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ORIGINAL ARTICLE

Estimating time-to-contact with temporal occlusion in relay swimming: a pilot study

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RUNNING HEAD: Swimming Relays

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Estimating time-to-contact with temporal occlusion in relay swimming: a pilot study

ABSTRACT

The purpose of this study was to analyse swimmers' perceptual judgements of a simulated time-to-contact task in freestyle swimming relays.

The study sample consisted of 31 national-level swimmers of both genders (n=18 males, 17.22±1.95 yrs.; n=13 females, 14.61±.76 yrs.). Participants were asked to watch two videos corresponding to the last course of a given swimmer during a competition of 4×100m and 4×200m freestyle events. These videos were presented with temporal occlusion correspondent to predetermined approaching distances (7.5m, 5.0m, and 2.5m). Participants were required to simulate a typical position in standby for exiting the block and estimate the time-to-contact of the incoming swimmer by pressing a switch. A Wilcoxon test was performed to determine differences between time-to-contact and real contact time.

The results showed that estimation of time-to-contact was generally lower than real contact time at all approaching distances (with occlusion) and for both genders ($p<.05$), except at a 7.5-m distance in the men's 4×200m ($p=.744$; $r=.09$) and at 5.0 m in both the 4×100 m and 4×200m for the female group ($p=.279$, $r=.22$ for 4×100 m; $p=.2453$, $r=.17$ for 4×200 m). The larger variation (Δ) between estimation and real contact time was found at a 7.5m occlusion distance in the female 4 × 100 m ($p<.001$; $r=.82$).

Swimmers tend to underestimate the time-to-contact of the incoming swimmer, in the context of a simulated relay race. Taken together, these results highlight the importance of perceptual abilities development in swimmers to optimize their technique and effectiveness during relay starts.

Keywords: *Swimming Relays; Decision making; Visual perception; Visual occlusion*

INTRODUCTION

Sport expertise has been thoroughly associated with the study of anticipation and decision making as a means to clarify the use of perceptual information (Williams and Ward, 2007). Decision making is known to be a cognitive process whereby a preferred option or course of action is chosen from among a set of alternatives based on certain criteria (Wang and Ruhem, 2007). Competitive sport opens valuable opportunities for studying decision making since it includes different decision makers (coaches, athletes, referees) and tasks (play calling, ball allocation, etc.) in multiple contexts (Catteeuw et al., 2010). One way to look at the decision-making process is through the isolation of different components such as visual perception, anticipation, and memory. Worthy of note is that the efficiency and velocity of the decision-making seems to be directly related to reaction time (Afonso et al., 2012). Conceived as the time-delay between the projection of the stimulus and the athlete's response, reaction time has stimulated an extensive body of research in many sport disciplines (Williams et al., 1995). In fact, reaction time appears to be one of the possibilities to depict the quickness and effectiveness of an athlete's decision making (Schmidt and Lee, 2016). Therefore, reaction time can be classified into two broad types: simple reaction time, when there is only one stimulus and one possible correct response; choice reaction time, representing the interval of time that elaspes between the presentation of one of several possible stimuli and the beginning of one of several possible responses (Schmidt & Wrisberg, 2008). Acording to the Hick's law, a theory that represents information (or entropy) in terms of uncertainty, which for a choice rection task increases as a (logarithmic) function of the number of equally likely alternatives (Proctor, & Schneider, 2018). The literature has not demonstrated strong evidence that expert athletes have superior visual hardware than beginner athletes (Williams, 2000). However, their capability to process information during the game seems to be clearly better (Vila-Maldonado et al., 2014), which seems to allow a higher rate of success in the decision making.

In competitive swimming, perceptual abilities play a crucial role in a swimmer's performance, at least in the following two situations: (i) while positioning in standby for exiting the block as a reaction to an auditory stimulus and (ii) during exchanges in relay races (4 × 100-m medley, 4 × 100-m freestyle, and 4 × 200-m freestyle) where an incoming swimmer triggers the take-off of the swimmer standing on the block. A solid body of research has demonstrated the relevant contribution of an effective start to overall swimming performance (Vantorre et al., 2014), particularly in short-duration events (Valvassori et al., 2017). Research has also shown that swimmers' reaction and movement time can be significantly improved through training (Blanksby et al., 2002) and plyometric work (Bishop et al., 2009). Conversely, optimal relay start strategies have been critically associated to exchange block time efficacy, where the swimmer standing on the block must accurately perceive the incoming swimmer's time of wall contact in order to execute take-off from the block (Saavedra et al., 2014; Fischer et al., 2017). In fact, in international competitions, the relay exchange block time stands as a key factor for team performance and, therefore, should be explicitly included as part of swimmer training (Saavedra et al., 2014).

