

Research article

Neuromuscular Activity of Upper and Lower Limbs during two Backstroke Swimming Start Variants

Karla De Jesus¹ ✉, Kelly De Jesus¹, Alexandre I. A. Medeiros^{1,2}, Pedro Gonçalves¹, Pedro Figueiredo^{1,3}, Ricardo J. Fernandes^{1,4} and João Paulo Vilas-Boas^{1,4}

¹Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, Portugal, ²Department of Physical Education, University of Fortaleza, Brazil, ³School of Physical Education, Federal University of Rio Grande do Sul, Brazil, ⁴Porto Biomechanics Laboratory, University of Porto, Portugal

Abstract

A proficient start is decisive in sprint competitive swimming events and requires swimmers' to exert maximal forces in a short period to complete the task successfully. The aim of this study was to compare the electromyographic (EMG) activity in-between the backstroke start with feet positioned parallel and partially emerged performed with the hands on the highest horizontal and on the vertical handgrip at hands-off, take-off, flight and entry start phases. EMG comparisons between starting variants were supported by upper and lower limb joint angles at starting position and 15 m start time data. Following a four-week start training to familiarize participants with each start variant, 10 male competitive backstroke swimmers performed randomly six 15 m maximal trials, being three of each start variant. Surface EMG of Biceps Brachii, Triceps Brachii, Rectus Femoris, Biceps Femoris, Gastrocnemius Medialis and Tibialis Anterior were recorded and processed using the time integral EMG (iEMG). Eight video cameras (four surface and four underwater) were used to determine backstroke start phases and joint angles at starting position. EMG, joint angles and temporal parameters have not evidenced changes due to the different handgrips. Nevertheless, clear differences were observed in both variants for upper and lower limb muscles activity among starting phases (e.g. Biceps Brachii at take-off vs. flight phase, $15.17\% \pm 2.76\%$ and $22.38\% \pm 4.25\%$; $14.24\% \pm 7.11\%$ and $25.90\% \pm 8.65\%$, for variant with hands horizontal and vertically positioned, respectively). It was concluded that different handgrips did not affect EMG, kinematics and temporal profile in backstroke start. Despite coaches might plan similar strength training for both start variants, further attention should be given on the selection of proper exercises to maximize the contribution of relevant muscles at different starting phases.

Key words: Biomechanics, surface electromyography, starting technique, backstroke events.

Introduction

A successful start is essential in swimming competition, being composed of several phases (block, flight, entry and underwater), which are interdependent (Vantorre et al., 2014). Backstroke is the only competitive swimming technique in which the swimmers start in the water. The start technique performed in backstroke events regulated by the Fédération Internationale de Natation Amateur (FINA) authorizes swimmers to position their feet above the water level (SW 6.1, FINA). This rule determination has led researchers to investigate the kinematics and/or

kinetics effects on different start variants performance (i.e. feet entirely immersed or emerged) (de Jesus et al., 2013; Nguyen et al., 2014; Takeda et al., 2014). According to Nguyen et al. (2014), swimmers often adopt the feet positioned above the water surface.

In 2008, FINA approved the Omega OSB11 starting block (Swiss Timing Ltd., Switzerland) with two horizontal and one vertical backstroke start handgrip. With this in mind, de Jesus, et al. (2014) has shown that the backstroke start variants with feet parallel and partially emerged but with hands positioned on the highest horizontal or vertical handgrips were often used by ~40% of swimmers regardless of the backstroke event (i.e. 50, 100 and 200 m) at London 2012 Olympic Games and Barcelona 2013 Swimming World Championships. As other high-velocity movements (e.g. squat jump, Van Soest et al., 1994), the backstroke start performance is related to the exertion of maximal force in the shortest time (de Jesus et al., 2011; Nguyen et al., 2014), which can be influenced by the set positioning used on the starting block/wall. In fact, handgrip start positioning might imply different upper and lower limb joint angles, influencing the muscular activity level from the starting signal throughout the flight and underwater phases. Therefore, it became indispensable for training support the study of current backstroke start variants from a neuromuscular standpoint, as also done in swimming turns (Pereira et al., 2015).

The handgrip effects on upper limbs electromyography (EMG) have been extensively studied in lat pull-down exercises, however contradiction remains about the upper limb muscles intervention across grip biacromial diameter and forearm orientation (e.g. Andersen et al., 2014). A wider grip, such as the vertical backstroke start handgrip might reduce the flexion and extension of the elbow and increase shoulder abduction compared with a narrow grip, such as the highest horizontal backstroke start handgrip, altering working conditions (Andersen et al., 2014). These changes at initial backstroke start instants might affect the upper body joints movement during the take-off and flight (i.e. shoulder adducted or abducted) (de Jesus et al., 2011), changing intrinsic muscle properties (e.g. force-length) and EMG amplitude (McGowan et al., 2013). Different handgrips might also alter lower limb joint angles at start positioning, a critical factor influencing jump EMG output (Bobbert et al., 2013; Mackala et al., 2013a; 2013b; Zajac, 2002), and

consequently affect the lower limb muscular activity level throughout the start phases. Despite the above-mentioned findings, Rodacki and Fowler (2001), Camomilla et al. (2009) and Van Soest et al. (1994) reported an overall consistency between EMG activity in extremely fast movements performed with different set positioning. According to Van Soest et al (1994), the variability of important movement patterns decreases as the instant of time on which achievement depends (e.g. take-off in jumping) is approached.

Scarce EMG literature in backstroke start has analyzed the upper and lower limb muscles activation sequence (Hohmann et al., 2008) and amplitude (de Jesus et al., 2011) during the wall, flight and underwater phases of outdated start variants. Hohmann et al. (2008) have shown that the backstroke start movement initiated with upper limb muscles, and the lower limb muscles contributed maximally during the take-off and underwater phase. de Jesus et al. (2011) have evidenced that greater Rectus Femoris activity during underwater phase has increased starting time, probably due to increased drag. Several authors have quantified and compared the EMG in-between movement phases in other sports (e.g. Escamilla and Andrews, 2009), which seems relevant due to the remaining confusion of some upper (Youm et al., 2009) and lower limb biarticular muscles (Cleather et al., 2015) contribution. In the light of these considerations, this study has a twofold aim: (i) to compare the EMG of upper and lower limb muscles between variants with hands positioned horizontally or vertically on the starting handgrips, supported by angular kinematic and temporal data and (ii) to compare the EMG of each muscle between start phases for each variant. We hypothesized that EMG response of upper limb muscles from the starting signal until the hands-off would be sensitive to different handgrips. Furthermore, once kinematical differences between start variants are expectedly detailed (with the exception for the first one) it is expected that the biarticular upper and lower limb muscles contribute similarly from the starting signal to the water immersion in both.

Methods

Participants

Ten swimmers (mean and standard deviations (\pm s): age 20.6 ± 6.0 yrs., stature 1.75 ± 0.05 m, body mass 71.63 ± 12.14 kg, body fat percentage $10.8 \pm 1.6\%$, training background 12.8 ± 8.43 yrs. and a personal best of 80.91 ± 3.09 % of the 100 m backstroke short course World Record) volunteered to participate in the study. Participants were healthy (no serious injury or illness in the last 6 months), able-bodied and were at the time of this study participating in national competitions with backstroke as their main specialty. Six swimmers preferred to use the variant with feet parallel and partially emerged and the highest horizontal handgrip, two preferred the feet parallel and partially emerged and the vertical handgrip, and two swimmers often used the variant with staggering feet positioned and hands on the lowest horizontal handgrip. After being informed of the benefits and potential risks of

the investigation, each participant (or parent/guardian when subjects were under 18 yrs.) provided written informed consent by signing a document approved by the local Ethics Committee. The procedures were conformed to the recommendations of the Declaration of Helsinki.

