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The spatiotemporal constraint on the swimmer's decision-making of turning

A restrição espaciotemporal sobre a tomada de decisão de virar do nadador

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ABSTRACT

This study investigated the swimmer's decision-making process for turning, based on spatiotemporal informational variables. The men and women 50-metre front crawl and backstroke events were selected and analyzed using TACTO software. Participants included 120 adults of both genders aged between 20 and 70 years. The distance to the pool wall at which the swimmers initiated the turn was analyzed with regards to velocity and variability of previous displacement. These factors were split into four groups adopting, quartiles as the cut-off points. Results showed that for all conditions, the swimmers who showed a higher velocity and a lower variability of displacement decided to initiate the turn at a greater distance to the pool wall. Furthermore, the greater distance seemed to be associated with a more successful performance. These results suggest that swimmers should be attuned to spatiotemporal and spatial information in order to maximize their performance.
Keywords: turn of swimming, spatiotemporal constraint, decision-making

RESUMO

Este estudo investigou a tomada de decisão de virar do nadador a partir de variáveis informativas espaciotemporais. Para este fim, provas de 50 metros dos nados crawl e costas para homens e mulheres foram selecionados de uma competição de natação, e analisadas através do software Tacto. Os participantes foram 120 adultos de ambos os sexos com idades entre 20 e 70 anos. As distâncias da parede da piscina em que os nadadores iniciaram a viragem foram analisadas em relação à velocidade e à variabilidade de deslocamento, as quais foram divididas em quatro grupos adotando-se quartis como os pontos de corte. Os resultados mostraram que para todas as condições, os nadadores que apresentaram maior velocidade e menor variabilidade de deslocamento decidiram iniciar a viragem a uma distância maior da parede da piscina, e vice-versa. Além disso, a maior distância pareceu estar relacionada ao desempenho bem-sucedido. Estes resultados sugerem que os nadadores devem estar em sintonia com a informação espaciotemporal e espacial a fim de maximizar o seu desempenho.
Palavras-chave: viragens em natação, restrição espaciotemporal, tomada de decisão

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INTRODUCTION

Swimming is one of the oldest activities still participated in by humans (Kehm, 2007; Mood, Musker, & Rink, 2012). Due the complexity of this human activity, research on swimming has been conducted at several analyses levels, including the physiological, biomechanical, behavioural, psychological, and sociocultural levels. Previous research has also focused on different areas of the sport of swimming, such as the development of programmes and the identification of mechanisms and processes subjacent to performance (Anderson & Petrie, 2012; Freudenheim, Wulf, Madureira, Pasetto, & Corrêa, 2010; Madureira, Freudenheim, Bastos, Corrêa, & Ferreira, 2012; Sanders, et al., 2012; Zamparo, Capelli, & Pendergast, 2011). Over the past few decades, there has been an increasing level of interest in research that focuses on swimming performance in competitive contexts, including research on the understanding of key components as one of the most influential aspects of the performance.

Similar to a complex system, the type of swimming components present is dependent of the hierarchical level of focus (Corrêa, Alegre, Freudenheim, Santos, & Tani, 2012). For instance, some researchers have carried out studies that consider the components of specific movement patterns. In this case, arm stroke and breathing have been the essential components investigated most often, especially in relation to front crawl swimming (Apolinário, et al., 2012; Chollet, Chalies & Chatard, 2000; Lerda & Cardelli, 2003; Lerda, Cardelli & Chollet, 2001; Payton, Bartlett, Baltzopoulos & Coombs, 1999; Seifert, Chehensse, Chollet, Lemaitre, & Chollet, 2008; Vezos et al., 2007).

Chollet et al. (2000) proposed an index of coordination of the front crawl (IdC). This index identifies three coordination patterns related to arm movements: opposition, catch-up, and superposition. The researchers analysed swimmers of three different skill levels (high, intermediate, and low) who swam 25 metres at maximal velocity three times, simulating competitions of 800, 100, and 50 metres. The results showed that for 800 metres, the coordination pattern was found to be catch-up for all groups. For the 100 and 50-metre races, the most skilled swimmers showed the pattern of opposition, unlike those swimmers that were less skilled. Furthermore, it was verified that with the increase in velocity, the most skilled swimmers increased the relative timing of the propulsive phases of the arm strokes more than did the less skilled swimmers. And finally, it was observed that only the most skilled swimmers were able to decrease the relative length of the entry and catch-up phases, due to the increased velocity. In summary, the authors found that IdC varies depending on the swimming velocity and skill level of the swimmer.

