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A temporal analysis of the swimmers' coordination in the relay start

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ABSTRACT

The main aims of the present research were 1) to characterise the inter-subject and intra-subject timing of the preparatory movements of competitive swimmers during relay starts and 2) to relate the preparatory movements with the relay start outcome. Nine international youth swimmers performed 10 relay freestyle starts (one-step technique) filmed at 120 Hz from a lateral viewpoint. Results obtained (0.14 ± 0.10 s changeover time, 0.31 ± 0.07 s entry time, 2.59 ± 0.09 m entry distance and 0.96 ± 0.06 s time to 5 m) indicated that the longer the preparation time (from the initial position to the swimmer's take-off), the better the changeover time, entry distance, and 5 m time. Specifically, a mixed linear model identified preparation time ($p < 0.001$, $F(1,80.01) = 56.36$), and entry distance ($p = 0.008$, $F(1,80.01) = 7.36$) as predicting variables for 5 m time. Also, faster swimmers on times to 5 m were found to be more consistent – lower levels of intra-subject variability – in 5 m ($r = 0.76$, $p = 0.018$) and changeover ($r = 0.72$, $p = 0.029$) times. In summary, the timing of the preparatory movements seems to be a key aspect to optimise relay start performances.

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Introduction

During the Olympic Games edition to be held in Tokyo, seven relay events will take place in the swimming competition due to the inclusion of the 4 × 100 m mixed races. Distributing at least 21 Olympic medals among competitors, relay events have an increasing impact on the swimming programme. The main feature of relay events is that swimmers can initiate their starting movements on the block before the incoming swimmer finishes his/her leg—unlike individual start events where they have to remain still on the starting block until the acoustic signal, according to Swimming 2.6.8 FINA Rules (FINA, 2020). This is the main reason of the performance differences observed between individual and relay swimming performances (Skorski et al., 2016).

Research indicates that the start segment has a meaningful impact on the swimming race result (Argüelles-Cienfuegos & De La Fuente-Caynzos, 2014; Veiga et al., 2016) as it is during this race phase that the swimmer's forward velocity is the greatest (Kiguchi et al., 2010). In individual events, high horizontal velocities of the

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centre of mass during block phase (Vantorre et al., 2014) or optimal underwater distance and time to maximise underwater velocity (Veiga & Roig, 2017) have been related to better performances. Moreover, due to the intrinsic characteristics of the relay starts, other variables relative to the performers temporal coordination should take into account. For instance, changeover time (denoted as the time from the hand-wall contact of the incoming swimmer to the take-off of the second swimmer) has been identified as a key indicator for optimal performance during relay starts (Saavedra et al., 2014).

Hence, a successful relay start should combine a great horizontal take-off velocity with a short changeover time. In this respect, the one-step relay start was associated with longer changeover times (Takeda et al., 2010) but, at the same time, allowed increasing the horizontal take-off velocity (McLean et al., 2000). Along this line of thought(Fischer et al., 2017) claimed that lower changeover times could lead to lower horizontal peak force during impulse. Pope and Sharples (2014) described how the swimmers on the block should move by maintaining their centre of mass in a low position and how important it is to train the changeover times at full speed. Accordingly, the ability of swimmers to adjust their preparatory movements during the relay start is considered a key aspect. Accurate synchronisation between both swimmers would allow them to reduce changeover times and, at the same time, to avoid disqualifications. Note that, in the last 5 years, up to 35 teams have been disqualified in World Championships or Olympic Games for this circumstance.

While there is a body of literature on movement variability among swimmers during free swimming (e.g., Seifert et al., 2014), there is an evident lack of research examining spatio-temporal variability in the framework of inter-personal interactions during relay starts. Therefore, the main aims of the present research were 1) to characterise the inter-subject and intra-subject timing of the preparatory movements of competitive swimmers during relay starts and 2) to relate the preparatory movements with the relay start outcome. In the light of the reviewed literature, it was hypothesised that faster relay starts (times to 5 m) would be preceded by faster preparatory movements and shorter changeover times. This is the first study focusing on the preparatory movements of relay starts and their impact on the interpersonal coordination and the starts performance. This is an innovative topic related to recently modified FINA races inclusion and allows to deduce some important information to improve relay's performance.