Procedures

Starting trials

Two backstroke start variants with feet parallel and partially emerged were studied (cf. de Jesus, et al., 2014): (i) hands on the highest horizontal (Figure 1a) and (ii) vertical handgrip (Figure 1b). Previous to data collection, a 1-month starting training intervention (3 sessions per week) was conducted to minimize performance bias and to provide similar standards in each of the two variants studied. In each session, swimmers performed 10 x 15 m maximal trials of each starting variant and were supervised two sessions a week to receive qualitative (i.e. video images) and quantitative (i.e. 15 m time) performance feedback.

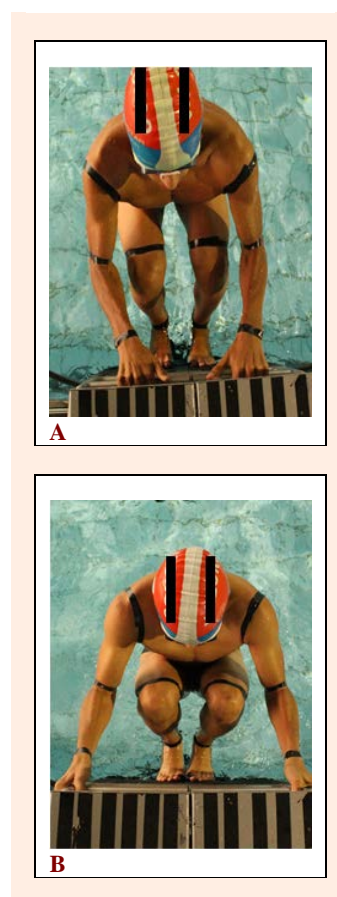


Figure 1. The backstroke start variants with feet partially emerged. **A)** The hands grasping the highest horizontal handgrip. **B)** The hands grasping the vertical handgrip.

In a 25 m indoor swimming pool, participants performed randomly six maximal 15 m trials, being three of each variant (2 min rest in-between trials), from which a mean value for each swimmer in each variant was calculated for statistical analysis. A starter device (Omega StartTime IV, Swiss Timing Ltd., Switzerland) produced the starting signals conform to swimming rules (SW 4.2, FINA) and simultaneously exported a light and trigger to

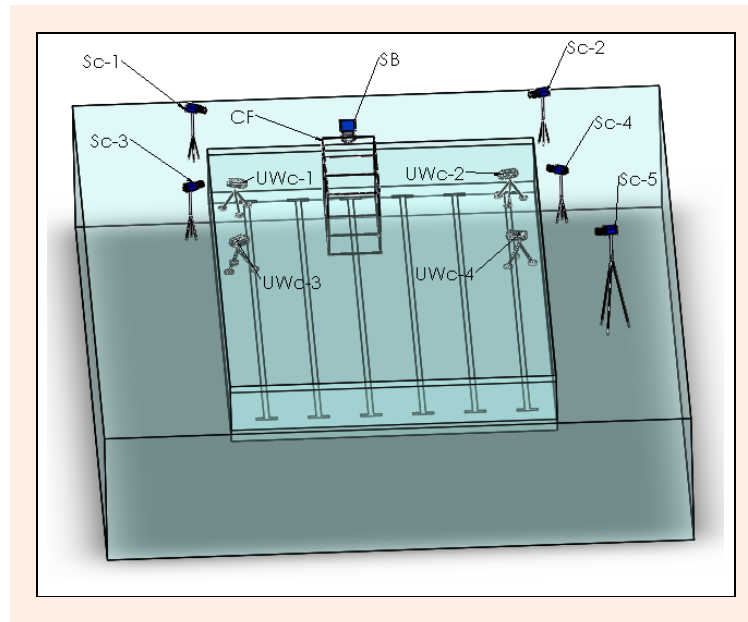


Figure 2. Experimental 3D kinematic set up. SB, starting block. CF, calibration frame. Sc, surface camera - 0.8 m height: 1, 2, 3 and 4 (5.5 and 7 m away from swimmers' plane of movement, aligned or 5 m away from SB). Sc-5, 3 m height, 8 m away from swimmers' plane of movement and 15 m away from SB. UWC, underwater camera - 1.4 m deep: 1, 2, 3 and 4 (4.5 and 6.5 m away from the swimmers' plane of movement, 0.5, 1.0 and 5 m away from SB).

the cameras and the analogue-to-digital (A/D) converter (MP150, BIOPAC Systems Inc., USA), respectively.

Video recording, starting phases and kinematical parameters

The swimmers' movements from the starting signal to the full water immersion were recorded by eight stationary and synchronized digital cameras (HDR CX160E, Sony Electronics Inc., Japan), four surface and four underwater, operating at a sampling frequency of 50 Hz with exposure time of 1/250 s. The angles between the axes of adjacent surface and underwater cameras varied from 75° to 110° (cf. de Jesus et al., 2012). To calibrate the starting space, a rectangular frame (4 m length [horizontal axis], 2.5 m height [vertical axis] and 2 m width [lateral axis]) was used. This frame was 0.80 m above the water surface and 0.50 m far from the starting pool wall with the horizontal axis aligned with the starting direction. A ninth stationary and synchronized surface camera was positioned perpendicularly to the swimming start lane to register 15 m start time. A pair of LEDs was fixed to the calibration volume visible in each camera view. Figure 2 illustrates the nine digital cameras and calibration volume positioning regarding to the starting block.

To enable swimmers' tracking the following 24 anatomical markers (being 22 fixed on the complete swim suit, Fastskin ©Speedo International Limited, UK) were defined: the vertex of the head (using a swim cap), mid-gonion, the right and left of the acromion, lateral epicondyle of humerus, styloid process of the wrist, 3rd hand distal phalanx, xiphoid, iliac crest, great trochanter of the femur, lateral epicondyle of the femur, lateral malleolus, calcaneus and tip of 1st foot distal phalanx. The anthropometric model assumed (de Leva, 1996) was similar to previous studies (Barbosa et al., 2008). Using the Ariel Performance Analysis System (Ariel Dynamics, Inc.,

USA) the video images were digitized manually and frame-by-frame. The independent digitization from the eight cameras was reconstructed with the help of calibration volume. Twelve calibration points were used and the image coordinates were transformed into three-dimensional object-space coordinates using the linear transformation algorithm (Abdel-Aziz and Karara, 1971), as done before (Barbosa et al., 2008). A 5 Hz cut-off value for data filtering (with a low pass digital filter) was selected according to residual analysis (residual error vs. cut-off frequency).

The variants were divided into four phases (de Jesus et al., 2013): (i) hands-off - the time between the starting signal and the instant the swimmers' hands left the handgrips; (ii) take-off - from the hands-off until the swimmers' feet left the wall; (iii) flight - from the take-off until the swimmers' fingertip water contacts; and (iv) entry - from the final instant of the flight until the swimmers' toe immersion. The critical instants used to define the starting phases (i.e., hands-off, take-off, 1st water contact and full water immersion) roughly corresponded to the respective 3D resultant right joint angles: maximal elbow extension, 1st maximal knee extension, maximal shoulder flexion and 2nd maximal knee extension. The 15 m starting time was defined between the auditory signal and the swimmers' vertex reached the 15 m mark. The resultant joint angles of the right shoulder (upper arm and upper trunk), elbow (upper and forearm), hip (lower trunk and thigh), knee (thigh and shank) and ankle (shank and feet) were determined at the 1st starting position frame.

The accuracy of the digitising procedure for the joint angles assessed was determined based on data from two repeated digitisations of a randomly selected trial (de Jesus et al., 2012), and subsequently tested with the statistical analysis described below.

