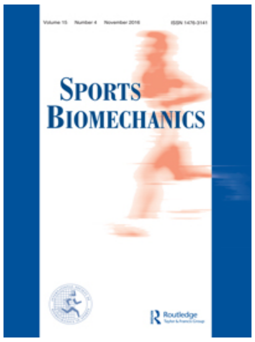

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ORIGINAL RESEARCH

The effect of different foot and hand set-up positions on backstroke start performance

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ABSTRACT

Foot and hand set-up position effects were analysed on backstroke start performance. Ten swimmers randomly completed 27 starts grouped in trials (n = 3) of each variation, changing foot (totally immersed, partially and totally emerged) and hand (lowest, highest horizontal and vertical) positioning. Fifteen cameras recorded kinematics, and four force plates collected hands and feet kinetics. Standardised mean difference and 95% confidence intervals were used. Variations with feet immersed have shown lower vertical centre of mass (CM) set-up position (0.16 m), vertical impulse exerted at the hands, horizontal and vertical impulse exerted at the feet (0.28, 0.41, 0.16 N/BW.s, respectively) than feet emerged with hands horizontal and vertically positioned. Most variations with feet partially emerged exhibited higher and lesser vertical impulse exerted at hands than feet immersed and emerged (e.g. vertical handgrip, 0.13, 0.15 N/BW.s, respectively). Variation with feet emerged and hands on the lowest horizontal handgrip depicted shorter horizontal (0.23, 0.26 m) and vertical CM positioning at flight (0.16, 0.15 m) than the highest horizontal and vertical handgrip, respectively. Start variations have not affected 15-m time. Variations with feet partially or totally emerged depicted advantages, but focusing on the entry and underwater biomechanics is relevant for a shorter start time.

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KEYWORDS
Motion analysis; reaction forces; swimming; back crawl; start variations

Introduction

In competitive swimming, the start phase effectiveness (commonly assessed from the start signal until swimmers' vertex passes the 15-m mark) is essential, particularly in short- and middle-distance events (Elipot et al., 2009; Tor, Pease, & Ball, 2015b; Veiga, Carla, Frutos, & Navarro, 2014), leading biomechanists to invest in new methods and technologies for

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detailed kinematic and kinetic analyses (e.g. Mourão et al., 2015). Greater scientific relevance has been given to the ventral start techniques (de Jesus, de Jesus, Fernandes, Vilas-Boas, & Sanders, 2014a), which has been noticed in the deterministic models developed through standardised key starting performance indicators (e.g. centre of mass coordinates—CM—at set-up position, resultant horizontal impulse, flight distance, entry angle and average underwater velocity; Guimaraes & Hay, 1985).

From the 1960s to early 2005, the Fédération Internationale de Natation (FINA) determined that backstrokers should perform the start with hands on the block grips with feet immersed. Performance with this start variation is strongly influenced by the peak force exerted at the feet before take-off, horizontal impulse exerted at the feet, as well as by CM-resultant glide velocity (de Jesus et al., 2011; Hohmann, Fehr, Kirsten, & Krueger, 2008). Following the FINA authorisation to position feet above water level in mid-2005, many backstrokers currently use the start variation with feet totally emerged (Nguyen, Bradshaw, Pease, & Wilson, 2014). The shortest 5-m time when performing start variation with feet totally emerged depends upon lower CM horizontal set-up position, greater take-off angle, take-off horizontal velocity and CM resultant glide velocity (de Jesus et al., 2011). However, backstroke start variation with feet emerged might pose biomechanical disadvantages if the handgrips configuration assumed is not compatible with an appropriated CM set-up position (de Jesus et al., 2013).

The contemporary start block configuration allows swimmers to perform the backstroke start with three handgrip types (two horizontal and one vertical) combined with different feet positioning (de Jesus, de Jesus, Medeiros, Fernandes, & Vilas-Boas, 2014b), which might imply changes on biomechanical performance indicators (e.g. horizontal and vertical reaction forces profile). Start variations with feet partially emerged and hands on the highest horizontal and vertical handgrips have been often chosen by elite swimmers in the backstroke event (de Jesus et al., 2014b). Swimmers were expected to prioritise a completely out of the water body set-up position minimising water resistance during flight, entry and underwater phases (Nguyen et al., 2014). Contrary to ventral starts, where swimmers take-off 0.7 m above water level, backstrokers have to perform the start close to the water surface, evidencing the importance of choosing a start variation that will generate proper partition between horizontal and vertical impulse, less resistance flight and entry phases, and consequently superior performance (Takeda, Itoi, Takagi, & Tsubakimoto, 2014). Higher back arc angle at take-off and lesser deceleration during entry phase have been considered more relevant than the higher impulse exerted at the feet (de Jesus et al., 2013; Takeda et al., 2014).

Studies lacking analysis on biomechanical advantages/disadvantages when using different foot and hand set-up positions for backstroke start make it hard to choose a start variation for training and competition (Seifert et al., 2010). Despite the set-up position adopted, one could expect that backstrokers would reveal different motor profile organisation to achieve similar 15-m start time (Rodacki & Fowler, 2001; Seifert et al., 2010). This study compared nine backstroke start variations with different feet (totally immersed, partially and totally emerged) and hands position (on the lowest, the highest horizontal, vertical). We hypothesised that start variations performed with feet partially or totally emerged with hands on the highest horizontal and vertical handgrips would demonstrate higher CM set-up position, higher impulse exerted at the hands and feet, take-off angle, longer and higher flight path and entry angle. These biomechanical advantages achieved during initial phases would imply lesser underwater horizontal intracyclic velocity fluctuations and 15-m backstroke start times.

