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review article

The use of hand paddles and fins in front crawl: biomechanical and physiological responses

Utilização de palmares e nadadeiras no nado crawl: respostas biomecânicas e fisiológicas

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Abstract – Paddles and fins are used during swim training and practice as tools for improving performance. The use of these equipment can alter physiological and kinematic parameters of swimming. The purpose of this literature review was to present and discuss the effects of paddles and fins on kinematic and physiological variables in front crawl, and provide update on the topic for teachers, researchers, coaches and swimmers. Thirty articles were reviewed. To crawl, paddles can change the averages of stroke length and stroke rate, the average swimming speed, the absolute duration of the stroke phases and the index of coordination. Fins can modify the average stroke rate, the average swimming speed, the kick frequency and deep, and the energy cost. We found no studies that verified the longitudinal effects of the use of paddles and fins on these parameters.

Key words: Equipment; Front crawl; Kinematics; Lactate.

Resumo – *Palmares e nadadeiras são utilizados durante a prática e o treinamento da natação como ferramentas para a melhora do desempenho. A utilização desses equipamentos pode alterar parâmetros cinemáticos e fisiológicos do nado. Os objetivos dessa revisão de literatura foram apresentar e discutir os efeitos dos palmares e nadadeiras sobre variáveis cinemáticas e fisiológicas no nado crawl e fornecer atualização sobre o tema a professores, pesquisadores, treinadores e nadadores. Trinta artigos foram revisados. Para o nado crawl, palmares podem alterar o comprimento e a frequência média de braçadas, velocidade média de nado, duração absoluta das fases da braçada e índice de coordenação. Nadadeiras podem modificar a frequência média de braçadas, velocidade média de nado, frequência de pernada e profundidade da pernada e custo energético. Não foram encontrados estudos que verificaram os efeitos longitudinais da utilização de nadadeiras e palmares nesses parâmetros.*

Palavras-chave: *Cinemática; Equipamentos; Lactato; Nado crawl.*

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INTRODUCTION

The main goal of the training process in competitive swimming is to increase swimming velocity. According to the first law of motion, any change of this parameter will only occur through the action of a force on the body (at rest or in motion). Then, it is extremely important to know the forces acting on body during the sport movement. In swimming, there are basically four forces to be considered: (1) weight, (2) buoyant, (3) drag and (4) propulsion.

Although there are translations and rotations due to the cyclical movements of the legs, arms, head and trunk, the main motion of the center of mass occurs along the longitudinal axis of the swimmer's body, i.e., parallel to pool lanes[1]. Because of this, there is a greater interest on drag and propulsion forces.

Training loads, which must be aligned to the sport demands, should provide several adaptations (mechanical, biochemical, physiological, neuromuscular and/or psychological) that will influence the magnitude of change of these physical forces and, consequently, swimming velocity. Changes on velocity are usually monitored by kinematic parameters such as the average of stroke length and rate. In response to training, they tend to increase and decrease, respectively, in unequal proportions though[17]. Still, monitoring of blood lactate levels throughout the different training exercises emerges as a possibility to verify energy metabolism predominance in a given swimming velocity.

In this context, the use of means of training, such as paddles and fins, is common at different levels of swimming, from recreational to competitive. They cause an artificial enlargement of hands and feet areas, allowing the swimmer pushing off against a greater amount of water[2,9]. Under these conditions, the resistance that should be overcome in each stroke or kick also increases, and an increment of propulsive force is expected as consequence of planned and systematic use of these materials.

Studies published so far noticed that, acutely, the use of paddles tends to increase the average stroke length[2,4,5], the average swimming velocity[2,4,5], the pull stroke phase duration[3,6], reduce the average stroke rate[4-6] and change the index of coordination[4]. In parallel, it was observed a similar blood lactate level, with and without paddle[7,8], at similar swimming velocity.

Concerning fins effects, previous cross-sectional studies reported an increase in average swimming velocity[9,10], increase[9] or decrease[11,12] in kick frequency, decrease in average stroke rate[12] and decrease in energy cost[11] (represented by the oxygen consumption during the motor task). However, until then, no studies were found comparing other physiological aspects between swimming with and without fins, besides the energy cost[11].