In addition to the contribution of the above-cited studies towards the understanding of swimming performance, variables beyond that of movement pattern, such as front crawl swimming, have recently been considered to be essential components of swimming performance. For example, Kjendlie, Haljand, Fjortoft, and Stallman (2006) analysed the velocities of starting, turning, and finishing of swimmers of different levels of expertise in a 100-metre freestyle race. Adding to this analysis, the swimming velocity in the middle of the path was also considered. It was verified that the more skilled swimmers showed the lowest proportion of time for turning, starting, and finishing. This led the authors to suggest the relative importance of these components, in this order, as a criterion of success.

The importance of the turns for swimming performance in competitive contexts has stimulated a number of studies in order to understand the variables involved in this component. It seems that the turn is crucial in the swimming performance, since the change of inertial acceleration after the turn is superior to that obtained from the execution of the movement pattern, such as the front crawl, when it is observed in isolation (Zamparo, Vicentini, Scattolini, Rigamonti & Bonifazi, 2012).

The current body of research has focused on the turns in swimming performances, primarily in the front crawl (Araújo et al., 2010; Blanksby, Gathercole, & Marshall, 1996; Lyttle, Blanksby, Elliott, & Lloyd, 1999; Lyttle & Mason, 1997; Pereira, Araújo, Freitas, Gatti, & Silveira 2006; Potdevin, Albety, Chevutschi, Pelayo, & Sidney, 2011; Prins, & Patz, 2006; Silveira et al., 2011). However, research has also been conducted in the turns of other movement patterns, including the backstroke, butterfly, and breaststroke (Blanksby, Skender, Elliott, McElroy, & Landers, 2004; Tourny-Chollet, Chollet, Hogie, & Papparodopoulos, 2002). These studies have used physical measures, such as peak force, time of contact of the feet on the wall, angle of knee flexion, and time of turn, which have produced information on "how" to turn. For example, Araújo et al. (2010) revealed the existence of a knee flexion angle to maximise performance between 100° and 120° for skilled swimmers. Yet, Silveira et al. (2011) showed the peak force and the contact of the feet with the wall as the decisive variables for greater velocity recovery in swimming.

In the present study, we extended the pre-existing knowledge on how to turn by investigating the decision-making on "where" and "when" to turn. Considering that the turn is performed by having the swimmers move quickly towards the pool wall, it seems important to investigate the timing of starting the turn in order to maximise the performance according to the aspects and items cited above.

Indeed, a number of studies developed at an ecological level of analysis, such as the competitive contexts, have shown that in several sports, the individual's decision-making is based on spatial and temporal informational variables (Corrêa, Vilar, Davids, & Renshaw, 2012; Vilar, Araújo, Davids, & Button, 2012). Specifically, studies have focused on the decision-making process in sports, based on information relating to three main types of physical measures of interaction: (1) between athletes, including interpersonal distance and relative velocity (Passos et al., 2008); (2) between athlete and an object or ball, such as the time to ball interception (Travassos et al., 2012); and (3) between athlete and a place, such as the distance to basket (Araújo, Davids, Bennett, Button & Chapman, 2004). The third physical measure of interaction is most relevant to this study. For example, Millar, Oldham, and Renshaw (2013) investigated which variable influenced the rowers' decision-making by considering a 2-person boat-rowing situation. In this example, one rower cannot see the actions of the other rower seated behind him. The researchers showed that both rowers coordinated their actions based on the changes in acceleration related to the flow of water passing by the boat. Still, Rocha, Araújo, and Fernandes (2005) showed that with regards to sailing athletes, decision-making is based on the perception of wind direction, the position of the opponent boat, including distance or angle, and the distance of a beacon.

The main assumption in these studies is that the performers make successful decisions by perceiving information related to the physical properties that reflect the interaction of the performer with his or her performance environment. The decision-making in the context of sports has been viewed as a consequence of the possibilities of action, such as affordances, that emerge from the interaction's purpose over time in the performance environment (Araújo, Davids, & Hristovski, 2006). Thus, the decision-making is most likely to be an emergent behavior, instead of something that occur a priori.

Studies have shown that in sporting contexts, decisions are made when spatiotemporal variables reach critical values and function as a potential control parameter (Passos et al., 2008). A control parameter refers to the naturally occurring environmental variations that move the system through patterned states and cause them to change (Kelso, 2000). In other words, a control parameter is something that causes changes. For example, Corrêa et al. (2012) showed that the futsal players decided the passing direction when the relative angles of interpersonal coordination involving (a) the ball carrier, ball receiver, and ball carrier relative to the direct defender reached 70°, and (b) the ball carrier, ball receiver, ball receiver's direct defender reached 31°.