Methods

Participants

Ten competitive male backstroke swimmers (mean ± *SD*: age 20.6 ± 6.0 yrs., stature 1.75 ± 0.05 m, body mass 71.6 ± 12.1 kg, training background 12.7 ± 8.0 yrs. and 60.56 ± 2.29 s 100 m backstroke mean performance in 25-m pool representing 80.91 ± 3.09% of the 100-m backstroke short course World Record) volunteered to participate. The University of Porto Research Ethics Committee approved the study design (ethic review: CEFADE 222,014), and all experimental procedures corresponded to the Declaration of Helsinki requirements. Swimmers and parents and/or guardians (when participants were under 18 yrs.) provided written informed consent to take part in this study.

Backstroke start variations

Nine backstroke start variations were determined based on FINA start (SW 6.1) and facility rules (FR 2.7) (Figure 1), combining three different foot (always parallel to each other) and hand positioning: (i) feet totally immersed with hands on the lowest and the highest horizontal (0.43 and 0.56 m above the water level) and vertical handgrip (Figure 1 (a)–(c)); (ii) feet partially emerged and hands on the positioning described in (i) (Figure 1 (d)–(f)); and (iii) feet totally emerged and hands on the above-described positioning (Figure 1 (g)–(i)).

Training protocol

One-month backstroke start training was conducted for familiarisation with the start positions, as previously done (Blanksby, Nicholson, & Elliott, 2002; Breed & Young, 2003). In each session, swimmers randomly performed three maximal 15-m trials of each variation (3-min passive resting in between trials) on an instrumented starting block, which met OSB11 block specifications (Swiss Timing Ltd., Switzerland) (Tor, Pease, & Ball, 2015a, 2015b). To standardise the starting procedure, an auditory buzzer signal similar to the one adopted in official events was used following FINA rules (SW 4.2). Participants performed with maximal effort to the 15-m mark at each start and returned to the starting block for the next following repetition. Each swimmer was supervised two sessions a week to receive qualitative (i.e. video images, verbal instruction) and quantitative (i.e. 15-m time) combined feedback. Video images were helpful for each swimmer's verbal instruction, offering great potential in facilitating the provision of rich and augmented feedback and ensuring that the starts were performed correctly (e.g. feet positioning height regarding the water surface). Familiarisation and subsequent experimental backstroke start protocol were performed in a 25-m indoor and heated (27 °C) swimming pool.

Testing protocol

Swimmers answered a questionnaire about their training and competitive 100-m backstroke performance background. Each swimmer's height and body mass were measured and recorded. Participants completed a warm-up before each of the two testing sessions (2-h rest in between each session). The warm-up involved swimming 600 m of front crawl and backstroke and one repetition of each start variation. Considering the total number

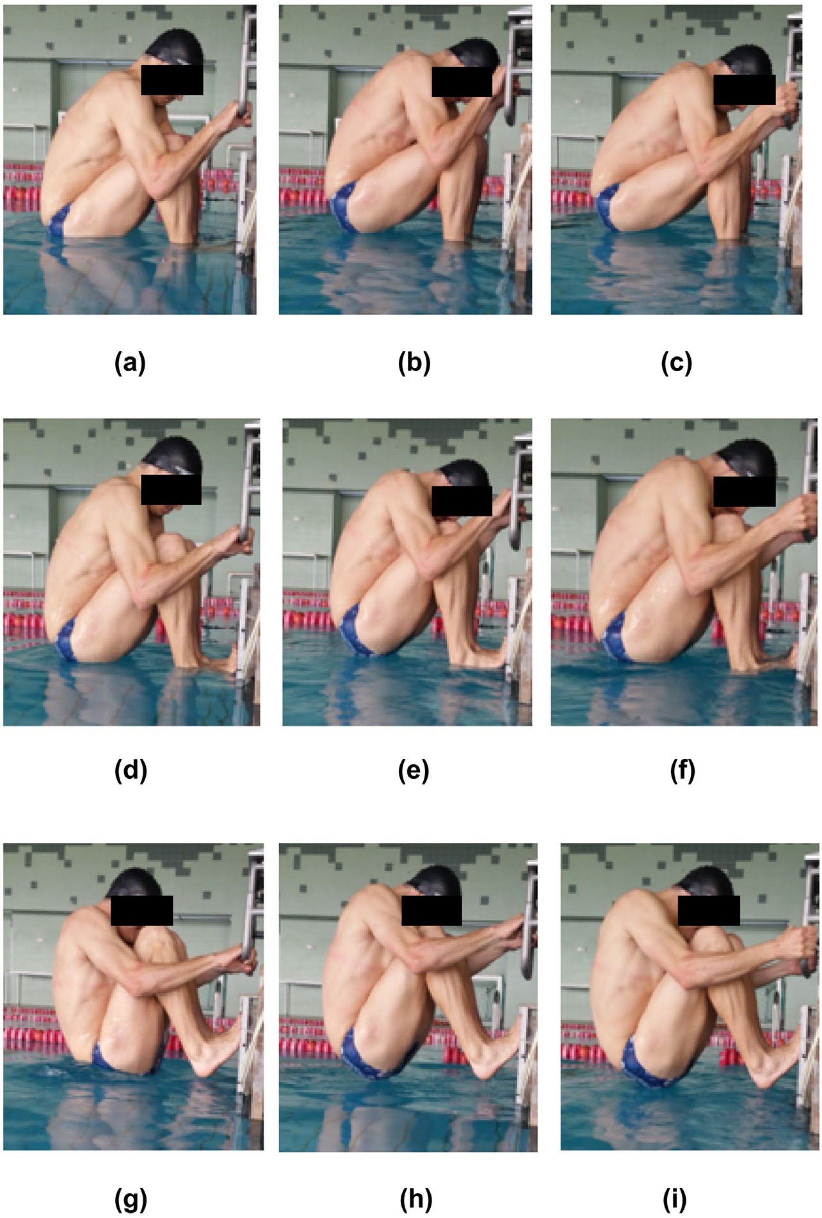

Figure 1. Backstroke start variations: (i) feet totally immersed with hands on the lowest and on the highest horizontal and vertical handgrips (Figure 1 (a)–(c), respectively); (ii) feet partially emerged with hands on the positioning described in (i) (Figure 1 (d)–(f), respectively); and (iii) feet totally emerged and hands on the above-described positioning (Figure 1 (g)–(i), respectively).

