©Journal of Sports Science and Medicine (2025) **24**, 227-235
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2025.227

Research article

What Is the Best Step Technique for Swimming Relay Starts?

Santiago Veiga[1]✉, Sebastian Fischer [2], Xiao Qiu [1,2], Jelena Stosic [1], Stefan Fuhrmann [3], Armin Kibele [2] and Claudia Braun [2]
[1] Sports Department, Universidad Politécnica de Madrid, Spain; [2] Institute for Sports and Sport Science, University of Kassel, Germany; [3] Hamburg Olympic Training Centre, Germany

Abstract
There is a great heterogeneity in the starting techniques used by international-level swimmers in relay events. The aim of the present study was to analyse and compare the two most commonly used relay start techniques by male and female competitive swimmers. Thirteen males and seven females national and international-level swimmers performed several 25-m trials with their preferred relay start (n = 91, short-step; n = 54, long-step technique). Linear mixed models examined the effects of gender and start technique, with 5-m start times as a covariate. Swimmers performing long-step showed faster 5-m (0.09 s, $d = 1.10$) and 10-m (0.09 s, $d = 0.39$) times than those performing short-step starts, regardless of gender (all $p < 0.001$). This was the result of i) longer block times, ii) faster horizontal velocities with lower peak forces during the leg step and iii) faster velocities with higher peak forces when driving-off the block in the long-step technique. In both relay techniques, females showed 0.11 s ($d = 1.38$) longer 5-m and 0.69 s ($d = 2.99$) longer 10-m (both $p < 0.001$) times compared to males with longer block times and slower velocities in all key events. Swimmers should take advantage of the new starting platforms to apply long-step start techniques that increase horizontal displacement but also forward velocity before leaving the block.

Key words: Step-start, kinetic, kinematics, performance.

Introduction

Relay starts are a unique technique in swimming events as World Aquatics regulations allow block preparatory movements on the starting blocks (no grab starts) before the swimmers take-off for the flight and entry phase. These relay starts are characterized by clear kinematic and kinetic differences (for the second to fourth swimmers in the relay team order) compared to individual starts (Qiu et al., 2021b), where the swimmers must maintain a stationary starting position with at least one foot at the front of the block until the start signal sounds (World Aquatics, 2023). In relay starts, preparatory actions on the starting block are typically characterized by one or two steps from the rear to the front edge of the block and a circular backswing of the upper limbs with the goal of increasing the application of horizontal impulse and, consequently, achieving higher take-off velocities (Takeda et al., 2010). In fact, even though the preparatory movements should provide a mechanical advantage for the relay versus individual track starts, kinematic comparison revealed no clear differences in competitive swimmers (Qiu et al., 2021b). According to evidence in other sport disciplines, an upper limbs swing in the vertical jump would optimize the proximal-to-distal coordinative timing of the leg extension (Chiu et al., 2014) and would decrease the rate of muscle shortening (Blache and Monteil, 2013). This would improve jump performance by increasing take-off velocity by 6-10% (Feltner et al., 2004; Lees et al., 2004). Interestingly, female athletes show a lower ability to increase jump performance with upper-limbs swing, due to their lower levels of strength on the upper limbs compared to males (Walsh et al., 2007). Another strategy to improve jump performance is to incorporate a horizontal step approach, as shown in volleyball players who achieved 30% greater height with their spike jump (approach) technique (Sattler et al., 2015). However, the fact that horizontal jumps (like in a swim start) are characterized by a rotation phase of the body before leg extension for take-off (Ridderikhoff et al., 1999) clearly distinguishes them from vertical jumps.

In 2008, the new starting block Omega OSB11 was introduced to official competitions. Its significantly greater platform and an adjustable back plate offered new opportunities for the development of new relay start techniques. But today, even 15 years after the starting block changeover, there is still no clear consensus on which specific sequence of block movements swimmers should use for their relay starts. Early studies suggested an increase in horizontal take-off velocity when swimmers would perform one-step before driving off the block (McLean et al., 2000) but Takeda et al. (Takeda et al., 2010) showed no significant differences for take-off velocities between step and non-step relay start techniques. Using the Omega OSB 11, Qiu et al. (Qiu et al., 2021a) reported similar take-off velocities and overall start performances between the parallel feet, separated feet (track) and one-step relay techniques but a trend for a superior performance when using step techniques. According to Takeda et al. (Takeda et al., 2010), the major disadvantage for the relay step techniques would be the small space for correct foot placement after the step on the front edge of the block. Additionally, the longer movement time due to performing a step on the starting block presents a challenge regarding the proper timing of one's own take-off with the teammate's arrival at the wall (Fischer et al., 2017). This could lead to some gender differences in the choice of relay techniques, as female swimmers tend to display greater change-over times compared to males (Fischer et al., 2019).

When examining the techniques used by top swimmers, there is a wide range of relay start techniques, some of which have only recently been developed. For example, during 4 x 100 m relay finals (freestyle and medley events of males, females and mixed) at the Olympic Games in

Received: 04 March 2024 / Accepted: 05 March 2025 / Published (online): 01 June 2025

Tokyo 2020 (conducted in 2021), finalists employed up to five different techniques on the block with none of them representing more than 40% of all relay starts (Note: one of the authors, who attended this championship as a member of one national swimming team, collected data on the frequency of relay start techniques performed by Olympic finalists in Tokyo. He recorded the change-overs with a video camera and analysed the video footage by classifying all performed relay starts into five different relay start techniques according to the swimmers' preparatory movements in the block phase of the start). Interestingly, the most favored technique especially for males was not previously described in the literature and can be described as follows: the swimmer's initial position is with one foot behind the back plate and the other foot on the inclined plane of the back plate. Then they perform one long step with the rear foot over the back plate to the front edge of the block and drive-off with their feet positioned separated as in an individual start. According to previous research investigating the swimmers' center of mass shift (from rear to front foot support) during individual track starts, the longer acceleration path provided by this long step technique could lead to higher horizontal take-off velocities (e.g., Welcher et al., 2008). The second most used relay start technique was the traditional one-step technique (22% of relay starts), which starts from an initial foot separated position (track start position). Then, the swimmers step with the rear foot from the back plate to the front edge of the starting block next to the other foot and they jump into the water from a parallel foot position. The purpose of this study was to analyse and compare the two most commonly used relay start techniques by male and female competitive swimmers. It was hypothesized that differences on performance times (when controlling change-over times) would be detected between relay start techniques, with greater horizontal take-off velocities in the long step technique for male swimmers.