After reviewing prior research, we sought to understand the nature of the spatiotemporal information that a swimmer uses in the competitive context of performance. We also wanted to understand how the velocity and the variability of displacement influences when and where to turn. Considering the spatiotemporal characteristic of competitive swimming that the displacement on and in the water is fast, we hypothesized that swimmers would decide to turn based on their distance to the pool wall and the velocity of displacement.

METHOD

Participants

Participants included 120 adults, including both males and females (*M*= 41.0 years, *SD*= 13.7). They were all swimmers that participated in at least one of the following 50 meter races in a Master Championship of Swimming: (i) front crawl swim for males (n= 37), (ii) front crawl swim for females (n= 25), (iii) backstroke for males (n= 34), and backstroke for females (n= 24).

Data collection

The swimming races were recorded using a digital camera with a frequency of 25 Hz. The camera was located above and behind the short axis of a pool that measures 12.5 × 25 meters. This procedure involved the collection of data on the displacement of each swimmer from 5.4 meters before the pool wall until the moment he or she initiated the turn.

Descriptive analysis

TACTO software (Fernandes, Folgado, Duarte, & Malta, 2010) was used to capture the swimmers' movement displacement trajectories by following the head of each swimmer as the working point with a computer mouse in a slow motion video image with a frequency of 25 Hz. Then, the virtual coordinates (pixels) were transformed into real coordinates (meters) using a bi-dimensional direct linear transformation method (2D-DLT) filtered with a low pass filter (6 Hz) (Winter, 2005). This method considers the z-coordinates to be equal to zero and directly correlates an object point located in the object space/plane and a corresponding image point on the image plane (Duarte et al., 2010; Fernandes et al., 2010).

In summary, the TACTO software allowed us to obtain the x and y values of displacement in a frequency of 25 frames per second, from the initial point at a distance of 5.4 meters from the pool wall to the turning point at the moment he or she initiated the turn.

The x-coordinates were those related to the deep pool wall. This was defined as the pool wall related to the direction of the swim. The y-coordinates were considered in relation to the lateral pool wall. For front crawl and the backstroke for males and females, the turning point was defined as the moment the swimmer's head began to submerge. From the displacement coordinates of the swimmers from the initial point to the turning point, we calculated the (i) distance of turning, (ii) velocity of swimming, and (iii) variability of swimming with regards to the y-axis (swimmer´s displacement on the streak).

The distance of turning was used to infer the decision-making on when and where to turn, and the variability and velocity of swimming were considered in regards to those spatial and spatiotemporal variables that would constrain such decision-making behavior. The overall race position was used to analyze the effectiveness of the decision-making. The distance of turning referred to the value of the y-coordinate related to the turning point.

The velocity of swimming was obtained by $vs = (yIP - yTP) / \Delta t$, where vs was the velocity of swimming. In addition, yIP was the y coordinate at the initial point where yTP referred to the y coordinate at the turning point. Finally, Δt was the swimming time between these two points. The variability of swimming with regards the *y*-axis was calculated by $yCV = s / \bar{x}$, where *yCV* is the coefficient of variation of the *y* coordinates, *s* refers to the standard deviation, and $\bar{x}$ is the arithmetic mean. Both the velocity and the variability of swimming were considered as spatiotemporal and spatial ratios of displacement of the swimmer's approach to the wall. The analyses were made by three examiners that were experienced in using the TACTO software. In order to verify the intra-analyzer reliability, the images of five athletes were randomly selected and re-digitized. Pearson's correlation test found $r = 0.91$, $p < 0.01$.

Statistical analyses

In order to understand the swimmer's decision-making on the turn, the distance of turning was analyzed as dependent in relation to the velocity and variability of swimming. Additionally, the swimmer's overall race position and overall time of race were considered in the analyses. All of these independent variables were split into four groups (G1, G2, G3, and G4). Data were ordered from the smallest to the largest with respect to the distance of the turn's beginning and the quartiles adopted as the cut-off points (Altman & Bland, 1994). For each one, the comparisons were made by using ANOVA, followed by the Tukey HSD post-hoc tests. For all analyses, the level of significance was set at $p < 0.05$, using the STATISTICA® 11.0 program by Tulsa, Oklahoma's Stat Soft.