According to Saavedra et al. (2014), the literature suggests at least three main components for optimal exchange: strength production during the impulsion phase (West et al., 2011), motor coordination between upper and lower body, and perceptual-motor ability (Gambrel et al., 1991), with the latter being unequivocally acknowledged as an essential function for performing successfully (and without disqualification). Despite widespread acceptance of these performance criteria, very few studies have been carried out on relay strategies in swimming. Surprisingly, the recent study of Fischer et al. (2017) shows that swimmers should focus on strength production to maximize horizontal peak force rather than minimizing exchange block time. Unfortunately, this study did not analyse the effect of an integrative learning strategy, combining both recommendations (feedback on strength production and on exchange block time). Moreover, only elite swimmers were evaluated, who usually have very fast changeover times during relays (Saavedra et al., 2014).

As far as one can tell from the literature, no study has been conducted on swimming relay strategies that takes into consideration the analysis of the swimmers' perceptual abilities, namely, their capacity to effectively estimate the time-to-contact (TTC) of the incoming swimmer. Swimmers with better perceptual capacity will be able to perform an exchange within the limits of the competitive swimming regulation (leave the starting block at the same instant the incoming swimmer touches the pool wall).

There is a solid body of research on the prediction of TTC (Benguigui and Bennett, 2010), usually assessed in tasks where objects in motion are fully or partially occluded before reaching the specified target observer (Bove et al., 2017). In general, studies have suggested that participants underestimate TTC for longer occlusions and overestimate it for shorter (Oberfeld and Hecht, 2008), with loss of estimation accuracy when attention is affected by secondary targets (Marinovic and Wallis, 2011). With regard to competitive swimming, other variables may influence swimmers' estimation accuracy of TTC (Benguigui and Bennett, 2010), namely, the acceleration and variation of the kinematic pattern of the incoming swimmer in the final meters before touching the wall (Vantorre et al., 2014). An accurate TTC estimation will support better decision-making processes and hence faster reaction times during relay exchanges. Therefore, the aim of this study was to analyse the ability to predict the temporal outcome of a simulated TTC in swimming relay events.

METHODS

PARTICIPANTS

Thirty-two participants, including 18 males (age: 17.22 ± 1.95 yrs; weight: 65.46 ± 8.89 kg; height: 174.83 ± 8.91 cm) and 14 females (age: 14.61 ± 0.76 yrs; weight: 53.79 ± 5.65 kg; height: 161.46 ± 5.77 cm), agreed to participate in this study. All participants were national level swimmers, exhibiting, at the time of this study, good overall performance. Table 1 summarizes participants' training and competition experience, self-reported in the begining of the study.

Table I

All subjects and their parents/guardians (for those under 18 yrs.) were informed in advance about the procedures and asked to sign an informed consent prior to the start of the study. The experimental procedures were performed with compliance with the ethical standards as laid down in the Declaration of Helsinki.

PROCEDURES

The experiments were performed at room temperature (23 ± 2°C). Before testing, the participants were familiarized with all equipment and test procedures. During the familiarization session, all athletes were informed about the position and posture they should assume during the data collection. All swimmers tested used commercial headphones (Sony MDR-ZX310 AP) that reproduced the typical auditory sound of a swimming competition (team mates, spectators, horns), mimicking the sound environment of an indoor pool with a medium intensity volume (about 60%).

Six (two-dimensional) videos were randomly projected through a multimedia projector (Toshiba EX21) on a screen (1.60 × 1.60 m) positioned in front of the swimmer at a distance of 3.60 m. Each swimmer was asked to simulate a typical position in standby for exiting the block (no-step start tecnique), while positioned in front of a projection screen. This technique seems to be the most common (even among swimmers in our sample) and according to the literature gives swimmers a faster exchange block times (Takeda et al., 2010). No swimming goggles were used and none of the swimmers in the sample reported pathologies of vision.

