of the recovery, and each phase was expressed in a percentage of the complete cycle leg duration.

The arm-leg coordination was determined from the temporal gaps between the cycle phases of each limb (5). Being indentified T1 (associated to the glide), and T2, T3 and T4 (associated to the recovery), the set of the temporal gaps expressed the tendency of coordination of the complete stroke. The T1 (glide duration) was divided in T1a (the time between the end of the leg propulsion and the beginning of the arm propulsion), and T1b (the time between the end of the leg insweep and the beginning of the arm propulsion). The temporal gaps associated to the recovery were defined as T2 (the time between the beginning of arm recovery and the beginning of the leg recovery), T3 (the time between the end of arm recovery and the end of leg recovery), and T4 (the time between 90º of flexion during arm recovery and 90º of flexion during leg recovery) (20). The time gaps between the different stroke phases of each pair of limbs expresses the differences on the arm-leg coordination (6).

The IFBP corresponds to total propulsion duration, and was considered as the sum of leg propulsion, arm propulsion and elbow push, except if T1a>0. In this case, arm propulsion overlapped leg propulsion, and T1a had to be subtracted from the total propulsion. When T2 and T3 were <0, a propulsion phase of one limb overlapped a negative phase of the other limb. Therefore, IFBP was measured as the total duration of propulsion as related to the arm and leg phases and the temporal gaps, and was based on the index of butterfly propulsion [3,20].

$$\text{IFBP} = \text{leg propulsion} + \text{arm propulsion} + \text{elbow push} + \|(T2 + T3)\| - T1a$$

If T1a<0 and T2 and T3 >0, the IFBP corresponds to:

$$\text{IFBP} = \text{leg propulsion} + \text{arm propulsion} + \text{elbow push}$$

Notably, it is important to evidence that although the insweep phase of the leg action is considered as an important phase in the propulsive action of the lower limbs (12,18), some studies (e.g. [3,20]) did not included it in the propulsion calculation. In the current study it was tried to overlap this problem by assessing also $IFBP_{II}$ that including the leg insweep. So, the same trend of the temporal gaps, T1a<0 and T2 and T3 >0, it was applied the formula:

IBFP = Leg Propulsion + Leg Insweep + Arm Propulsion + Elbow Push

Following the above referred authors, it were defined four “effective” breaststroke phases determined based on time gaps, and the relationships between the arm and leg cycle phases: propulsion effective (was the time during which only occurred propulsive action); recovery effective (was the time between the beginning of the first recovery and the end of the last recovery); glide effective (was the time between end of leg insweep, and the beginning of arm propulsion); and insweep effective (was the time between the extension and joining of the legs) (6).

STATISCAL ANALYSIS

The SPSS program version 18.0 (SPSS inc., Chicago, USA) was used for both exploratory data analysis, and for the statistical data treatment. The distributions normality was tested using the Kolmogorov-Smirnov (n>50), and the Shapiro Wilk (n<50) tests. Means and SD values were calculated for all measured parameters. After exploratory data analysis, the study of the interaction between the dependent and independent variables (gender and maturation) was performed. The posterior statistical analysis was dependent of the interaction result: when interaction was found, a t-test for dependent variables was applied to compare results by gender and maturation, and 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, with application a One Way ANOVA. The comparisons were made using a *Bonferroni* adjustment. The statistical significance was set at 5% for all tests used.

RESULTS

The study of the interaction between gender and maturation revealed significant values for the dependent variables stroke rate (F=6.077, p=0.015), stroke length (F=5.476, p=0.021), second half leg recovery (F=5.511, p=0.021), leg recovery

(F=6.183, p=0.014), T3 (F=3.657, p=0.058) and recovery effective. (F=7.556, p=0.007). Mean and SD values for these variables are presented in Table 2.

Table 2. Mean (± SD) values of the variables for which interaction between gender and maturation was observed.

	Boys		Girls	
	Pubertal	Post-pubertal	Pubertal	Post-pubertal
Stroke rate ($cycle.min^{-1}$)	41.31±6.49[a]	45.52±7.60[b]	41.86±6.26	40.20±4.76
Stroke length($m.cycle^{-1}$)	1.52±0.25[a,b]	1.39±0.19	1.41±0.26	1.48±0.16
2º 1/2 leg recovery (%)	29.55±6.43[a]	33.46±8.81[b]	32.00±7.23	29.26±7.61
Leg recovery (%)	47.27±8.52[a]	52.74±11.67	52.40±11.82	47.91±10.56
T3 (%)	27.34±9.17[a]	20.71±10.81	23.18±8.03	23.36±9.48
Recovery effective (%)	21.76±12.06[a,b]	30.54±13.96	30.25±15.01	24.85±13.75

Legend: T3: time gap between end of arm recovery and end of leg recovery; significatively different ($p \leq 0.05$) from [a] post-pubertal boys and [b] post-pubertal girls, [c] pubertal girls.

All the studied variables in which interaction between gender and maturation was not significant are presented in Table 3.

Table 3. Mean (± SD) values of the variables for which interaction between gender and maturation was not observed.

	Gender		Maturation	
	Boys	Girls	Pubertal	Post-Pubertal
Velocity ($m.s^{-1}$)	1.04±0.09	0.98±0.07	1.01±0.09	1.02±0.10
Arm propulsion (%)	12.59±4.84	11.52±5.30	11.32±4.94	12.90±5.16
Elbow push (%)	15.72±5.03	15.98±4.12	15.39±4.16	16.39±5.00
Up limbs propulsion (%)	28.62±7.59[a]	27.42±5.58	26.63±6.44	29.61±6.62
Arm glide (%)	23.48±9.37	23.62±11.27	23.16±10.53	23.98±10.51
1[st]half arm recovery (%)	26.59±9.02	28.35±9.59	28.41±8.88	26.39±9.76
2[st]half arm recovery (%)	20.73±9.26	19.59±11.43	20.78±9.55	19.44±11.30
Arm recovery (%)	46.10±8.87	47.20±10.97	50.50±10.74	44.44±10.60
Leg insweep (%)	16.98±11.08	16.01±9.69	17.71±10.37	15.09±10.29
Leg glide (%)	25.47±10.33	25.96±9.86	24.30±9.15	27.34±10.86
Leg propulsion (%)	11.31±5.03	10.78±4.13	11.36±4.64	10.67±4.55
1[st] half leg recovery (%)	18.33±5.11	19.46±5.82	18.86±5.65	18.95±5.34
T1a (%)	-62.77±14.46	-63.87±16.47	-62.28±15.03	-64.52±15.96
T1b (%)	-23.37±10.01	-22.51±11.46	-21.98±10.65	-24.04±10.89
T2 (%)	27.99±14.36	25.66±12.46	26.47±12.22	27.23±14.83
T4 (%)	35.50±14.19	34.22±15.21	35.02±14.16	34.69±15.34
IFBP (%)	39.61±8.30	38.20±6.62	37.50±7.74	39.00±7.03
$IFBP_{II}$ (%)	56.41±13.86	54.39±11.35	52.50±7.74	51.87±12.25
Propulsion effective (%)	39.61±8.30[a]	38.20±6.62	38.10±7.86	39.84±7.04
Insweep effective (%)	17.09±11.33	16.15±10.02	17.68±10.36	15.39±10.97
Glide effective (%)	24.67±5.92	24.61±7.09	23.73±6.97	25.68±5.81

Legend: T1a, the time between the end of the leg propulsion and the beginning of the arm propulsion; T1b, the time between the end of the leg insweep and the beginning of the arm propulsion; T2, the time between the beginning of the arm recovery and the beginning of the leg recovery; T4, the time between the flexion of 90º during the arm recovery and the flexion of 90º during the leg recovery; IBFP, index of breaststroke flat propulsion; $IFBP_{II}$, (Leg propulsion + Leg insweep + Arm propulsion + Elbow push); Significatively different (p≤0.05) from [a] girls.

DISCUSSION

The purpose of this study was to assess the general biomechanical parameters, and to characterize the arm-leg coordination, and temporal gaps pattern in young breaststrokers performing at a 100m race pace. These aims are perfectly justified once no data in this topic is available in age group swimmers, allowing a deep interpretation of spatial-temporal coordination patterns in the complete breaststroke cycle when performing at very high intensities. It were tested eventual differences between four sample sub groups (boys, girls, pubertal and post-pubertal), through the study of the interaction of the dependent variables. Since no studies in this area were conducted with young swimmers, the obtained results were compared with studies carried out with older elite and non-elite swimmers.