RESULTS

Concerning the front crawl for males, the ANOVAs revealed significant effects for the velocity of swimming ($F_{(3, 33)} = 4.20$, $p = 0.012$, $\eta^2 = 0.27$) and for the variability of swimming ($F_{(3, 33)} = 37.57$, $p = 0.001$, $\eta^2 = 0.77$). Regarding velocity, the Tukey_{HSD} test showed that G1 had a smaller distance of turning than did G4. In addition, for the variability of swimming, it was observed that G1 had a smaller distance of turning than did the other groups, and that G4 had a greater distance of turning than did the remaining groups. No effects were revealed for the overall position.

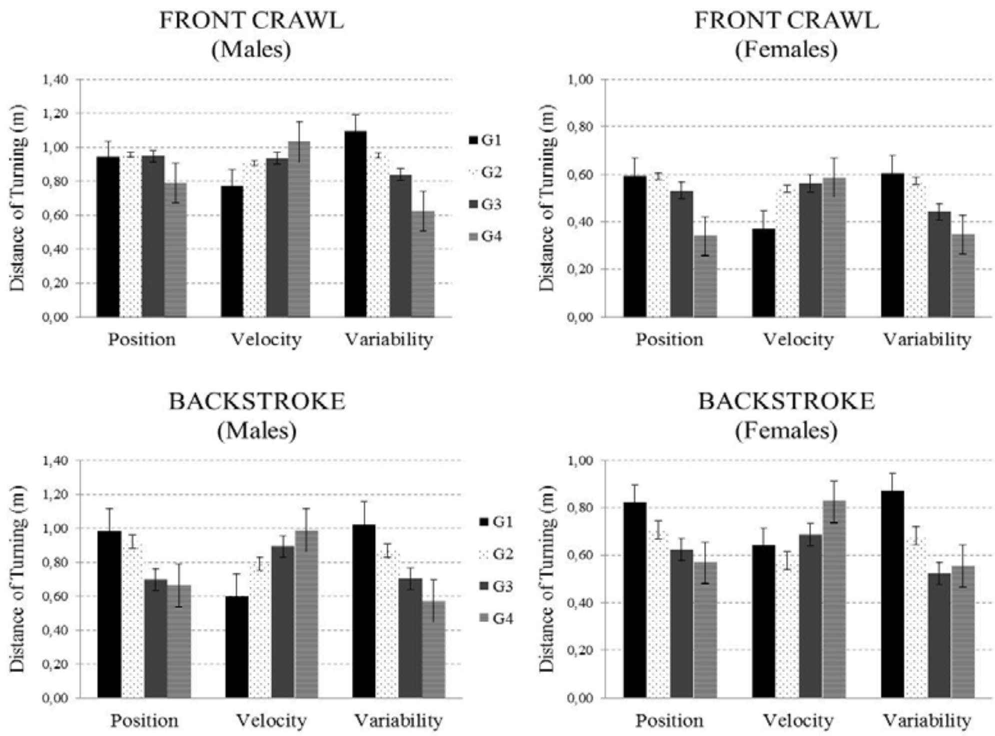

Figure 1. Mean distance of turning for overall position, velocity and variability of swimming, of the swimmer's in the front crawl swim and backstroke for males and females

With respect to the front crawl for females, the ANOVAs revealed significant effects for all variables: overall position regarding swimming time ($F_{(3, 21)}$= 15.22, p< 0.001, η^2= 0.68), velocity of swimming ($F_{(3, 21)}$= 5.54, p< 0.005, η^2= 0.44), and variability of swimming ($F_{(3, 21)}$= 13.85, p< 0.001, η^2= 0.66). The Tukey$_{HSD}$ tests showed that: (i) the swimmers in last positions (G4) had a smaller distance of turning than did the remaining groups; (ii) the swimmers who approached the pool wall more slowly (G1) had a smaller distance of turning than did the remaining groups; and (iii) the lower the variability of turning implied a greater distance of turning.

Regarding the backstroke for males, the ANOVAs revealed effects for overall position ($F_{(3, 30)}$= 8.21, p= 0.001, η^2= 0.45), velocity of swimming ($F_{(3, 30)}$= 10.59, p= 0.001, η^2= 0.51), and variability of swimming ($F_{(3, 30)}$= 29.35, p= 0.001, η^2= 0.74). Similarly, the post-hoc tests showed that (i) swimmers who started the turning in smaller distances (G3 and G4) completed the tests in late positions and, conversely, swimmers that started the turning in greater distance (G1 and G2), finished the race in the first positions; (ii) the swimmers in G3 and G4 had a greater distance of turning than did slower swimmers (G1 and G2); and, (iii) the lower the variability of turning implied greater distance of turning.