The videos showed the last 50 m of two relay events, representing different approach speeds: 4 × 100-m and 4 × 200-m freestyle. The videos were performed by swimmers with similar characteristics to the study sample (of both genders, according to swimmer tested) in a simulated relay, who swam based on their best 100- and 200-m times (freestyle): male swimmer swam the last 50m at the speed of 1.72 m/s [(stroke rate - 48.5 (Hz)] and 1.82 m/s [(stroke rate - 52.1 (Hz)], representing different approach speeds - 100-m and 200-m freestyle, respectively; female swimmer swam the last 50m at the speed of 1.49 m/s [(stroke rate - 48.9 (Hz)] and 1.70 m/s [(stroke rate - 53.5 (Hz)], representing different approach speeds - 100-m and 200-m freestyle, respectively.

A temporal occlusion of the global scene was implemented to both relay races at predetermined moments corresponding to the distances of 7.5 m, 5.0 m, and 2.5 m between the swimmer and the wall. These distances were selected according to previous publications (Vantorre et al., 2014; Fisher et al., 2017).

The videos involving different scene occlusion distances (7.5 m, 5.0 m, and 2.5 m) and relay events (4 × 100 m and 4 × 200 m) were randomly presented, with the total number of combinations being counterbalanced across participants. Each participant was asked to estimate the TTC of the incoming swimmer by pressing a switch, while holding a typical (simulated) standby position for exiting the block.

A number of easily manipulated race conditions such as stroke rate of the incoming swimmer, race position and full or half stroke finish were omitted from the trials conditions. However, it should be noted that swimmers touched the wall with full stroke. As a temporal occlusion of the video was applied, this touch on the wall was not visualized, so the prediction of the touch on the wall always depended on the perceived ability of the swimmer tested. Each swimmer conducted two attempts, and the better one was used for analysis.

STATISTICAL ANALYSIS

Anaconda (Continuum Analytics, 2015), IPython, and SPSS 23.0 were used for all calculations. The data was stored and organized by using Pandas (McKinney, 2010) and NumPy (Walt et al., 2011). The variables were expressed as the means and standard deviations (SD). Normality assumptions were checked by the Shapiro-Wilk test. The Wilcoxon test was used to compare differences between real contact time (RCT) and TTC by gender and event. Friedman was used to test the differences between groups, particularly to compare the variation (Δ) between RTC and TTC for each occlusion distance, and a Dunnett test was used for post hoc comparisons. Nonparametric effect size (r) was also obtained from the following equation (Rosenthal, 1994):

$$r = \frac{Z}{\sqrt{N}},$$

where Z is the Z statistic, N the sample size ($r < .1$ was considered a trivial effect, $.1 \leq r < .3$ a small effect, $.3 \leq r \leq .5$ moderate, and $r > .5$ a large effect); thus, the greater the effect size, the greater the manifestation of the phenomenon in the population. The level of significance was set at $p \leq 0.05$.

RESULTS

Table II shows the results of RCT and TTC in both relay events (4 × 100-m and 4 × 200-m freestyle) and prescribed occlusion distances. In all tested situations and for both genders, there was an overestimation of TTC. With respect to male swimmers, significant differences ($p < .05$) between the RCT and TTC were found in both relay events and with all occlusion distances, except for the 7.5 m occlusion distance in the 4 × 200 m ($p = .744$; $r = .09$, with small effect size). Concerning female swimmers, significant differences between RCT and TTC were identified in most tested situations, except at 5.0-m occlusion distances in both relay events ($p = .279$, $r = .22$ in 4 × 100 m; $p = .245$, $r = .17$ in 4 × 200 m, both with small effect size).
Table II

Notably, the greatest effect size was found in the male group, in occlusion distances of 2.5 m (4 × 100 m), 2.5 m, and 5.0 m (4 × 200 m); for the females, the greatest effect size was found at 7.5 m (4 × 100 m), as shown in Table II.

Figure 1 shows the variations (Δ) between the RCT and TTC in all tested situations. No significant statistical differences were found (corresponding to TTC overestimation) in any of the occlusion distances in the male group, which means that the variation was very similar in the three occlusion distances; however, the female group obtained a greater variation in the approximation speed of 4 × 100 m, especially between the 2.5 m and 7.5 m distances ($p = .001$) and 5.0 m and 7.5 m distances ($p = .001$).
Figure I

DISCUSSION

During freestyle relays, the decision to leave the block as a reaction to the observation of the oncoming swimmer is paramount to achieve higher performances. Accordingly, the goal of this study was to analyse swimmers' prediction of time-to-contact in freestyle relays. The results showed that all participants presented a smaller TTC than RCT, which denotes an underestimation in temporal prediction. Females presented greater variations in temporal prediction than males when the occlusion distances were greater.
The difficulty in accurately predicting the contact time of the upcoming swimmer may be related to previous training of these skills in daily training routines. In this regard, recent research has emphasized the importance of visual feedback to perform certain motor actions (Giblin et al., 2017) and consequent improvement in the temporal prediction. Hence, even if swimmers are experienced in individual events, they need specific training to optimize their decision making and reaction time during relay exchanges.