of backstroke start variations that should be performed by each swimmer (i.e. 3 trials per start variation), testing was divided into two sessions. Each swimmer randomly performed 13 and 14 maximal starts (1st and 2nd session, respectively) with maximum effort to 15 m. Three-min rest in-between trials were provided, and all trials were performed on the same starting block previously described. The mean value of the three trials for each swimmer in each start variation was calculated and then used in subsequent statistical analysis. Start signal procedures complied with FINA rules (SW 4.2) and were produced through a device (StartTime IV acoustic start, Swiss Timing Ltd., Switzerland). The start signal was provided simultaneously to a light towards digital cameras, to a pulse in the direction of a motion capture system (MoCap; Qualisys AB, Sweden) and to force plates with convenient signal conditioning.

Data collection

A three-dimensional (3D) kinematic set-up consisting eight (four surface and four underwater) stationary digital video cameras (HDR CX160E, Sony Electronics Inc., Japan), operating at a 50-Hz sampling frequency and at a 1/250 s exposure time was used to record starts from the auditory signal to water immersion. Each camera was fixed to a tripod (Hama Star 63, Hama Ltd., UK) at 0.8 m height (surface), 1.4 m deep (underwater), with underwater cameras being inside a waterproof housing (Sony SPK-HCH, Sony Electronics Inc., Japan). The angles between adjacent surface and underwater camera axes varied from 70 to 110° (de Jesus et al., 2015; Figueiredo, Seifert, Vilas-Boas, & Fernandes, 2012). A ninth stationary, synchronised surface camera fixed on a tripod at 3 m height was positioned perpendicularly to the swimmer's start lane. A prism to calibrate starting space (4 m length [horizontal axis, *x*], 2.5 m height [vertical axis, *y*], 2 m width [lateral axis, *z*]) was used and was placed 0.80 m above the water level with the horizontal axis aligned towards starting direction. A pair of light-emitting diodes, visible in each camera view, was fixed to this frame.

Simultaneously, another 3D kinematic MoCap set-up was implemented, consisting six cameras, each one recording at 100 Hz (Oqus, Qualisys AB, Sweden), to track automatically swimmers' right side of the body from full immersion until 15-m mark. Cameras were alternatively placed at 0.10 m below water level, also at swimming pool bottom (2 m depth) with respective lens focusing on the swimmers' trajectory. Each camera was configured to: (i) mask, cover unwanted area and sunlight reflections; (ii) to adjust exposure delay/flash time and marker threshold (values ranged between 0.0002 and 0.0012 s; 5 and 20, respectively); and (iii) filter and remove background light. Calibration was firstly performed with a static L frame (positioned 5 m further from the starting wall) to create a virtual origin in the 3D environment followed by a wand dynamic calibration with two markers fixed with 0.75 m inter-point distance (covering expected performance volume). All camera calibration mean values were achieved with ~0.008 m wand length standard deviations, in agreement with previous studies using smaller calibrated volume (e.g. Silvatti et al., 2013). A short data acquisition was performed to determine the water level and orientation relative to the calibration frame origin.

To enable swimmers' tracking in both digital video and MoCap system, a complete swimsuit was used (Fastskin, Speedo International Limited, UK) with fixed anatomical landmarks. Twenty-four anatomical markers (16 body segments, c.f. Barbosa, Fernandes, Morouco, & Vilas-Boas, 2008) were defined for digital cameras (cf. de Leva, 1996): the vertex of the head (using a swim cap), mid-gonion, the right and left of the acromion, lateral epicondyle of humerus, ulnar styloid process of the wrist, 3rd hand distal phalanx, xyphoid, iliac crest, great trochanter of the femur, lateral epicondyle of the femur, lateral malleolus, calcaneus, and tip of 1st foot distal phalanx. An additional reflective spherical marker (19 mm diameter) was fixed on the swimmer's hip (cf. Nguyen et al., 2014).

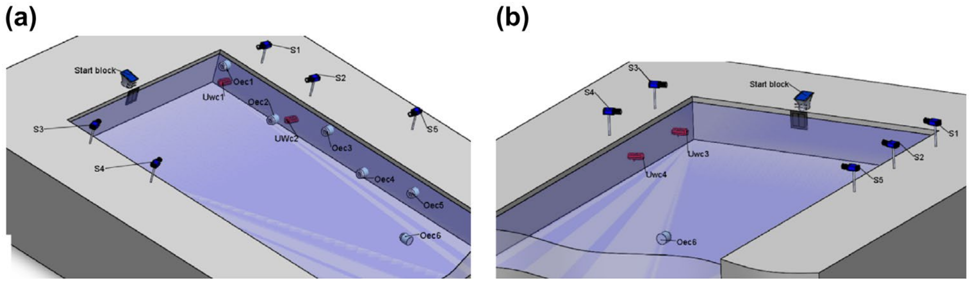

Figure 2. Digital video cameras, MoCap system, start block and respective positioning in the swimming pool. Panel a: S1 to S5, UWc1 and UWc2, digital surface and underwater cameras, respectively. Oec1 to Oec6, opto-electronic cameras. Panel b: S1 to S5, UWc3 and UWc4, digital surface and underwater cameras, respectively. Oec6, opto-electronic camera.