EMG recordings and parameters

Biceps Brachii, Triceps Brachii, Rectus Femoris, Biceps Femoris, Gastrocnemius Medialis and Tibialis Anterior were right body side selected based on their main function in backstroke start and anatomic localization (de Jesus et al., 2011; Hohmann et al., 2008). Swimmer's skin was shaved and cleaned with alcohol-soaked cotton to reduce skin impedance. Active silver/silver chloride surface electrodes (Dormo, Telic, S.A., Spain) with preamplifiers (AD621BNZ, Analog Devices Inc., USA) recorded bipolar EMG (2 cm apart) with an eight-channel device (de Jesus et al., 2011). EMG system presents $Z_{in} \geq 10 \Omega/2 \times 10^{-12} F$, common rejection mode of 110 dB and a total gain of 1100 (Basmajian and De Luca, 1985). Modern pre-amplifier design reduces the importance of measuring EMG with low level of electrode skin-impedance (Day, 2002). Electrodes were placed in the mid-point of the contracted muscle belly, in line with the fiber orientation (Hermes et al., 2000) and a reference electrode was attached to the patella.

Preceding the electrodes insulation and cables immobilization (for more information see de Jesus et al., 2011; Figueiredo et al., 2013; Stirn et al., 2011), each swimmer performed three dry land maximal voluntary isometric contractions (MVIC) for each muscle studied. Each MIVC was held for 5 s (followed by 5 min rest) and verbal encouragement was given to the subjects. The maximum value of the three measurements was defined for normalization. Raw EMG signals were sampled at 1000 Hz per channel with a 16-bit A/D conversion and recording system (BIOPAC System, Inc., USA) and stored on a computer for later analysis. EMG data analysis was performed with MATLAB R2014a (MathWorks Inc., USA) (Conceição et al., 2014; de Jesus et al., 2011; Figueiredo et al., 2013).

Baseline and MVIC values were recorded sequentially and in the same file. After the trigger, baseline was assessed between 1500 to 2500 ms, followed by the MVIC test. Each raw EMG signal was filtered with a 4th order band-pass Butterworth filter with cut-off frequencies of 35 and 500 Hz, full-wave rectified and smoothed with a 4th order low pass Butterworth filter of 10 Hz to get the linear envelope. All filtering actions were implemented to assure that zero-phase distortion exists, by processing the input data in both the forward and reverse directions. The mean values plus two standard deviations (Hodges and Bui, 1996) were calculated from the baseline, and the MVIC maximum values were extracted from above referred files. Dynamic EMG signals were considered active or inactive when located above or below the baseline values, respectively, and then normalized to each respective MVIC value. Integration of the resulting linear envelope signal (iEMG) of active signals, in each phase, was calculated for active EMG normalized time, instead of each respective normalized total phase time. The time normalization results, in any case, in a time vector from 0 to 100%. The relative activation time was a percentage of each start phase time.

Statistical analysis

The reconstruction accuracy was tested with the root

mean square error of 12 validation points, which did not serve as control points, being noticed resultant errors < 6.5 mm for both the surface and underwater cameras. EMG, temporal and kinematical data are presented as mean and respective standard deviation. It was used the magnitude-based inferences and precision of estimation approaches (Hopkins, 2010), for the digitization error, kinematical and EMG parameters. Magnitude based inference assessed the practical difference in joint angle values between digitization and re-digitization procedures, in phase time, iEMG and relative activation time in-between starting variants and upper and lower limb joint angles at 1st backstroke starting position and starting time between start variants. Differences were assessed via standardized mean differences (SMD), computed with pooled variance, and respective 95% confidence intervals (95% CI) (Cohen, 1988). Magnitude thresholds for difference in a mean were described using the following scale: 0-0.2 trivial, > 0.2-0.6 small, > 0.6-1.2 moderate, > 1.2-2.0 large, and > 2.0 very large (Hopkins, 2010). Effects with 95% CI overlapping zero and/or the smallest worthwhile change (i.e., 0.2 standardized units) were unclear. Statistical computations were performed using the software ESCI (Exploratory Software for Confidence Intervals) (Cumming, 2013).

The iEMG and relative activation time repeatability among starting trials was tested for each upper and lower limb muscle in each start phase and in both start variants by calculating the intraclass correlation coefficient (ICC). It was considered a good reproducibility if $ICC \geq 0.75$, moderate if $0.4 \leq ICC < 0.75$ and poor if $ICC < 0.4$ (Asseldonk et al., 2014)

Results

Unclear differences were noticed for shoulder, elbow, hip, knee and ankle joint angles between digitizing and re-digitizing procedures with trivial magnitude of effect. ICC correlation coefficients calculated among trials for iEMG and relative activation time in each start phase ranged from moderate to good reproducibility values for both variants: (i) hands positioned on the highest horizontal handgrip ($ICC = 0.46$ to 0.93) and (ii) hands positioned on the vertical handgrip ($ICC = 0.49$ to 0.82).

Table 1 depicts mean and respective standard deviation of each phase and 15 m start time in both variants.

Table 1. Means (\pm standard deviations) of each phase and 15 m time for both backstroke start variants.

Phase	Upper limbs horizontally positioned	Upper limbs vertically positioned
Hands-off (s)	.55 (.06)	.55 (.05)
Take-off (s)	.21 (.02)	.21 (.03)
Flight (s)	.17 (.08)	.17 (.06)
Entry (s)	.39 (.12)	.39 (.11)
15 m (s)	7.14 (.54)	7.12 (.51)

Figure 3 displays standardized mean difference and respective 95% CI of comparisons between variants for the phase and 15 m start time. All differences were rated as unclear.

Table 2 exhibits mean and respective standard

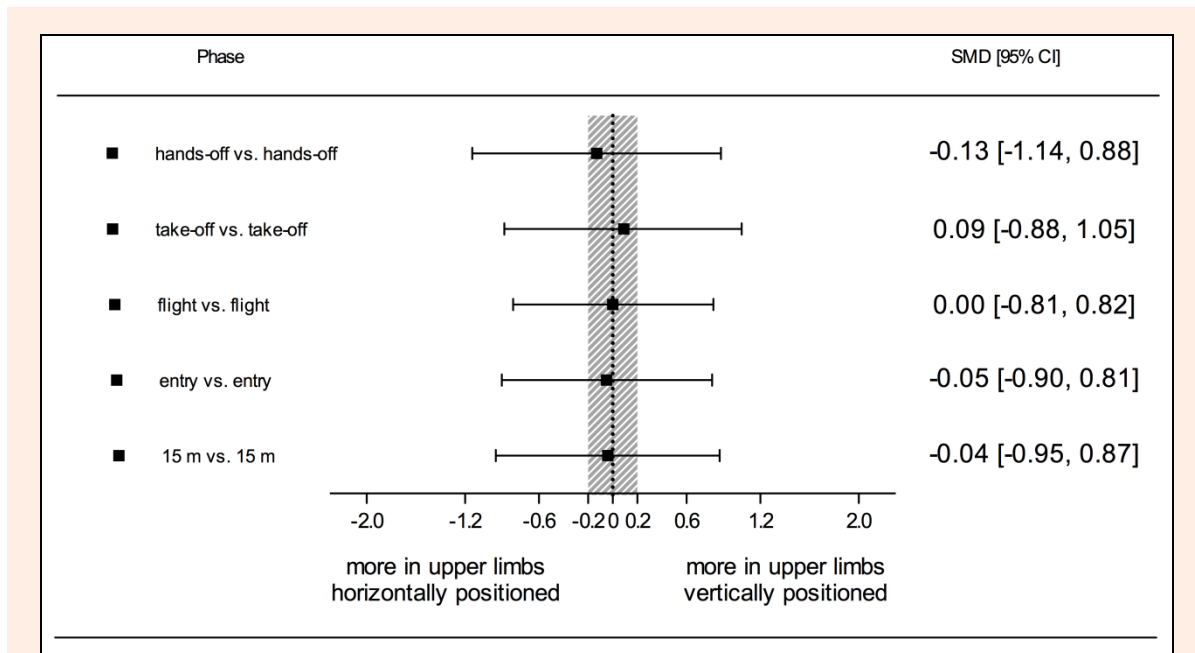


Figure 3. Standardized mean difference and 95% CI for start phase and 15 m time from comparisons between start variants. The shaded area represents the smallest (trivial differences) worthwhile change.

deviation of shoulder, elbow, hip, knee and ankle angles at the backstroke start position instant for both variants. All differences between start variants were rated as unclear (i.e. effects with 95% CI overlapping zero and/or the smallest worthwhile change).