When comparing RCT and TTC, one can note that swimmers tend to be more accurate with larger occlusion distances, perhaps because they have had more time to process the information previously perceived by the visual cues, such as the speed of the approaching swimmer. In this line of reasoning, accumulated training time may have created an advantage in the detection of visual cues that allow for better temporal estimation. Notably, this study found a small effect size precisely at the largest occlusion distances, which to some extent indicates that the sample size may have influenced the final TTC results.

Recently, Bove et al. (2017) observed a significant lower value of absolute time error in swimmers compared to other sports when they were asked to make a temporal prediction with an occluded interval of short duration (i.e., 3 s compared to 6 s and 12 s). The authors noted that the swimmers were more accurate when the occlusion time was lower (i.e., 3 s), a conflicting result with the present study.

In other sports, one can also acknowledge a process of transfer between visual attention and decision-making ability, regarding the specificity of the sport, when the scene is occluded. Causer and Ford (2014) compared this variable among different sports and verified that the skill was positive when it was related to the sport itself, indicating that there is a specific transference of learning in these situations. Also, Causer et al. (2017) observed that less experienced players were less accurate in identifying the motor action of the penalty batter in a video with occlusion of the scene. These results showed the importance of anticipatory cues and how they may evolve with practice time, which, in turn, may have relevant implications for the design of training programmes to improve the cognitive-perceptual ability of the athlete. The results of the present study also reaffirm the need to incorporate the block in dry land training as a fundamental part of the training in relay swimming, as already suggested by other authors (Saavedra et al., 2014).

Another important facet of this study is related to the variations found. In general, male swimmers had a smaller variation in all distances of occlusion and approach velocities. Female swimmers presented greater variability, especially in the larger distances, showing less precision in these approach speeds. This gender inequality is observed in several studies, indicating that women have a longer reaction time in certain sport situations. Dogan (2016), comparing multiple-choice and visual perception in female and male elite athletes, also reported that males obtained a lower total level of incorrect responses to a stimulus than female athletes. In the case of the present study, this difference theoretically seems to be related to an enhanced visual perception capacity in the male gender, perhaps due to their greater experience in relay swimming. In fact, male swimmers are older and accumulate more training and competition experience, also reporting a higher incidence of specific training tasks to develop relay exchange performance in their usual swimming training programe (Table I). Indeed, age is a determining factor of cognitive development (Brydges et al., 2013), which can explain an increased visual search skill from childhood to adolescence. Johnson (2006) also reports that feedback from previous experiences is a key element in cognitive processes, reinforcing the results of this study.

In addition, there are other explanatory factors that can influence decision-making capacity, such as stimulus-response compatibility, practice quantity, perception, and memory (Gois and Almeida, 2013), that may be influenced by the biological and physiological changes that occur in adolescence (Smidt et al., 2015). This confirms the theory that greater precision in temporal prediction of TTC in relay swimming is related to athletes' level of experience and the ability to perceive and differentiate the importance of details and cues at the time of decision making.

The results of the present study suggest that visual feedback is critical information for accuracy in relay swimming and that the anticipatory process of motor action, in this case, should be thoroughly investigated, since it becomes paramount for an effective exchange block time. In addition, this study highlights the need to include in swimmers' training programmes perceptual-visual skills to improve the identification of cues for faster and more accurate decision making at the time of relay.

It is important to note the methodological limitations of the current study. For example, the small population used in this study consisted exclusively of young swimmers with small expertise in relay swimming. Moreover, the use of a 2D video does not represent true augmented reality.

PRATICAL APPLICATIONS

This study presented relevant contribution to the scientific knowledge and practical application for training in swimming relays, namely the need to improve the detection of visual cues that allow for better anticipation in relay swimming. Visual search increases with age and but with specific experience, so coaches should consider training the exchanges in greater depth. Sensorimotor skills acquired during specific motor training may affect the temporal estimation of an observed action, allowing subjects to use relevant information to guide their subsequent actions. This goal could be achieved by the design of in-situ tasks (using, for example, video-based techniques) where the approaching speed of the incoming swimmer could be manipulated.