The starting block comprised one surface and one underwater force plate pair on force measurements exerted at the hands and feet (cf. Roesler, Haupenthal, Schutz, & Souza, 2006). Surface force plates (300 Hz resonance frequency) were laterally fixed on each side of the starting block with an independent handgrip fixed on each force plate top. Underwater force plates (200 Hz resonance frequency) were vertically fixed on a starting pool wall support (0.3 m above and below water level). Dynamical calibration followed previous study steps with a rigid body falling (Mourão et al., 2015) revealing homogeneity of static calibrations. The two force plate pairs had a sensitivity of 0.5 N, error < 5%, displaying accurate and reliable measurements (Roesler et al., 2006). All strain outputs were converted to digital data through an analogue to digital converter via strain gauge input modules NI 9237 connected to chassis CompactDAQ USB-9172 and Ethernet-9188 National Instruments Corporation, USA (both from National Instruments, NI Corporation, USA). Figure 2 (Panels a and b) illustrates the instrumented starting block, digital video and MoCap system positioning.

Data processing

Surface and underwater video images were independently and manually digitised frame-by-frame by the same operator using Ariel Performance Analysis System (Ariel Dynamics Inc., USA) (Barbosa et al., 2015; de Jesus et al., 2012; Gourgoulis et al., 2008). Digitising accuracy calculation is described in detail by Barbosa et al. (2015) and has revealed unclear differences in-between digitised-re-digitised trials for each variable of interest (with trivial magnitude of thresholds; cf. Hopkins, 2010). Independent digitisation was 3D reconstructed (direct linear transformation algorithm; Abdel-Aziz & Karara, 1971) with 12 calibration points (four surface, four underwater, and four common to both camera view; de Jesus et al., 2012; Gourgoulis et al., 2008; Puel et al., 2012). Reconstruction accuracy was tested with root-mean-square error using 12 validation points (de Jesus et al., 2012), which did not serve as control points and were as follows (for the *x*, *y* and *z* axis, respectively): (i) 2.96, 2.84, 2.10 mm representing 0.074, 0.11, 0.10% of the calibrated dimension for surface view; (ii) 3.46, 4.80, 3.01 mm, representing 0.08, 0.19, 0.15% of the calibrated dimension for underwater view. A 5 Hz cut-off value was selected for data filtering done according to residual analysis (Barbosa et al., 2015).

Qualisys Track Manager (QTM, Qualisys AB, Sweden) processed hip velocity–time curves, and a referential transformation was applied to the original calibration referential to align it with the water level at the starting block, setting this point as the new referential origin to the system. Each individual velocity–time curve was filtered with a fit to 2nd degree curve and subsequently normalised in time from swimmer's hallux water immersion until the beginning of arm propulsion (Vantorre, Chollet, & Seifert, 2014). Data processing software was created in LabView2013 (SP1, National Instruments, NI Corporation, USA) to acquire, plot, and save the four force plates data in real time (2000 Hz sampling rate). Two processing routines created in MATLAB R2014a (The MathWorks Incorporated, USA) were used to convert strain readings into force values of previous filtered data (moving average 32 samples) and to filter force curves exerted at the hands and feet (4th order zero-phase digital Butterworth filter with a 10-Hz frequency cut-off). Hands and feet right and left force data were summed and normalised to each swimmer's body weight.

Data analysis

Linear and angular kinematic and kinetic parameters have been set up: CM horizontal and vertical positioning at starting signal assessed at 1st frame; horizontal and vertical impulse exerted at the hands, calculated as the normalised integral time of horizontal and vertical force exerted at the hands from the starting signal until the swimmer's hands left the handgrips; horizontal and vertical impulse exerted at the feet, calculated as the normalised integral time of horizontal and vertical force exerted at the feet from the starting signal until the swimmer's feet left the platform; take-off angle, as the angle formed by the right trochanter of the femur, lateral malleolus and horizontal axis at the instant of swimmer's feet left the platform; CM horizontal and vertical positioning at the flight, as the horizontal and vertical coordinate at the 3rd distal phalanx water contact; entry angle, as the angle formed by the right acromion, styloid process of the wrist and horizontal axis at the instant of swimmer's feet water immersion; intracyclic velocity variation during the underwater phase, as the horizontal right hip intracyclic velocity variation (*SD*/mean) from the swimmer's full immersion until the beginning of the arm propulsion; and 15 m start time, as the time between the starting signal and the swimmer's vertex reach the 15-m mark.

Statistical analysis

Data are presented as mean and respective standard deviation. Magnitude-based inference and precision of estimation approach was calculated (Hopkins, 2010) to assess practical differences in kinematic and kinetic parameters (dependent variables) between backstroke start variations (independent variable). Differences were assessed via standardised mean differences computed with a pooled variance and with 95% confidence intervals (Cohen, 1988). Magnitude thresholds setting up the difference in a mean were described using the following scale: 0–0.2 trivial, >0.2 (small), >0.6 (moderate), >1.2 (large), and >2.0 very large (Hopkins, 2010). Effects with 95% confidence intervals overlapping zero and/or the smallest worthwhile change (i.e. 0.2 standardised units) were defined as unclear.

Results

Descriptive analysis

Table 1 depicts the mean and respective standard deviation of the linear and angular kinematic and kinetic parameters calculated for each backstroke start variation.

Tables 2–4 display standardised mean difference and respective 95% confidence intervals of comparisons between variations, which evidenced small to large effect size and narrow confidence intervals. No clear difference was noticed when comparing different handgrip positioning with feet immersed. These start variations have shown lesser vertical impulse exerted at the hands rather than variations with feet partially emerged, except with hands on the highest horizontal handgrip. Notwithstanding the handgrip positioning, start variations with feet immersed depicted lesser vertical impulse exerted at the hands and feet and horizontal impulse exerted at the feet rather than variations with feet emerged. Moreover, variations performed with feet immersed evidenced lower CM vertical set-up position than feet emerged with hands on the highest horizontal and vertical handgrip (Table 2).