Methods

Participants

Thirteen male (18.24 ± 3.17 years, 1.90 ± 0.05 m and 85.38 ± 4.53 kg) and seven females (16.89 ± 2.11 years, 1.79 ± 0.04 m and 80.51 ± 3.82 kg) swimmers belonging to the Olympic Training Center in Hamburg (Germany) and with a current average World Aquatics Swimming Points in their personal best times of 742 ± 93 and 700 ± 76 points, respectively, participated in the present study. All swimmers took part in an international-level training program, with a weekly plan of nine water sessions and five land training sessions per week. They were all specialized in 50 m to 200 m events. The unbalanced distribution between males and females was due to the actual composition of the national swimming team. The Local Ethics Committee approved experimental procedures with code 2020-080 and all participants (or their parents in case athletes were under 18 years old) signed a written informed consent before the commencement of the study. The study complied with the recommendations of the Declaration of Helsinki.

Procedure

This was an observational and comparative study where participants were divided in two groups according to their preferred (and thus well-trained) relay start technique. Data collection took place in a 50 x 25 m swimming-pool equipped with OSB11 starting blocks and with water temperatures at 27ºC. After performing their usual out-of-water and in-water warm-up routine of approximately 1200 m distance covered, swimmers performed several 25 m sprints front-crawl at 100 m race pace with at least three minutes of passive rest between each. Each 25 m repetition began from a dive start where swimmers adopted their preferred relay start technique and where competition conditions were simulated with an incoming swimmer arriving at the wall. In total, 145 trials were collected corresponding to two different start techniques: i) the short step technique (N = 91; n = 45 females, n = 46 males), where swimmers had an initial position with one foot in the front edge of the block and another foot on the back plate; ii) the long step technique (N = 54; n = 10 females, n = 44 males), where swimmers began with one foot behind and the other foot on the back plate. From these initial positions, swimmers in both techniques performed one step forward with the initial rear foot and a circular backswing with the upper limbs, before beginning the lower-limbs extension for take-off. In the short step technique, the swimmer's take-off from a parallel foot position, and in the long step techniques they take-off from a track start position (feet separate). A graphical description of each relay start technique is depicted in Figure 1.

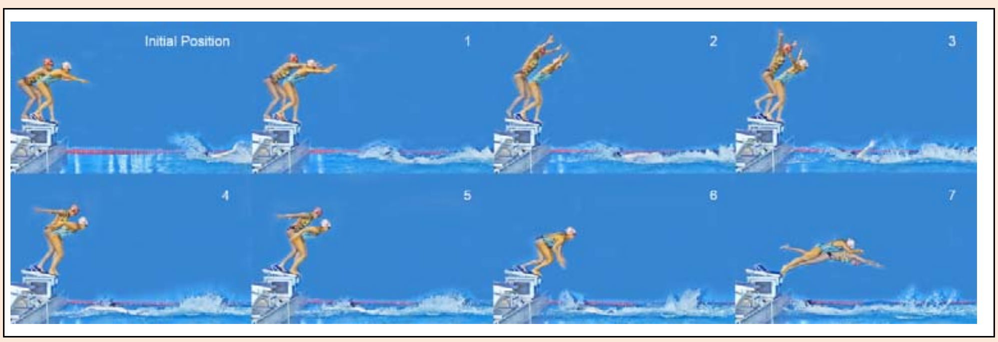

Figure 1. Key events of the block preparatory movements for the short-step and long-step relay start techniques. Note: 1 = upper limbs horizontal 1, 2 = rear foot take-off, 3 = upper limbs vertical 1, 4 = rear foot support, 5 = upper limbs horizontal 2, 6 = upper limbs vertical 2, 7 = take-off.

Force measurements during relay starts were acquired with four biaxial force transducers (ALTHEN, DMS F307-Z3065, Germany, measurement precision provided by the distributor: 0.5%) mounted on an Omega OSB11 starting block and by a custom-made analysis software (Holder Petersberg, Germany) employed to record the force signals at 1000 Hz. Once collected, the horizontal and vertical force signals were filtered with a Butterworth 2nd order filter at 10 Hz. Trials were filmed from a lateral view with one aerial and two underwater video cameras (Sony SNCVB630) operating at 50 Hz and with Full HD. The aerial camera was located at 2.5 m from the starting wall and 1.39 m above the water surface level. The underwater cameras were placed at 5 and 10 m (underwater) from the start wall and one meter below the water surface. The video signals for different cameras were automatically synchronized with a red coloured LED light in the field of view of each camera and the Utilius® Kiwano system (Utilus version: 1.5.2.0) produced by ccc software GmbH.

Times to 5 m and 10 m from take-off to the swimmers' head reaching the reference mark were used to evaluate overall start performances. In addition, an experienced observer manually coded the key events of the swimmer's preparatory movements on the block, according to previous definitions in Peralvo-Simon et al. 2021. Correspondingly, the times when swimmers reached the first and second horizontal and vertical positions with their upper limbs during the circular swing as well as the times when the swimmers lifted and placed the rear foot during the leg step were collected (Figure 1). For the kinetic analysis, variables related to the first (leg step) and to the second (lower limbs extension) peak forces were collected. During leg step, the peak horizontal force (body weight), the time of peak horizontal force (s), the horizontal velocity while performing the step (m/s) and the horizontal velocity at foot contact after step swing (m/s) were collected. During the lower limbs extension for take-off, the maximum force (body weight), the time of maximum force (s), the velocity at time of maximum force (m/s) and the take-off velocity (m/s) were measured both for the horizontal and vertical axes. In addition, the take-off angle (°) defined as the angle between the velocity vector of the swimmer's centre of gravity and the horizontal (positive: upward direction; negative: downward direction) was calculated. For all relay starts, the beginning of the block movements was considered when a 10 N horizontal force threshold was surpassed.