CONCLUSIONS

Our findings suggest that swimmers tend to underestimate the time-to-contact of the incoming swimmer during simulated relay exchanges. In general, swimmers tend to be more accurate with larger occlusion distances. Male swimmers had a smaller variation in all distances of occlusion and approach velocities, while females showed greater variability, especially in larger distances.

Taking all these factors into account, it seems that this study may open the possibility for future investigation to expand the analysis of visual perception and decision making in relay swimming and, by this means, endow the field with significant contributions.

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FIGURES

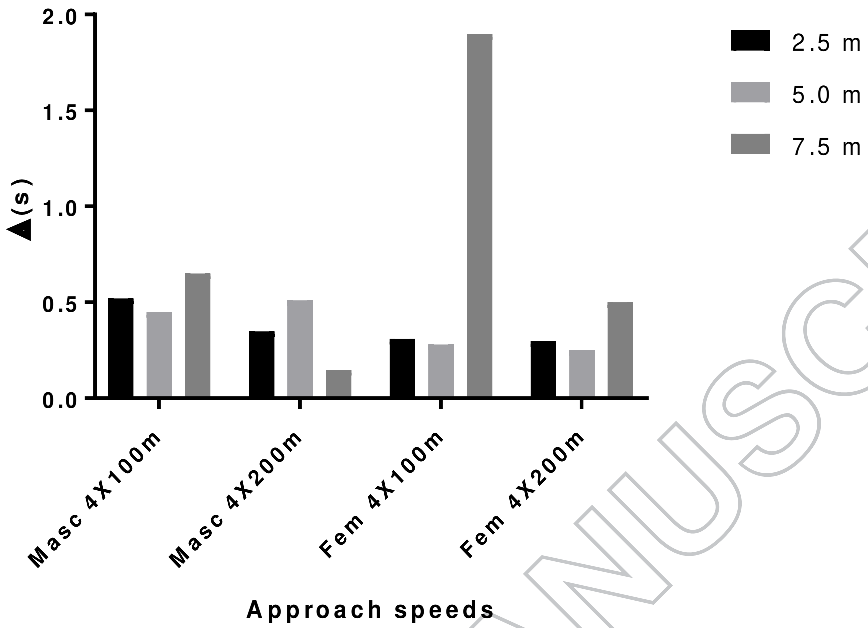

Figure 1: *Variation (Δ) between RTC and TTC for occlusion distances of 2.5 m, 5.0 m, and 7.5 m and between the genders.*

TABLES

Table I. *Participants' training and competition experience.*

	Total Training experience	**Participation in relay events** (last season)	**Participation in specific training tasks to develop relay exchange performance** (last season)
Male (n=18)	5.0 ± 1.6 yrs	5.6 ± 2.9 events per season	2.1 ± 1.2 tasks per mouth
Female (n=14)	3.0 ± 1.2 yrs	4.2 ± 3.1 events per season	0.7 ± 0.3 tasks per mouth

Table II. *Comparison between RCT and TCT (mean, standard deviation, p-value, and effect size) in the 4 × 100-m and 4 × 200-m freestyle (both genders) for all occlusion distances.*

Relay event	**Occlusion distance (m)**	**Male**				**Female**			
		RCT (s)	**TTC (s)**	**p-value**	**Effect size (*r*)**	**RCT (s)**	**TTC (s)**	**p-value**	**Effect size (*r*)**
4 × 100 m	2.5	1.30	0.78 ± .31	.000*	.76	1.53	1.22 ± .52	.016*	.39
	5.0	2.66	2.21 ± .77	.011*	.38	3.16	2.88 ± .87	.279	.22
	7.5	4.50	3.85 ± 1.02	.028*	.41	5.37	3.47 ± .93	.001*	.82
4 × 200 m	2.5	1.50	1.15 ± .27	.001*	.68	1.66	1.36 ± .44	.041*	.43
	5.0	2.93	2.41 ± .53	.002*	.56	3.20	2.95 ± 1.05	.245	.17
	7.5	3.87	3.72 ± 1.23	.744	.09	5.0	4.50 ± .80	.041*	.40

*$p < 0.05$; Note: RCT = real contact time; TTC = time to contact