Clear differences were only noticed in the horizontal impulse exerted at the hands when comparing start variations performed with feet partially emerged and different handgrips, being higher in the hands on the lowest rather than on the highest horizontal handgrip. Variations with feet partially emerged, regardless of handgrip configuration, evidenced lesser vertical impulse exerted at the hands than variation with feet emerged and hands on the lowest horizontal handgrip. Start variations with feet partially emerged and the highest horizontal handgrip depicted greater and smaller take-off angle than variations with feet emerged and the lowest horizontal and vertical handgrip, respectively. Moreover, variations with feet partially emerged and hands on the lowest horizontal handgrip have shown shorter vertical CM position at flight than variations performed with feet emerged and hands on the lowest horizontal and vertical handgrip (Table 3).

Several biomechanical similarities were noticed in Table 4 in comparison with variations performed with feet emerged with hands on the highest horizontal and vertical handgrip, except in the take-off angle that was greater on the hands on the vertical handgrip. Start variations performed with feet emerged with hands on the highest horizontal and vertical handgrip displayed higher CM horizontal and vertical coordinate at first water contact than hands on the lowest horizontal handgrip (Table 4). All comparisons (Tables 2–4) have shown that the start variation performed has not affected the 15-m time.

Discussion and implications

This study has compared nine backstroke start variations (three foot vs. hand positioning) to verify the biomechanical advantages and disadvantages provided by the combination of current FINA start (SW 6.1) and facility (FR 2.7) rules on the start performance. Findings have shown that: (i) variations performed with feet immersed depicted lesser vertical impulse exerted at the hands and feet and horizontal impulse exerted at the feet than those with feet emerged (regardless of handgrips positioning); (ii) variations with feet partially emerged, regardless of handgrip position displayed lesser vertical impulse exerted at the hands than that with feet emerged and hands on the lowest horizontal handgrip; (iii) variations with feet emerged with hands on the highest horizontal and vertical handgrip presented greater CM coordinates at 1st fingertip water contact than that performed with feet emerged but hands on the lowest horizontal handgrip; and (iv) regardless the start variations used, no effect was noticed on the 15 m start time. Findings have not corroborated the previously established hypothesis, since variations with feet partially and totally emerged and hands on the highest and vertical handgrip had not displayed overall superiority when compared to the other start variations using biomechanical performance indicators.

Table 1. Mean and respective standard deviations of each kinematic and kinetic parameter for each backstroke start variation.

	Variables											
	CMssx (m)	CMssy (m)	Himpx (N/BW.s)	Himpy (N/BW.s)	Fimpx (N/BW.s)	Fimpy (N/BW.s)	TOA (°)	CMflx (m)	CMfly (m)	EA (°)	IVVx	15 m ST (s)
Feet immersed and 1st handgrip	0.51 ± 0.03	0.16 ± 0.08	−0.77 ± 0.18	0.52 ± 0.13	1.02 ± 0.27	0.46 ± 0.08	28.95 ± 8.18	1.70 ± 0.20	0.24 ± 0.07	8.69 ± 4.00	0.26 ± 0.03	7.23 ± 0.45
Feet immersed and 2nd handgrip	0.50 ± 0.03	0.21 ± 0.07	−0.88 ± 0.22	0.52 ± 0.10	0.94 ± 0.25	0.44 ± 0.07	31.60 ± 5.05	1.69 ± 0.13	0.25 ± 0.08	7.06 ± 3.31	0.25 ± 0.02	7.19 ± 0.45
Feet immersed and vertical handgrip	0.49 ± 0.03	0.19 ± 0.08	−0.80 ± 0.11	0.52 ± 0.11	0.95 ± 0.26	0.44 ± 0.07	29.47 ± 8.44	1.64 ± 0.12	0.24 ± 0.07	8.27 ± 4.14	0.26 ± 0.03	7.23 ± 0.49
Feet partially emerged and 1st handgrip	0.51 ± 0.03	0.20 ± 0.09	−0.68 ± 0.14	0.74 ± 0.12	1.27 ± 0.23	0.52 ± 0.10	23.52 ± 6.41	1.69 ± 0.17	0.23 ± 0.09	9.19 ± 4.51	0.26 ± 0.03	7.23 ± 0.45
Feet partially emerged and 2nd handgrip	0.49 ± 0.04	0.26 ± 0.10	−0.92 ± 0.22	0.64 ± 0.12	1.17 ± 0.25	0.52 ± 0.06	25.54 ± 4.63	1.69 ± 0.17	0.28 ± 0.06	8.60 ± 5.21	0.25 ± 0.03	7.14 ± 0.50
Feet partially emerged and vertical handgrip	0.49 ± 0.04	0.23 ± 0.10	−0.82 ± 0.17	0.65 ± 0.12	1.19 ± 0.24	0.51 ± 0.05	26.68 ± 5.42	1.72 ± 0.17	0.25 ± 0.07	8.82 ± 4.59	0.26 ± 0.03	7.12 ± 0.51
Feet emerged and 1st handgrip	0.51 ± 0.04	0.28 ± 0.08	−0.61 ± 0.12	0.90 ± 0.16	1.56 ± 0.19	0.56 ± 0.12	20.10 ± 6.80	1.55 ± 0.16	0.16 ± 0.13	13.97 ± 7.56	0.24 ± 0.03	7.25 ± 0.36
Feet emerged and 2nd handgrip	0.49 ± 0.05	0.35 ± 0.12	−0.79 ± 0.23	0.81 ± 0.13	1.38 ± 0.27	0.61 ± 0.08	25.08 ± 7.37	1.78 ± 0.16	0.32 ± 0.08	12.12 ± 7.20	0.25 ± 0.03	7.17 ± 0.53
Feet emerged and vertical handgrip	0.49 ± 0.04	0.34 ± 0.15	−0.72 ± 0.16	0.80 ± 0.17	1.39 ± 0.29	0.61 ± 0.13	31.46 ± 4.85	1.81 ± 0.21	0.31 ± 0.05	11.77 ± 7.08	0.25 ± 0.04	7.21 ± 0.53