No interaction between gender and maturation was obtained for velocity; however, boys obtained higher values than girls, which are explained by the higher stroke rate of post-pubertal boys, and by the higher stroke length of pubertal boys. The study of the interaction between gender and maturation revealed significant values for the stroke rate variable, being observed that, to obtain a high swimming velocity, the post-pubertal boys adopted a higher stroke rate comparing to the pubertal boys and to the post-pubertal girls, but were not able to maintain a higher stroke lenght. In breaststroke, this situation is worsened by the fact that both arms and legs recovery are subaquatic. The interaction between gender and maturation also revealed significant values for the stroke lenght, with the pubertal boys presenting higher values relatively to post-pubertal boys, and to the pubertal girls, expressing the existence of different ways of achieving and maintaining a high swimming velocity. Craig et al. (9) analysed the temporal and velocity changes during the stroke cycle for a range of stroke rates, and suggested that the swimming biomechanical parameters may be more critical in breaststroke than in other swimming techniques, which could be due to anthropometric differences, maturational characteristics, and different interpretation of the arm-leg coordination. During the age-groups period, growth causes changes in body size (25), being well accepted that the different physical parameters influence swimming performance (30). When compared to the literature, our sample shows low values of relatively velocity, stroke rate and stroke lenght (6,15,21).

The interaction between gender and maturation did not reveal significant values for the arm cycle phases. Comparing maturational status, post-pubertal swimmers of both genders obtained higher values than the their pubertal counterparts in the variables arm propulsion and up limbs propulsion (arm propulsion + elbow push), which could be justified due to the post-pubertal higher height and arm span, implying higher force levels optimizing the arm cycle propulsion. When compared to the literature (6,15,21), the current sample showed low values of relatively arm propulsion and arm glide, and higher values of elbow push and arm recovery; in fact, our swimmers shorten the arm propulsion phase to increase the elbow push, what is a significant error a the breaststroke technique, probably justified by their lower strength levels.

The study of the interaction between gender and maturation revealed significant values for the 2nd half leg recovery, being observed that the post-pubertal boys presents higher values relatively to the pubertal boys, and to the post-pubertal girls. So, the post-pubertal boys take a long time to realize the final phase of the leg recovery, starting later the propulsive phase of the leg cycle. The leg recovery phase is the sum of the two parts of leg recovery Chollet et al. (6), the higher 2nd half leg recovery phase values influence directly the leg recovery variable. So, the study of the interaction between gender and maturation also revealed significant values for the leg recovery. In addition the post-pubertal boys continue to present higher values of leg recovery relatively to the pubertal boys. The arm recovery, just like the leg recovery, should occur with maximally streamlined movements (11), confirming the importance of a good arm-leg coordination (13). Thus, post-pubertal boys present difficulties in the leg recovery that limit the coordenation with the arm cycle. The interaction between gender and maturation did not reveal significant values for the leg glide, but when compared maturational status, post-pubertal group obtained higher values than the pubertal group, the time evidencing that the more maturated swimmers performs long time in streamline position and without adding velocity. When compared to the literature, our sample shows low values of relatively leg propulsion and leg glide, and high relatively values of 1st and 2nd half leg recovery phases, leg insweep and leg recovery (6,15,21).

The time gap T3, an important variable expressing synchronization between the end of arm recovery and the end of leg recovery (6,15), revealed to be influenced by the interaction between gender and maturation, being also evident that the pubertal boys group presented higher values relatively to the post-pubertal boys group. When T3>0, this positive gap corresponds to the glide of the arms during the recovery of the legs, which means that no energy waste was added to the recovery phase, because the rest of the body was in a streamlined position (6). The obtained T3 values resulted from a difficulty in the arm-leg spatial-temporal structuring in their recovery phases, presenting higher expression in the pubertal boys than the post-pubertal boys. Interaction between gender and maturation was not observed for T1a, T1b, T2 and T4, being observed very high temporal gaps compared to the literature (6,15,21). The temporal gaps associated to the glide (T1a and T1b) are negative, indicating difficulties in obtaining high continuity between the actions of the arms and legs; so, it was observed that the glide of the arms and legs occurred simultaneously, leading to a decrease in overall swimming velocity (23,29). The values of the temporal gaps associated to the recovery (T2, T3 and T4) are high when comparing to the literature (6,15,21) that indicate the existence of low synchronization timings between the actions of the arms and legs during the recovery phases (21). The time gaps seem to be useful parameters to evaluate the swimmer's skill, particularly when adapting his/her arm-leg coordination to biomechanical constraints.

Lastly, regarding the effective phases, the study of the interaction between gender and maturation revealed significant values for the recovery effective; this result confirms the values obtained for the second half of leg recovery and leg recovery. Complementarily, the pubertal boy presented lower values than the post-pubertal boys, and pubertal girls, which seems to be due to the pubertal boys lower second part of leg recovery. It were not observed any interaction between gender and maturation for the glide effective variable; when comparing maturational status, post-pubertal group obtained higher values than the pubertal group, which could be explained by differences in the leg glide phase. When comparing to the literature, it were observed similar values of all effective variables (6,15,21).

CONCLUSION

It was found than the stroke rate, stroke length, second half leg recovery, leg recovery, T3 and recovery effective are significantly influenced by gender and status of maturation in young swimmer, when performed breaststroke at 100m race pace, thus coaches should consider the differences existing between the young groups swimmers.

It was found than the velocity is the only variable significantly different between boys and girls when compared genders. In addition, when compared maturational status, the arm propulsion, up limbs propulsion, leg glide and glide effective were significantly different between pubertal and post-pubertal groups.

Swim in glide is the swimming mode adopted by the young swimmers when performs the breaststroke technique at high intensity, however the young swimmers also show lows values of coordination between actions arms-legs in the recovery phases. The knowledge of the age particularities, and of the year-by-year dynamics of technical characteristics, may allow us to control and to correct coordination in the process of the technical preparation of young swimmers (18).

SUGESTIONS

It's important our coaches focus on improving the technical quality of the leg action, mainly in the second part of recovery. They should also try to implement a greater and better stimulation of the coordination between the actions of the arms and of the legs, during all the phases of breaststroke. And, in addition, they should take care to encourage the use of different types of coordination in the breaststroke, according to the specific speeds of the 50m, the 100m, and the 200m distances.

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Chapter 3

ASSESSMENT OF THE ARM-LEG COORDINATION IN YOUNG BUTTERFLY SWIMMERS

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Abstract

The purpose of this study was to analyze the effects of breathing (non inspiratory cycles; one breathing per arm stroke cycle – 1:1; and one breathing per two arm cycles – 1:2) on arm-leg coordination and general biomechanical parameters in the butterfly technique. 50 young swimmers (age 11-13 years), performed three 25m butterfly trials, each one at the velocity corresponding to the 100m butterfly event, with in water starts and, without diving. For each trial, it was required randomized breathing pattern individually imposed swimming pace, which corresponded to a specific frontal breathing frequency (non inspiratory cycles; frequency ratio of 1:1, and frequency ratio of 1:2 respectively). To calculate the four time gaps in the arm-leg coordination (T1, T2, T3 and T4), each arm and leg phases were identified by video analysis through a mean of two entire stroke cycles. Taking into consideration gender, maturation and breathing variables, it was verified significant differences in the velocity, stroke rate, catch arm phase, pull arm phase, second downward kick, second upward kick, time gap T2, T3 and total time gaps parameters. This new concept to assess the coordination in the butterfly technique, enables characterize the arm-leg coordination in a complete cycle and respective relation between the position of the leg kick to the arm cycle phase.

Key Words: Swimming, Biomechanics, Motor Control, Maturation, Breathing

INTRODUCTION

Performance in swimming is highly dependent on swimmer's technique (Louro, Silva, Anguera, Marinho, Oliveira, Conceição, Campaniço, 2010; Barbosa, Fernandes, Morouço, Vilas-Boas, 2008). The butterfly swimming technique rules requires that the actions of the two arms and the actions of the two legs, are simultaneous, each other, which dictates that the arms actions alternate with the legs movements. This alternation does not favour a propulsive continuity, leading to strong resisting phases, particularly during the arm recovery phase (Sanders, Cappert, Devlin, 1995). In this sense the body undulation and kick seems to facilitate the aerial recovery of the arms; nevertheless, to be effective, it should indeed resemble a wave motion (Sanders et al., 1995), and, therefore, the arm and leg actions need to be highly coordinated (Costill, Maglischo, Richardson, 1992; Kolmogorov, Rumyantseva, Gordon, Cappaert, 1997).