Finally, with respect to the backstroke for females the ANOVAs also revealed significant effects for all variables: overall position ($F_{(3, 20)}$= 3.91, p= 0.023, η^2= 0.37), velocity of swimming ($F_{(3, 20)}$= 3.39, p= 0.037, η^2= 0.33), and variability of swimming ($F_{(3, 20)}$= 34.92, p< 0.001, η^2= 0.84). The Tukey$_{HSD}$ tests pointed out that (i) the swimmers in last positions (G4) had a smaller distance of turning than did those in G1 (first positions); (ii) the swimmers in G4 had a greater distance of turning than did the remaining positions; and (iii) G1 and G2 (lower variability) had a greater distance of turning than did the groups with higher variability of swimming (G3 and G4), and, G1 had a greater distance of turning than did G2.

DISCUSSION

The aim of this study was to investigate the spatiotemporal information that a swimmer uses in the competitive context of swimming performance. Specifically, we sought to understand how the velocity and the variability of displacement would influence when and where to turn. Results showed that the decision-making on where to turn was constrained by the swimmer's ratios of displacement. More precisely, it was observed that in the four competitive situations (front crawl and backstroke each for male and female), swimmers who moved faster in their approaching of the pool wall decided to turn earlier than did those swimmers who swan more slowly. The results also showed that the distance of turning was influenced by variability, because those swimmers who had lower variability of swimming decided to initiate the turn earlier than did those swimmers who had a high variability of swimming.

It seems that together, the spatiotemporal and spatial variables, such as velocity and variability of swimming, might have functioned as control parameters and, therefore, supplied the essential information for swimmers' decision-making for the turn. For instance, in terms of velocity, it has been proposed that the temporal rate of change throughout space seems to provide the necessary information for the regulation or prospective control of movement (Corrêa, et al., 2012; Fajen, Riley & Turvey, 2009). In addition, we could hypothesize that the high variability of swimming might have reflected a certain level of uncertainty on when and where to turn. As a consequence of the uncertainty, the swimmers may have decided to perform the turn closer to the pool wall.

Several types of dragging, such as friction drag, wave, and body shape, are influenced by the speed of swimming. Consequently, the high variability in the velocity might affect the maintenance of the velocity as the pattern of swimming which, in turn, would directly affect the performance in the turn (Stager & Tanner, 2008). For example, sprinters tend to initiate the turn earlier, because they are probably moving to the pool end faster and without loss of speed. The high variability in the velocity affects the turning, especially in the approaching phase, because it can cause the swimmer to lose the velocity (Maglischo, 2003). Important to highlight that the recent studies by Puel et al. (2012), Chakravorti et al. (2012), and Veiga, Cala, Frutos, and Navarro (2013) have described the pool wall as an important point of reference for the approaching phase.

Moreover, the results of this study support those findings related to how to perform the effective turn, since the swimmers who achieved the first race positions turned at greater distances than did those in the last positions in the front crawl for females and in the backstroke for both males and females. In this regard, studies have shown that the turn at a greater distance allows the swimmers to optimise the knee flexion and extension, the contact of the feet with the pool wall, and the time of recovery of swimming (Araújo et al., 2010; Puel et al., 2012; Rejman & Borowska, 2008; Silveira et al., 2011). Furthermore, the literature has suggested that the swimmers must be aware of the pool end in order to adjust the turn without losing speed (Maglischo, 2003). Thus, we could suggest that the swimmers should be attuned to the spatiotemporal and spatial information in order to maximize their performance. In other words, swimmers should be alert to the edge of the pool so that they can make changes in their approaching phase in order to turn without losing velocity (Maglischo, 2003).

In summary, the results of the present study allow us to conclude that the turns in the races investigated were influenced by the spatiotemporal and spatial variables. Regardless of swimming style and gender, the swimmers who had a higher velocity and lower variability during the approach of the pool wall decided to initiate the turn at a greater distance of the pool wall. Further studies could consider additional visual references of the approach to the wall, for example, the "T" reference in the bottom of the pool, in order to achieve additional support for this conclusion.

PRACTICAL IMPLICATIONS

In terms of practical implications, results point to how to improve the ability of swimmers to make decisions regarding where to turn based on information from the spatiotemporal ratio of displacement. For instance, during training, the swimmers should be advised to try to keep the approaching velocity of the wall in mind. In other words, they should be aware of the pool end in order to adjust the turn without losing speed. In addition, swimmers should practice the turns far from the pool wall.

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Nothing to declare.

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