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Performance in 200 m front crawl: coordination index, propulsive time and stroke parameters

Desempenho em 200 m nado crawl: índice de coordenação, tempo propulsivo e cinemática de nado

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Abstract – The aim of this study was to compare coordination index, propulsive time, duration of stroke phases and kinematic parameters over 200 m front crawl. Variables were compared among four sections of 50 m (T1 to T4) in fifteen competitive swimmers (age: 21.1 ± 7.1 years; height: 180.1 ± 6.1 cm; height: 187.3 ± 8, 1 cm; body mass: 72.1 ± 10.1 kg; better performance in the race: 77.5 ± 4.7% of the world record). Data were obtained with two video cameras (60 Hz - coupled to a cart on rails on the side of the pool) for simultaneous images of the swimmer's sagittal plan: below the water line and above the water line. Mean stroke rate stroke length, assumed as the mean distance traveled per cycle, and mean swimming speed were obtained with manual timing. Over the 200 m, the coordination index remained unchanged (p >0.05), but there was an increase in the frequency of cycles (p <0.05) and reduction of distance traveled per cycle (p <0.05). Between T1 and T2, there was an increase in the propulsive time (p <0.05) and between T1 and T4, there was an increase in the length of the pull phase (p <0.05). The swimming speed decreased only between T1 and T2 (p <0.05). Over 200 m front crawl, well-trained swimmers increment propulsive time and pull phase duration and frequency of stroke cycles, and such changes may be due to the speed maintenance attempt over the 200 m.

Key words: Efficiency; Kinematics; Swimming.

Resumo – *O objetivo deste estudo foi comparar índice de coordenação, tempo propulsivo, duração das fases da braçada e parâmetros cinemáticos ao longo de 200 m nado crawl. Variáveis foram comparadas entre os quatro trechos de 50 m (T1 a T4) em quinze nadadores competitivos (idade: 21,1 ± 7,1 anos; estatura: 180,1 ± 6,1 cm; envergadura: 187,3 ± 8,1 cm; massa corporal: 72,1 ± 10,1 kg; melhor desempenho na prova: 77,5 ± 4,7% do recorde mundial). Obtiveram-se os dados com duas câmeras de vídeo (60 Hz - acopladas a um carrinho sobre trilhos na lateral da piscina), para imagens simultâneas do plano sagital do nadador: abaixo da linha da água e acima da linha da água. Frequência média de ciclos, comprimento de braçada (assumida como a distância média percorrida pelo corpo a cada ciclo) e velocidade média de nado foram obtidos com cronometragem manual. Ao longo dos 200 m, o índice de coordenação não se alterou (p > 0,05), mas houve incremento da frequência de ciclos (p < 0,05) e redução da distância percorrida por ciclo (p < 0,05). Entre T1 e T2, houve incremento do tempo propulsivo (p < 0,05) e entre T1 e T4, da duração da fase de puxada (p < 0,05). Velocidade de nado diminuiu apenas entre T1 e T2 (p < 0,05). Ao longo de 200 m nado crawl, nadadores bem treinados incrementam tempo propulsivo, duração da fase de puxada e frequência de ciclos de braçadas, tais mudanças podem ser devidas à tentativa de manutenção da velocidade ao longo dos 200 m.*

Palavras-chave: *Cinemática; Eficiência; Natação.*

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INTRODUCTION

The performance in swimming can be described as the ability to swim the prescribed distance according to the rules in the shortest time possible[1,2], being dependent on biomechanical, physiological, anthropometric, psychological factors[3]. The biomechanics of swimming, the temporal organization of the stroke phases[4,5], determined by the coordination index (IdC), expressed as a percentage of the average length of the stroke cycles and their durations, appear to be important tools for the evaluation of a swimmer's technique.

From the temporal relationship between phases of both arms, the coordination of stroke movements in front crawl can be described from three models: (1) opposition: the propulsive phase of an arm starts at the end of the propulsive stage of the other (IdC = 0%); (2) capture: shows a time with no propulsion between the end of the propulsive phase of an arm and the beginning of the propulsive phase of the other arm (IdC < 0%), and (3) overlap: the beginning of the propulsive phase of an arm occurs before the end of the propulsive phase of the other arm (IdC > 0%)[6]. Stroke in front crawl they can be divided into four stages: hand entry in the water and support, pull, push, and recovery. The pull and push phases are assumed to be responsible for the swimmer's propulsion, and the entry, support and recovery phases are considered non-propulsive phases of the stroke[7-9]. In addition, the time spent for propulsion per distance unit (T_{prop}) recently proposed by Alberty et al.[10] estimate the time required for propulsion per each swimming section.