In the last decade, studies also investigated the effects of these equipment in the front crawl stroke spatial-temporal organization[3,4,6]. This analysis qualitatively determines the beginning and end of entry and catch, pull, push and recovery phases, enabling the quantification of their respective durations and spatial-temporal organization patterns adopted by swimmers (catch-up, opposition and superposition) in the crawl-stroke[13]. Still, as observed in many studies[15-17], different swimming intensities provide distinct values of kinematic parameters, coordination patterns and physiological indicators of intensity. Thus, the effects of paddles and fins could also vary according to swimming intensity, i.e., maximum or sub-maximum. Therefore, it is essential to identify the swimming intensities in which differences between, with and without equipment, are found, in order to obtain specific mechanical and physiological responses to the race requirements.

Given this, the aim of this study is to present, review and discuss the effects of paddles and fins on kinematic and physiological parameters in the front crawl stroke, and through this to provide an update on the topic for those who seek swimming performance, considering that such equipment are often used among competitive and recreational swimmers.

Biomechanical and physiological aspects - delimitation and concepts

This review emphasizes the effects of paddles and fins on biomechanical and physiological aspects in the front crawl stroke. Then, prior to the discussion of the selected articles, we will present concepts related to biomechanics and physiology of swimming, pertinent to the study.

Regarding biomechanics, the kinematic analysis is usually employed as a way for monitoring technique in swimming. Average swimming velocity (SV), average stroke rate (SR) and average stroke length (SL) are among the most commonly used parameters. The SV, usually expressed[18,19] in $m{\bullet}s^{-1}$, is defined by the ratio between distance and time variation and/or the product between SL and SR, and it should be obtained without start and turns influence. The average horizontal distance covered by the body during a complete stroke cycle is defined as the average stroke length (SL), expressed in meters[18,19]. SR is the average number of stroke cycles performed in a given time[18,19]; it may be expressed in cycles per minute ($cycles{\bullet}min^{-1}$) or Hz ($cycles{\bullet}s^{-1}$). As the clean swimming velocity can be obtained by the product of the SR and SL, the increment of the SV can occur: by increasing the SR (acutely), and in response to training, by increasing the SL[17] (chronically).

Other kinematic parameters can help to understand upper limb coordination in front crawl stroke, as observed by Cholet et al.[13] and Seifert et al.[16] These studies[13,16] proposed to divide each complete arm stroke into four different phases (two propulsive and two non-propulsive): phase A (entry and catch of the hand in water: entry of the hand into water until the beginning of its backward movement. It is assumed that propulsion is not generated during this phase); phase B (pull: the time between the beginning of the backward hand movement until its alignment in the vertical plane with the shoulder. It is accepted that propulsion is generated during this phase); phase C (push: from hand alignment in the vertical plane with the shoulder to its release from the water. It is also well accepted that this phase generates propulsion); and phase D (recovery: the above-water phase. It begins with hand release to the water and ends with its entry into the water, ahead of the swimmer's head. Propulsion is not generated in this phase).

The qualitative analysis of these events allows the determination of the index of coordination (IdC), which is the lag time between the end of the push phase of one arm and the beginning of the pull phase of the opposite one, expressed as a percentage of the total duration of the stroke cycle (two complete strokes). According to Chollet et al. [13], the purpose of the IdC is to identify and quantify the coordination mode adopted by a swimmer. The IdC should be calculated between the end of the propulsive phase of the left stroke and the beginning of the propulsive phase of the right stroke (IdC1) and between the end of the propulsive phase of the right stroke and the beginning of the propulsive phase of the left stroke (IdC2)[20].

Based on the average between IdC1 and IdC2, Chollet et al.[13] proposed three coordination modes in front crawl: (1) opposition (IdC=0): one arm begins the propulsion phase at the same moment that the other arm ends its propulsive phase, providing propulsive continuity between both arms phases; (2) catch-up (IdC<0): there is an interval between the end of the propulsive phase of one arm and the beginning of the propulsive phase of the other, that is an interval when there is no propulsion; and (3) superposition (IdC>0): there is a simultaneous propulsive action of both arms, thus, one arm begins the pull phase before the other arm finishes the push phase. The IdC analysis allows to estimate the propulsive continuity between the upper limbs in front crawl. The propulsive continuity may be a key factor to adjust swimmer's coordination to competitive demands, since the predominant and expected coordination modes are opposition or superposition in short-distances races, and catch-up during long-distance ones.