In fact it is known that an efficient arm-leg coordination requires one arm cycle per two leg cycles (ratio of 1:2), with the upward and the downward phases of the leg kicks synchronised with arms (Chollet et al., 2006; Seifert, Delignières, Boulesteix, Chollet, 2007). In addition Maglischo (2003) emphasize that the downward phase of the first leg kick should occur during the arms catch phase, and the upward phase of the second leg kick should occur during the arms pull phase.

However, swimmers usually use one breath for every two arm cycles, or they breathe for every cycle. Moreover, several other breathing patterns (e.g. breath-holding, frontal breathing or lateral breathing) also are used with different ratios of breaths with the arms cycles (Seifert, Chollet, Sanders, 2010). Since frontal breathing may disturb arm to leg coordination, by increasing the intracycle velocity fluctuations (Hahn and Krug, 1992), controlling the ratio of breaths to arm cycles could help ensure a high degree of propulsive continuity and also of the coordination (Seifert et al., 2010). Young butterfly swimmers see the butterfly technique as difficult to perform because of the arm strength that it requires. In fact, the fear of being unable to bring the arms forward leads initiates to focus almost exclusively on the aerial recovery, with far less attention given to their legs (Seifert and Chollet, 2008). In fact, although the assessments in young swimmers must be less expensive, less invasive and less complex in comparison to the ones carried in adult swimmers (Marinho, Barbosa, Costa, Figueiredo, Reis, Silva, & Marques, 2010), few studies were conducted in young swimmers, in order to analyze the effect of breathing on propulsion, kinematics, instantaneous velocity fluctuations (Barbosa, Sousa, Vilas-Boas, 1999; Barbosa, Santos Silva, Sousa, Vilas-Boas, 2003; Hahn et al., 1992). Arm-leg coordination profile of expert butterfly swimmers is known from previous studies (Chollet et al., 2006; Seifert et al., 2008), but as far as we know, no study was conducted yet with young swimmers, although recently Boulesteix et al. (2003), confirmed the importance of the arm-to-leg coordination for the propulsion in the butterfly (Chollet et al., 2006).

Due to their less developed technique and lower strength levels, it would be useful to know how these young swimmers organize their arm-leg coordination in the butterfly technique (Seifert et al., 2008). Thus, it was aimed to characterize the butterfly’s arm-leg coordinating, in swimmers aged 11-13 years old, through: (i) identifying differences between gender, maturational groups, and between gender and maturational groups in the coordination made at each breathing patterns; and (ii) analyzing the effects of the specific breathing patterns (non inspiratory cycles, one breathing per arm cycle, and one breathing per two a cycles) in the coordination mode. It was hypothesised an interaction between gender and maturation with breathing patterns could contribute to explain differences in arm to leg coordination.

MATERIAL AND METHODS

Subjects

Fifty young swimmers, from the infant competitive swimming age group category (girls of 11-12 and boys of 12-13 years of age) volunteered to participate in this study. The mean ± SD values regarding their anthropometric, sexual maturation status and training frequency characteristics are described in Table 1. Swimmers, parents, and respective coaches, were informed about the details of the experimental protocol before the beginning of the measurements. The local Ethics Committee approved the experimental procedures and the swimmers' parents signed a consent form in which the protocol was explained. Tests were implemented in the preparatory period of the first macrocycle of the training season.

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

	Boys			Girls		
	Pubertal (n=16)	Post-pubertal (n=9)	Total (n = 25)	Pubertal (n=13)	Post-pubertal (n=12)	Total (n = 25)
Age (years old)	11.6±0.6[a]	12.1±0.7	11.8±0.7	10.8±0.5[b]	11.1±0.7	10.9±0.6
Breast development (stage)	-	-	-	2.72±0.5	3.7±0.4	3.4±0.7
Genital development (stage)	2.5±0.5	3.7±0.4	2.9±0.8	-	-	-
Pubic hair (stage)	2.5±0.5	4.3±0.5	3.2±1.0	3.08±0.3	4.3±0.7	3.6±0.8
Height (cm)	152.2±5.7[a]	160.8±5.4	155.3±6.9	147.9±5.3[b]	156.6±0.5	152.1±7.7
Body mass (kg)	47.6±6.1[a]	55.0±7.8	50.3±6.6	42.5±6.2[b]	48.0±7.8	45.1±7.4
Arm Span (cm)	155.8 ±5.6[a]	163.8±6.8	158.7±7.0	150.3±7.5[b]	158.7±7.5	154.3±8.5
Training Frequency (training units/week)	5.2±0.4	5.8±0.5	5.5±0.5	5.3±0.5	5.9±0.4	5.5±0.5
Training (years)	3.6±0.4	3.6±0.4	3.6±0.4	3.3±1.2	3.3±1.2	3.3±1.2

Legend: Significatively different (p≤0.05). [a] different post-pubertal boys, [b] different post-pubertal girls.

Maturational Level Assessment

Knowing that children of the same chronological age can differ significantly, by several years, in their levels of biological maturity, it was conducted an evaluation of the swimmers' maturation, according to Tanner and Whitehouse (1982). It was made an identification of the swimmers maturation stadium, using images relating to the development of secondary sex characteristics – genital (boys), breast (girls) and pubic hair (boys and girls). After parent's authorization, images were presented to the swimmers and a self-evaluation rating was carried out; afterwards, those images were presented to swimmers parents, and the final result was the mean value of these two evaluations. According to Tanner and Whitehouse (1982), during the process of sexual maturation it is possible to identify until six stages in the evolution of gender according to the three secondary sexual characteristics mentioned above, thus allowing to identify the developmental stage of the subject.

Experimental Procedure

In a 25m swimming pool, 1.90m deep, with a water temperature of 27.5ºC, swimmers performed three 25m butterfly trials, at the velocity corresponding to the 100m event butterfly. In water starts were used, without diving. For each trial, it was required an individually imposed swimming breathing patterns: non inspiratory cycle; one breathing with one completed arm cycle (frequency ratio of 1:1); and one breathing with two arm cycles (frequency ratio of 1:2), in a randomized order. A digital camera (Sony® DCR-HC42E, 1/250 digital shutter, Nagoya, Japan) placed inside a sealed housing (Sony® SPK-HCB, waterproof box, Tokyo, Japan), recorded two complete underwater butterfly cycles, on the sagital plane. The digital camera was placed 1m depth and at 11.5m perpendicular distance from the swimming lane. For calibration of the registered plan, to allow the transformation of virtual coordinates in real coordinates, it was used a bi-dimensional structure (2.10m width x 3m height, and thirteen calibration points). Biomechanical analysis was performed with the software APASystem (Ariel Dynamics, Inc., USA), being digitized frame by frame (at 50Hz), two complete arm-leg cycles, particularly the distal end of the middle finger, the wrist, the elbow, the shoulder, the hip (femoral condyle), the knee, the ankle and the foot of each swimmer. The digitize-redigitize reliability was very high (ICC = 0.996). The average of swimming velocity was assessed through the ratio of the displacement of the hip in two arm cycles to its total duration. Stroke length was determined by the average of the horizontal distance traveled by the hip during two arm cycle, and stroke rate as the number of stroke cycles performed per min.

Coordination Assessment

According to Chollet et al. (2006), the arm stroke cycle in butterfly is divided in four distinct phases: entry and catch, pull, push and recovery; the pull and the push phases correspond to the arm propulsive actions. The leg cycle is also composed of four different phases: first downward, first upward, second downward and second upward. In the present study, only swimmers with two leg kicks per arm stroke cycle were studied, once it is the ideal pattern (Chollet et al., 2006). Arm-leg coordination was determined by measuring of the time gaps between the different arms and legs phases, and this, in turn, enabled to analyze the propulsive and the non-propulsive times. Four time gaps were identified, T1, T2, T3 and T4 that enable us to analyze arm-leg coordination (Chollet et al., 2006): T1 (time gap between the entry of the hands in the water and the high point of the first upward kick); T2 (time gap between the beginning of the pull hands and the low point of the first downward kick); T3 (time gap between the hands' arrival in a vertical plane to the shoulders and the high point of the second upward kick); T4 (time gap between the hands' release from the water and the low point of the second downward kick). In each trial, each time gap was expressed as the percentage of a complete leg cycle that was calculated as the mean of four leg strokes that were representative of the imposed swim paces. The total time gap (TTG) expressed as percentage of a complete cycle, was defined as the sum of the absolute values of T1, T2, T3 and T4, and it was used to assess the effectiveness of the global arm–leg coordination.

