Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: http://www.tandfonline.com/loi/rjsp20

Kinematic, kinetic and EMG analysis of four front crawl flip turn techniques

Suzana Matheus Pereira, Caroline Ruschel, Marcel Hubert, Leandro Machado, Helio Roesler, Ricardo Jorge Fernandes & João Paulo Vilas-Boas

To cite this article: Suzana Matheus Pereira, Caroline Ruschel, Marcel Hubert, Leandro Machado, Helio Roesler, Ricardo Jorge Fernandes & João Paulo Vilas-Boas (2015) Kinematic, kinetic and EMG analysis of four front crawl flip turn techniques, Journal of Sports Sciences, 33:19, 2006-2015, DOI: 10.1080/02640414.2015.1026374

To link to this article: http://dx.doi.org/10.1080/02640414.2015.1026374

Published online: 27 Mar 2015.

Journal of Sports Sciences, 2015
Vol. 33, No. 19, 2006–2015, http://dx.doi.org/10.1080/02640414.2015.1026374

Kinematic, kinetic and EMG analysis of four front crawl flip turn techniques

SUZANA MATHEUS PEREIRA[1,2], CAROLINE RUSCHEL[2], MARCEL HUBERT[2], LEANDRO MACHADO[1,3], HELIO ROESLER[2], RICARDO JORGE FERNANDES[1,3] & JOÃO PAULO VILAS-BOAS[1,3]

[1]*Faculty of Sport, Centre of Research, Education, Innovation and Intervention in Sport (CIFI2D), University of Porto, Porto, Portugal,* [2]*Aquatic Biomechanics Research Laboratory, Centre of Health and Sport Sciences, University of the State of Santa Catarina (CEFID/UDESC), Florianópolis, Brazil and* [3]*Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Porto, Portugal*

(*Accepted 2 March 2015*)

Abstract
This study aimed to analyse the kinematic, kinetic and electromyographic characteristics of four front crawl flip turn technique variants. The variants distinguished from each other by differences in body position (i.e. dorsal, lateral, ventral) during rolling, wall support, pushing and gliding phases. Seventeen highly trained swimmers (17.9 ± 3.2 years old) participated in interventional sessions and performed three trials of each variant, being monitored with a 3-D video system, a force platform and an electromyography (EMG) system. Studied variables: rolling time and distance, wall support time, push-off time, peak force and horizontal impulse at wall support and push-off, centre of mass horizontal velocity at the end of the push-off, gliding time, centre of mass depth, distance, average and final velocity during gliding, total turn time and electrical activity of *Gastrocnemius Medialis*, *Tibialis Anterior*, *Biceps Femoris* and *Vastus Lateralis* muscles. Depending on the variant, total turn time ranged from 2.37 ± 0.32 to 2.43 ± 0.33 s, push-off force from 1.86 ± 0.33 to 1.92 ± 0.26 BW and centre of mass velocity during gliding from 1.78 ± 0.21 to 1.94 ± 0.22 $m \cdot s^{-1}$. The variants were not distinguishable in terms of kinematical, kinetic and EMG parameters during the rolling, wall support, pushing and gliding phases.

Keywords: *biomechanics, swimming, turning, performance*

Introduction

The importance of the turning phase for the swimming race's total performance is well documented (Blanksby, Gathercole, & Marshall, 1996; Chow, Hay, Wilson, & Imel, 1984; Mason & Cossor, 2001) and studies indicate that optimisation of the turn technique can reduce times by at least 0.20 s per lap in a swimming event (Maglischo, 2003). According to Lyttle and Benjanuvatra (2004), little changes on the turning action performance can imply substantial improvements on the final event time.

Nowadays, all competitive front crawl swimmers use the flip (or tumble) turn technique (Puel et al., 2012). However, the flip turn technical execution has been changing over the years and recently a wide variability of styles could be observed during the freestyle events in high-level competitions. The flip turn involves a complex turning action that includes a main rotation around the transverse axis, on the sagittal plane, combined or not with rotation around the other axis, specially the longitudinal one (Vilas-Boas & Fernandes, 2003). Depending on the body position assumed by the swimmer during the rolling, wall touch, pushing and giding phases, the flip turn can be performed in different ways (Lyttle & Benjanuvatra, 2004; Maglischo, 2003).