Materials and methods

Participants

Nine international-level swimmers (three men and six women) from the National Youth Team with personal best performances of 762.0 ± 31.0 FINA points, weekly training volumes greater than 20 hours and at least 5 years of experience on competitive swimming volunteered to participate. The Universidad Politécnica de Madrid Research Ethics Committee approved the study (Reference: 2020–080). All participants had at least 5 years of experience in systematic swimming training and a weekly volume of at least 20 hours of practice. Their mean ± SD height, body weight and age were 1.67 ± 0.05 m, 56.4 ± 6.9 kg and 16.0 ± 1.3 years, respectively.

Material

Two high-speed cameras (EXILIM ZR EXZR800, Casio Computer Co., Japan) filmed the relay starts at 120 frames per second. Surface camera recorded an aerial lateral view of the relay start and was located at 2.5 m from the starting wall, 1.5 m above the water surface and 4 m away from the swimmer's lane (with the optical axis perpendicularly oriented to the swimmer's sagittal plane). Underwater camera was placed at the opposite side of the pool at 5 m from the starting wall, 1 m below the water surface and 15 m away from the swimmer's lane. Surface camera was calibrated with a PVC square of 2 m by 2 m situated in the middle of the swimmer's lane and covering both the starting block space and part of the swimmer's aerial phase. On the other hand, for the underwater camera, a vertical visual reference consisting on a non-elastic rope with a 5 kg dumbbell attached at the lower end of it (to ensure a strictly vertical line) was employed to calibrate the space(García-Ramos et al., 2015). Footage from both cameras was synchronised according to the starting swimmer's fingers first touching the water surface. The relay starts were performed with Omega OSB11 starting blocks (Swiss Timing Ltd., Switzerland).

Procedure

After a standardised warm up of 1200 m, each swimmer performed 10 trials of 2 × 25 m freestyle swimming with 30 s rest at maximal velocity. Each repetition involved performing a one-step relay start and coming back from approximately 20 m, so that the same swimmer acted as the starting competitor and straightaway as the incoming competitor. This made possible to somehow replicate in the same trial the fatigue conditions swimmers present at the end of their relay leg. Between trials, swimmers had at least five minutes of passive rest to avoid fatigue effects. The starting swimmers were instructed to perform their regular one-step relay start (usually practised one or two days per week during the weekly training routine), with their preferred leg side to approach the front edge of the block and beginning with the arms pointing at the water surface at approximately 1.5–2 m from the starting wall. From this initial position, swimmers performed the arm swing and one leg step before take-off (Pope & Sharples, 2014).

Definition of variables

Two main groups of variables were analysed: seven performance and four outcome measures. Performance measures indicated the timing of the swimmers' movements (arm swing and leg step) on the starting block, with respect to the first observable movement in the arm swing from the initial position. The following variables were coded: (i) Arms horizontal 1 when the rising arms of the starting swimmer reached the horizontal position (ii) arms vertical 1 when the arms reached the vertical position, (iii) arms horizontal 2 when the descending arms reached the horizontal and (iv) arms vertical 2 when the descending arms again reached the vertical. For the leg movements, (v) foot take-off was coded at the instant of the rear foot leaving the back plate of the starting block for the one-step action whereas (vi) foot support was coded when the same moving foot first contacted the front part of the block before take-off. Also, (vii) Preparation time referred to the total duration of the preparatory actions, from the first observable movement until the incoming swimmers touching the wall.

Also, four outcome measures were analysed: (i) Changeover time, defined as the time elapsed between the touch on the wall of the incoming swimmer and the take-off from the block; (ii) entry time, from take-off to head-water contact; (iii) Entry distance, as the horizontal distance from the starting wall to the head-water contact point; and (iv) 5 m time, from the touch on the wall of the incoming swimmer until the starting swimmer's head reached the 5 m mark.

All variables were coded by an experienced observer from the start footage using Kinovea V.0.8.27 (Bordeaux, France). Intra-observer reliability was confirmed by checking the agreement when repeatably coding (10 times) the same relay start in separate weeks (ICC: 0.998). Furthermore, the validity of distance measurements was checked by reconstructing distances in a known length segment with a root mean square error lower than 0.015 m.