STATISCAL ANALYSIS

The SPSS program version 18.0 (SPSS inc., Chicago, USA) was used for both exploratory data analysis and for the statistical data treatment. The distributions normality was tested using the Kolmogorov-Smirnov (n>50), and the Shapiro Wilk (n<50) tests. Means and SD values were calculated for all measured parameters. After exploratory data analysis, the study of the interaction between the dependent and independent variables (gender, maturation and breathing) was performed. The posterior statistical analysis was dependent of the interaction result. When interaction was found, a t-test for dependent variables was applied to compare results by gender and maturation. When interaction was not present, ANOVA comparisons were performed between gender, without considering the effect of maturation and breathing; by maturation, without considering the effect of gender and breathing; and by breathing, without considering the effect of gender and maturation. The comparisons were made using a *Bonferroni* adjustment. The statistical significance was set at 5% for all tests used.

RESULTS

The study of the interaction between gender, maturation and breathing do not revealed significant values for all relevant measure of the variables.

When comparing gender (independently of maturation and breathing), boys group showed significant differences in velocity, stroke rate, catch duration, pull duration, recovery duration, second downward kick, second upward kick, temporal gaps T2 and TTG, than girls group; when comparing maturational status (independently of gender and breathing), pubertal group showed significant differences in velocity, stroke rate, catch arm, pull arm, push arm, arm propulsion, recovery arm, and time gaps T1, T2, T3, comparing to post-pubertal group; in addition, when comparing breathing pattern (independently of gender and maturation), breathing patter ratio 1:1 showed significant differences in catch duration than other two breathing patterns; breathing pattern ratio 1:2 showed significant differences in pull duration than other two breathing pattern, and breathing pattern ratio 1:2 showed significant differences in time gap T3 than non breath pattern.

Table 2. Mean (±SD) values of the variables for which interaction between gender, maturation, and breathing pattern was not observed.

	Gender		Maturation		Breathing patterns		
	Boys	Girls	Pubertal	Post-pubertal	Non Breath	Breathing pattern ratio1:1	Breathing pattern ratio1:2
Velocity ($m.s^{-1}$)	1.06±0.17 [a]	0.92±0.12	1.02±0.17 [b]	0.95±0.14	1.02±0.16	0.95±0.16	0.99±0.16
Stroke rate ($cycle.min^{-1}$)	42.47±8.17 [a]	34.26±6.49	40.86±7.90 [b]	34.92±7.95	39.29±8.78	37.03±8.45	38.77±8.03
Stroke length ($m.cycle^{-1}$)	1.53±0.23 [a]	1.66±0.24	1.53±0.23 [b]	1.68±0.24	1.61±0.24	1.59±0.24	1.58±0.25
Catch arm phase (%)	34.03±10.67 [a]	36.71±10.37	32.48±9.23 [b]	39.26±10.96	36.08±10.97	39.06±11.14 [c]	30.97±7.83
Pull arm phase (%)	19.37±4.63 [a]	17.45±3.87	19.68±4.16 [b]	16.65±4.04	17.14±4.03	18.79±4.52	19.31±4.31 [c]
Push arm phase (%)	20.14±4.31	20.58±4.15	21.41±4.13 [b]	18.92±3.94	20.65±4.69	19.92±4.08	20.51±3.91
Recovery arm phase (%)	24.43±6.36 [a]	20.59±5.55	23.39±6.18 [b]	21.19±6.18	22.66±6.56	22.02±6.19	22.84±6.09
1º Downward kick (%)	19.11±2.38	18.82±2.37	18.97±2.80	18.96±2.32	18.83±2.70	19.23±3.04	18.84±1.98
1ºUpward kick (%)	29.61±5.35	29.83±4.83	30.26±5.16	28.98±4.92	30.05±5.43	29.29±5.17	29.82±4.69
2ºDownward kick (%)	22.19±5.15 [a]	20.02±3.34	21.01±4.44	21.23±4.52	21.49±4.81	21.04±4.79	20.87±3.75
2ºUpward kick (%)	28.74±7.64 [a]	31.49±5.38	29.69±7.24	30.71±5.95	29.33±6.06	30.21±7.60	30.81±6.48
T1 (%)	1.66±7.86	-0.20±8.29	2.28±6.89 [b]	-1.36±9.19	0.90±8.19	-0,07±9.12	1.36±6.96
T2 (%)	-9.95±10.04	-8.37±7.64	-10.31±9.76 [b]	-7.56±7.42	-10.69±10.16	-8.89±7.99	-7.89±8.45
T3 (%)	1.98±5.30	2.91±4.75	1.15±4.75 [b]	4.24±4.90	3.60±5.97	2.81±4.23	0.92±4.45 [d]
T4 (%)	7.14±8.45 [a]	10.11±7.11	8.07±7.96	9.39±7.88	7.08±6.72	9.39±8.58	9.41±8.28
TTG (%)	37.36±7.78 [a]	34.26±10.41	35.49±9.04	36.26±1.22	37.41±9.01	35.44±9.94	34.85±8.92

Legend: Significatively different ($p<0.05$) from: [a] girls; [b] post-pubertal; [c] other two breathing patterns; [d] non breath pattern. T1: time gap between the entry of the hands in the water and the high break-even point of the first undulation; T2: time gap between the beginning of the hands backward movement and the low break-even point of the first undulation, T3: time gap between the hands arrival in a vertical plane to the shoulders and the high break-even point of the second undulation; T4: time gap between the hands release from the water and the low break-even point of the second undulation; TTG: sum of the absolute values of T1, T2, T3 and T4.

DISCUSSION

The purpose of this study was to analyze the effects of breathing on arm-leg coordination and general biomechanical parameters in the butterfly technique, as a function of gender and maturation. These aims are perfectly justified once no data in this topic is available in age group swimming, allowing a deep interpretation of spatial-temporal coordination patterns in the complete butterfly cycle when swam on different breathing patterns and performing at very high intensities. The study of the interaction between gender, maturation and breathing do not revealed significant values for all the variables measured.

In this study when compared gender when compared for in the velocity and stroke rate, the boys presented higher values than girls. Also, when compared maturational status, the pubertal group showed higher values than the post-pubertal group, on the same variables. However, when stroke length was compared between gender, and between maturational groups, the girls and post-pubertal group showed higher results than the boys and pubertal swimmers, respectively. So, independently of the breathing pattern, boys and pubertal groups, in order to obtain a higher swimming velocity, choosed to use a stroke rate significantly higher than the girls and post-pubertal group. In all swimming techniques, the variation in the velocity is due to a combined variation between stroke length and stroke rate, respectively (Craig, Skehan, Pawelczyk, Boomer, 1985). This is due to the increase in the propulsive time duration and the decrease in the non propulsive time duration which leads to a better timing between arm and leg key points (Delignières, Chollet, 1999). In the butterfly technique, velocity and stroke rate may be control parameters of coordination, because their increase led to a closer in phase mode of arm to leg coordination (Seifert et al., 2007).

In the arms stroke phases, when compared between gender and between maturational statuses, the girls and the post-pubertal group showed higher values in the catch duration than the boys and the pubertal group, respectively. In this phase, which corresponds to the time duration between the entry of the hands in to the water and the beginning of their backward movement (Chollet et al., 2006), these two groups (girls and post-pubertal) showed longer time in glide position, slowing the pull arm action. This fact may be explained by some difficulties in the coordination between arms and legs.

When comparing breathing patterns, the young swimmers present higher values of catch duration, in the breathing pattern ratio 1:1, than in the other two breathing patterns. This may be due to the action of the head at breathing, which allowed an easy movement of the arms in the recovery phase, affecting the balance of the body in the water, and generating higher values in the catch duration. Few studies have analyzed the effect of breathing on propulsion, kinematics, instantaneous velocity fluctuations or coordination, in the butterfly technique (Barbosa et al., 1999; Barbosa et al., 2003; Hahn et al., 1992). Barbosa et al. (2003) analyzed the difference between hip and centre of mass as regarding kinematic variables (vertical amplitude of displacement, intra-cycle variation of the horizontal velocity and acceleration) when different breathing patterns were used (frontal, lateral and restrained inhalation), but without emphasizing the effect of the breathing pattern. In fact, none of the referred studies compared non-breathing cycles with breathing pattern ratios of 1:1 and 1:2.