Pereira et al. (2011), based upon an exploratory analysis of freestyle flip turns in World Championships and Olympic Games, described the four variants most commonly used by the top-level swimmers (Figure 1): (1) dorsal rolling, lateral touch in the wall, pushing with rotation and ventral gliding; (2) dorsal rolling, dorsal touch in the wall, pushing with rotation and ventral gliding; (3) dorsal rolling, lateral touch in the wall, pushing in a lateral position and lateral gliding; and (4) lateral rolling, lateral touch in the wall, pushing with rotation and ventral gliding.

Correspondence: Caroline Ruschel, Centre of Health and Sport Sciences, University of the State of Santa Catarina, Rua Pascoal Simone, 358, Florianópolis 88080-350, Brazil. E-mail: caroline.ruschel@udesc.br

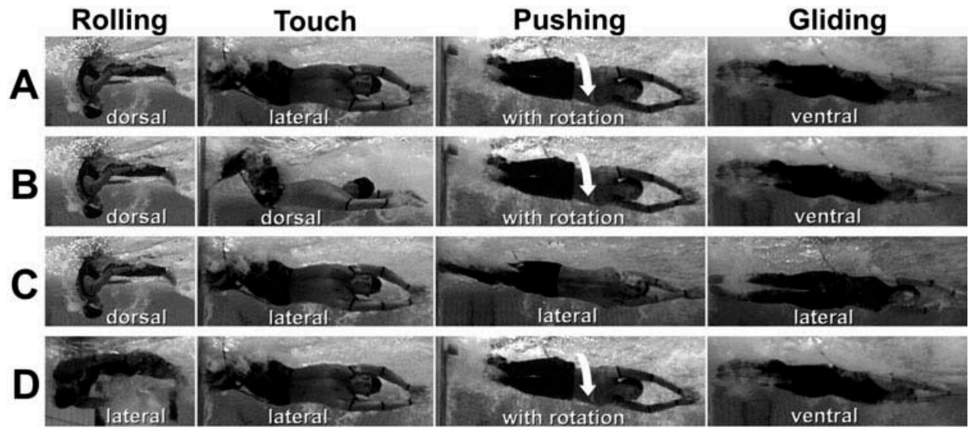


Figure 1. Representation of body positions assumed by swimmers during the turning phases of the four variants most commonly used by the top-level swimmers in freestyle events.

Haljand (1998) and Maglischo (2003) indicated that variations on the turning technique, such as different body positions during the rolling phase and different strategies used by the swimmers when pushing off the wall, could directly influence performance. Some studies have been carried out to analyse biomechanical parameters during the different turning phases (Blanksby et al., 1996; Lyttle, Blanksby, Elliott, & Lloyd, 1999; Puel et al., 2012) but, with the exception of a preliminary study on temporal parameters (Pereira et al., 2011), there is no literature regarding the analysis of different flip turn variants in front crawl swimming.

Considering that the turning action is an important phase of the swimming competitive events, and that the flip turn variant performed by the swimmer is expected to lead to different biomechanical parameters, this study aimed to describe and compare the kinematic, kinetic and electromyographic characteristics of the four variants most used in the top front crawl flip turn technique.

Methods

Participants

Seventeen highly trained national level swimmers (nine male and eight female, with >8 training units per week and >7 years of training background) participated in this study. Mean ± *s* age, body mass and height for the male were 19.5 ± 2.6 years old, 73.5 ± 9.1 kg and 1.80 ± 0.09 m, respectively. For the female, mean ± *s* age, body mass and height were 16.0 ± 2.8 years old, 57.7 ± 9.0 kg and 1.66 ± 0.03 m. Free written consent was obtained from participants on a consent form previously approved by the Ethical Committee for Human Research of the hosting institution.