Notes. CMssx and CMssy, centre of mass horizontal and vertical coordinate at 1st frame, respectively; Himpx and Himpy, horizontal and vertical impulse exerted at the hands, respectively; Fimpx and Fimpy, horizontal and vertical impulse exerted at the feet, respectively; TOA, take-off angle; CMflx and CMfly, centre of mass horizontal and vertical coordinate at 3rd distal phalanx water contact, respectively; EA, entry angle; IVVx, horizontal hip intracyclic velocity variations; 15-m ST, 15-m start time.

Table 2. Standardised mean difference and respective 95% confidence interval of comparisons between start variations with feet immersed and hands on the lowest, the highest horizontal and vertical handgrip with the other six variations for kinematic and kinetic parameters with magnitude of effects above than trivial and reduced confidence intervals.

	Variables								
	CMssy (m)	Himpx (N/BW.s)	Himpy (N/BW.s)	Fimpx (N/BW.s)	Fimpy (N/BW.s)	TOA (°)	CMflx (m)	CMfly (m)	EA (°)
Feet immersed and 1st handgrip vs. Feet partially emerged and 1st handgrip	–	–	1.46 (0.64, 2.27)	0.83 (0.03, 1.63)	–	–	–	–	–
Feet immersed and 1st handgrip vs. Feet partially emerged and 2nd handgrip	0.97 (0.00, 1.94)	–	0.83 (0.00, 1.66)	–	–	–	–	–	–
Feet immersed and 1st handgrip vs. Feet partially emerged and vertical handgrip	–	–	0.83 (0.02, 1.65)	–	–	–	–	–	–
Feet immersed and 1st handgrip vs. Feet emerged and 1st handgrip	0.99 (0.01, 1.98)	0.82 (0.08, 1.56)	2.52 (1.55, 3.50)	1.74 (0.98, 2.49)	1.13 (0.01, 2.26)	−0.99 (−1.86, −0.12)	–	–	–
Feet immersed and 1st handgrip vs. Feet emerged and 2nd handgrip	1.97 (0.85, 3.08)	–	1.89 (1.03, 2.76)	1.18 (0.32, 2.05)	1.60 (0.74, 2.47)	–	–	–	–
Feet immersed and 1st handgrip vs. Feet emerged and vertical handgrip	1.92 (0.58, 3.26)	–	1.83 (0.83, 2.83)	1.20 (0.30, 2.10)	1.69 (0.50, 2.87)	–	–	–	–
Feet immersed and 2nd handgrip vs. Feet partially emerged and 1st handgrip	–	0.79 (0.07, 1.52)	1.96 (1.02, 2.91)	1.12 (0.30, 1.94)	1.04 (0.06, 2.14)	−1.24 (−2.25, −0.24)	–	–	–
Feet immersed and 2nd handgrip vs. Feet partially emerged and 2nd handgrip	–	–	1.13 (0.16, 2.09)	–	0.97 (0.15, 1.79)	−1.05 (−1.93, −0.17)	–	–	–
Feet immersed and 2nd handgrip vs. Feet partially emerged and vertical handgrip	–	–	1.13 (0.19, 2.07)	–	0.94 (1.16, 1.73)	−0.89 (−1.79, 0.00)	–	–	–
Feet immersed and 2nd handgrip vs. Feet emerged and 1st handgrip	–	1.08 (0.37, 1.78)	3.38 (2.18, 4.58)	2.08 (1.32, 2.85)	1.57 (0.25, 2.88)	−2.09 (−3.31, −0.86)	−0.96 (−1.92, −0.01)	–	1.81 (0.00, 3.38)
Feet immersed and 2nd handgrip vs. Feet emerged and 2nd handgrip	1.71 (0.48, 2.93)	–	2.54 (1.52, 3.57)	1.50 (0.61, 2.39)	2.13 (1.17, 3.09)	−1.18 (−2.27, −0.09)	–	–	–
Feet immersed and 2nd handgrip vs. Feet emerged and vertical handgrip	1.65 (0.16, 3.15)	–	2.46 (1.22, 3.69)	1.52 (0.59, 2.45)	2.23 (0.85, 3.61)	–	–	0.75 (0.00, 1.50)	–
Feet immersed and vertical handgrip vs. Feet partially emerged and 1st handgrip	–	–	1.66 (0.79, 2.53)	1.08 (0.27, 1.89)	–	–	–	–	–
Feet immersed and vertical handgrip vs. Feet partially emerged and 2nd handgrip	–	–	0.94 (0.05, 1.83)	–	0.91 (0.09, 1.73)	–	–	–	–
Feet immersed and vertical handgrip vs. Feet partially emerged and vertical handgrip	–	–	0.94 (0.07, 1.81)	–	0.88 (0.10, 1.66)	–	–	–	–
Feet immersed and vertical handgrip vs. Feet emerged and 1st handgrip	–	1.53 (0.63, 2.42)	2.89 (1.81, 3.96)	2.02 (1.26, 2.78)	1.50 (0.20, 2.80)	–	–	–	–
Feet immersed and vertical handgrip vs. Feet emerged and 2nd handgrip	1.68 (0.55, 2.82)	–	2.16 (1.23, 3.10)	1.45 (0.57, 2.33)	2.06 (1.10, 3.01)	–	0.99 (0.06, 2.04)	–	–
Feet immersed and vertical handgrip vs. Feet emerged and vertical handgrip	1.64 (0.27, 3.01)	–	2.09 (0.98, 3.19)	1.47 (0.55, 2.39)	2.16 (0.79, 3.53)	–	1.26 (0.01, 2.51)	–	–