Table 2. Means (\pm standard deviations) of shoulder, elbow, hip, knee and ankle joint angles for both backstroke start variants.

Phase	Upper limbs horizontally positioned	Upper limbs vertically positioned
Shoulder (°)	77.86 (14.86)	73.70 (16.10)
Elbow (°)	89.08 (26.93)	90.07 (20.82)
Hip (°)	57.77 (7.06)	58.64 (15.45)
Knee (°)	52.44 (5.34)	53.35 (7.99)
Ankle (°)	38.01 (8.97)	44.29 (10.76)

Table 3 depicts iEMG mean and respective standard deviation for each muscle, starting phase and variant.

Figure 4 shows standardized mean difference and respective 95% CI for each muscle when comparing the iEMG of each starting phase between start variants. All differences were rated as unclear.

Table 4 shows standardized mean difference and respective 95% CI for each muscle iEMG when comparing the starting phases for both variants. For upper limbs, the clear differences of the Biceps Brachii comparing flight and entry with the take-off phase presented large to very large magnitude of effect. Triceps Brachii depicted substantial differences between hands-off, take-off and entry and the flight phase (moderate to large magnitude of effect). For lower limbs, Tibialis Anterior displayed clear differences (moderate to large practical effects) between hands-off and take-off with flight phase. Gastrocnemius Medialis has revealed meaningful differences comparing take-off with hands-off, flight and entry phases (moderate to large magnitude of effect). Rectus Femoris and Biceps

Femoris have demonstrated clear differences with large meaningful inferences comparing entry and hands-off phase.

Table 5 presents mean and respective standard deviation of relative activation time for each muscle in each starting phase and for both variants.

Standardized mean difference and respective 95% CI for each muscle when compared relative activation time between variants are presented in Figure 5. All differences were rated as unclear.

Table 6 shows standardized mean difference and respective 95% CI for each muscle comparing relative activation time between starting phases for both variants. Considering upper limbs, Biceps Brachii and Triceps Brachii depicted unclear differences at most comparisons. For lower limbs, Tibialis Anterior has shown clear differences between take-off and flight phase (moderate magnitude of effect). Gastrocnemius Medialis and Rectus Femoris displayed substantial differences between take-off and flight, and hands-off phase (moderate to large meaningful inference). For all starting phase comparisons Biceps Femoris depicted unclear differences.

Discussion

This study compared the muscular activity level and relative activation time in-between two actual backstroke start variants (Figure 1a and 1b). Comparisons were made from the starting signal to the water immersion, underpinned by temporal and angular kinematic data. Our main findings have shown that, independently of the starting phase, all differences between the two variants were considered unclear with magnitude of effect ranging from trivial to moderate in iEMG (Figure 4) and relative activation time (Figure 5), which did not agree with the previous hypothesis established in this study. It was assumed

Table 3. Means (\pm standard deviations) of iEMG of each muscle in each phase for both backstroke start variants.

Variant	Variable	Phase	Biceps Brachii	Triceps Brachii	Tibialis Anterior	Gastrocnemius Medialis	Rectus Femoris	Biceps Femoris
Upper limbs horizontally positioned	Active iEMG (%CIVM)	Hands-off	15.12 (6.76)	12.37 (6.80)	17.19 (5.92)	12.38 (6.18)	9.13 (3.78)	17.43 (4.16)
		Take-off	15.17 (2.76)	2.76 (.26)	8.94 (5.79)	14.47 (5.40)	24.92 (8.88)	19.89 (9.73)
		Flight	22.38 (4.25)	3.51 (2.31)	8.48 (4.00)	11.35 (4.65)	15.40 (6.62)	18.06 (10.65)
		Entry	22.14 (6.74)	7.59 (5.36)	10.29 (4.56)	11.84 (6.39)	19.22 (9.95)	10.40 (5.87)
Upper limbs vertically positioned	Active iEMG (%CIVM)	Hands-off	18.15 (9.54)	12.02 (8.45)	15.54 (7.70)	15.20 (7.07)	9.66 (4.77)	19.45 (6.70)
		Take-off	14.24 (7.11)	8.06 (4.30)	12.94 (4.73)	27.66 (9.84)	16.94 (8.44)	17.20 (10.65)
		Flight	25.90 (8.65)	3.40 (1.93)	6.65 (3.94)	11.88 (5.24)	14.20 (5.14)	16.47 (8.41)
		Entry	24.59 (10.22)	7.14 (3.41)	11.68 (4.72)	15.19 (8.94)	18.81 (8.27)	10.02 (6.22)

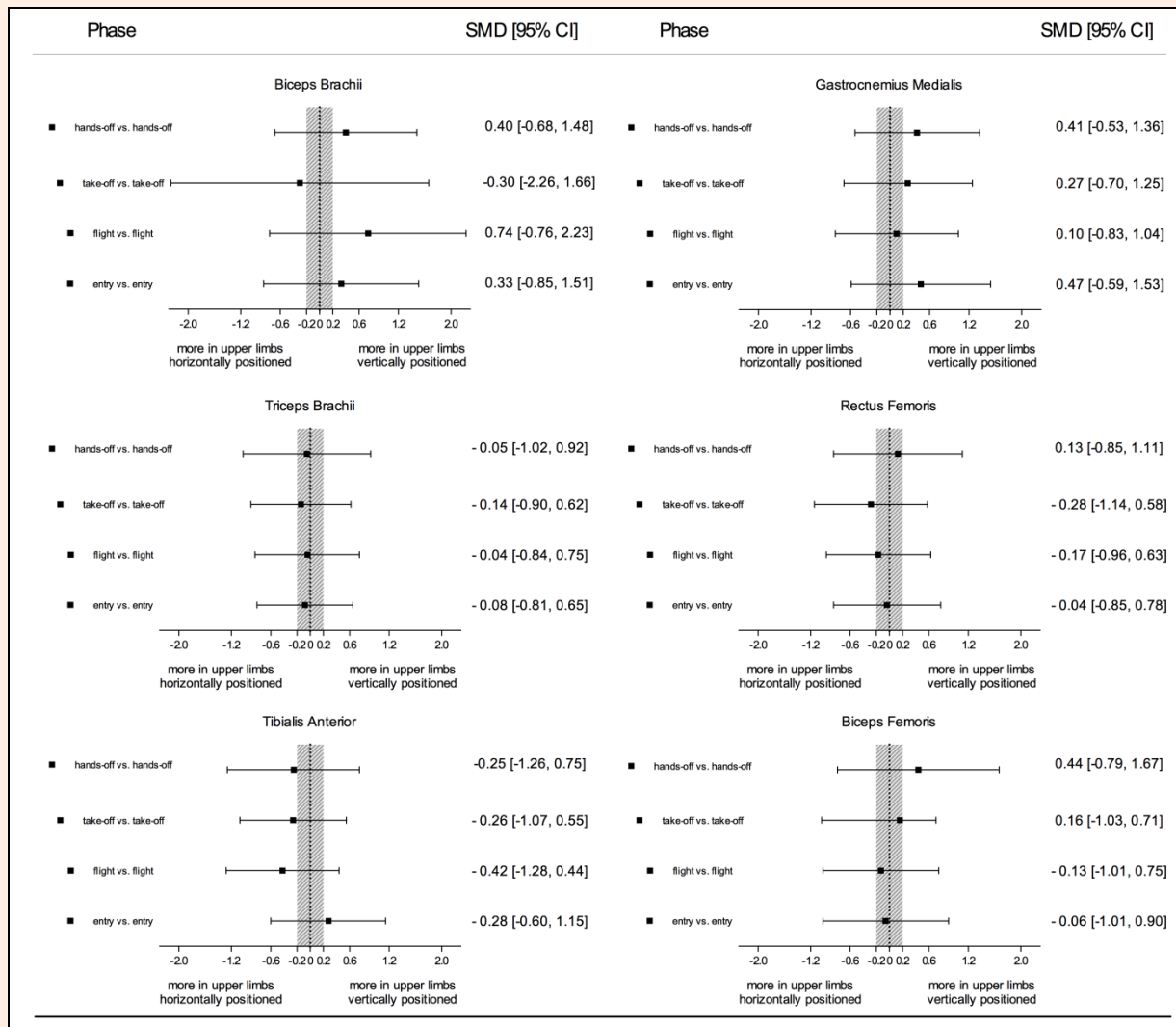


Figure 4. Standardized mean difference and 95% CI for active iEMG from comparisons between start variants for each muscle and starting phase. The shaded area represents the smallest (trivial differences) worthwhile change.