Statistics

As a result of a technical failure, one trial was lost, so 89 trials were collected. We first reported descriptive statistics (n = 89) and individual profiles of participants (average of 10 trials per participant). A mixed model was applied to analyse possible differences between men and women swimmers, with sex as a fixed factor (level 3), participants as a clustering factor (level 2) of nested trials (level 1). Then, we performed a correlation analysis using Pearson's *r* between the performance and the outcome measures (n = 89). We also developed a regression model to estimate 5 m time out of the rest of the performance and outcome variables which were submitted to a mixed linear model. To this end, we submitted the rest of performance and outcome variables -centred covariates scaling- to a Mixed Linear Model (Trials as level 1 and participants as level 2). We first tried random intercepts with fixed slopes, then random intercepts and slopes, and finally possible interaction between fixed factors (Field, 2018). We adjusted the number of variables to find the best fitted model (lower BIC and −2 LogLikelihood). Afterwards, scatterplots checked homoscedasticity of residuals. Finally, to analyse variability we calculated the individual mean and standard deviation out of the 10 trials per participant, so that the individual standard deviation reflected the intra-participant variability. We then performed correlations using Pearson's correlation test between performance indicators and their standard deviation values (n = 9). The level of significance for all analyses was set at $\alpha = 0.05$. IBM SPSS Statistic software (Version 25, Armonk, NY) and Jamovi (V1.0.2, an R-based software available at https://www.jamovi.org.) were employed for the statistical analysis and figure production.

Results

Performance of the swimmers

Table 1 shows the performance of the swimmers during relay starts in chronological order. Competitive swimmers spent around 0.80 ± 0.16 s in their relay start block movements (Table 1). Individual profiles of the relay start performances are shown in Figure 1. The times of the swimmers seemed to be rather close to each other, except for the male swimmer 2 who obtained longer values than his counterparts. Between gender, mixed model analysis of variance did not find any differences ($p > 0.05$) in the analysed variables.

Table 1. Mean, median, standard deviation, and 0.95 confidence interval of the mean of the performance and outcome measures of swimming relay starts in absolute values.

	Descriptive statistics				
				95% CI	
	M	Mdn	SD	Lower	Upper
Performance variables					
Arms horizontal 1 [s]	0.26	0.23	0.11	0.24	0.29
Foot take-off [s]	0.31	0.28	0.12	0.28	0.33
Arms vertical 1 [s]	0.41	0.39	0.12	0.38	0.43
Foot support [s]	0.51	0.48	0.13	0.48	0.53
Arms horizontal 2 [s]	0.56	0.54	0.13	0.53	0.59
Arms vertical 2 [s]	0.70	0.69	0.13	0.67	0.73
Preparation time [s]	0.80	0.79	0.16	0.76	0.83
Outcome variables					
Changeover time [s]	0.14	0.14	0.10	0.09	0.19
Entry time [s]	0.31	0.29	0.07	0.29	0.32
Entry distance [m]	2.59	2.48	0.09	2.53	2.64
5 m time [s]	0.96	0.93	0.06	0.92	1.00

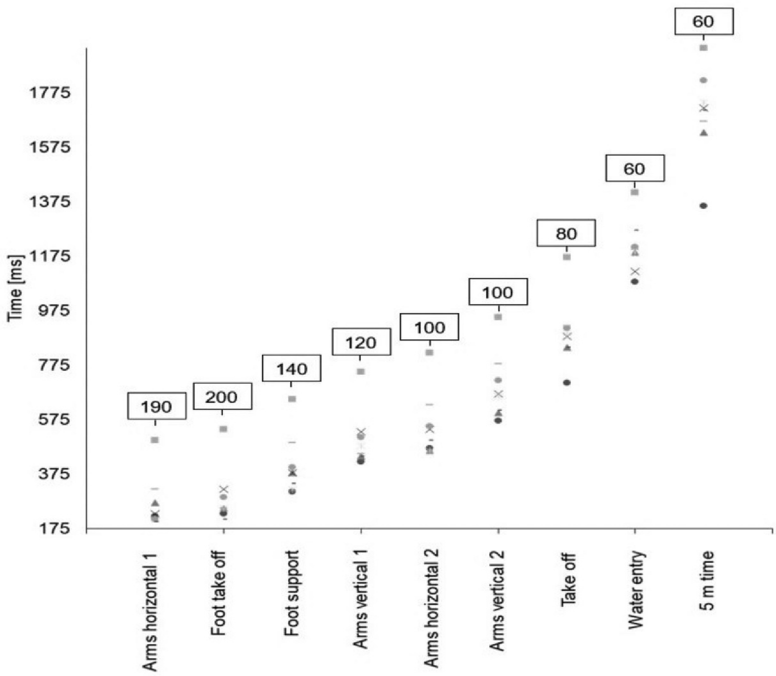

Figure 1. Individual timing profile (mean of ten trials) of the international swimmers during relay starts (error bars were removed to improve clarity). Instead, the average of individual CV's is depicted.