Statistical analysis

The kinematic and kinetic start parameters were analysed with linear mixed models (LMM) to account for the multiple starts of the same swimmer. Gender (male or female) and the relay start technique (short step or long step) were defined as fixed effects. Differences in the general start performance between swimmers was controlled by using the personal best 5-m time in an individual start as a covariate. A diagonal structure was used as repeated covariance type (Verbeke and Molenberghs, 2009). To account for alpha error inflation, the Bonferroni method was used for post hoc comparisons (Bland and Altman, 1995). Group differences were reported based on estimated marginal means and standard deviations of the LMM. The magnitude of differences was expressed as Cohen's d effect sizes, with 0.2, 0.5 and 0.8 being the thresholds for the small, medium and large effect, respectively (Cohen, 1988). The significance-level for all analyses was set to $p < .05$.

Results

Relay Step Technique

The LMM revealed significantly faster 5 m (0.09 s) and 10 m (0.09 s) times ($F_{1, 118.67} = 40.21$, $p < 0.001$, $d = 1.10$ and $F_{1, 42.42} = 5.02$, $p = 0.030$, $d = 0.39$, respectively) for the long step compared to the short step relay start technique. This occurred regardless of gender, as no interaction (gender × relay start technique) was detected in the 5 m or 10 m start times (both $p > 0.05$). The differences in performance were accompanied by a number of significant differences in timing, with all of the following key moments occurring later in the long step technique (see Table 1): the rear foot take-off (+0.04 s, $F_{1, 80.01} = 6.66$, $p = 0.012$, $d = 0.44$) and support (+0.15 s, $F_{1, 48.99} = 147.53$, $p < 0.001$, $d = 2.10$), the upper-limbs vertical position 1 (+0.05 s, $F_{1, 90.37} = 12.46$, $p < 0.001$, $d = 0.61$), the upper-limbs horizontal position 2 (+0.06 s, $F_{1, 107.83} = 20.07$, $p < .001$, $d = 0.78$), and the upper-limbs vertical position 2 (+0.09 s, $F_{1, 60.75} = 30.07$, $p < 0.001$, $d = 0.95$). This resulted in swimmers using the long step technique taking 0.11 s longer until take-off ($F_{1, 71.01} = 36.23$, $p < 0.001$, $d = 1.04$).

For the velocity and force parameters (Figure 2 and Figure 3), swimmers performing the long step technique had a 17% smaller peak horizontal force during the leg step ($F_{1, 92.14} = 7.87$, $p = .006$, $d = 0.48$), but significantly larger (17%) horizontal velocities while performing the step ($F_{1, 101.11} = 8.33$, $p = 0.005$, $d = 0.50$) and at foot contact after the step (11%, $F_{1, 79.60} = 5.83$, $p = 0.018$, $d = 0.42$), regardless of gender. The maximal force outputs were significantly larger, and occurred significantly later, for the long compared to the short step technique in the horizontal (+24%, $F_{1, 131.73} = 66.85$, $p < 0.001$, $d = 1.41$ for force and +0.07 s, $F_{1, 37.03} = 17.50$, $p < 0.001$, $d = 0.72$ for time), and vertical (+15%, $F_{1, 115.83} = 50.87$, $p < 0.001$, $d = 1.23$ for force and +0.10 s, $F_{1, 64.59} = 34.09$, $p < 0.001$, $d = 1.01$ for time) directions. This was accompanied by significantly larger horizontal (+18%, $F_{1, 110.71} = 229.10$, $p < 0.001$, $d = 2.62$) and resultant (+16%, $F_{1, 125.22} = 194.37$, $p < 0.001$, $d = 2.41$) velocities at take-off and larger horizontal (+17%) velocities at time of maximal horizontal force ($F_{1, 93.47} = 47.16$, $p < 0.001$, $d = 1.19$) for the long step technique in male and female swimmers.

Gender

Female swimmers obtained 0.11 s longer 5-m-times compared to male swimmers ($F_{1, 118.67} = 64.31$, $p < 0.001$, $d = 1.38$), as well as 0.69 s longer 10-m-times ($F_{1, 42.42} = 302.30$, $p < 0.001$, $d = 2.99$) regardless of the start technique. This gender gap in overall start performance included several timing differences, especially in the long step technique (gender × relay start technique, $p < 0.05$). First, female swimmers performed the rear foot take-off (+0.04 s, $F_{1, 80.02} = 10.47$, $p = 0.002$, $d = 0.56$) and support (+0.09 s, $F_{1, 48.99} = 59.25$, $p < 0.001$, $d = 1.33$) significantly later compared to male swimmers. The same occurred for the upper-limbs vertical position 1 (+0.04 s, $F_{1,\ 90.37} = 11.00$, $p = 0.001$, $d = 0.57$), the upper-limbs horizontal positon 2 (+0.06 s, $F_{1,\ 107.83} = 4.70$, $p = 0.032$, $d = 0.37$), as well as the upper-limbs vertical position 2 (+0.09 s, $F_{1,\ 60.75} = 18.28$, $p < 0.001$, $d = 0.74$). This resulted in female swimmers taking significantly more time (+0.10 s) to conduct the entire relay start movements ($F_{1,\ 71.01} = 33.46$, $p < 0.001$, $d = 1.00$). Moreover, several force events occurred later in the timing of female compared to male swimmers: a later time of peak horizontal force while performing the step (+0.04 s, $F_{1,\ 75.38} = 5.63$, $p = 0.020$, $d = 0.41$), as well as a later time of peak horizontal (+0.1 s, $F_{1,\ 37.03} = 40.57$, $p < 0.001$, $d = 1.10$) and vertical (+0.1 s, $F_{1,\ 64.59} = 31.94$, $p < 0.001$, $d = 0.97$) forces.