that clear differences between start variants would be observed in upper limbs EMG parameters from the starting signal to the hands-off instant. Secondly, upper and lower limb biarticular muscles were not recruited similarly by the two start variants in hands-off, take-off, flight and entry start phases, in opposite with our initial supposition.

To assess iEMG calculation per phase and relative activation time, the absolute starting phase time was assessed in both variants. Like starting phase times, the two

start variants did not differ for the starting performance indicator (i.e. 15 m starting time) (Figure 3). These similarities in performance may justify previous observations (de Jesus et al., 2014), that elite backstroke swimmers tend to use both starting variants, independently of the gender and competitive event. Van Soest et al. (1994) stated that performance will be successful as long as starting postures are close to the preferred position and the jumping execution did not seem to be hampered when the movement has to be started from widely different starting

Table 4. Standardized mean difference and 95% CI for iEMG from comparisons between starting phases of each muscle and for both backstroke start variants.

Phase		Biceps Brachii	Triceps Brachii	Tibialis Anterior	Gastrocnemius Medialis	Rectus Femoris	Biceps Femoris
Upper limbs horizontally positioned	Hands-off vs Take-off	.01[-.76,.77]	-.46[-1.26,.34]	-.42[-1.25,.41]	1.83[.64,3.03]	2.61[.85,4.37]	.37[-1.53,2.27]
	Hands-off vs Flight	.96[.14,1.77]	-1.65[-2.30,-.99]	-1.35[-2.09,-.60]	-.15[-.96,.66]	1.52[.27,2.77]	.14[-2.05,2.32]
	Hands-off vs Entry	.92[.03,1.82]	-1.57[-2.23,-.91]	-1.07[-1.84,-.29]	-.08[-1.00,.84]	2.44[.54,4.34]	-1.53[-2.71,-.35]
	Take-off vs Flight	2.32[1.07,3.58]	-.86[-1.54,-.17]	-1.02[-1.78,-.25]	-1.36[-2.14,-.58]	-.42[-1.17,.32]	-.09[-1.05,.88]
	Take-off vs Entry	2.25[.60,3.89]	-.21[-1.04,.62]	-.71[-1.51,.09]	-1.31[-2.14,-.48]	-.06[-.96,.84]	-.72[-1.47,.04]
Flight vs Entry	-.05[-1.21,1.11]	1.61[.03,3.20]	.41[-.51,1.34]	.10[-1.00,1.19]	.53[-.64,1.70]	-.63[-1.46,.21]	
Upper limbs vertically positioned	Hands-off vs Take-off	-.38[-1.18,.43]	-.43[-1.13,.27]	-.31[-1.04,.42]	1.61[.51,2.71]	1.39[-.03,2.82]	.00[-.90,.90]
	Hands-off vs Flight	.74[-.11,1.59]	-.93[-1.60,-.26]	-1.06[-1.76,-.35]	-.43[-1.19,.33]	.87[-.06,1.80]	-.40[-1.43,.63]
	Hands-off vs Entry	.62[-.31,1.54]	-.53[-1.21,.16]	-.46[-1.19,.27]	.00[-.99,.98]	1.75[.51,2.99]	-1.27[-2.15,-.40]
	Take-off vs Flight	1.46[.43,2.48]	-.99[-1.68,-.30]	-1.22[-2.01,-.42]	-1.45[-2.19,-.71]	-.29[-1.09,.51]	-.40[-1.43,.63]
	Take-off vs Entry	1.29[.16,2.43]	-.19[-.97,.58]	-.24[-1.11,.62]	-1.15[-1.99,-.30]	.20[-.69,1.09]	-1.27[-2.15,-.40]
Flight vs Entry	-.14[-1.13,.86]	1.77[.51,3.03]	1.17[.22,2.12]	.58[-.65,1.80]	.81[-.36,1.98]	-.69[-1.50,.11]	