We accomplished a correlation analysis to determine relationships between the timing of the swimmers' movements on the starting block and their starting outcomes (Table 2). As shown in Table 2, entry times and entry distances negatively correlated with performance measures whereas changeover times positively correlated with performance variables. Moreover, we performed a mixed linear model to discover whether the performance and outcome variables would predict the 5 m time in relay starts, as this variable is of

Table 2. Correlations between performance and outcome variables of the swimming relay start.

	Changeover time	Entry time	Entry distance	5 m time
Foot take-off	0.20	−0.57***	−0.46***	0.15
Foot support	0.21*	−0.56***	−0.48***	0.19
Arms horizontal 1	0.25*	−0.37***	−0.14	0.03
Arms vertical 1	0.34**	−0.47***	−0.30**	0.17
Arms horizontal 2	0.32**	−0.52***	−0.34**	0.18
Arms vertical 2	0.33**	−0.58***	−0.46***	0.24*
Preparation time	−0.55***	−0.24*	−0.29**	−0.38***

* p < .05, ** p < .01, *** p < .001

particular importance in the start. The best fitting model (*−2 Loglikelihood* = 61.44, *BIC* = −100.44; R^2 conditional = 0.69) followed a fixed slope and random intercept structure, and besides Intercept (*estimate* = 0.93, $p < 0.001$), was formed by Entry Distance (*estimate* = −0.36, F (1,80.01) = 7.36, $p < 0.008$) and Preparation Time (*estimate* = −0.72, F (1,80.01) = 56.36, $p < 0.001$). Further regression models including random slopes of fixed factors and interactions did not significantly improve the estimation.

Variability

With the intention of exploring any relationship between variability and relay start performances, we correlated the intra-participant variability and individual outcomes (see section 2.5 for details). As depicted in Figure 2(a), faster participants in 5 m time showed less variability in that measure, $r = 0.76$, $p = 0.018$. Moreover, the variability in 5 m time also positively correlated with changeover time, $r = 0.72$, $p = 0.029$, suggesting that more consistent swimmers in the 5 m time displayed shorter changeover times (Figure 2(b)). Relationships between the performance variables and the intra-participant variability were also examined but no correlations were found.

Discussion and implications

We aimed to examine the timing of the preparatory movements of competitive swimmers during one-step relay starts and the relationships with the start outcome. Shorter

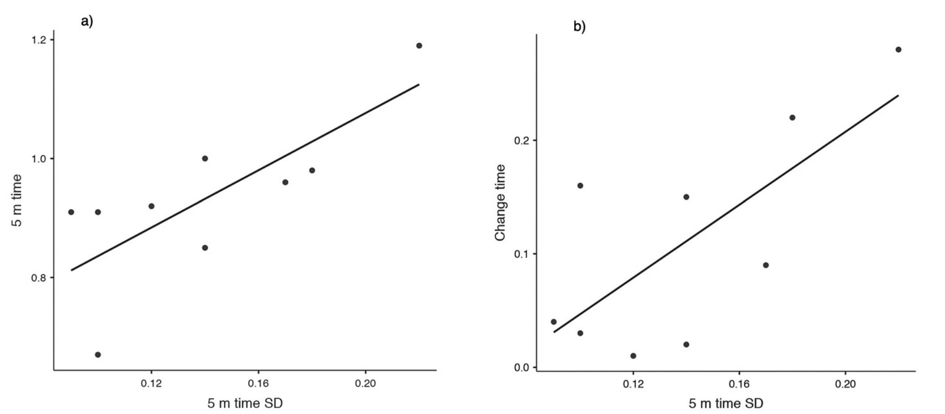

Figure 2. Correlations between intra-participant variability and individual outcomes during relay starts.

5 m times can be predicted by longer preparation times and entry distances. Also, faster swimmers at 5 m showed a greater consistency on their performances on the changeover and the 5 m times. No previous studies have ever examined the swimmer's movements on a relay start and their effect on performance.