In the arms propulsion phases, when compared gender and, maturational status, the boys and the pubertal groups showed higher values in this phase, increasing the arm propulsion time, comparing to girls and post-pubertal groups. In accordance with this, Boulesteix, Seifert, Chollet (2003), reported that swimming parameters presented different behaviours between males and female swimmers. In fact the increase in the relative duration of the pull phase enabled the application of high propulsive forces and hence, increases of the body velocity (Mason, Tong, Richards, 1992). When comparing breathing patterns, the young swimmers presented higher values in pull arm with the breathing pattern ratio 1:2, comparing to the two others breathing patterns. This results may be explained by the fact that some swimmers probably privileged more an anterior-posterior trajectory, and therefore, a propulsive drag force generation was emphasized (Schleihauf et al., 1988). Contrarily, the others privileged a more lateral-medial trajectory, and consequently, the propulsion force with origin in the lift force was favoured (Schleihauf et al., 1988). Martins-Silva & Alves (2000), evaluated the importance of the hand’s velocity in butterfly swimming, and showed significant correlations between all directional components of the hand's velocity during the most propulsive phases (insweep and upsweep) and can increase the instant and mean body horizontal velocity (Mason et al., 1992; Maglischo, 2003).

In the recovery arm phase, when compared gender and maturational status, the boys and the pubertal group showed higher values in the recovery time duration than the girls and the post-pubertal group, respectively. Being the recovery of the arms slower in these two groups, indeed, the aerial recovery seemed to lead to a more vertical trunk position (Chollet et al., 2006). At high velocity and stroke rate, swimmers must reduce the time during which the head is over the water to facilitate the aerial and lateral recovery of the arms (Seifert et al., 2007). On the legs actions, when genders are compared, the boys showed higher values in the second downward kick than girls. The downward actions are clearly connected to propulsion through lower limbs actions in the butterfly technique (Jensen, Mc Ilwain, 1979), so boys showed a higher time in performing the second propulsive leg in the water. In the second upward kick, the girls showed higher values in the second upward kick than the boys; so, these are faster in the second upward kick and can prepare more quickly the first downward kick. In order to keep a high pace, swimmers have to make a strong first downward movement to reduce body deceleration due to hand's entry. The second downward movement has to be as strong as possible, to keep the hip near to surface, avoiding that this anatomical landmark emerges from the water (Hahn et al., 1992). It is usual that coaches stress the importance of a strong second downward kick during the butterfly stroke. This is especially evident in butterfly swimmers with a strong first downward kick and a weak or non-existent second downward kick (Barbosa et al., 2008).

In the time gap T1, comparing maturation, pubertal group shows higher values than the pos-pubertal group. Being positive the results obtained by pubertal swimmers when leg propulsion began after the arm recovery and the entry of the hands in the water, the arms glided forward while the legs completed their upward kick; this corresponds to a lag time in the glide position (Chollet et al., 2006). However, the results of the post-pubertal group are negative; so, when the legs propulsion began, the arm recovery was not finished. This corresponds to a superposition of two contradictory actions (Chollet et al., 2006). This coordination can be suboptimal because, although the legs were propelling, the arms and hands were not streamlined in an extended position to prepare for the catch (Colwin, 2002). In the time gap T2, comparing maturation, pubertal group shows higher values than the post-pubertal group. In this variable this two groups have negative results, so, there was a lag time in glide position of the arms while the legs performed the upward kick (Chollet et al., 2006). According to Hahn et al. (1992), the first leg kick in the cycle is the strongest, which is characteristic of higher velocities. So, when pubertal swimmers perform butterfly technique at a velocity corresponding to the 100m race pace, show a coordinative tendency to the glide position. However, it is important to aim for perfect timing between the push phases of the arms and the downward kick of the legs (Sanders et al., 1995), because this superposition of the two propulsive phases provides the highest body acceleration in the stroke (Mason et al., 1992).

In the time gap T3, comparing maturation, the pos-pubertal group show higher values in the coordination between arm-leg than the pubertal group. So, when post-pubertal swimmers performs butterfly, the downward kick began after the passage of the hands below the shoulders (Chollet et al., 2006). In addition, when compared breathing patterns, the young swimmers showed higher values in non breathing pattern, than the breathing pattern ratio 1:2, are near zero.

In the time gap T4, comparing gender, girls shows higher values than boys when the hands released from the water. So, the arm completed their release before the end of the leg propulsion; this corresponds to a negative superposition of two contradictory actions, because the leg propulsion did not provide a maximal advantage for the exiting hands (Chollet et al., 2006).

In the TTG, comparing gender, boys showed higher values than girls in the sum of the absolute values of the all temporal gaps; however, the two groups of young swimmers have very high values of TTG. Although there are significant differences between these two groups thus showed the same pattern of coordenation. As in the breaststroke (Chollet et al., 2004), higher velocity in butterfly stroke is reached through higher continuity in the arm and leg propulsive actions. Thus, the systematic observation and analysis during training and competition, seems to be a determinant procedure to the evaluation of the swimmer’s performance (Louro et al., 2010).

CONCLUSION

The arm-leg coordination in butterfly technique is very important to the swimmer to attain a high performance, but this knowledge is very difficult to apply and develop in young swimmers groups. Between gender, maturation, and breathing pattern were not observed significant interactions in studied variables, so, when the coaches work in arm – leg coordination butterfly, the swimmers do not need to be differentiated. In the general biomechanical parameters, independently of the breathing pattern, boys and pubertal group, in order to obtain a higher swimming velocity, reported a stroke rate statistically higher than girls and the post-pubertal swimmers. Boys and pubertal swimmers, when performed butterfly technique showed coordination between the arms and legs in a glide mode. The girls and the post-pubertal swimmers showed the coordination between the arms and legs, in overlap mode.

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Chapter 4

General Discussion

The aim of this thesis was to characterize the arm-leg coordination in young male and female swimmers, in breaststroke (IFBP) and in butterfly technique (TTG). This study is distinctive of others, because is the first one which is study to be conducted with young competitive swimmers in both the simultaneous techniques (breaststroke and butterfly) at high velocity (velocity corresponding to 100m, in each swimming technique). In the Butterfly technique, it was also studied the relationship of the arm-leg coordination considering three breathing patterns (breath-holding; a respiratory frequency ratio 1:1 and 1:2).

The search of new knowledge in the swimming performance is focused on the assessment of the biomechanical parameters and the efficiency stroke of the swimming movements. However, traditionally, swimming performance has been analysed in parallel with race components (start time, swim time, turn time, final time), particularly the swim time (i.e. in the central part of the pool and, thus, not affected by the dive start or by the turn-in and turn-out) centred all analysis in elite adult swimmers, leaving aside young swimmers. Moreover, biomechanical research on active drag, on power output and on propelling efficiency (Pendergast et al., 2006; Pendergast et al., 2005; Toussaint, & Beek, 1992; Toussaint, & Truijens, 2005), as well as on hand kinematics and on kinetics during the underwater path (Schleihauf, 1979), has greatly improved our understanding of what constitutes the swimming skill, but nevertheless, little attention has been given to motor organization.

Thus, this Thesis was oriented in order to analyse the performance of young swimmers in the breaststroke and in the butterfly techniques, by studying the arm-leg coordination, in order to better understand motor organization in the performance of these techniques. In **appendix 1**, it was conducted a preliminary pilot study on the breaststroke technique and, thus, a bibliography review was conducted, and obtained a first set of specific results in this field of study.

Based on Newell's concept of constraints, for whom constraints may be viewed as features that reduce the degree of freedom of the human motor organization (Seifert & Chollet, 2008), a new approach to assessing swimming skill was shown by Chollet et al. (2000), through the analysis of the inter-limb coordination: inter-arm coordination in the alternate strokes (front crawl and backstroke) and of the arm-leg coordination in the simultaneous strokes (breaststroke and butterfly) (Seifert et al., 2008).