Notes. CMssx and CMssy, centre of mass horizontal and vertical coordinate at 1st frame, respectively; Himpx and Himpy, horizontal and vertical impulse exerted at the hands, respectively; Fimpx and Fimpy, horizontal and vertical impulse exerted at the feet, respectively; TOA, take-off angle; CMflx and CMfly, centre of mass horizontal and vertical coordinate at 3rd distal phalanx water contact, respectively; EA, entry angle; IVVx, horizontal hip intracyclic velocity variations; 15-m ST, 15-m start time.

Table 3. Standardised mean difference and respective 95% confidence interval of comparisons between start variations with feet partially emerged and hands on the lowest, the highest horizontal and vertical handgrip with the other variations for kinematic and kinetic parameters with magnitude of effects above than trivial and reduced confidence intervals.

	Variables								
	CMssy (m)	Himpx (N/BW.s)	Himpy (N/BW.s)	Fimpx (N/BW.s)	Fimpy (N/BW.s)	TOA (°)	CMflx (m)	CMfly (m)	EA (°)
Feet partially emerged and 1st handgrip vs. Feet partially emerged and 2nd handgrip		–1.50 (–2.68, –0.31)							
Feet partially emerged and 1st handgrip vs. Feet emerged and 1st handgrip	–	–	1.20 (0.14, 2.26)	1.07 (0.28, 1.87)	–	–	–	–	–
Feet partially emerged and 1st handgrip vs. Feet emerged and 2nd handgrip	1.41 (0.36, 2.45)	–	–	–	–	–	–	0.84 (0.03, 1.64)	–
Feet partially emerged and 1st handgrip vs. Feet emerged and vertical handgrip	1.36 (0.12, 2.61)	–	–	–	–	0.94 (0.17, 1.70)	–	0.81 (0.09, 1.53)	–
Feet partially emerged and 2nd handgrip vs. Feet emerged and 1st handgrip	–	1.20 (0.50, 1.91)	1.83 (0.80, 2.86)	1.34 (0.57, 2.12)	–	–0.99 (–2.17, –0.19)	–	–1.87 (–3.44, –0.30)	–
Feet partially emerged and 2nd handgrip vs. Feet emerged and 2nd handgrip	–	–	1.15 (0.25, 2.06)	–	1.28 (0.26, 2.31)	–	–	–	–
Feet partially emerged and 2nd handgrip vs. Feet emerged and vertical handgrip	–	0.77 (0.02, 1.53)	1.08 (0.03, 2.14)	–	–	0.97 (0.15, 1.80)	–	–	–
Feet partially emerged and vertical handgrip vs. Feet emerged and 1st handgrip	–	1.08 (0.33, 1.83)	1.91 (0.85, 2.97)	1.33 (0.55, 2.11)	–	–	–0.87 (–1.69, –0.04)	–	–
Feet partially emerged and vertical handgrip vs. Feet emerged and 2nd handgrip	0.99 (0.03, 1.95)	–	1.20 (0.27, 2.13)	–	1.48 (0.36, 2.60)	–	–	–	–
Feet partially emerged and vertical handgrip vs. Feet emerged and vertical handgrip	–	–	1.13 (0.03, 2.22)	–	–	–	–	0.88 (0.10, 1.67)	–

Notes. CMssx and CMssy, centre of mass horizontal and vertical coordinate at 1st frame, respectively; Himpx and Himpy, horizontal and vertical impulse exerted at the hands, respectively; Fimpx and Fimpy, horizontal and vertical impulse exerted at the feet, respectively; TOA, take-off angle; CMflx and CMfly, centre of mass horizontal and vertical coordinate at 3rd distal phalanx water contact, respectively; EA, entry angle; IVVx, horizontal hip intracyclic velocity variations; 15-m ST, 15-m start time.

Table 4. Standardised mean difference and respective 95% confidence interval of comparisons between start variations with feet totally emerged and hands on the lowest, the highest horizontal and vertical handgrip for kinematic and kinetic parameters with magnitude of effects above than trivial and reduced confidence intervals.

	Variables								
	CMssy (m)	Himpx (N/BW.s)	Himpy (N/BW.s)	Fimpx (N/BW.s)	Fimpy (N/BW.s)	TOA (°)	CMflx (m)	CMfly (m)	EA (°)
Feet emerged and 1st handgrip vs. Feet emerged and 2nd handgrip	–	–1.37 (–2.71, –0.03)	–	–	–	–	1.25 (0.37, 2.13)	1.05 (0.32, 1.77)	–
Feet emerged and 1st handgrip vs. Feet emerged and vertical handgrip	–	–	–	–	–	1.45 (0.60, 2.30)	1.46 (0.45, 2.47)	1.03 (0.34, 1.72)	–
Feet emerged and 2nd handgrip vs. Feet emerged and vertical handgrip	–	–	–	–	–	0.79 (0.05, 1.53)	–	–	–

Notes. CMssx and CMssy, centre of mass horizontal and vertical coordinate at 1st frame, respectively; Himpx and Himpy, horizontal and vertical impulse exerted at the hands, respectively; Fimpx and Fimpy, horizontal and vertical impulse exerted at the feet, respectively; TOA, take-off angle; CMflx and CMfly, centre of mass horizontal and vertical coordinate at 3rd distal phalanx water contact, respectively; EA, entry angle; IVVx, horizontal hip intracyclic velocity variations; 15-m ST, 15-m start time.