Compared to previous data on changeover times in elite swimmers (i.e., 0.10 s; Pope & Sharples, 2014) youth swimmers in the present research showed mean changeover times of 0.14 ± 0.10 s and no differences between gender were observed, contrary to what expressed by Saavedra et al. (2014). Entry times of 0.31 ± 0.02 s were similar to those obtained in individual starts (0.26 ± 0.02 s; Vantorre et al., 2010), whereas entry distances (2.75 ± 0.30 m for men and 2.50 ± 0.09 m for women) were slightly shorter than previously reported in elite swimmers (Tor et al., 2015). The times to 5 m in the relay start were considerably lower (around 40%) than times to 5 m displayed by elite swimmers in individual starts (Tor et al., 2015). Differences between individual and relay start were also observed in relation to block times, defined from the starting signal in the individual starts (García-Hermoso et al., 2013) or as changeover times in relays. Finally, preparation times of around 0.80 s before the arrival of the incoming swimmer were in line with those obtained (about 0.90 s) by Pope and Sharples (2014).

Analysis of the timing revealed that segment movements of the swimmers on the starting block did not seem to be directly related with the time at 5 m. However, longer preparation times and longer entry distances seemed to predict 5 m times. This partly agrees with flight distance being the most determinant parameter of the individual (not relay) starting performance (Peterson Silveira et al., 2018). However, interestingly, it also indicates that preparation time might represent an important parameter for relay start performance. As was previously suggested by Maglischo (2003), swimmers must begin their starting movements with enough anticipation with respect to the touch of the incoming swimmer. This might help them to balance their body over the platform, and such a proper placement of the lower body facilitates in turn the force application (Vantorre et al., 2014). Indeed, the movement phases on the block need to last long enough to maximise the swimmer's impulse to achieve high horizontal velocity (Breed & Young, 2003; Vantorre et al., 2014). Research suggests a trade-off between minimising changeover times and force production on the starting platform (Fischer et al., 2017). Therefore, the ability to begin the preparatory movements with enough anticipation could represent a great strategy to optimise the changeover times without decreasing the applied forces to dive.

During preparation time on the starting block, swimmers typically performed an arm swing in an analogue way to a countermovement jump (Lees et al., 2004). This strategy would allow them to increase the horizontal impulse on the starting block and, therefore, to achieve a greater horizontal take-off velocity (García-Ramos et al., 2015). Previous data from vertical jumps indicate that jump height could be augmented by 38% by the arm movements (Vaverka et al., 2016) due to an increased height and velocity of the centre of mass at take-off. The elevation of the arm segments would allow this initial height-increase and the greater levels of kinetic and potential energy due to the arm swing would allow the augmented take-off velocity (Lees et al., 2004). In the present study, both arms and legs movements seemed to be negatively correlated with the entry distance and entry time (Table 2). This suggested that swimmers performing faster preparatory movements on the block would achieve longer aerial phases. No previous research, to our knowledge, has ever explored the timing of the arm swing movements in relation to the jump performance (either vertical or in a specific situation with swimming starting blocks).

Repeated execution of relay starts revealed an inverse relationship between variability across trials and performance success. The fastest swimmers (better times at 5 m) demonstrated more consistent actions during the changeover and in the time at 5 m. In other words, the best relay starters showed a superior ability to calibrate the timing of their actions to the incoming partner. These findings extend the innovative idea of considering the performer and the environment together (Seifert et al., 2013), far away from the previous and separately understanding. The present work addresses the intra-participant timing variability during the execution of an externally constrained action (time to contact of the incoming swimmer). Nonetheless, additional research is required to substantiate these exploratory observations.

Although the present study presents some limitations such as the low number of participants, research design was implemented (10 trials by each participant) to ensure a high number of relay start repetitions (n = 89) was registered and to increase the strength of data. In this way, we do believe that some insights can be used by coaches in training. For instance, suggesting the relay swimmers anticipate the incoming swimmer with enough time (longer preparation times) and perform fast segmental movements during preparation may benefit better inter-personal coordination (shorter changeover time) at the same time as maximising the distance of water entry. This, in turn, would assist swimmers in achieving shorter times to 5 m.

Conclusions

After a characterisation of swimmers' preparatory movements on a relay start and their influence on the relay start outcome, it could be concluded that better results—shorter times to five meters—were obtained with longer preparation times and entry distances. Also, greater levels of consistency, both during changeover and 5 m times, were observed in the faster swimmers. Therefore, the timing of preparatory movements seems to be a key aspect to optimise relay start performances.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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