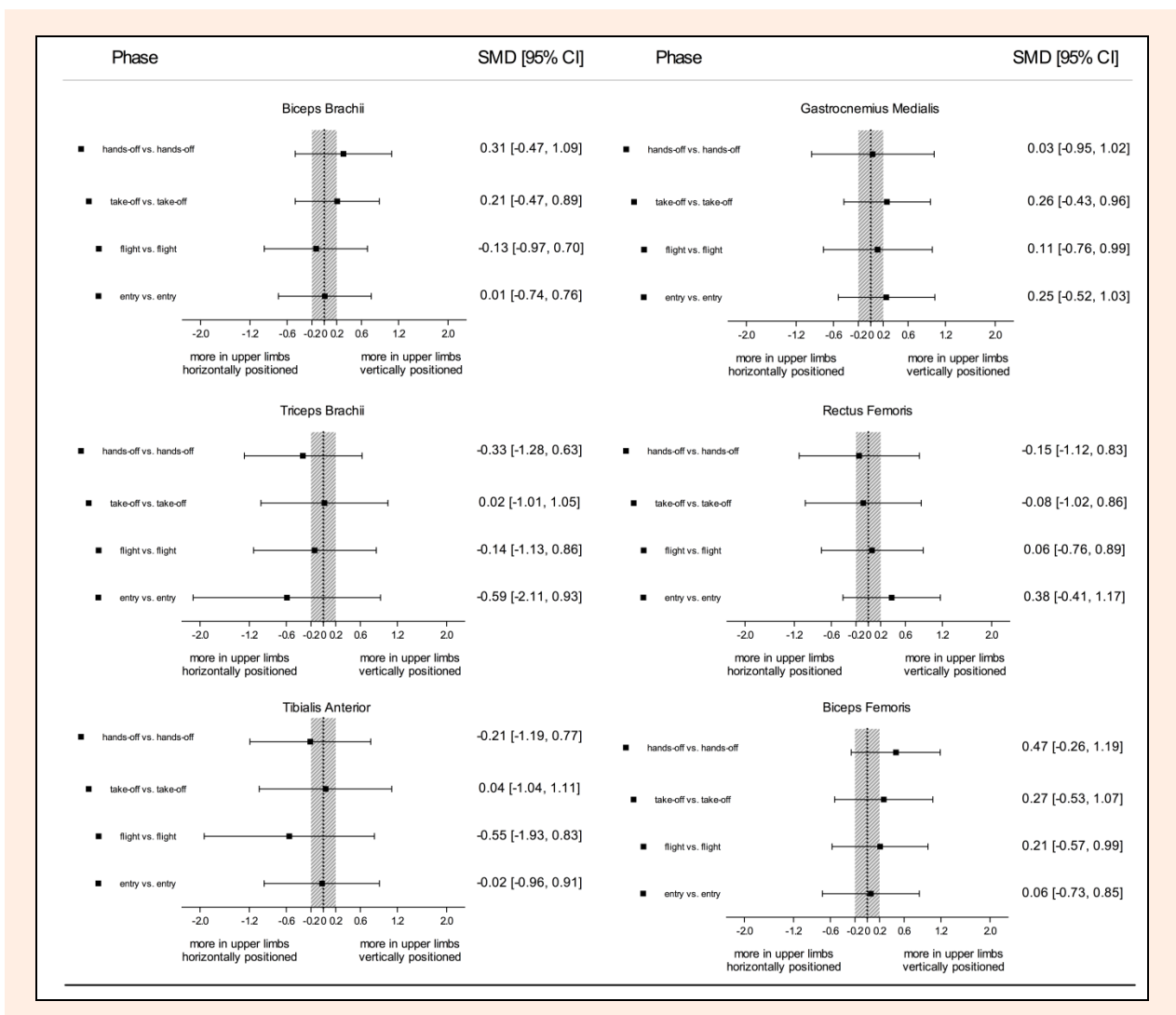


Figure 5. Standardized mean difference and 95% CI for relative activation time from comparisons between start variants for each muscle and starting phase. The shaded area represents the smallest (trivial differences) worthwhile change.

positions. Despite those resemblances, different motor profiles might lead to similar performances (Vantorre et al., 2014). In terms of muscular activity, different body geometries assumed at set positioning have affected the EMG signal amplitude in lat-pull down exercise (Andersen et al., 2014), in throwing (Escamilla and Andrews, 2009) and in jumping (Bobbert et al., 2013;

Mackala et al., 2013a; 2013b). These findings are often attributed to the effects of muscle length changes on their ability to generate force during high velocity contractions (McGowan et al., 2013; Zajac, 2002).

Following the temporal findings, the different handgrip positioning showed an overall similitude between start variants for shoulder, elbow, hip, knee and

ankle joint angles at set positioning frame and upper and lower limb EMG parameters throughout the different starting phases. The unclear muscular activation changes during the initial backstroke start phase is probably due to similar intrinsic muscle properties (i.e. muscle length) (McGowan et al., 2013) and seem to reflect similar solicitation of the nervous system as maximal effort is intended (Giroux et al., 2015). As we are dealing with proficient backstroke swimmers, their ability to keep constant the already planned and learned motor task is somewhat prevalent with respect to the necessity to suddenly modify the specific motor task substantially (Camomilla et al., 2009). According to Van Soest et al. (1994) for specific task groups (e.g. explosive leg extensions) a muscle stimulation pattern stored at present in some unspecified form within the central nervous system, which drives to a muscle stimulation pattern that yields successful performance for a wide range of, for instants, starting positions. Complementarily, Rodacki and Fowler (2001) mentioned that the past experiences of individuals could have a meaningful influence on movement output, as they tend to select a stereotyped strategy similar to that previously learnt.

In both variants clear differences in upper and lower limb muscles activation between starting phases were observed. Monoarticular muscles have been pointed out to generate more propulsive energy (Zajac, 2002); however, biarticular muscles were already identified as the most important to increase jumping performance (Pandy and Zajac, 1991). This fact reinforce the still remaining contradictions in biarticular muscles role (Cleather et al., 2015; Youm et al., 2009) highlighting the need to study the respective activation in different backstroke start phases, as previously conducted in upper

limbs sports (e.g. Escamilla and Andrews, 2009). In this study, despite Biceps Brachii and Triceps Brachii have displayed several unclear differences between start phases for the relative muscle activation time, indicating that they were involved in sustaining, propelling and stabilization movements (Hohmann et al., 2008), muscle activity level revealed that these biarticular muscles were more required in specific phases. Regardless of the start variant, Biceps Brachii was more recruited during the flight and entry compared to take-off phase, which might be due to the important glenohumeral stabilizer role. Youm et al. (2009) mentioned that with elbow and forearm movements controlled, Biceps Brachii long head plays an essential active compensatory role in the unstable shoulder. For both start variants, Biceps Brachii also revealed similar iEMG during hands-off and take-off phase, corroborating previous findings in lat pull-down exercises that observed similar Biceps Brachii activation throughout the entire movement (Andersen et al., 2014). Antagonist Triceps Brachii was highly recruited during hands-off and entry compared to the flight phase, suggesting a predominant elbow extension during hands-off followed by the synergistically contraction for shoulder adduction and anterior-posterior stabilization (Hohmann et al., 2008). Biarticular muscles involved in simultaneous joint actions produce less energy themselves, since they are activated to distribute net joint moments to control the direction of force applied externally by the limb (Zajac, 2002).

Considering the mono and biarticular lower limb muscles in both variants, only Biceps Femoris relative activation time was consistent throughout the starting phases, corroborating (Takeda et al., 2014) statement that coaches should focus on hip motion during backstroke

Table 5. Means (\pm standard deviation) of relative activation time for each muscle in each starting phase for both backstroke start variants.

Variant	Variable	Phase	Biceps Brachii	Triceps Brachii	Tibialis Anterior	Gastrocnemius Medialis	Rectus Femoris	Biceps Femoris
Upper limbs horizontally positioned	Active iEMG (%CJVM)	Hands-off	90.63(12.43)	73.47 (23.91)	74.91 (15.48)	53.50 (14.35)	53.71 (17.23)	86.86 (11.76)
		Take-off	95.14 (10.28)	72.76 (17.59)	83.77 (15.98)	89.46 (13.41)	86.34 (13.08)	90.68 (12.00)
		Flight	95.59 (12.18)	55.39 (20.90)	68.46 (14.55)	79.76 (21.01)	72.42 (19.48)	87.77 (14.52)
		Entry	90.84 (19.54)	64.56 (13.22)	65.45 (15.49)	69.22 (21.59)	71.93 (19.88)	88.75 (11.13)
Upper limbs vertically positioned	Active iEMG (%CJVM)	Hands-off	94.84 (9.87)	64.83 (27.95)	71.29 (19.45)	54.05 (16.60)	50.96 (21.63)	92.86 (7.33)
		Take-off	97.51 (3.86)	73.15 (23.71)	84.45 (22.83)	93.31 (6.24)	85.16 (14.87)	94.24 (10.11)
		Flight	91.81 (11.35)	52.23 (24.83)	59.70 (26.92)	82.37 (21.59)	73.72 (16.70)	91.12 (11.43)
		Entry	91.06 (13.44)	55.82 (27.44)	65.03 (17.99)	75.14 (15.88)	80.13 (15.32)	89.42 (9.17)

Table 6. Standardized mean difference and 95% CI for relative activation time from comparisons between starting phases of each muscle and for both backstroke start variants.