It is known that, in response to changes in the mean swimming speed (SS), there are adjustments in IdC and the relative duration of the stroke phases. Increases in the SS leads to decrease in the relative duration of the entry and support phases, reducing the interval between the propulsive phases between arms and hence increasing the IdC value. These adaptations are also accompanied by greater relative duration of the propulsive phase of the stroke[8,10]. However, in maximum protocols, since speed may change due to fatigue or race strategy adopted, different adjustments may occur. Moreover, studies[10,11] have shown that T_{prop} was described in submaximal efforts, not during maximum tests. Such information can be useful to coaches and athletes as a tool to evaluate competitive technique, not only for training intensities.

Several studies[2,12-14] have found decreased of SS and the stroke length (SL) with significant increase of IdC over 100 and 200 m of front crawl at maximum intensity, which can be explained by the development of fatigue, resulting in decreased capacity to generate force. However, Chollet et al.[15] and Toussaint et al.[16] found that swimmers with the best performance in 100 m showed smaller reductions of SS and DC throughout the race. They also showed greater stability in IdC values and mean stroke rate (SR)[16]. Furthermore, such technical changes may be in response to drag, which increases the square of the speed, so, predetermining the hull speed of a swimmer can be crucial to understand the possible adaptations that occur in maximum swimming intensities[16].

In response to training, coaches and swimmers seek to increase or change the variables involved in swimming performance for greater energy intake, greater resistance to fatigue, more force used efficiently and better technical indicators, as well as better race strategy[2]. The identification of the behavior of spatio-temporal organization variables, the duration of the stroke phases and the T_{prop} adopted by swimmers over this distance can indicate specific training needs of swimming technique and the possibility of changing the race strategy. Knowing the importance of biomechanical parameters for the best swimming performance, the aim of this study was to compare the coordination index, the time spent for propulsion per distance unit, duration of stroke phases, the average cycle frequency of strokes, the average distance traveled by the body every cycle and the average swimming speed over 200 m in front crawl at maximum intensity. Thus, based on results of previous studies[8,10,14], the following hypotheses were formulated for this study over the 200 m: (1) the coordination index is constant, indicating capture model; (2) there will be increase in duration of the pull phase, and (3) the time spent for propulsion per distance unit will increase.

METHODOLOGICAL PROCEDURES

The sample was composed of 15 regional and national level swimmers (age: 21.1 ± 7.1 years; height: 180.1 ± 6.1 cm; height: 187.3 ± 8.1 cm; body mass: 72.1 ± 10.1 kg; best performance in competition in 200 m: 77.5 ± 4.7% of the world record), all men, experts in the freestyle events in the pool (200, 400, 800 and 1,500 m) and open water. Participants had at least four years of competitive experience and trained for at least 12 hours weekly, with training volume between 35,000 and 80,000 m per week. As exclusion criteria, no swimmer could have been injured in the last twelve months that could compromise the swimming technique. The test, 200 m in front crawl under maximum intensity, was held in the training schedule of participants and all were familiar with the test procedures. Swimmers were recommended to reduce the exercise levels for a minimum of 24 hours and abstain from the consumption of any substance containing alcohol and / or caffeine for 12 hours before testing.

Protocol

The test was conducted in 25 m indoor pool (water temperature: 29.5 ± 0.7 °C; air temperature: 24.2 ± 0.9 °C) and between 03:00 pm and 06:00 pm in order to minimize the effects of circadian variation on performance[17]. Tests were carried out with start inside the pool and then a 800 m standard free swimming warm-up. Figure 1 shows the time diagram of the protocol adopted in this study.

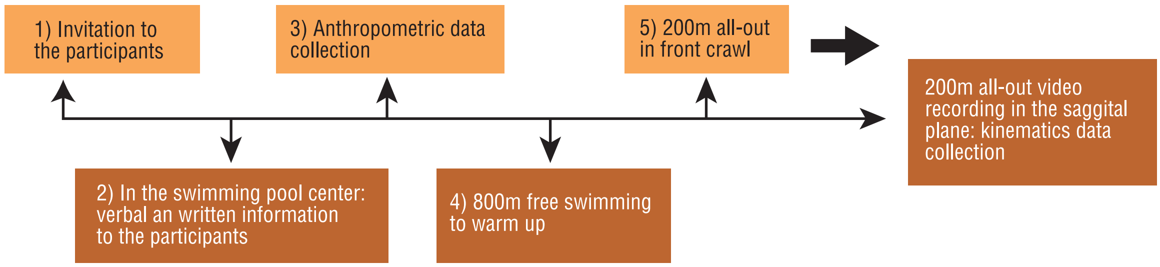

Figure 1. Scheme of the temporal organization of the protocol used.