For the block velocities, female swimmers showed slower horizontal and vertical velocities than males. Differences in horizontal velocity were detected at the peak horizontal force during the step (-16%, $F_{1,\ 101.11} = 9.17$, $p = 0.003$, $d = 0.52$), at foot contact after the step (-22% , $F_{1,\ 79.60} = 38.08$, $p < 0.001$, $d = 1.06$), but also at the instants of peak horizontal force (-11%, $F_{1,\ 93.47} = 35.55$, $p < 0.001$, $d = 1.03$) and at take-off (-5%, $F_{1,\ 110.71} = 24.54$, $p < .001$, $d = 0.86$). Differences in vertical velocity were detected at peak vertical force (-25%, $F_{1,\ 123.79} = 17.39$, $p < 0.001$, $d = 0.72$) and at take-off (-79%, $F_{1,\ 120.84} = 43.10$, $p < 0.001$, $d = 1.13$). Concerning force production, the LMM revealed significantly lower (-19%, $F_{1,\ 92.14} = 9.64$, $p = 0.003$, $d = 0.54$) peak horizontal force (relative to bodyweight) for female swimmers while performing the step, but no gender differences for the maximal horizontal ($F_{1,\ 131.73} = 2.49$, $p = 0.117$) or vertical ($F_{1,\ 115.83} = 0.46$, $p = 0.501$) force. Indeed, female swimmers showed higher peaks of horizontal force during the long step technique (+12%, $F_{1,\ 128.50} = 7.75$, p = 0.002, $d = 0.69$) and lower ($F_{1,\ 56.03} = 50.14$, $p < 0.001$, $d = 1.22$) take-off angles ($M = -16.4°$, $SD = 7.1$) compared to males ($M = -9.0°$, $SD = 4.1$).

Table 1. Descriptive values (estimated marginal means and standard deviations) and results of the LMM analyses for the relay starts according to the relay technique and gender.

		Gender		Relay start technique		Linear Mixed Model					
Parameter	**Parameter**	**Male (*n*=90)**	**Female (*n*=55)**	**Short step (*n*=91)**	**Long step (*n*=54)**	**Gender**		**Relay technique**		**Technique × gender**	
						P	**d**	**P**	**d**	**P**	**d**
TIMING OF BLOCK MOVEMENTS	Upper-limbs horizontal (s)	0.28 (0.04)	0.23 (0.05)	0.26 (0.04)	0.26 (0.05)	<.001	1.14	0.95	0.09	<.001	0.88
	Rear foot take-off (s)	0.31 (0.07)	0.35 (0.09)	0.31 (0.07)	0.35 (0.08)	0.002	0.56	0.012	0.44	0.020	0.51
	Upper-limbs vertical (s)	0.41 (0.06)	0.45 (0.07)	0.41 (0.06)	0.46 (0.07)	0.001	0.57	<.001	0.61	<.001	0.95
	Rear foot support (s)	0.53 (0.05)	0.62 (0.08)	0.50 (0.07)	0.65 (0.07)	<.001	1.33	<.001	2.10	<.001	1.12
	Upper-limbs horizontal 2 (s)	0.57 (0.08)	0.60 (0.10)	0.56 (0.08)	0.62 (0.10)	0.032	0.37	<.001	0.78	0.004	0.63
	Upper-limbs vertical 2 (s)	0.68 (0.08)	0.75 (0.10)	0.67 (0.08)	0.76 (0.10)	<.001	0.74	<.001	0.95	<.001	0.94
	Take-off (s)	0.88 (0.09)	0.98 (0.12)	0.88 (0.10)	0.99 (0.12)	<.001	1.00	<.001	1.04	0.039	0.45
STEP PHASE	Peak HF while performing the step (bodyweight)	0.42 (0.09)	0.34 (0.16)	0.41 (0.13)	0.35 (0.15)	0.003	0.54	0.006	0.48	0.004	0.63
	Time of peak HF while performing the step (s)	0.14 (0.09)	0.18 (0.12)	0.14 (0.09)	0.17 (0.11)	0.020	0.41	0.051	0.34	0.404	0.18
	HV at peak HF while performing the step (m/s)	0.61 (0.16)	0.51 (0.16)	0.52 (0.15)	0.61 (0.20)	0.003	0.52	0.005	0.50	0.438	0.17
	HV at foot contact after step swing (m/s)	1.08 (0.19)	0.84 (0.25)	0.91 (0.20)	1.01 (0.24)	<.001	1.06	0.018	0.42	0.653	0.10
DRIVING PHASE	Maximal HF (bodyweight)	1.62 (0.20)	1.69 (0.27)	1.48 (0.21)	1.83 (0.27)	0.117	0.27	<.001	1.41	0.002	0.69
	Time at max. HF (s)	0.75 (0.09)	0.85 (0.10)	0.77 (0.09)	0.84 (0.10)	<.001	1.10	<.001	0.72	0.003	0.68
	HV at max. HF (m/s)	3.10 (0.21)	2.76 (0.39)	2.72 (0.31)	3.17 (0.35)	<.001	1.03	<.001	1.19	0.757	0.07
	Max. VF (bodyweight)	1.99 (0.20)	1.96 (0.24)	1.84 (0.19)	2.12 (0.24)	0.501	0.12	<.001	1.23	0.120	0.33
	Time at max. VF (s)	0.70 (0.09)	0.80 (0.11)	0.70 (0.09)	0.80 (0.11)	<.001	0.97	<.001	1.01	0.031	0.47
	VV at max. VF (m/s)	-0.91 (0.27)	-1.14 (0.35)	-1.04 (0.27)	-1.01 (0.35)	<.001	0.72	0.618	0.09	<.001	1.12
TAKE-OFF PHASE	HV at take-off (m/s)	4.3 (0.23)	4.07 (0.29)	3.84 (0.23)	4.54 (0.29)	<.001	0.86	<.001	2.62	0.876	0.03
	VV at take-off (m/s)	-0.68 (0.37)	-1.22 (0.54)	-0.88 (0.40)	-1.02 (0.52)	<.001	1.13	0.099	0.29	0.011	0.55
	Resultant velocity (m/s)	4.38 (0.26)	4.29 (0.45)	3.97 (0.26)	4.70 (0.33)	0.087	0.30	<.001	2.41	0.703	0.08
	Take-off angle (°)	-8.99 (4.13)	-16.42 (7.08)	-12.85 (5.20)	-12.57 (6.59)	0.001	1.22	0.791	0.05	0.031	0.47
OVERALL PERFORMANCE	Time span take-off till 5 m (s)	0.82 (0.07)	0.93 (0.08)	0.92 (0.07)	0.83 (0.08)	<.001	1.38	<.001	1.10	0.249	0.25
	Time span take-off till 10 m (s)	2.96 (0.16)	3.65 (0.27)	3.35 (0.22)	3.26 (0.24)	<.001	2.99	0.030	0.39	0.227	0.26