The lower limbs action, in front crawl, is characterized by the flutter and alternate kick, which is predominantly executed in the sagittal plane. The kick frequency (KF) is commonly identified as six-, four- and two- lower limbs movements per complete arm stroke cycle. These movements respond by approximately 15% of the maximum swimming velocity[21] in front crawl and provide better conditions for displacement, since they reduce body vertical oscillation and, consequently, the active drag, besides generating propulsive forces[21]. In addition to the frequency, the kick depth is also another parameter correlated with swimming performance and energy cost[11].

Regarding parameters, for exercise intensity prescription and/or monitoring training-induced adaptations – acute or chronic –, the present study examines the blood lactate level (LA) and energy cost. LA in response to the exercise is used with several goals: invasive determination of anaerobic threshold[22], to detect physiological effects of training[15,23] and physiological responses to the effort[14] and performance prediction as well[24]. The energy cost can be represented by the net amount of oxygen uptake (VO_2) necessary to perform a given task[12]. However, at swimming velocities in which the anaerobic metabolism participation is significant, the energy cost must include the anaerobic energy contribution.

METHODOLOGICAL PROCEDURES

Searches were conducted between January and December 2011. We used CAPES Periodic Portal database through the following structures: SCOPUS, ISI WEB OF KNOWLEDGE and GOOGLE SCHOLAR. We employed the words "front crawl", "swimming", "paddle" and "fin" for swimmers and divers, without any prior gender definition and/or competitive level. The Boolean operators "and", "or" and "not" were also used with these words. The studies were limited between 1976 and 2011. We did not consider in-press articles, but only those full versions already published and articles presented in related conference proceedings.

RESULTS

This review used 30 articles and one book chapter; from these, 17 items composed the revision, delimitation and concepts of biomechanical and physiological parameters (six of them were related to physiological aspects, seven concerned biomechanical aspects, and four biophysics analysis). Regarding the effects of paddles and fins among swimmers during front crawl and divers (in the case of fins), 14 articles were found (eight of them verified the effects of paddles, and the other six the effects of fins on biomechanical and physiological variables, or both). Figure 1 presents a summary of the number of items and areas reviewed.

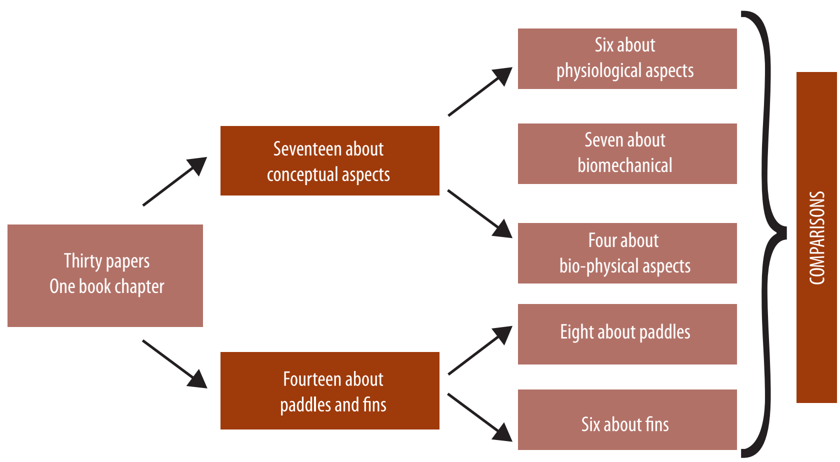

Figure 1. Summary of the number of items analyzed and areas reviewed and compared.

Paddles

Paddles are used for upper limbs force development in swimming and are made from synthetic resins, which provide lightness and stiffness to the product. Such equipment are used to increase the propulsive force of the swimmers by increasing the water volume displaced during underwater stroke phases. In literature, we found paddle sizes ranging from $116cm^2$ to $462cm^2$ [2 2-5].

During situations in which maximum intensity is required, the use of paddles can cause decreases in average stroke rate, hand velocity during underwater movements and increments in average stroke length and average swimming velocity[3,4,5,8]. When the stroke rate is standardized, there is also an increase in swimming velocity, related to the significant increase in propelling efficiency[6].

At maximum velocity, paddles surfaces between 116cm^2 and 268cm^2 provide significant increases in the total stroke and pull durations [3]. According to Gourgoulis et al.[3], such changes are related to the size of paddle used. Additionally, with paddles of 462cm^2, there is a little time increase in absolute values of all stroke phases, without a significant increase in the relative duration of the phases, in relation to the cycle total duration[4].