Before evaluation, participants were informed of all methodological procedures and signed the informed consent form for their participation in the study. Parents and / or guardians for participants under 18 years also signed the informed consent form for their participation. Swimmers younger than 18 years read and signed a consent term. The study was approved by the Ethics Research Committee of the Federal University of Rio Grande do Sul under protocol number 17367.

Swimming and strokes parameters

Data collection for the acquisition of swimming parameters consisted of manual timekeeping and recording of external and underwater images of the front crawl. For external and underwater recording, a videogrammetry system was used in two dimensions with recording of the front crawl in the sagittal plane. The images were collected at a frequency of 60 Hz in the 25 m stretches that preceded partials of 50 m (T1), 100 m (T2), 150 m (T3) and 200 m (T4).

For manual timekeeping, a range between 10 and 20 m in the pool was marked to minimize effects of propulsion against the edge. Thus, the time of 10 m in pure swimming and the time for the execution of three full stroke cycles were timed by two experienced evaluators using timers (Technos, model 100 lap memory, Switzerland) with 0.01 s of resolution for all sections. If the two timekeepers did not obtain the same time in tenth of a second, the intermediate value was used (difference greater than 0.2 s) or the highest value (difference of 0.1). As a reference, the swimmer's head passing by the demarcated area markers of 10 m was always used. The swimming speed was obtained by dividing the distance (10 m) and the time needed to go through it (in s). Through the ratio of the three stroke cycles performed in the range of 10 m of the pool and the time to perform it, the frequency of cycles was determined; the distance covered per cycle was obtained by the ratio between SS obtained in the range of 10 m and SR.

From the external and underwater images, the following parameters were determined: (1) the duration of the stroke phases, (2) the coordination model adopted by the swimmer and (3) the time taken for the propulsion per distance unit during the 200 m front crawl. During the test, the swimmer was accompanied by two video cameras (Sanyo® VPC-WH1), displaced by a trained evaluator using a cart on rails positioned on the side edge of the pool. A video camera was positioned approximately 30 cm below the water surface (underwater camera), and another camera was positioned approximately 20 cm above the water surface (external camera). The distance between the lens of the cameras and the swimmer's displacement plane was approximately 7.5 m. The equipment displacement course was 15 m, between 5 m and 20 m of the pool, with the lenses of the cameras lined up with the swimmer's shoulder. For synchronization of images obtained by two cameras, a light signal was used, which was simultaneously fired for both cameras through a light emitting diode (LED). This measure aimed to determine the single framework for the beginning of analyses of images obtained of both cameras.

To duration of the stroke phases and coordination model, the key moments of the beginning and end of each stroke phase (propulsive and non-propulsive) were identified by visual analysis, frame by frame, held by experienced evaluators with this procedure, as previously described by Chollet et al.[6]:

- Entry and hand support in water: time between the hand entering the water until the start of the hand movement back (identifying the hand entry frame);
- Pull: time elapsed between the start of the hand movement back until it was at the same plane as the swimmer's shoulder (identifying the frame of the beginning of the backward movement);
- Push: time elapsed between the time that the hand exceeded the vertical plane at the line of the shoulder and the time that the hand broke the water surface (identifying the frame of the hand at the same plane as the shoulder);
- Recovery: time elapsed between the hand out of the water and the same hand entering the water ahead of the swimmer's body (identifying the frame of the hand coming out the water).

When the start of the propulsive phase of a stroke coincided with the end of the propulsive phase of the counter-lateral stroke, the interval between stroke phases is zero, the model is opposed and the IdC value in the percentage of average duration of a complete cycle is 0%. When the start of the propulsive phase of a stroke is previous to the end of the propulsive phase of the counter-lateral stroke, there is interval in which two arms simultaneously generate propulsion, the model was overlap and the IdC value is greater than 0%. But when there was some interval in which there was no propulsive action of any of the arms, the coordination model was capture and the IdC value was less than 0%[8].