HF = horizontal force, VF = vertical force, HV = horizontal velocity, VV = vertical velocity

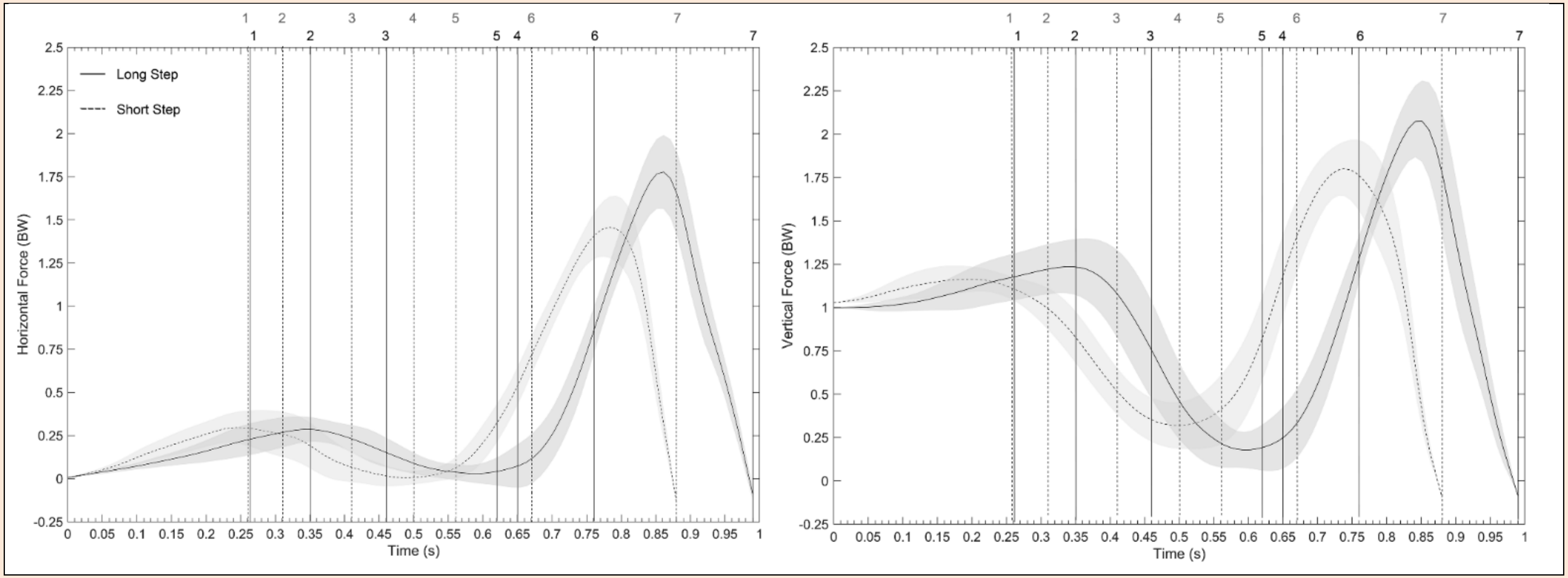

Figure 2. Observed mean horizontal and vertical forces (±standard deviation in shaded area) for the short step and long step relay start techniques. 1 = upper limbs horizontal 1, 2 = rear foot take-off, 3 = upper limbs vertical 1, 4 = rear foot support, 5 = upper limbs horizontal 2, 6 = upper limbs vertical 2, 7 = take-off.

Discussion

The present study aimed was to determine the best relay start technique for male and female competitive swimmers. The results indicated that the long step outperformed the short step relay start technique in both genders by demonstrating longer preparatory movements on the block, which assisted in the application of higher ground reaction forces and increased take-off velocity. Female swimmers showed a later timing of the key preparatory movements compared to males, and this resulted in slower velocities during the leg step and driving leg phases despite similar peak force application during take-off.

Overall performance differences at the 5 m mark between both relay techniques (≈0.09 s) were similar to those reported between step and non-step techniques with Omega OSB11 by Qiu et al. (Qiu et al., 2021a) and represent meaningful improvements according to the narrow differences in competitive swimming (Mujika et al., 2019). The increase in take-off velocity of 18% with the long step technique was markedly higher than the 5% increase shown with a double step technique (McLean et al., 2000) when compared to the short step technique. Indeed, a take-off velocity of 4.5 m/s as reported as mean value for the long step technique in this study (Table 1) depicts an excellence value and highlights the high expertise level of the analysed swimmers as those amounts were reported as maximum values for take-off velocities for relay starts in the literature.