Chollet et al. (2000) created a new Index of Coordination (IdC) to quantify arm coordination in the front crawl. In alternate strokes (front crawl and backstroke), the degree of coordination between the two arms was measured by means of the IdC, which is the time gap between the beginning of the propulsion at the first right arm stroke and the end of the propulsion at the first left arm stroke, and between the beginning of the propulsion in the second left arm stroke and the end of the propulsion in the first right arm stroke (Seifert & Chollet, 2009). Considerable research has been conducted and documented on the front crawl, the most popular and fastest stroke. For the other alternate stroke (backstroke) and the two simultaneous strokes (butterfly and breaststroke), our revision shows the influence of organismic constraints, particularly the skill level, which includes expertise, experience and age effects. Breaststroke is presented last because it is the slowest, the most resistive, and the most regulated stroke. The challenge is, therefore, to monitor the duration of the glide between the arm propulsion and the leg propulsion (Seifert & Chollet, 2008). Chollet & Boulesteix (2001) then calculated four time gaps that characterize the arm-leg coordination in the butterfly. In the simultaneous strokes (butterfly and breaststroke), four temporal gaps (T1, T2, T3 and T4) measured a lag time, between the arms and leg cycle phases of each pair of limbs. Then, TTG, which was defined as the sum of the absolute values of T1, T2, T3 and T4, was used to assess the effectiveness of the global arm-leg coordination in butterfly (Chollet et al. , 2006). In all of these studies, Chollet et al. (2004); Leblanc et al. (2005); Seifert & Chollet (2005) analyzed the arm to leg coordination in breaststroke by calculating time gaps between the key points marking the beginning and the end of the arm and of the leg stroke times. Given that a breaststroke cycle lasts about 2s, an efficient motor organization is difficult to achieve, particularly regarding two points: (i) combining two contrasting modes of coordination within the same cycle, the alternation of the arm and leg propulsions and the synchronization of the recoveries, and (ii) managing the glide time. For this reason, the beginner's coordination is quite different from that of the expert (Seifert et al., 2010). These studies indicate that the arm-leg coordination seems to be very important for breaststroke, but few studies have described differences of the arm-leg coordination by event, gender and performance level using comprehensible measures (Chollet et al., 2000).

In **Chapter 2**, our research was conducted with young swimmers, to characterize their arm-leg coordination, according to gender and maturational status. Thus, it was try to provide answers to our thirst for more and better knowledge on this area, through the study of the interaction between gender and maturation which revealed significant values for the dependent variables stroke rate ($F=6.077$, $p=0.015$), stroke length ($F=5.476$, $p=0.021$), second half leg recovery ($F=5.511$, $p=0.021$), leg recovery ($F=6.183$, $p=0.014$), T3 ($F=3.657$, $p=0.058$) and recovery effective. ($F=7.556$, $p=0.007$), which allowed us to identify the predominant motor organization, as well as some difficulties and errors in the arm-leg coordination. It was also established a parallel analysis with other studies already realized with elite and non-elite adult swimmers. Our analysis shows that the obtained results exhibit great differences in relation to those studies carried out with older elite and non-elite adult swimmers, which enabled us to check the trend of the results for the breaststroke technique. The research sought to reinforce the importance of developing studies with young swimmers and also of broadening the knowledge foundations in this area. Craig et al. (1988) investigated the temporal and velocity changes during the stroke cycle for a range of stroke rates, and found that the increase of velocity combined with an increase of stroke rate was not caused by acceleration, due to arm or leg action, but mainly by the timing of the different movements. The breaststroke has the highest intra-cyclic velocity variation, because the recovery times of the two pairs of limbs causes strong forward resistances in the opposite direction of movement. For this reason, arm and leg recoveries should not be performed in isolation: expert breaststroke coordination is characterized by synchronized recovery times to diminish this negative time (Chollet et al., 2004; Seifert et al., 2005; Takagi et al., 2004). Thus, the propulsion of one set of limbs should be performed while the other set is in hydrodynamic position, as when the limbs are extended to glide (Chollet et al., 2004; Seifert et al., 2005). Manley et al. (1992) suggested that the mechanics of swimming may be more critical in the breaststroke than in other competitive stroke styles and those swimmers could reach the same mean velocity by using different coordination patterns.

Young butterfly swimmers often see the butterfly technique as difficult to perform because of the arm strength that it requires. Conversely, an efficient arm-leg coordination requires one arm cycle for two leg cycles or a ratio of 1:2, with the upward and downward phases of the leg kicks synchronised (Chollet, et al., 2006 ;Seifert, et al., 2007). Therefore, a high degree of motor control in the breaststroke and in the butterfly, which depends on the swimmer's ability to decrease the time gaps between the arm and leg phase key points, notably by monitoring the glide times, should favour propulsive continuity, increase propulsive times (Chollet et al., 2004; Seifert & Chollet, 2005; Chollet et al., 2006) and decrease instantaneous velocity fluctuations. Usually, swimmers use one breath per every two arm strokes or they breathe once per every stroke. In fact, several breathing patterns (breath-holding, frontal breathing, lateral breathing) with different ratios of breaths to arm strokes have, at times, been adopted, yet there is little evidence about which is the best compromise between oxygen supply, the disturbance in propulsive continuity, instantaneous velocity fluctuations and variations in active drag (Seifert et al., 2010).

Although a profile of expert coordination in butterfly has emerged from these studies (Chollet et al., 2004; Seifert et al., 2005; Chollet et al., 2006), little is known about the coordination used by young swimmers. In this sense, as in the breaststroke technique, it was assessed the arm-leg coordination in the butterfly technique. In **Chapter 3**, when the interaction between gender, maturation and breathing do not revealed significant values for all relevant measure of the variables. However, when comparing gender (independently of maturation and breathing), boys group showed different velocity, stroke rate, pull arm phase, second downward kick, second upward kick, time gap T2 and TTG than girls group; when comparing maturation states (independently of gender and breathing), pubertal group exhibited higher catch arm phase, second upward kick and time gap T2 than post-pubertal group; in addition, when comparing breathing pattern (independently of gender and maturation), breathing patter ratio 1:1 exhibited higher catch arm phase than other two breathing pattern, and breathing pattern ratio 1:2 exhibited different pull arm phase and time gap T3 than other two breathing pattern.

On the same line of thought, in **Chapter 3**, it was expanded the scope of the current study with an analysis of three specific breathing patterns (breathing; one breathing per one completed arm stroke; one breathing per two completed arm strokes). From the statistical study of the comparison between all specific breathing patterns, were obtained results more favourable to the butterfly, in the specific breathing pattern ratio 1:2. In addition, it was also possible to identify difficulties in coordination of the groups of the sample in the butterfly, through the time gaps T2 and T3. In the simultaneous strokes (breaststroke and butterfly stroke), a high degree of arm-leg coordination ensures the propulsive continuity between the arm and the leg actions (Chollet et al., 2004; Seifert et al., 2005) and induces fewer instantaneous fluctuations in velocity (Mason, et al., 1992; Sanders, 1996). The greatest intra-cyclic velocity fluctuations in swimming (45-50% of the mean velocity) were found in butterfly and in breaststroke (Craig & Pendergast, 1979) and were related to high energy cost, i. e. to less efficient swimming (Barbosa et al., 2005). Since frontal breathing may disturb arm to leg coordination and increase the velocity fluctuations (Hahn et al., 1992), controlling the ratio of breaths to arm strokes could help to ensure a high degree of propulsive continuity and a streamlined body position. Indeed, Barbosa et al. (2005) showed that high fluctuations generate early fatigue in butterfly. Therefore, a high degree of motor control in the breaststroke and in the butterfly, which depends on the swimmer’s ability to decrease the time gaps between the arm and leg phase key points, notably by monitoring glide times, should favour propulsion.

In breaststroke, when compared the present results with those recorded in the studies conducted with older swimmers, it is possible to verify that in the variables biomechanics, arm and leg cycle phases, temporal lags and effective phases, our sample, although presenting higher values, follows the same trend of swimming groups from other studies. So, it can be hypothesized that swimmers of different skills levels may have different coordination patterns, and that young swimmers show more discontinuity in their technique. The greater time lag between propulsive actions of the young swimmers could be due to technical mistakes (for example, back drop of elbow during insweep and less streamlined position during non-propulsive times). However, differences in skill levels would be not only caused by each technical mistake, but by their relationships which induced different arm-leg coordination (Leblanc et al., 2005). On the other hand, the spatial-temporal differences between males and females may be due to anthropometric differences and different cycle phases durations linked to arm and leg coordination (Seifert et al., 2005).