At a fixed stroke rate with paddles of 360cm^2, phases A (entry and catch of the hand in water) and D (recovery) decrease whereas phases B (pull) and C (push) increase[6]. In fact, when paddles were worn, a negative correlation was found ($r=-0.76$, $p<0.01$) between the duration of phase A and IdC (the shorter the duration of phase A, the higher the IdC), and a positive one ($r=0.60$, $p<0.05$) was detected between the duration of phase C and IdC (the longer the duration of phase C, the higher the IdC). Without paddles, similar correlations were found between phase A and IdC ($r=-0.64$, $p<0.05$; the shorter the duration of phase A, the higher the IdC) and also between phase C and IdC ($r=0.64$, $p<0.05$; the longer the duration of phase C, the higher the IdC)[6].

From these data, we can observe that the increase of the average swimming velocity caused by the paddles generates changes of the duration of phases A (decrease) and C (increase), and also of the IdC, which switches from a catch-up mode to a continuous and/or superposition propulsion pattern. Thus, one of the expected effects from the use of paddles with relatively large areas is the increase of the duration of the propulsive phases, especially the pull, which will allow a longer time of force application, mainly produced by shoulder extenders and adductors, which are directly related to propulsion[6].

However, these result does not seem to be repeated when smaller paddles are used (116cm^2 and 286cm^2).As shown by Gourgoulis et al.[5], they did not cause changes in the IdC. This divergence can also be related to gender, since there are differences between men and women IdCs[16]. At velocities corresponding to distances of 3000m and 200m, men tend to present a capture coordination model in swimming. This changes when maximum velocity and 100-m and 50-m race paces are adopted, so that the coordination mode varies between opposition and superposition. On the other hand, the coordination mode in front crawl among women remains in capture regardless of velocity, fact that may be related to anthropometric and kinematic differences compared to men[16].

When the same rate of perceived effort is used to prescribe swimming intensity with and without paddles, the use of such equipment causes a decrease in the average stroke rate, accompanied by a proportionate increase in the average stroke length, so that no significant change in swimming velocity is detected[25]. It is believed that with small (183cm^2) and medium

(260cm²) paddles there is a greater force application per stroke and, therefore, an increase in energy demand (compared to swimming without paddles). This higher energy demand will reduce swimmer's SR, so that the SV remains constant[25].

The lactate level tends not to modify in the situations below, above and on maximum aerobic velocity with and without paddles[7,8]. It is believed that the greater swimming velocity with paddles is not dependent on a higher energy output, but rather on a greater propelling efficiency, generated by the artificial increase of swimmer's hand area[7].

Water is not a fixed point in which swimmer can push off from for his or her own displacement. Thus, during generation of propulsion, part of the external mechanical power is used to overcome drag, while another is wasted moving the water[26,27]. In this sense, propelling efficiency is defined as the ration between the power used to overcome the drag and total external mechanical power[26,27]. The increase or decrease of this parameter is closely related to subject's technical capacity[28]. Toussaint[28] showed that swimmers use, on average, 61% of the total power to overcome the drag, while triathletes use only 44%, i.e., much of the triathletes' external mechanical power is wasted moving water. Thus, in a similar velocity, paddles cause major changes in the SL, SR, SS, IdC and duration of stroke phases, compared to conventional swimming.

Fins

Fins are made from different materials such as rubber, silicone and glass fiber. They enable the artificial enlarge feet area, and are widely used for displacements below or on water surface[29]. The different shapes, lengths, widths, areas, levels of stiffness and density can provide various responses of velocity, economy and swimming efficiency, no matter the comparison between their different types or swimming without them[10,11,30]. The principle underlying its use is the same as those used for paddles, i.e., by increasing the area of the feet it is possible to displace a greater mass of water.

In relation to the physical characteristics of the commercial fins available, it was observed that, relative to the area, the larger ones occasion a lower energy cost and a higher thrust (improving the horizontal position of the swimmer's body), while those that have smaller areas produce a higher energy cost and a lower thrust; regarding stiffness, the strictest ones generate a lower maximum velocity and a higher energy cost, compared to less rigid fins[9].