	Phase	Biceps Brachii	Triceps Brachii	Tibialis Anterior	Gastrocnemius Medialis	Rectus Femoris	Biceps Femoris
Upper limbs horizontally positioned	Hands-off vs Take-off	.33[-.46,1.12]	-.03[-.81,.76]	.52[-.38,1.43]	2.26[1.41,3.12]	1.73[.95,2.52]	.30[-.57,1.17]
	Hands-off vs Flight	.22[-.64,1.07]	-.68[-1.54,.17]	-.38[-1.22,.46]	1.65[.56,2.75]	.99[.07,1.91]	.07[-.90,1.04]
	Hands-off vs Entry	.02[-1.13,1.16]	-.34[-1.10,.42]	-.56[-1.42,.30]	.99[-.13,2.11]	.97[.04,1.90]	.15[-.69,.99]
	Take-off vs Flight	-6.47[-7.17,-5.78]	-.90[-1.89,.08]	-.87[-1.71,-.02]	-.66[-1.81,.48]	-.96[-2.07,.15]	-.22[-1.18,.74]
	Take-off vs Entry	-.38[-1.72,.96]	-.4 [-1.23,.38]	-1.04[-1.90,-.17]	-1.38[-2.55,-.21]	-.99[-2.12,.13]	-.15[-.98,.68]
	Flight vs Entry	-.21[-1.37,4.96]	.40 [-.39,1.18]	-.19 [-1.08,.70]	-.46 [-1.33,.42]	-.02[-.89,.85]	.06[-.71,.83]
Upper limbs vertically positioned	Hands-off vs Take-off	.25 [-.44,.93]	.27[-.53,1.07]	.62 [-.32,1.56]	2.14[1.42,2.85]	1.45[.70,2.19]	.17[-.87,1.22]
	Hands-off vs Flight	-.28[-1.21,.65]	-.41[-1.25,.43]	-.54[-1.64,.55]	1.54[.53,2.55]	.96[.17,1.75]	-.22[-1.36,.92]
	Hands-off vs Entry	-.35[-1.39,.69]	-1.89[-2.55,-1.23]	-.29[-1.13,.54]	1.15[.26,2.04]	1.23[.47,2.00]	-.43[-1.40,.55]
	Take-off vs Flight	-1.35[-3.32,0.63]	-.81[-1.72,.11]	-.99[-1.97,-.01]	-1.60[-3.92,.72]	-.70[-1.65,.25]	-.28[-1.20,.64]
	Take-off vs Entry	-1.52[-3.86,.81]	-.67[-1.64,.30]	-.78[-1.55,.00]	-2.66[-4.50,-.82]	-.31[-1.21,.60]	-.44[-1.26,.39]
	Flight vs Entry	-.06[-1.01,.89]	.13[-.83,1.09]	.18[-.59,.95]	-.31[-1.08,.47]	.35[-.52,1.22]	-.14[-.92,.65]

start. In fact, swimmers are required to extend their hip joint since the hands-off until the entry phase. Possible great activation of Tibialis Anterior during take-off compared to flight phase can be explained by the antagonist co-activation to prevent ankle hyper-extension (Giroux et al., 2015). To date, none research conducted previously to the current study had concerned about the Tibialis Anterior EMG during backstroke start. Gastrocnemius Medialis was confirmed as the most important contributor to the plantar flexor (Giroux et al., 2015; Zajac, 2002) due to the greater activation displayed during take-off rather than in hands-off and flight phase. Pandy and Zajac (1991) noted that the Gastrocnemius Medialis contributed similarly to the monoarticular ankle plantarflexors during to improve vertical jump performance. The slight Rectus Femoris relative activation time at hands-off compared to take-off, flight and entry might be explained by lower limb joint rotations sequence timing, which is initiated by the hip extensors during hands-off phase (Takeda et al., 2014). Following take-off, Rectus Femoris is activated to decelerate hip joint extension during flight phase (Giroux et al., 2015) and to extend the knee during the entry phase to maintain the hole-entry (Takeda et al., 2014).

Notwithstanding the originality and relevance of the current data, limitations should be mentioned. Firstly, considering the complexity of our methodology and consistency with previous findings, these results should be considered as preliminary, however important, and used with caution until data on a larger sample can be obtained. Authors recognize that enhanced statistical inference power of results depend upon substantial number of observations, though, ten swimmers is a common mean number used in complex EMG swimming scenarios (Figueiredo et al., 2013; Hohmann et al., 2008; Stirn et al., 2011), being reported noticeable signal variability even in larger sample study designs using normalization procedures (Martens et al., 2015; Pereira et al., 2015). Secondly, five from the six studied muscles have biarticular characteristics (i.e., generating torque, transferring energy and protecting joint passive structures), which are considered to develop less propulsive energy than mono-articular muscles (Zajac, 2002). As contribution of mono and bi-articular muscles were not compared in this study, as previously done for jumping (e.g. Pandy and Zajac, 1991), further researches should analyze if bi-articular muscles display nuanced activity than mono-articular independently of the starting phase. Thirdly, measuring EMG in water is challenging (Martens et al., 2015; Stirn et al., 2011) and findings obtained are considered essential for neuromuscular responses understanding. Nevertheless, it is recommended that further research should integrate EMG, kinematic and kinetic data for better understanding about eventual influence of the new feet wedge on biomechanics of the backstroke start variants. Based on the results reported in this article, it is suggested that similar strength training can be planned for both backstroke start variants; however, coaches should attempt to select proper exercises for muscles activated at different starting phases to enhance neuromuscular function.

Conclusion

This study has shown unclear differences between two backstroke start variants in EMG parameters (i.e., iEMG and relative activation time) throughout hands-off, take-off, flight and entry starting phases, highlighting swimmers' ability to keep constant the already planned and learned motor task. These results were supported by temporal (15 m time) and angular kinematics (upper and lower limb joint angles at starting position) data, which also displayed similarities between start variants. In addition, comparison of upper and lower limb muscles activation between starting phases evidenced that the bi-articular muscles had contribute differently along starting phases, suggesting a crucial role in backstroke start propulsive actions, as mono-articular muscles. These findings provide coaches with some initial objective evidence to understand the biomechanical effects of different hand-grips in backstroke start performance. Coaches should plan similar strength training to improve backstroke start performance of both variants. However further attention should be given on the selection of exercises that activates properly the involved muscles at different starting phases.

Acknowledgements

This work was supported by the CAPES Foundation under doctoral grant (BEX 0761/12-5/2012-2015) and FCT Foundation under grant (EXPL/DTP-DES/2481/2013- FCOMP-01-0124-FEDER-041981).

References

- Abdel-Aziz, Y. and Karara, H. (1971). Direct linear transformation: from comparator coordinates into object coordinates in close range photogrammetry. In: *Proceeding of the Symposium on Close-Range Photogrammetry, January 26-29, Falls Church United State*. 1-18
- Andersen, V., Fimland, M., Wiik, E., Skoglund, A. and Saeterbakken, A. (2014) Effects of grip width on muscle strength and activation in the lat pull-down. *Journal of Strength & Conditioning Research* **28**(4), 1135-1142.
- Asseldonk, E., Campfens, S., Verwer, S., Putten, M. and Stegeman, D. (2014) Reliability and agreement of intramuscular coherence in tibialis anterior muscle. *PLoS ONE* **9**(2), 1-10.
- Barbosa, T., Fernandes, R., Morouco, P. and Vilas Boas, J.P. (2008) Predicting the intra-cyclic variation of the velocity of the centre of mass from segmental velocities in butterfly stroke: A pilot study. *Journal of Sport Science and Medicine* **7**, 201-209.
- Basmajian, V. and De Luca, J. (1985) *Muscles alive: Their functions revealed by electromyography*. 5th edition. Baltimore.
- Bobbert, M., Casius, L. and Kistemaker, D. (2013) Humans make near-optimal adjustments of control to initial body configuration in vertical squat jumping. *Neuroscience* **1**(237), 232-242.
- Camomilla, V., Sbriccoli, P., Di Mario, A., Arpante, A. and Francesco, F. (2009) Comparison of two variants of a Kata technique (Unsu): The neuromechanical point of view. *Journal of Sports Science and Medicine* **8**(3), 29-35.
- Cleather, D., Southgate, D. and Bull, A. (2015) The role of the biarticular hamstrings and gastrocnemius muscles in closed chain lower limb extension. *Journal of Theoretical Biology* **365**, 217-225.
- Cohen, J. (1988) *Statistical power analysis for the behavioral sciences*. 2 edition. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Conceição, A., Silva, A., Barbosa, T., Karsai, I. and Louro, H. (2014) Neuromuscular Fatigue during 200 M Breaststroke. *Journal of Sports Science and Medicine* **13**(1), 200-210.
- Cumming, G. (2013) The new statistics: Estimation for better research. Available from URL: <http://www.thenewstatistics.com>.
- Day, S. (2002) *Important factors in surface EMG measurement*. Bortec Biomedical Ltd., Calgary.