The main reasons to explain the performance gap between the short and the long step relay techniques may be based first on block times. Swimmers performing the long step technique spent longer movement time on the block because their initial body position was located at the rear edge of the block (Figure 1). In this way, total preparatory time before take-off was ≈0.11 s longer, although the relative timing of the upper-limbs swing and rear foot take-off was similar to the short step techniques. The magnitude and duration of forces applied to the block determine the total impulse during relay starts (Ruddock and Winter, 2016). Swimmers adopting the long step technique maximised the time of force application during the preparatory movements, although peak forces during the leg step were lower than in the short step technique (Table 1). While performing the leg step forward, swimmers with the long step achieved faster horizontal (forward) velocities that, subsequently, translated into greater peak forces and faster velocities when driving off the block. The stance position with separated feet after the step (track start position), possibly assisted swimmers using the long step technique to apply greater peak forces. The reason may be that the separated foot position is similar to the start position of the individual starts, which may be more familiar to the swimmers than a parallel foot position. The benefits of the long step technique related to the faster block velocities may be similar to the horizontal approach phase used by volleyball players to improve maximum height in vertical jumps (Sattler et al., 2015). Indeed, higher jump performance is associated with faster horizontal of center of mass velocities during the step approach (Wagner et al., 2009) and this may be similar to the mechanical advantages of the long step relay start technique. However, jumps for horizontal distance (such as swim starts) have some mechanical differences with vertical jumps, such as different net moments of the joints (Ridderikhoff et al., 1999), which makes comparison between them with caution.

Although this study revealed several advantages for the long step technique, there are greater challenges to performing this technique compared to the short step technique that swimmers and coaches should be aware of. Indeed, the small space for correct foot placement after stepping on the front edge of the block (Takeda et al., 2010) is a general limitation of step techniques. In addition, the amplitude of the long step technique is greater and the separated foot position (track position) for take-off is less stable than the parallel foot position. This could prevent swimmers from applying a greater impulse to the block if they are not completely familiar with this technique and are not accurate enough to place the lower limbs in the correct position. Lastly, greater block times on the long step technique could difficult swimmers to minimize change-over times with the incoming swimmer although, as previously confirmed (Fischer et al., 2019), their importance appears to be overrated in previous research.

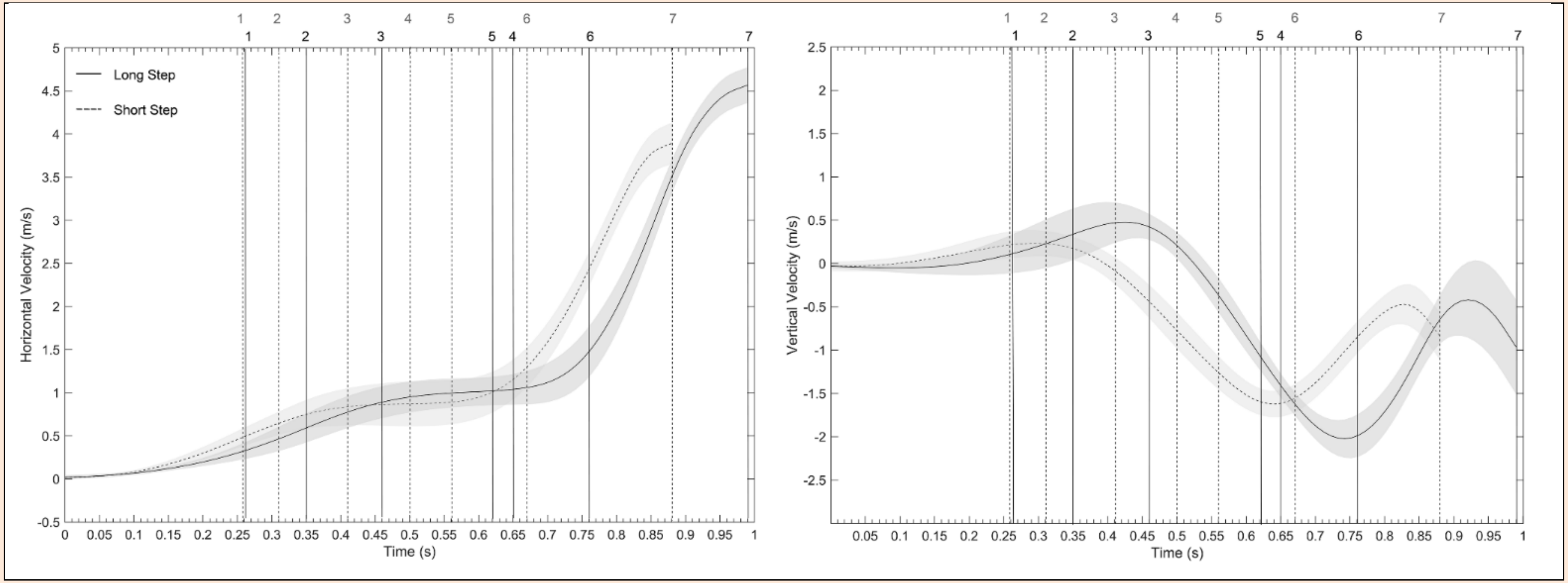

Figure 3. Observed mean horizontal and vertical velocities (±standard deviation in shaded area) for the short step and long step relay start techniques. 1 = upper limbs horizontal 1, 2 = rear foot take-off, 3 = upper limbs vertical 1, 4 = rear foot support, 5 = upper limbs horizontal 2, 6 = upper limbs vertical 2, 7 = take-off.

In terms of gender differences, the overall relay start performance of females was lower than that of their male counterparts, consistent with differences observed in free-swimming ability (Seifert et al., 2010). The gender gap in 5-m-times was 13.4%, consistent with that presented by Shepherd et al. (Shepherd et al., 2021), but larger than previously reported in 5-m-times (≈11%) of individual track starts (Thng et al., 2020). Interestingly, the gender gap in relay start performances was mainly based on the early part of the block movements. Female swimmers showed lower peak forces and slower forward velocities during the leg step, which then translated into slower velocities when driving off the block. However, males did not outperform females in the relative peak forces applied during lower limbs extension for take-off. Male swimmers would be expected to display greater strength values than females due to different muscle architecture with a greater proportion of type-II fibers (Laffaye et al., 2014) and also due to greater levels of testosterone (Cardinale and Stone, 2006) and lower body fat percentage (Caia et al., 2016). However, applying maximum levels of horizontal force during step starts is more difficult because athletes are already moving forward after the leg step and have their time for legs extension action reduced (Takeda et al., 2010). This could hinder gender differences in peak forces but it would highlight the importance of the timing of preparatory movements and forward velocity early in the block. Compared to males, females performed their leg step and upper limbs swing at a slower velocity (longer times) (Table 1). This has been previously associated with shorter aerial phases and poorer relay start performance in competitive swimmers (Peralvo-Simón et al., 2021) due to a reduced transfer of kinetic energy from the upper limbs to the rest of the body. One possible explanation may be the lower upper-body strength levels of female versus male athletes. In fact, previous evidence on vertical jumps with arm swing has suggested the important role of shoulder muscles, which would provide an advantage in jumping performance for males compared to females (Walsh et al., 2007; Sattler et al., 2015).