Experimental procedure

Prior to data collection, swimmers underwent an interventional process to practice all of the four analysed turning variants (based on Pereira et al. (2011)): (1) *variant A*: dorsal rolling, lateral touch in the wall, pushing with rotation and ventral gliding; (2) *variant B:* dorsal rolling, dorsal touch in the wall, pushing with rotation and ventral gliding; (3) *variant C:* dorsal rolling, lateral touch in the wall, pushing in a lateral position and lateral gliding; and (4) *variant D:* lateral rolling, lateral touch in the wall, pushing with rotation and ventral gliding. From the 17 participants, seven of them had the variant “A” as the preferred one, four of them the variant “B”, three of them the variant “C” and also three preferred the variant “D”.

Two practice and two theoretical lessons with 1.30 h of duration each (total of 6 h) were carried out. The swimmers participated in specific exercises for all of the turning variants in duos or trios to better memorise the technical actions, and feedback was continuously provided to the swimmers by the researchers. A total of about 60 turns (15 for each variant) were performed in each training session. During the theoretical lessons, an audiovisual instruction and feedback was given to the participants through the use of video images.

After the training sessions, the data collection was scheduled for each swimmer. All the tests were carried out in a 25 × 12.5 × 1.9 m indoor swimming pool. The water temperature was set at 27.5°C. Firstly, the anthropometrical measures were obtained and a video with images of the four variants was shown to the swimmer to reinforce the technical characteristics of each one. The trials started and finished from a marked spot (at 12.5 m from the turning wall, using a line separation rope transversely installed in the middle of the pool), and swimmers were instructed to swim in and out at maximum speed till the 12.5 m reference. Each swimmer performed three times each of the four analysed turning variants, in a total of 12 flip turns per participant. The order of the executions was randomly determined and a 2-min interval was observed between each trial.

Measurements

A 3-D video analysis was carried out by using four underwater and two surface-fixed cameras (DCR-HC42E, 50 Hz, Sony®, Japan). The two surface cameras were fixed on a 3-m height support, one at each lateral wall of the pool, 2.5 m distant from the turning wall. The underwater cameras were fixed on specially designed supports, two of them in each side of the pool, providing right and left views of the turning movement. The anthropometric biomechanical model used was from Zatsiorsky and Seluyanov adapted by de Leva (1996) using 11 anatomical reference points: vertex, ear lobe, acromion, lateral condyle of humerus, styloid process of the wrist, 3rd dactylion, great trochanter of the femur, the lateral epicondyle of the femur, lateral malleolus, calcanei and halux. High-contrast markers were positioned in each of the anatomical landmarks and image coordinates were transformed to 3-D object-space coordinates using the Direct Linear Transformation algorithm (Abdel-Aziz & Karara, 1971).

Kinetic assessment was conducted using an underwater extensometric platform (Roesler, 2003) connected to a 16-bit acquisition system (Biopac, Biopac Systems, USA) sampling at 1000 Hz. The force plate was mounted on a specially built support fixed to the pool wall and due to the 0.07-m thickness of the platform, the marks at the bottom of the pool were modified to adapt to the new configuration.

Active differential surface electromyography (EMG) signals were recorded from *Gastrocnemius Medialis*, *Tibialis Anterior*, *Biceps Femoris* and *Vastus Lateralis* muscles with the same system and sampling rate described above. Bipolar Ag–AgCl circular surface electrodes (inter-electrode distance of 2 cm) with pre-amplifiers (AD621 BN, total gain set at 1100 and common mode rejection ratio of 110 dB) were placed parallel to the direction of muscle fibres in the mid-point of the contracted muscle belly (Clarys & Cabri, 1993). Before electrode fixation, the skin was shaved, abraded and cleaned. The electrodes were covered with an adhesive bandage (Opsite Flexifix®, Smith & Nephew, USA) and cables were fixed to the skin by adhesive tape. In addition, swimmers wore a complete swimsuit (Fastskin, Speedo®, UK) with a cable entrance opened in the medium-dorsal position; over the water, a steel cable was extended with a sheave to which the cables were fixed.