- de Jesus, K., de Jesus, K., Figueiredo, P., Gonçalves, P., Pereira, S., Vilas-Boas, J.P. and Fernandes, R. (2011) Biomechanical analysis of backstroke swimming starts. *International Journal of Sport Medicine* **32**(7), 546-551.
- de Jesus, K., Figueiredo, P., de Jesus, K., Pereira, F., Vilas-Boas, J., Machado, L. and Fernandes, R. (2012) Kinematic analysis of three water polo front crawl styles. *Journal of Sport Science* **30**(7), 715-723.
- de Jesus, K., de Jesus, K., Figueiredo, P., Gonçalves, P., Pereira, S., Vilas-Boas, J.P. and Fernandes, R. (2013) Backstroke start kinematic and kinetic changes due to different feet positioning. *Journal of Sport Science* **31**(15), 1665-1675.
- de Jesus, K., de Jesus, K., Medeiros, A., Fernandes, R. J. and Vilas Boas, J.P. (2014) The backstroke starting variants performed under the current swimming rules and block configuration. *Journal of Swimming Research* **22**(1), 1-11.
- Escamilla, R. and Andrews, J. (2009) Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Medicine* **39**(7), 569-590.
- Figueiredo, P., Rouard, A., Vilas Boas, J.P. and Fernandes, R. (2013) Upper- and lower-limb muscular fatigue during the 200-m front crawl. *Applied Physiology, Nutrition, and Metabolism* **38**(7), 716-724.
- Giroux, C., Guilhem, G., Couturier, A., Chollet, D. and Rabita, G. (2015) Is muscle coordination affected by loading condition in ballistic movements? *Journal of Electromyography and Kinesiology* **25**(1), 69-76.
- Hermes, J., Freriks, B., Disselhorst-Klug, C. and Rau, G. (2000) Development of recommendation for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology* **10**(5), 361-374.
- Hodges, P. and Bui, B. (1996) A comparison of computer-based methods for determination of onset of muscle contraction using electromyography. *Electroencephalography and Clinical Neurophysiology* **101**(6), 511-519.
- Hohmann, A., Fehr, U., Kirsten, R. and Krueger, T. (2008) Biomechanical analysis of the backstroke start technique in swimming. *E-Journal Bewegung und Training* **2**, 28-33.
- Hopkins, W. (2010) Linear models and effect magnitudes for research, clinical and practical applications. *Sport Science* **14**, 49-57.
- de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics*, **29**(9), 1223-1230.
- Mackala, K., Stodółka, J., Siemiński, A. and Coh, M. (2013a) Biomechanical analysis of standing long jump from varying starting positions. *Journal of Strength and Conditioning Research* **27**(10), 2674-2684.
- Mackala, K., Stodółka, J., Siemiński, A. and Coh, M. (2013b) Biomechanical analysis of squat jump and countermovement jump from varying starting positions. *Journal of Strength and Conditioning Research* **27**(10), 2650-2661.
- Martens, J., Figueiredo, P. and Daly, D. (2015) Electromyography in the four competitive swimming strokes: A systematic review. *Journal of Electromyography and Kinesiology* **25**(2), 273-291.
- McGowan, C., Neptune, R. and Herzog, W. (2013) A phenomenological muscle model to assess history dependent effects in human movement. *Journal of Biomechanics* **46**(1), 151-157.
- Nguyen, C., Bradshaw, E., Pease, D. and Wilson, C. (2014) Is starting with the feet out of the water faster in backstroke swimming? *Sports Biomechanics* **13**(1), 1-12.
- Pandy, M. and Zajac, F. (1991) Optimal muscular coordination strategies for jumping. *Journal of Biomechanics* **24**(1), 1-10.
- Pereira, S.M., Ruschel, C., Hubert, M., Machado, L., Roesler, H., Fernandes, R.J. and Vilas-Boas, J.P. (2015) Kinematic, kinetic and EMG analysis of four front crawl flip turn techniques. *Journal of Sports Sciences* **27**, 1-10.
- Rodacki, A. and Fowler, N. (2001) Intermuscular coordination during pendulum rebound exercises. *Journal of Sport Science* **19**(6), 411-425.
- Stirn, I., Jarm, T., Kapus, V. and Strojnik, V. (2011) Evaluation of muscle fatigue during 100-m front crawl. *European Journal of Applied Physiology* **111**(1), 101-113.
- Takeda, T., Itoi, O., Takagi, H. and Tsubakimoto, S. (2014) Kinematic analysis of the backstroke start: differences between backstroke specialists and non-specialists. *Journal of Sport Science* **32**(7), 635-641.
- Van Soest, A.J., Bobbert, M.F. and Van Ingen Schenau, G.J. (1994) A control strategy for the execution of explosive movements from varying starting positions. *Journal of Neurophysiology* **71**(4), 1390-1402.
- Vantorre, J., Chollet, D. and Seifert, L. (2014) Biomechanical analysis of the swim-start: a review. *Journal of Sports Science and Medicine* **13**(2), 223-231.
- Youm, T., Attache, N., Tibone, J., McGarry, M. and Lee, T. (2009) The effect of the long head of the biceps on glenohumeral kinematics. *J Shoulder Elb Surg* **18**(1), 122-129.
- Zajac, F. (2002). Understanding muscle coordination of the human leg with dynamical simulations. *Journal of Biomechanics* **35**(8), 1011-1018.

Key points

- An effective swim start component (from the starting signal until the swimmers' vertex reaches the 15 m mark) is decisive in short distance events.
- In 2008, FINA approved the Omega OSB11 starting block (Swiss Timing Ltd., Switzerland) with two horizontal and one vertical backstroke start handgrip and currently swimmers can adopt different starting variants.
- The start performance is related to the exertion of maximal force in the shortest time, as other high-velocity movements; thus, the study of the current variants in-between them from a neuromuscular standpoint is indispensable for training support.
- The use of different handgrips did not affect upper and lower limb electromyographic activity; angular kinematics and overall 15 m backstroke start profile.
- Independent of the start variant selected, the role played by each upper and lower limb muscles at different starting phases should be considered in specific resistance training program to optimize backstroke start performance.

AUTHOR BIOGRAPHY



Karla DE JESUS

Employment

PhD student, Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, Porto, Portugal

Degree

MSc

Research interests

Biomechanical research in swimming, sports training technology, sport performance

E-mail: karla_de_jesus@yahoo.com.br



Kelly DE JESUS

Employment

PhD student, Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, Porto, Portugal

Degree

MSc

Research interests

Biomechanical research in swimming, sports training technology, sport performance

E-mail: kellyjesuzinha@hotmail.com

	<p>Alexandre MEDEIROS Employment Professor, University of Fortaleza, Brazil Degree PhD Research interests Game analysis, team sports, training methodology, sport performance E-mail: alexandreararipe@hotmail.com</p>
	<p>Pedro GONÇALVES Employment Electro technical engineer at Faculty of Sport - University of Porto Degree MSc Research interests Biomechanical research in swimming, sports training technology, sport performance E-mail: pgoncalves@fade.up.pt</p>
	<p>Pedro FIGUREIREDO Employment Postdoctoral fellow at School of Physical Education, Federal University of Rio Grande do Sul, Brazil. Degree PhD Research interests Bioenergetics and biomechanics of human locomotion. Sport performance and training. E-mail: pedfig@me.com</p>
	<p>Ricardo J. FERNANDES Employment Teacher and researcher at Faculty of Sport – University of Porto Degree PhD Research interests Biophysical research in aquatic activities, sport training methodology, training evaluation and control E-mail: ricfer@fade.up.pt</p>
	<p>João Paulo VILAS-BOAS Employment Professor, Faculty of Sport – University of Porto Degree PhD Research interests Biomechanical research in swimming, sports training technology, sport performance E-mail: jpvb@fade.up.pt</p>

✉ **Karla De Jesus**

Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, Porto, Portugal