The propulsive time was calculated according to Equation 1, previously described by Alberty et al.[10]:

Equation 1

$$T_{prop} = T_{ciclo}(100\% + 2IdC)\,d / L$$

Where T_{prop} is the time taken for the propulsion per distance unit, T_{ciclo} is the total length of the stroke cycle (s) and d/SL represents the fraction between the total distance of the section and the SL value of every section. The average hull-speed of swimmers was calculated as proposed by Prange and Schmidt-Nielsen[19]:

Equation 2

$$v_h = \sqrt{\frac{g \cdot l_w}{2 \cdot \pi}}$$

Where g is the gravity acceleration (in m • s²) and l_w is the body length in the surface water displacement (in m).

Statistical analysis

First, the normality of the data distribution of numerical variables was tested with the Shapiro-Wilk test. After, with descriptive statistics, averages, deviations and standard errors were calculated. ANOVA was applied for repeated measures and the sphericity of the data was verified with the Mauchly test. The main effects were checked by a post-hoc Bonferroni between times T1, T2, T3 and T4 of 200 m. The effect size (eta^2) was also calculated. Calculations were performed using SPSS 20.0 software for α <0.05.

RESULTS

Mean values and standard deviations for swimming speed in the 200 m, time and percentage of the world record at the time of collection, were respectively: 1.53 ± 0.07 $m.s^{-1}$; 130.7 ± 6.5 s, and 76.1 ± 3.5%. Table 1 shows the IdC values, the duration of the entry and support, pull, push and recovery phases in relation to the entire duration of a stroke cycle, the T_{prop} and its standard deviations in sections T1, T2, T3 and T4. There was a significant increase only of the relative duration of the pull phase between T1 and T4 ($F_{1.13}$ = 4.268; p < 0.05; h^2 = 0.247) and T_{prop} between T1 and T2 ($F_{1.13}$ = 4.921; p < 0.05; h^2 = 0.275). There were no differences in the other stroke phases (entry and support, push and recovery) and in IdC over the four sections.

Table 1. Coordination Index (IdC), duration of stroke phases (entry-support, pull, push and recovery) and time spent for the propulsion per distance unit (Tprop) in each section of 200 m; n = 15.

	IdC (%)	Entry-support (%)	Pull (%)	Push (%)	Recovery (%)	T_{prop} (s)
T1	-10.7 ± 5.0	36.8 ± 7.2	14.8 ± 3.2	23.2 ± 3.7	25.1 ± 8.5	17.9 ± 2.0
T2	-10.1 ± 5.2	36.4 ± 7.1	15.1 ± 2.4	22.9 ± 3.6	25.4 ± 8.3	18.8 ± 1.3[a]
T3	-9.3 ± 4.7	36.7 ± 6.7	15.4 ± 3.0	23.3 ± 3.8	24.4 ± 8.1	18.8 ± 1.2
T4	-8.3 ± 4.1	33.2 ± 7.1	17.0 ± 4.9[a]	23.1 ± 4.2	26.4 ± 9.9	18.6 ± 1.4

* Indicates difference in relation to section T1 (p <0.05).

The expected hull speed (v_h) of swimmers in this study was 1.68 m • s^{-1}. Figures 2A, 2B and 2C show the SR, SL and SS values, respectively, which were obtained in sections of 25 m prior to partials of 50, 100, 150 and

200 m (T1, T2, T3 and T4, respectively). Increased SR values were found only between T1 and T4 ($F_{1.13}$ = 5.084; p < 0.01; h^2 = 0.281). Decreased SL values were found from T1 to T2, T3 and T4 ($F_{1.13}$ = 16.775; p < 0.001; h^2= 0.563). In addition, in the SS values (Figure 1C), decreased values were found only between T1 and T2 ($F_{1.13}$ = 4.971; p < 0.01; h^2 = 0.277).