Three maximal isometric voluntary contractions lasting 5 s were performed with 5 min rest between contractions, the highest being accepted as the reference value. The maximal isometric voluntary exercises were arranged on a regular therapy bench, using belts in combination with manual resistance, according to the positions described by Konrad (2006). To synchronise EMG, video and the force platform, an electronic flashlight signal/electronic trigger was marked simultaneously on the recording systems.

Data analysis

The video images were digitised at a frequency of 50 Hz using the APASystem (Ariel Dynamics, USA). Kinematical analyses comprised four intermediate phases of a flip turn: (1) *rolling*, which starts on the last frame before hand's entry in the last swimming stroke before turning and ends on the last frame before the first touch in the wall; (2) *wall support*, which starts on the frame that corresponds to the first wall contact and ends on the last frame before the swimmer starts to extend the knees in order to project the body away from the wall; (3) *pushing*, which starts in the frame that corresponds to the first knee extension and ends on the frame that corresponds to the last wall contact; and (4) *gliding*, which starts on the first frame after the swimmer completely leaves the wall and ends on the frame that corresponds to the wider stage of the first leg kick out of the wall.

After image filtering using a 5 Hz low-pass Butterworth, as previously used by de Jesus et al. (2011), the following kinematical variables were analysed: (1) time duration of each turn phase: rolling time (RT), wall support time (WST), pushing time (PT) and gliding time (GT); (2) total turn time (TT, defined as the sum of RT, WST, PT and GT); (3) 5 m round trip time (5 mRTT, time from 5 m into the wall to 5 m out); (4) initial rolling distance (IRD, corresponding to the distance between the swimmer's vertex and the pool wall at the beginning of rolling); (5) centre of mass horizontal velocity at the end of the push-off ($VxCM_{push\text{-}off}$); (6) centre of mass maximum depth during the gliding phase ($CM_{maxdepth}$); (7) centre of mass horizontal average velocity during the gliding phase ($VxCM_{glide}$); (8) centre of mass horizontal instantaneous velocity at the end of the gliding phase ($VxCM_{end}$); and (9) distance from the swimmer's centre of mass at the end of the gliding phase and the pool wall ($DxCM_{end}$). Graphs of the 3-D kinematics (displacement, velocity and acceleration in horizontal, vertical and medial–lateral axes) were also constructed to compare variants. The coordinate axes were defined according to the International Society of

Biomechanics (x = horizontal; y = vertical; z = medial–lateral) (Wu & Cavanagh, 1995) and the origin was located at the turning wall, in the intersection between the vertical plane and the water line and at the central point of the lane.

Both kinetic and EMG data were acquired and exported using the Acknowledge 3.2.5 software (BIOPAC Systems, Inc., USA). Data analysis was carried out through bespoke routines created in the MatLab 2010b software (The MathWorks Inc., USA). For the kinetic data, the routine comprised the following steps: (1) offset correction; (2) filtering (4th order low-pass Butterworth at 100 Hz); (3) normalisation of data based on the individual's body weight; (4) graphic removal of water wave impact in the pool wall during the flip turn, as before (Pereira et al., 2010); (5) verification of the kinetic selected variables: force peak (F_{peak}, the maximum value of the horizontal force produced by the lower limbs) and horizontal impulse (Imp, the time integral of the horizontal force component produced by the lower limbs) for both wall support and pushing phases; and (6) average calculation for each variable considering the three valid trials per swimmer for each analysed variant. Raw EMG data were analysed as follows: (1) filtering (digital Hamming band-pass 35–500 Hz); (2) offset correction; (3) full-wave rectification; (4) onset/offset detection (muscles were considered active when the EMG amplitude exceeded 3 standard deviations above the mean baseline calculated over 25 ms, and this procedure was supplemented by visual verification); (5) smoothing with a 4th order Butterworth filter (10 Hz) for the linear envelope; (6) amplitude scaling to maximal isometric voluntary contraction; (7) verification of the selected variable for each muscle in each turn phase: activation time (the time duration of the active EMG signal), average EMG (the average value of EMG signal amplitude), maximum EMG (the maximum value of EMG signal amplitude) and EMG integral (the time integral of the EMG signal). Graphs of EMG activity of each muscle during the turn, expressed as arbitrary units, were also constructed to compare variants.