The measurement of the IFBP and of the temporal gaps has practical applications. For example, depending on the race pace, coaches and swimmers could use these two indicators to guide them in the development of: an increased stroke length; a glide in a more streamlined body position, with a decrease in active drag; or a higher stroke rate with a longer propulsive phase, via a greater continuity in the propulsive actions (or some of the strategies of superposition in coordination). During training, the IFBP and the temporal gap measurement provides information on the duration of the propulsive phases and on the degree of continuity in the propulsive actions (arm and leg coordination), respectively. Moreover, both are indicators of the instantaneous velocity fluctuation and of the mean velocity variation (Seifert et al., 2005). However, direct manipulation of coordination in order to improve performance requires great care, however, and the swimmer should initially strive to adopt the imposed behavior, without trying to improve performance (Seifert, 2010). Therefore, rather than focusing on developing an ideal coordination mode, coaches would do better to vary the learning situations for swimmers, as they seek to develop optimal coordination (Seifert, 2010). The main contribution of inter-limb coordination analysis, over the past decade, has been the development of a useful tool for understanding motor skills in swimming. Consequently, more future research is required: to provide a better understanding of the arm-leg coordination for young swimmers to identify the main limitations and technical errors associated with IdC values obtained in all swimming techniques; to provide an adequate knowledge, in order for us be able to establish a causal relationship between biomechanical parameters and coordination parameters in the teaching of swimming techniques, to adjust young swimmers' development of swimming techniques to the different solicitations required by swimming distances; to provide a level of swimming development, so as to maintain a high arm-leg coordination and to improve competitive performance.

The main findings can be summarized as follows: (i) there is no "correct" coordination, but only coordination in relationship to interacting constraints, (ii) appropriate coordination is not synonymous with good propulsion, because a certain coordination mode is also adopted to facilitate breathing or floating, and (iii) coordination is not the cause, but mostly the consequence of these constraints; thus, imposing a certain coordination mode does not guarantee high performance or efficiency (Seifert, 2010). Following this Chapter, the Chapter 5 consists in the presentation of all conclusions that it was possible to reach with this thesis.

Chapter 5

Conclusions

The present Thesis intended to contribute for a wider characterization of breaststroke and butterfly techniques, namely through arm-leg coordination thematic in young swimmers. In both techniques, the arm-leg coordination in butterfly technique is very important to the swimmer to attain a good performance, but this knowledge is very difficult to apply and develop in young swimmers. From the results obtained it seems reasonable to highlight the following conclusions:

(i) the studies conducted on the arm-leg coordination in breaststroke and butterfly techniques, are mostly conducted in elite/adults swimmers; nevertheless studies conducted with young swimmers are still scarce;

(ii) the general biomechanical parameters SR and SL were significantly influenced by gender and status of maturation;

(iii) in breaststroke, the leg recovery parameters (second half leg recovery and leg recovery) are significantly influenced by gender and status of maturation;

(iv) the more difficulty in the arm-leg coordination in breaststroke is registered on the leg recovery phases;

(v) swim in glide is the swimming mode most adopted in young swimmers in breaststroke;

(vi) the young swimmers breaststroke show lows results of coordination in the recovery phases;

(vii) the main differences and difficulties identified in the breaststroke, between young swimmers and the older swimmers are related to the recovery phases (arm and leg) and their arm-leg coordination;

(viii) swimmers of different gender and/or different maturational status, using different breathing patterns in the butterfly techniques, reported no significant differences in the arm-leg coordination;

(ix) independently of the breathing pattern, boys and pubertal group, obtained higher butterfly swim velocity by using a stroke rate significantly higher;

(x) the arm-leg coordination presented by the boys and pubertal swimmers, was glide in the butterfly technique;

(xi) the girls and the post-pubertal swimmers showed a negative superposition of two contradictory actions (arm recovery and leg propulsion) in the butterfly technique;

(xii) the young swimmers showed lows index of efficiency in the arm-leg coordination in the butterfly technique;

Summarizing, the results of this study can contribute for a wider knowledge regarding arm-leg coordination in the simultaneous swimming techniques, in young swimmers, understanding its importance in improving the technical performance of swimmers. However, in order to reinforce the existing knowledge and to improve the performance of the swimmers, more research is needed.

Chapter 6

Suggestions for Future Research

Although we have obtained very interesting results, studies conducted with young swimmers are practically inexistent. Despite of the IdC research an area of recent interest, and usually oriented to elite athletes, a lot of documentation is already produced. Thus, it is of great importance develop further studies with young swimmers, to better understand the relevance of the IdC on the acquisition, development and consolidation of swimming techniques, both in training and competitive conditions. So, interesting future researches, the study of the relationship between biomechanical acquisition and the spatial-temporal coordination, of each stage of the arms and legs.

It is known, from studies conducted with elite and non-elite athletes, the existence of different coordination modes according to the distances and the speeds performed. In this sense, it will be of great interest develop studies that will focus on the analysis of the relation of the IdC, in young swimmers and in all swimming techniques, with the implementation of different distance and velocities (50, 100 and 200m) so that it could be possible to identify and characterize the coordinative mode predominance adopted for each distance and respectively velocity.

Considering also that swimmer changes the quality of technique along the distance swum, it is relevant, to study the coordinative adaptations conducted by the swimmers along the distance race. This, by allowing us to know when, how and where such changes occur, may help coaches to improve their daily work. Finally, knowing that anthropometric measures and physiological capacities in age throughout their training period are constantly changing, it will be of interest analyze the IdC according to the chronological and biological age, anthropometric measures and swimming profile, among others.

INDICE DE COORDENAÇÃO NA TÉCNICA DE BRUÇOS. UM NOVO MÉTODO DE ANÁLISE DA TÉCNICA

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INTRODUÇÃO

As técnicas convencionais de nado têm sido analisadas frequentemente sobre uma perspectiva biomecânica. No entanto, mesmo aceitando-se que a sincronização entre membros é fundamental para obter técnicas de nado mais contínuas (e, como tal, mais eficientes), o estudo da coordenação motora em natação apresenta-se deficitário.

Chollet et al. (2000) propuseram um novo instrumento de avaliação (o Índice de Coordenação - IdC), o qual permite avaliar a coordenação entre os membros superiores (MS) na técnica de crol. Várias têm sido as publicações neste âmbito, incidindo sobretudo, no entanto, em nadadores adultos de vários níveis desportivos.

Na técnica de bruços a investigação na área da coordenação motora é menos significativa, sobretudo se tiver por alvo de estudo crianças praticantes de natação. No entanto, também para esta técnica, Chollet et al. (2004) apresentaram uma proposta de avaliação do tipo de coordenação existente entre a acção dos MS e dos membros inferiores (MI). O objectivo do presente estudo foi determinar o IdC na técnica de bruços, realizada a velocidade elevada, em nadadores infantis.

MÉTODOS

Sessenta e nove nadadores Infantis voluntariaram-se para participar no presente estudo. As suas principais características foram 11.2±0.6 anos, 42.8±6.8kg, 150.7±6.7cm e 151.5±8.4cm de envergadura para as raparigas (n=33) e 12.1±0.7anos, 49.3±7.6kg, 157.7±8.4cm e 160.6±9.3cm de envergadura para os rapazes (n=36).

Numa piscina de 25m, cada nadador efectuou 25m à velocidade da prova de 50m na técnica de bruços. Para a determinação do IdC foram recolhidas imagens através de uma câmara de vídeo (Sony DCR-HC42E ®) colocada em imersão de forma a captar imagens no plano sagital do nadador. A avaliação biomecânica foi realizada com o software APASystem num ciclo de MS e MI, através da digitalização manual (frequência de 50Hz) de oito pontos-chave do corpo do nadador.