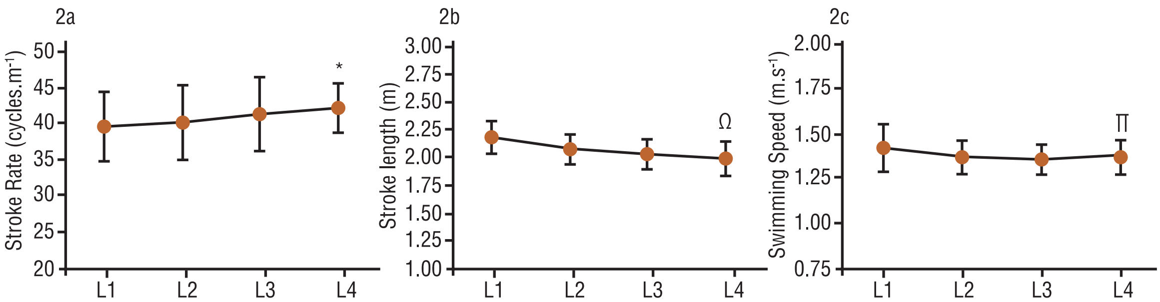

Figure 2. A: Stroke rate; B: stroke length and C: average swimming speed in sections T1, T2, T3 and T4 of 200 m; n = 15. 2A: * indicates difference from T1 to T4 (p <0.05); 2B: Ω indicates differences from T1 to T2, T3 and T4 (p <0.05); 2C: ∏ indicates difference between sections T1 and T2 (p <0.05).

DISCUSSION

In order to understand how space-time organization and duration parameters of the stroke phases behave over 200 m in front crawl performed at maximum intensity, simulating a competitive test, the general aim of this study was to compare the coordination index, the time spent for propulsion per distance unit, the duration of the stroke phases, the average frequency of strokes cycle, the average distance traveled by the body every cycle and the average swimming speed over 200 m in front crawl at full intensity.

The IdC value did not change in the sections analyzed, confirming the hypothesis that had been determined for this variable in this study. The values reported in this study corroborate the findings of Seifert et al.[8], which found average IdC values of all sections in the 200 m, featuring a capture model (-5.9% ± 4.6).

It is noteworthy that in addition to the average IdC value indicates the capture model, all subjects of this study have adopted this coordination model over the four sections (T1, T2, T3 and T4) of 200 m. The IdC result can be explained by the average speed used in this group of swimmers, since according to Seifert et al.[20], motor organization in swimming is related to three constraints defined by Newell[21]: those imposed by the body, environment and the task itself. As swimming is performed in liquid environment, changes in swimming speed imply changes in the restrictions imposed by the body, since the swimming speed determines the intensity and the respective physiological adaptations[22], by the environment, the hydrodynamic drag is proportional to the square of the displacement speed[23], and by the task, because swimming short or long distances at high or low swimming speeds implies adjustments to the restrictions imposed by both the body and the environment. The results presented by Seifert et al.[24] suggest through a mathematical modeling, that IdC plays an important role in solving the problem of generating more propulsion to swim faster. This modeling indicates that the constraints imposed by the environment are those with the greatest influence on motor organization in swimming, i.e., swimmers modify the stroke coordination from a capture model to an overlapping model, to overcome the hydrodynamic drag when swimming at higher speeds. They also suggest that the hull speed (V_h), speed at which the wave length created by the swimmer displacement in the water is equal to body length in displacement[25,26] would be related to the transition from a coordination capture model to a coordination overlapping model.

V_h was determined by the equation proposed by Prange and Schmidt-Nielsen[19], and, in fact, considering the average stature values observed in the sample of the present study (1.80 m), the average V_h was consequently 1.68 $m.s^{-1}$, much higher than the average swimming speed of swimmers to perform the 200 m in maximum intensity values (1.53 $m.s^{-1}$), which justifies the coordination capture model adopted by them. Furthermore, the sample was composed of swimmers with endurance characteristics, training in both pool and in open waters. Such training tends to occur at lower swimming speeds[20] along the different swimming series, which could lead to adaptation of the technique to the coordination model.

Regarding the duration of the entry and support, push and recovery phases, no significant differences in the sections analyzed were found. Only the duration of the pull phase had an increase over 200 m in this study (Table 1), confirming the hypothesis previously raised for this variable. These results differ from the findings by Figueiredo et al.[4], who found no intra-phase difference in the four sections of 200 m at maximum intensity. One explanation for this difference may be the speed at which the maximum test was performed in this study compared to the study of Figueiredo et al.[4]: in the present study, the speed was, on average, 1.53 ms^{-1}, while in that study, 1.49 $m.s^{-1}$.