Due to technical issues such as electrodes detachments and malfunction of one of the cameras, which compromised the Direct Linear Transformation required redundancy, some trials were excluded for different parameters and thus kinematic data of 10 (6 men and 4 women), kinetic data of 17 (9 men and 8 women) and EMG data of 11 (7 men and 4 women) swimmers were used for statistical analysis. All participants that took part in the kinematic analysis (n = 10) were also part of kinetic and EMG analyses.

Statistical analysis

Mean and standard deviation computations for descriptive analysis were obtained for all variables (all data were checked for distribution normality with the Shapiro–Wilk test). Repeated measures ANOVA were used for the comparison between the four variants and effect sizes were estimated through partial eta-squared (η_p^2). An alpha level of 5% was used for all statistical tests.

Results

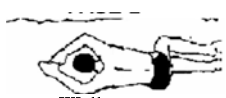
Table I presents the mean ± s values of kinematical (rolling time, wall support time, pushing time and total turn time) and kinetic (force peak and horizontal impulse) variables for each phase of the analysed flip turn variants. The comparison between variants is also displayed. The mean values for the 16 kinematic and kinetic variables studied were very similar considering the four flip turn variants and the comparison showed no statistical difference between them. Despite non-significant differences in performance time between the variants were observed, it is worthy to mention that 9 out of 17 swimmers had their fastest trial using a technique different from the preferred one. Additionally, nine swimmers performed their fastest trial when using the variant "A", one swimmer using the variant "B", three swimmers using the variant "C" and four swimmers using the variant "D".

The 3-D kinematics (displacement, velocity and acceleration) of the swimmers' centre of mass during each turn variant is presented in Figure 2. Regarding the flip turn variations, the displacement patterns were very similar in all directions (x, y and z) and, however, a little more variability is observed in velocity and acceleration curves; common patterns can be clearly identified for all A, B, C and D variants.

Regarding the muscle activity, Table II presents data on average EMG in each turn phase and the results of the comparison between the variants A, B, C and D. No difference was found between variants when comparing the average EMG, activation time, maximum EMG and EMG integral measured in *Gastrocnemius Medialis, Tibialis Anterior, Biceps Femoris* and *Vastus Lateralis*. Considering all the variants, turning phases and analysed muscles, P-values ranged from 0.415 to 0.989 (η_p^2 from 0.003 to 0.075) for activation time; from 0.176 to 0.995 (η_p^2 from 0.002 to 0.127) for maximum EMG; and from 0.531 to 0.999 (η_p^2 from 0.001 to 0.059) for EMG integral.

The results indicate the activation patterns were the same during rolling, wall support, pushing and gliding phases independently of the flip turn variant, corroborating to the results found for kinetic and

Table I. Mean ± *s* (95% confidence interval) values of the kinematical and kinetic variables in each phase of the analysed flip turn variants (A, B, C and D) and results of the comparison between the variants (*P*-value and effect size).