Gender differences on the block preparatory movements were especially evident on the long step relay technique. In this technique, female swimmers applied greater values of peak horizontal forces when driving off the block, despite their lower overall start performance. The asymmetrical feet positioning after the leg step (and during lower limbs extension) as well as the changes in the position of the rear leg when pushing off the back plate could reduce the ability to produce force (Takeda and Nomura, 2006) in this technique. This would emphasize the importance of increasing forward velocity on the early stages on the block, where females specifically displayed a slower timing of the upper-limbs swing and leg step movements compared to males that undoubtedly impaired their start performance.

Conclusion

Our study shows that the long step relay start technique seems to be superior to the traditional short step technique for competitive swimmers on an OSB11 start block. This advantage seems to be due to longer preparatory movements with the long step relay start technique and a greater center of mass displacement on the block that may allow swimmers to increase their forward velocity during the leg step and to apply higher maximum forces when driving off the block. This resulted in faster take-off velocities and shorter 5-m times compared to the short step technique. Regardless of the used relay start technique, gender gaps in start performance seem to be based on the early part of the block movement, where females showed slower horizontal velocities and lower forces with a later timing of the leg step and upper-limbs swing actions. This pattern resulted in slower overall performances compared to their male counterparts, despite similar relative peak forces applied during lower limbs extension for take-off. Swimmers should take advantage of the possibilities the new starting platform offers to increase horizontal displacement before driving off the block.

Acknowledgements

The authors would like to thank to swimmers who participated in this swimming study. One of the authors (Xiao Qiu) was supported by the China Scholarship Council with a bursary. The experiments comply with the current laws of the country where they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who organized the study.

References

Blache, Y. and Monteil, K. (2013) Effect of arm swing on effective energy during vertical jumping: Experimental and simulation study. *Scandinavian Journal of Medicine and Science in Sports* **23**. https://doi.org/10.1111/sms.12042

Bland, J.M. and Altman, D.G. (1995) Multiple significance tests: the Bonferroni method. *BMJ* **310**, 170. https://doi.org/10.1136/bmj.310.6973.170

Caia, J., Weiss, L.W., Chiu, L.Z.F., Schilling, B.K., Paquette, M.R. and Relyea, G.E. (2016) Do lower-body dimensions and body composition explain vertical jump ability? *Journal of Strength and Conditioning Research* **30**, 3073-3083. https://doi.org/10.1519/JSC.0000000000001406

Cardinale, M. and Stone, M.H. (2006) Is testosterone influencing explosive performance? *Journal of Strength and Conditioning Research* **20**, 103-107. https://doi.org/10.1519/00124278-200602000-00016

Chiu, L.Z.F., Bryanton, M.A. and Moolyk, A.N. (2014) Proximal-to-distal sequencing in vertical jumping with and without arm swing. *Journal of Strength and Conditioning Research* **28**, 1195-1202. https://doi.org/10.1519/JSC.0000000000000388

Cohen, J. (1988) The effect size. In: Statistical power analysis for the behavioral sciences. New York: Abingdon-on-Thames: Routledge Academic. 77-83.

Feltner, M.E., Bishop, E.J. and Perez, C.M. (2004) Segmental and kinetic contributions in vertical jumps performed with and without an arm swing. *Research Quarterly for Exercise and Sport* **75**, 216-230. https://doi.org/10.1080/02701367.2004.10609155

Fischer, S., Braun, C. and Kibele, A. (2017) Learning relay start strategies in swimming : What feedback is best? *European Journal of Sport Science* **17**, 257-263. https://doi.org/10.1080/17461391.2016.1221471

Fischer, S., Braun, C. and Kibele, A. (2019) Jason Lezak again and again-linear mixed modelling analysis of change-over times in relay swimming races. *Journal of Sports Science* **37**, 1609-1616. https://doi.org/10.1080/02640414.2019.1578448

Laffaye, G., Wagner, P.P. and Tombleson, T.I.L. (2014) Countermovement jump height: Gender and sport-specific differences in the force-time variables. *Journal of Strength and Conditioning Research* **28**, 1096-1105.