O IdC foi calculado tendo por base a divisão da acção dos MS e MI em cinco fases (Chollet et al., 2004; Seifert e Chollet, 2005): MS - (i) deslize, (ii) propulsão, (iii) acção lateral interior, (iv) 1ª fase de recuperação e (v) 2ª fase de recuperação e MI - (i) acção descendente, (ii) acção lateral interior, (iii) deslize, (iv) 1ª fase de recuperação e (v) 2ª fase de recuperação. Posteriormente calcularam-se os intervalos de tempo propulsivos e não propulsivos entre as acções motoras dos MS e MI, tendo sido identificados quatro intervalos de tempo não propulsivos: (i) T1, representando o tempo de deslize e dividindo-se em T1a (tempo entre fim da acção descendente dos MI e o inicio do movimento propulsivo dos MS) e T1b (tempo entre o final da acção lateral interior dos MI e o início da fase propulsiva dos MS); (ii) T2 (tempo entre o início da 1ª parte da recuperação dos MS e o início da 1º parte da recuperação dos MI); (iii) T3 (tempo entre o final da 1ª parte da recuperação dos MS e o final da 1ª recuperação dos MI) e (iv) T4 (tempo entre o início da 2ª parte da recuperação do MS e o início da 2ª parte da recuperação dos MI). Com base no somatório destes intervalos de tempo não propulsivos aplicam-se as seguintes fórmulas para o cálculo do IdC (Chollet et al. 2004): (i) se T1a > 0 e T2 e T3 < 0, aplica-se "IdC = fase propulsiva MI + fase propulsiva MS + acção lateral interior + (T2+T3) - T1a"; (ii) se T1a < 0 e T2 e T3 > 0, aplica-se "IdC = fase propulsiva MI + fase propulsiva MS + acção lateral interior". Adicionalmente, baseando-se na relação existente entre os tempos das acções motoras dos MS e MI, Chollet et al. (2004) propuseram quatro fases "efectivas" das acções dos MS e MI: (i) propulsão efectiva ($Prop_{efect}$), sendo o somatório das durações da fase propulsiva dos MI, da fase propulsiva dos MS e da acção lateral interior; (ii) recuperação efectiva (Rec_{efect}), sendo o intervalo de tempo entre o inicio da 1ª recuperação e o fim da 2ª recuperação; (iii) deslize efectivo (Des_{efect}), sendo a fase compreendida entre o fim da acção lateral interior do MI e o inicio da acção ântero-posterior dos MS e (iv) acção lateral interior dos MI (ALI_{efect}), intervalo de tempo entre o final da extensão dos MI e o final da sua abdução. A duração efectiva de um ciclo de nado completo, corresponde à soma do tempo de todas estas fases "efectivas".

O tratamento estatístico 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. O coeficiente de correlação de *Pearson* foi igualmente utilizado (software SPSS Statistics versão 17.0). A significância estatística foi considerada para p<0.05.

RESULTADOS

Na Tabela 1 são sintetizados os resultados obtidos no presente estudo.

Tabela 1. Valores médios (±SD) relativos a velocidade, frequência gestual, distância de ciclo, intervalos de tempo propulsivos e não propulsivos entre as acções motoras, índice de coordenação (equivalendo à propulsão efectiva), deslize efectivo, acção lateral interior efectiva e recuperação efectiva.

Parâmetros	Raparigas (n = 33)	Rapazes (n = 36)	Total (n = 69)
v (m/s)	0.97 ± 0.1	1.05 ± 0.1	1.01 ±0.1
FG (braçada.m-1)	41.28 ± 4.6	45.36 ±7.1	43.41 ±6.3
DC (m/ciclo)	1.43 ± 0.2	1.41 ± 0,2	1.42 ± 0.2
T1a (%)	-0.93 ± 0.2	-0.86 ± 0.2	-0.89 ± 0.2
T1b (%)	-1.17 ± 0.2	-1.12 ± 0.2	-1.14 ± 0.2
T2 (%)	0.31 ± 0.2	0.36 ± 0.1	0.34 ± 0.2
T3 (%) *	0.54 ± 0.1	0.32 ± 0.1	0.43 ± 0.1
T4 (%)	-0.41 ± 0.2	-0.45 ± 0,2	-0.43 ± 0.2
IdC = $Prop_{efec}$ (%)	30.29 ± 15.6	25.36 ± 12.0	27.82 ± 13.8
Des_{efect} (%)	34.88 ± 6.8	32.98 ± 7.8	33.93 ± 7.8
ALI_{efect} (%)	13.36 ± 8.5	16.57 ± 11.3	13.36 ± 9.9
Rec_{efect} (%)	23.79 ± 7.5	23.32 ± 5.52	23.79 ± 5.5

(*) diferenças significativas entre géneros, p< 0.05.

É possível observar a não existência de diferenças estatisticamente significativas entre géneros, à excepção para o parâmetro T3. No entanto, se considerarmos um nível de significância de p<0.01, pode-se referir que os nadadores apresentam valores superiores de v e FG comparativamente às nadadoras. Também no que se refere às quatro fases “efectivas” das acções dos MS e MI não foram observadas diferenças entre subgrupos sexuais. Complementarmente, foram observados algumas correlações significativas entre os parâmetros em estudo, nomeadamente as relações directas entre a v e a FG ($r=0.39$, $p<0.01$), a v e a DC ($r=0.49$, $p<0.01$), e a v e o IdC ($r=0.25$, $p<0.01$), e relação inversa entre a FG e a DC ($r=-0.59$, $p<0.01$).

DISCUSSÃO

Os valores de IdC obtidos evidenciam que os nadadores Infantis testados apresentam uma percentagem de propulsão efectiva menor comparativamente à literatura da especialidade (Chollet et al., 2004; Seifert e Chollet, 2005; Leblanc et al., 2005). De facto, o IdC em nadadores adolescentes e adultos (de níveis competitivos diferenciados) está compreendido entre 30 e 50%, enquanto o da nossa amostra total é inferior a 30%. De igual forma, os valores de v e DC são inferiores aos nadadores mais velhos, o que se pode explicar pelos menores valores de altura e envergadura dos nadadores Infantis e, eventualmente, pela menor qualidade da técnica dos mesmos.

Ainda no que se refere à coordenação entre MS e MI, é possível constatar-se uma predominância do Des_{efect} comparativamente às outras três fases “efectivas” das acções dos MS e MI, traduzindo uma maior importância das fases resistivas (não propulsivas) relativamente às propulsivas. Estes resultados 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 maior continuidade entre acções dos membros MS e MI (cf. Chollet et al., 2004; Leblanc et al., 2005). De facto, os nadadores do presente estudo apresentam uma menor duração relativa da fase de propulsão e de recuperação e uma maior duração da fase de deslize relativamente ao descrito na literatura, aproximando-se dos valores obtidos para nadadores aprendizes (Leblanc et al., 2005). De igual forma, foi descrito anteriormente uma superioridade no somatório das fases propulsivas no grupo de nadadores de elite (cf. Chollet et al., 2004; Leblanc et al., 2005), verificando-se o inverso no nosso grupo de Infantis (maior resultado na fase de deslize). Estes factos sugerem que o entendimento da coordenação motora específica da natação em adultos não pode ser directamente aplicado em crianças, ou que o estado maturacional e de desenvolvimento destas ainda não permitiram a sua consolidação. Neste sentido, o processo de crescimento e maturação parece interferir decisivamente na coordenação entre MS e MI na técnica de Bruços.

Complementarmente, as relações directas entre a v, a FG, a DC e o IdC, evidenciam que os nadadores mais rápidos são também aqueles com maior frequência e amplitude de ciclo de MS e MI, assim como melhor coordenação entre acções de MS e MI. A relação inversa entre a FG e a DC está de acordo com a literatura (e.g. Leblanc et al., 2005), evidenciando que, para se atingir uma determinada velocidade, existem diversas combinações entre estes parâmetros, nomeadamente que quando a FG aumenta a DC diminui, e vice-versa, não podendo aumentar em simultâneo.

Em termos de aplicação na prática do processo de treino diário, consideramos importante criar situações de estimulação da coordenação de uma forma variada, para além das que são clássicas e normalmente utilizadas no dia-a-dia, i.e., para além de utilizar a solicitação da coordenação entre membros MS e MI, deverá ser feita uma solicitação ao nível dos tempos de execução das diferentes fases da técnica. A estimulação da coordenação ao nível da estruturação espácio-temporal, irá permitir ao nadador ganhar uma noção dos diferentes tempos da execução da técnica e assim melhor gerir a sua execução. É importante que o nadador tenha noção do tempo utilizado na propulsão, recuperação e deslize para que, de acordo com os desafios com que se depara, possa alterar e controlar de forma consciente a sua técnica de nado.

Chapter 7

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Chapter 1

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