The main technical indicators related to legs movements in front crawl are the kick depth (KD) and frequency (KF)[10]. According to Zamparo et al.[10], swimmers who achieved best performance in incremental tests in annular pool were those who had lower values in both variables (KD and KF). Still, there is not a structural feature of the fin (stiffness, area, openings, among others) that is able to predict the best performance; however, a great indicator of the energy demand is the kick frequency[9,10]: the lower the KF, the lower the energy cost.

Compared to conventional swimming (with no equipment) at the same swimming velocity, fins (860m^2 and 1,100m^2 of area, classified as small and not rigid), decreased kick frequency in 43%[11,30]. Regarding the size of the fin, we observed that the kick frequency decreases when the fin area increases, [10]. Bigger fins create a greater drag and, in order to overcome it, a greater muscle force application is required, which leads to a reduction in muscle contraction velocity and, consequently, there is a reduction of kick frequency. Still, swimmers classified as less skilled have greater knee and ankle flexions[10,31].

The use of fins does not affects only the legs, but also swimmer's body as a whole[12,21], because they improve the propelling efficiency of both lower and upper limbs (in these last ones, less intensely)[12]. Zamparo et al.[12] observed that the propelling efficiency may increase, on average, 20% with fins.

The use of fins is not only associated with decreases in the kick frequency, but also with lower stroke rate. According to Zamparo et al.[12], this reduction can achieve approximately 20% when compared to conventional swimming in equal swimming velocities. The decrease in SR using the equipment may originate both from the increased production of propulsive forces of the legs (which may influence the strokes, change the trajectory of the wrist and, thus, increase the stroke length)[12,21] and from movements of the legs during front crawl. They attenuate the vertical oscillations of the hip, which tends to promote a greater stability for the body; therefore, the arms can increase the movement range[21].

Through the data of KF and SR, it is possible to estimate the internal working of the lower and upper limbs. From this, it was observed that, in the same velocity, fins reduce the internal working of the lower and upper limbs in 40%, compared to swimming without equipment[12].

The kick depth (KD) can also be changed with fins. They provide decreases between 14% and 15% of the KD[10,11], which are related to drag and energy cost reductions. On the other hand, kick amplitude and trunk inclination do not seem to suffer drastic changes [10,11]. Therefore, the use of fins does not appear to be an alternative for the improvement of body position in water.

With less rigid fins (flexibility determined in tests to show stress-strain curves), decreases up to 40% of the energy cost were observed at submaximal velocities[11]. Regarding the energy cost, we observed decreases of approximately 10% when using fins at the same swimming velocity[12].

Compared to small fins, the large ones have better floatation due to the greater buoyant force and similar propelling efficiency. Still, the distance by leg-kicking is about twice greater with fins[10].

Generally, fins affect the average swimming velocity, the average stroke rate, the kick frequency and kick depth, but little is known about their effects on the average stroke length, the duration of the stroke phases, the index of coordination and blood lactate levels.

CONCLUSION

Considering the studies analyzed (in front crawl), we conclude that paddles cause major changes in the average stroke length, the average stroke rate, the average swimming velocity, the index of coordination and duration of the stroke phases, although they do not modify the blood lactate levels in similar velocity (with and without paddles). Similarly, it is observed that fins affect the average swimming velocity, the average stroke rate, the kick depth and frequency, but there is still a lack of information about their effects on the average stroke length, the duration of the stroke phases, the index of coordination and blood lactate levels.

Although not justifiable, it seems natural that most of the publications on the use of external resistance in swimming has focused on upper limbs force development (in this case, the paddle), as they contribute about 85% of the total propulsion in front crawl.

Furthermore, it is important to consider the possibility of different sizes and shapes of paddles and fins produce different biomechanical and physiological responses. This deserves special attention, because it directly influences the organization of training loads throughout the periodization. As reported, acutely, different sizes may affect important parameters of the training load, as the average swimming velocity, for example. Whereas the neuromuscular adaptations are maximized in – or close to – the execution velocity of the training, the effectiveness of situations in which there is a very drastic reduction in the stroke rate could be argued.

Coaches should focus their goals, when using paddles and fins, in order to choose the sizes of them and the intensities that swims will be carried out, considering the changes in the biomechanical and physiological aspects of swimming related to the use of paddles and fins.

Through this review, in addition to achieving the goals, we instigate more questions, as the possible effects of the use of such equipment in other swims (backstroke, breaststroke and butterfly), and the long-term responses to the use of paddles and fins, in longitudinal studies.

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