https://doi.org/10.1519/JSC.0b013e3182a1db03
Lees, A., Vanrenterghem, J. and De Clercq, D. (2004) Understanding how an arm swing enhances performance in the vertical jump. *Journal of Biomechanics* **37**, 1929-1940. https://doi.org/10.1016/j.jbiomech.2004.02.021
McLean, S.P., Holthe, M.J., Vint, P.F., Beckett, K.D. and Hinrichs, R.N. (2000) Addition of an approach to a swimming relay start. *Journal of Applied Biomechanics* **16**, 342-355. https://doi.org/10.1123/jab.16.4.342
Mujika, I., Villanueva, L., Welvaert, M. and Pyne, D.B. (2019) Swimming fast when it counts: A 7-year analysis of Olympic and World Championships performance. *International Journal of Sports Physiology and Performance* **14**, 1132-1139. https://doi.org/10.1123/ijspp.2018-0782
Peralvo-Simón, M., Veiga, S. and Navia, J. (2021) A temporal analysis of the swimmers' coordination in the relay start. *Sports Biomechanics* **8**, 1-10. https://doi.org/10.1080/14763141.2021.1921249
Qiu, X., Veiga, S., Calvo, A.L., Kibele, A. and Navarro, E. (2021a) A kinematics comparison of different swimming relay start techniques. *Journal of Sports Sciences* **39**, 1105-1113. https://doi.org/10.1080/02640414.2020.1860296
Qiu, X., Veiga, S., Lorenzo, A., Kibele, A. and Navarro, E. (2021b) Differences in the key parameters of the individual versus relay swimming starts. *Sports Biomechanics* **23**, 598-610. https://doi.org/10.1080/14763141.2021.1878262
Ridderikhoff, A., Batelaan, J.H. and Bobbert, M.F. (1999) Jumping for distance: Control of the external force in squat jumps. *Medicine and Science in Sports and Exercise* **31**, 1196-1204. https://doi.org/10.1097/00005768-199908000-00018
Ruddock, A.D. and Winter, E.M. (2016) Jumping depends on impulse not power. *Journal of Sports Sciences* **34**, 584-585. https://doi.org/10.1080/02640414.2015.1064157
Sattler, T., Hadzic, V., Dervisevic, E. and Markovic, G. (2015) Vertical jump performance of professional male and female volleyball players: effects of playing position and competition level. *Journal of Strength and Conditioning Research* **29**, 1486-1493. https://doi.org/10.1519/JSC.0000000000000781
Seifert, L., Barbosa, T. and Kjendlie, P.L. (2010) Biophysical appraoch in swimming: gender effect. In: *Gender Gap: Causes, Experiences and Effects*. Ed: Davies, S.A. 2010 Nova Science Publishers, Inc. 1-22.
Shepherd, I., Lindley, M.R., Logan, O., Mears, A., Pain, M.T.G. and King, M. (2021) The effect of body position and mass centre velocity at toe off on the start performance of elite swimmers and how this differs between gender. *Sports Biomechanics* **22**, 1659-1668. https://doi.org/10.1080/14763141.2021.1919750
Takeda, T. and Nomura, T. (2006) What are the differences between grab and track start. In: *X International Symposium on Biomechanics and Medicine in Swimming*. Eds: Marques, A., Alves, F. and Vilas-Boas, J.P. Porto: Porto: Faculty of Sport, University of Porto. 102-105.
Takeda, T., Takagi, H. and Tsubakimoto, S. (2010) Comparison Among Three Types of Relay Starts in Competitive Swimming. In: *XIth International Symposium for Biomechanics & Medicine in Swimming*. Eds: Kjendlie, P.-L., Stallman, R.K. and Cabri, J. Oslo: Norwegian School of Sport Science. 170-172.
Thng, S., Pearson, S., Rathbone, E. and Keogh, J.W.L. (2020) The prediction of swim start performance based on squat jump force-time characteristics. *PeerJ*. https://doi.org/10.7717/peerj.9208
Verbeke, K. and Molenberghs, G. (2009) *Linear Mixed Models for Longitudinal Data*. Springer series in statistics. New York: Springer US.
Wagner, H., Tilp, M., Von Duvillard, S.P.V. and Mueller, E. (2009) Kinematic analysis of volleyball spike jump. *International Journal of Sports Medicine* **30**, 760-765. https://doi.org/10.1055/s-0029-1224177
Walsh, M.S., Bohm, H., Butterfield, M.M. and Santhosam, J. (2007) Gender bias in the effects of arms and countermovement on jumping performance. *Journal of Strength and Conditioning Research* **21**, 362-366. https://doi.org/10.1519/R-19825.1
Welcher, R.L., Hinrichs, R.N. and George, T.R. (2008) Front-or rear-weighted track start or grab start: Which is the best for female swimmers? *Sports Biomechanics* **7**, 100-113. https://doi.org/10.1080/14763140701683247
World Aquatics. (2023) Fina Swimming Rules 2023-2025. 2022, October 5. Available from URL: https://www.fina.org/swimming/rules .

Key points

- Swimming relay starts using the long-step technique outperform the traditional short-step technique, regardless of starting skill level.
- The greater horizontal displacement of the swimmers on the starting block with the long-step technique allows for longer force application times.
- Female swimmers present longer average times on the block but lower forward velocities than their male counterparts

AUTHOR BIOGRAPHY

Santiago VEIGA
Employment
Departamento de Deportes, Universidad Politécnica de Madrid, Madrid, Spain
Degree
PhD
Research interests
Swimming, biomechanics, competition analysis
E-mail: santiago.veiga@upm.es

Sebastian FISCHER
Employment
Institute of Sports and Sport Science, University of Kassel, Kassel, Germany
Degree
PhD
Research interests
Swimming, Relay swimming, Competition analysis, Biomechanics
E-mail: sebastian.fischer@uni-kassel.de

Xiao QIU
Employment
Hong Kong Sports Institute Limited, Hong Kong, China
Degree
PhD
Research interests
Swimming, biomechanics, motion analysis, competition analysis
E-mail: xiaoq@hksi.org.hk

Jelena STOSIC
Employment
Part-time post-doctoral researcher, Universidad Politécnica de Madrid
Lecturer at Football Academy Belgrade, College for Coaching and Sport Management Swimming instructor and coach
Degree
PhD
Research interests
Biomechanical research in swimming, Neuro-mechanics of movement, Sports
training methodology & technology, Sports performances
E-mail: jstosic@gmail.com

Stefan FUHRMANN
Employment
Olympic Training and Testing Center Hamburg/Schleswig Holstein
Degree
Diploma
Research interests
Swimming, biomechanics, motion analysis, competition analysis
E-mail: sfuhrmann@osphh-sh.dd

Armin KIBELE
Employment
Institute for Sports and Sport Science, University of Kassel, Kassel, Germany
Degree
PhD habil.
Research interests
Biomechanics, Motor Learning, Motor Control, Movement Analysis, Exercise Science
E-mail: akibele@uni-kassel.de

Claudia BRAUN
Employment
Institute of Sports and Sport Science, University of Kassel, Kassel, Germany
Degree
PhD
Research interests
Team work, Motivation, Relay swimming, Competition analysis, Biomechanics
E-mail: cbraun@uni-kassel.de

✉ **Santiago Veiga**
Sports Department, Universidad Politécnica de Madrid, Spain