According to Seifert et al.[13], the increased relative duration of at least one propulsive stroke phase in the 100 m test can be explained by the incapacity of maintenance of power application as a consequence of the change of the spatio-temporal organization of swimming. Seifert et al.[13] also demonstrated that elite swimmers maintains high SR (53.7 $cycles.min^{-1}$) and adjust to the overlapping model at maximum speeds and short distances. At lower speeds and long distances, swimmers adjust to the capture model, with smaller SL values (29.7 $cycles.min^{-1}$). These findings were similar to results obtained by Seifert et al.[8], who observed reduction in the duration of the entry and support stages and increase the duration of the pull and push with phases with speed increases of 1.1 ms^{-1} to 1.8 ms^{-1}. Therefore, these studies suggest that SS *VN* and the level of performance are determining factors, namely, when analyzed at greater distances and proportionately low speeds (800, 1500 and 3000 m), swimmers adopt the capture model. In shorter distances and high speeds (50 and 100 m), they adopt the overlapping model.

T_{prop} has been previously investigated in swimming apparently only in situations of continuous training at intensities relative of the maximum lactate stable state (MLSS)[11] and speeds corresponding to the percentages of 95, 100 and 110% of the average speed of 400 m until exhaustion[10]. The study by Alberty et al.[10] found in all swimming intensities, increased T_{prop} combined with increased IdC and SR, and the concomitant decreased SL. In addition, Figueiredo et al.[11] found similar IdC and T_{prop} values in addition to increased SR value and decreased SL only from the first to the last time of testing at MLSS intensity. The present study is pioneer in presenting T_{prop} values in effort of maximum intensity in 200 m, in which T_{prop} showed increase only when decreased SS was identified. Based on values reported in literature[10,11] and in this study, T_{prop} appears to increase in situations of fatigue during submaximal intensity efforts and in situations of decreased speed from one section to the other at maximum intensity efforts, confirming the hypothesis that had been determined for this variable in this study.

Regarding kinematic variables, it was found that SR showed increases in each of the analyzed sections (Figure 2A), with higher values in T4 compared to T1. Concomitantly, SL showed a decrease in values over the sections (Figure 2B). However, SS decreased significantly only from T1 to T2. Comparing with other sections, there were no differences in SS values (Figure 2C). SL and SR are representative of the swimmer's technique and tend to change according to the onset of fatigue process during the performance of any swimming test[5]. In fact, Zamparo et al.[26] showed good relationship between the propulsive efficiency of the stroke (η_p) and the distance covered per cycle at a maximum test of 200 m front crawl performed only with arms at maximum intensity ($\eta_p = 0.151 \times DC + 0.045$; $N = 232$; $R = 0.899$; $p<0.001$).

The results of this study show a reduction in SL and SS values of and maintenance of SR over the 200 m in front crawl at maximum intensity. The ability to achieve and maintain SR adequate to the desired SS is closely related to metabolic capabilities[5]. Based on results found in this study, swimmers can maintain certain gestural frequency along a swimming test, which are usually unable to maintain SL values along the test due to possible occurrence of fatigue.

Similar behavior of SS was found for the 200 m front crawl among the 16 finalists of the 200 m freestyle race at the French national championship, among four high competitive level Portuguese swimmers and among six competitive Portuguese swimmers[4], when SS presented decreased between the first 50 and the last 50 m of the race. The reduction in SL would be related to the inability to maintain the swimming technique, which would allow a larger distance traveled in each stroke cycle, on the other hand, an attempt to eliminate the effect of the reduced SL on the SS values would be to increase SR. These results can be explained by the development of localized muscle fatigue[27], resulting in a decreased ability to generate power[28]. These differences in result in different studies are possibly related to two factors: (1) level of performance of athletes and (2) training stage, when swimmers may present different conditioning states.

Thus, it could be inferred that: Hypothesis 1 (the coordination index is constant, indicating capture model) was confirmed, while IdC remained constant and in capture; Hypothesis 2 (there will be an increase in the duration of the pull phase) was confirmed, while this stage had its length increased over the 200 m and Hypothesis 3 (the time taken for propulsion per distance unit will increase) was partially confirmed, since there was increase only in this variable between T1 and T2.

The main limitation of this study was not assessing the variation of the intracyclic speed and propulsive efficiency[24], which are parameters that greatly contribute to the understanding of the swimming performance. However, the identification of T_{prop} in maximum effort of 200 m front crawl, whose behavior seems to reflect the efforts of swimmers to maintaining high and constant speed, seems to be pioneer in studies in this area.

CONCLUSIONS

The findings of this study indicate that in 200 m front crawl at maximum intensity among well-trained swimmers, there is increased T_{prop}, length of the pull phase and SR, concomitant with SL and such changes may be due to an attempt to maintain SS over the 200 m, responding to the objectives and confirming the hypotheses that have been formulated for this study.

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