When swimmers perform backstroke start variations with feet immersed (independently of the handgrips positioning), buoyance force increases (Aspenes & Karlsen, 2012) reducing weight effects with limbs contact but increasing drag forces during take-off in comparison with those performed with feet emerged, which reduce vertical impulse exerted at the hands and feet and horizontal impulse exerted at feet. Moreover, CM was positioned lower than when swimmers using their feet emerged with hands on the highest horizontal and vertical handgrips, which is considered a biomechanical disadvantage, hampering low resistance flight and entry phases (Nguyen et al., 2014). Previous researchers have observed that variation with feet emerged set the hip higher regarding water level (~0.18 m) than feet immersed (~0.07 m); however, the handgrips positioning adopted have not been mentioned. As the new wedge for feet support (FR 2.10) allows swimmer's feet indentation and a better wall contact, backstrokers will probably choose a higher set-up position to generate higher vertical reaction force. To position CM higher out of the water and to generate higher vertical impulse during hands-off phase is crucial, as it has been already observed that the angle formed by the CM, centre of pressure and horizontal axis progressively reduces until take-off (Mourão et al., 2015). This angle value reduction after the hands-off instant restricts the conditions to generate vertical displacement (Mourão et al., 2015).

Notwithstanding the handgrips used, positioning feet partially emerged has implied a higher and a lesser vertical impulse exerted at the hands than feet immersed (except with hands on the highest horizontal handgrip) and emerged (except with hands on the lowest horizontal handgrip), which can also be explained by the buoyance force influencing the force profile exerted at the hands. Most of the vertical impulse exerted at the hands has been accounted for sustaining swimmers out of the water and for changing the trunk moment of inertia (de Jesus et al., 2011, 2013). The upper limb actions also set-up swimmers' impulse exerted at the feet (Breed & Young, 2003; Guimaraes & Hay, 1985; Mourão et al., 2015), and strong positive correlations have been found between impulse exerted at the hands and feet (Guimaraes & Hay, 1985). Start variation with feet partially emerged and with hands on the highest and on the lowest horizontal handgrip has also affected both the take-off angle and CM vertical position at flight when swimmers start with feet emerged and hands on the vertical handgrip. Previous studies have already pointed out that swimmers have adopted feet entirely emerged (Nguyen et al., 2014) and hands on the vertical handgrip (de Jesus et al., 2014b), probably to avoid body contact with the water and, consequently prevent drag forces during propulsion out of the wall (Nguyen et al., 2014).

Start variations with feet emerged can provide swimmers with more biomechanical advantages during hands-off and take-off phases mainly when compared to feet immersed (e.g. higher horizontal impulse exerted at the feet), but using hands positioned at the lowest horizontal handgrip seems to be detrimental for the flight path. Therefore, swimmers adopting the above-referred variation have depicted shorter CM horizontal position at the fingertip water contact than the variation with feet immersed with hands on the highest horizontal handgrip and feet partially and totally emerged with hands on the highest horizontal and vertical handgrip. Despite backstrokers' constraints in performing similar ventral starts take-off angle (Breed & Young, 2003; Mourão et al., 2015) due to the proximity to the water level (Takeda et al., 2014), swimmers should prioritise a start variation that allows minimal drag deleterious effects during flight (Blanksby et al., 2002; Takeda, Ichikawa, Takagi, & Tsubakimoto, 2009). The current findings suggest that swimmers can achieve similar times when adopting the variation with feet emerged, as already mentioned (Nguyen et al., 2014), but they should preferentially position their hands on the highest horizontal or vertical handgrip. The new wedge might help swimmers to increase a set-up position height requiring less upper limb muscles activation, but further research is needed on this topic.

In summary, any biomechanical advantage obtained when swimmer's feet have been positioned partially or totally emerged when comparing with feet immersed during wall contact phases was not transferred along entry and underwater phase with 15 m start times being similar. Previous studies have been reinforcing the idea that swimmers can perform backstroke start during entry and underwater phase guided by a common motor strategy to achieve similar performance, irrespective of the variation adopted (Rodacki & Fowler, 2001; Seifert et al., 2010). Moreover, it had already been observed that the differences noticed among start variations tended to disappear once immersion is completed (Vantorre et al., 2014). Based on these findings, the use of the start variations with feet partially or totally emerged and hands on the highest horizontal or vertical handgrip might be recommended, although still focusing on entry and underwater biomechanics improvement, as previously mentioned (de Jesus et al., 2013; Takeda et al., 2014; Veiga et al., 2014).

Some limitations should be addressed. In the current study, ten swimmers were evaluated, which can be considered a reasonable sample size when swimmers' availability is required for familiarisation and testing using complex data collection methodology (e.g. Puel et al., 2012). It has been recognised that enhancing statistical power depends on a large number of observations, which would reduce CI, and consequently improves the precision of estimation on inferences about population effects. Thus, future studies should verify how reproducible these findings could be in a larger sample. The start variation familiarisation period has followed previous studies (e.g. Blanksby et al., 2002). However, future studies should consider taking a longer familiarisation period, as already mentioned (cf. Blanksby et al., 2002). Lastly, as the new wedge for feet support has not been available for all the swimmers during training sessions, we have not included it in this study. Further studies should consider the analysis of the effects of the wedge when used in different height and handgrip positioning.

Conclusion

The current study has compared nine backstroke start variations (combining three foot and three hand positioning), being noticed that feet partially and totally emerged have depicted clear biomechanical advantages rather than feet immersed during wall contact phase, independently of handgrip positioning. Notwithstanding these findings, no clear difference was noticed among start variations considering entry and underwater phases, as well as at 15 m start time. Therefore, coaches should focus on maintaining these advantages all over entry and underwater phases, which would consequently reflect in a shorter 15 m start time.

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