		Turning variant					
Turning phase	Variable	A	B	C	D	*P-value*	η_p^2
 Rolling	RT (s)	1.29 ± 0.18 (1.20–1.38)	1.29 ± 0.25 (1.16–1.41)	1.35 ± 0.19 (1.25–1.44)	1.33 ± 0.26 (1.20–1.46)	0.728	0.021
	IRD (m)	1.75 ± 0.17 (1.63–1.87)	1.75 ± 0.25 (1.57–1.92)	1.73 ± 0.12 (1.65–1.81)	1.76 ± 0.42 (1.46–2.06)	0.986	0.005
 Wall support	WST (s)	0.14 ± 0.03 (0.13–0.16)	0.15 ± 0.05 (0.13–0.18)	0.14 ± 0.04 (0.11–0.16)	0.14 ± 0.05 (0.11–0.17)	0.712	0.022
	F_{peak} (BW)	1.38 ± 0.36 (1.20–1.56)	1.49 ± 0.41 (1.27–1.70)	1.39 ± 0.41 (1.18–1.60)	1.32 ± 0.46 (1.08–1.55)	0.663	0.026
	Imp (BW · s)	0.11 ± 0.04 (0.09–0.13)	0.12 ± 0.05 (0.09–0.15)	0.11 ± 0.04(0.09–0.13)	0.10 ± 0.04 (0.08–0.12)	0.577	0.032
 Pushing	PT (s)	0.25 ± 0.05 (0.23–0.28)	0.26 ± 0.08 (0.22–0.30)	0.26 ± 0.07 (0.22–0.29)	0.26 ± 0.08 (0.22–0.30)	0.988	0.002
	F_{peak} (BW)	1.87 ± 0.25 (1.74–2.00)	1.89 ± 0.29 (1.74–2.03)	1.92 ± 0.26 (1.78–2.06)	1.86 ± 0.33 (1.69–2.03)	0.916	0.008
	Imp (BW · s)	0.33 ± 0.05 (0.30–0.36)	0.34 ± 0.05 (0.31–0.36)	0.33 ± 0.06 (0.30–0.36)	0.32 ± 0.06 (0.29–0.36)	0.933	0.007
	$VxCM_{push\text{-}off}$ (m · s^{-1})	2.62 ± 0.18 (2.49–2.75)	2.58 ± 0.20 (2.43–2.72)	2.59 ± 0.15 (2.48–2.70)	2.49 ± 0.24 (2.31–2.66)	0.477	0.074
 Gliding	GT (s)	0.68 ± 0.20 (0.58–0.78)	0.73 ± 0.21 (0.62–0.84)	0.65 ± 0.19 (0.55–0.75)	0.67 ± 0.19 (0.57–0.77)	0.755	0.019
	$CM_{maxdepth}$ (m)	0.49 ± 0.08 (0.43–0.55)	0.47 ± 0.13 (0.38–0.56)	0.49 ± 0.10 (0.42–0.56)	0.52 ± 0.12 (0.43–0.60)	0.781	0.033
	$VxCM_{glide}$(m · s^{-1})	1.85 ± 0.22 (1.69–2.00)	1.78 ± 0.21 (1.63–1.92)	1.94 ± 0.22 (1.78–2.09)	1.85 ± 0.23 (1.63–2.03)	0.357	0.095
	$VxCM_{end}$(m · s^{-1})	1.43 ± 0.46 (1.10–1.76)	1.42 ± 0.92 (0.76–2.07)	1.58 ± 0.66 (1.11–2.06)	1.53 ± 0.49 (1.34–1.73)	0.957	0.010
	$DxCM_{end}$ (m)	2.60 ± 0.22 (2.44–2.76)	2.68 ± 0.23 (2.51–2.84)	2.58 ± 0.20 (2.43–2.72)	2.51 ± 0.26 (2.32–2.70)	0.487	0.072
	TT (s)	2.37 ± 0.32 (2.21–2.53)	2.43 ± 0.33 (2.26–2.60)	2.40 ± 0.34 (2.22–2.57)	2.40 ± 0.40 (2.20–2.61)	0.957	0.005
	5 mRTT (s)	5.76 ± 0.72 (5.39–6.13)	5.81 ± 0.82 (5.39–6.23)	5.80 ± 0.78 (5.40–6.20)	5.82 ± 0.81 (5.40–6.23)	0.957	0.005

Note: BW: units of body weight; $CM_{maxdepth}$: centre of mass maximum depth during the gliding phase; $DxCM_{end}$: distance from the swimmer's centre of mass at the end of the gliding phase and the pool wall; η_p^2: partial eta squared; 5 mRTT: turn time from 5 m into the wall to 5 m out; F_{peak}: force peak; GT: glide time; Imp: impulse; IRD: initial rolling distance; RT: rolling time; TT: total turn time; $VxCM_{end}$: centre of mass horizontal instantaneous velocity at the end of the gliding phase; $VxCM_{glide}$: centre of mass horizontal average velocity during the gliding phase; $VxCM_{push\text{-}off}$: centre of mass horizontal velocity at the end of the push-off; WST: wall support time.

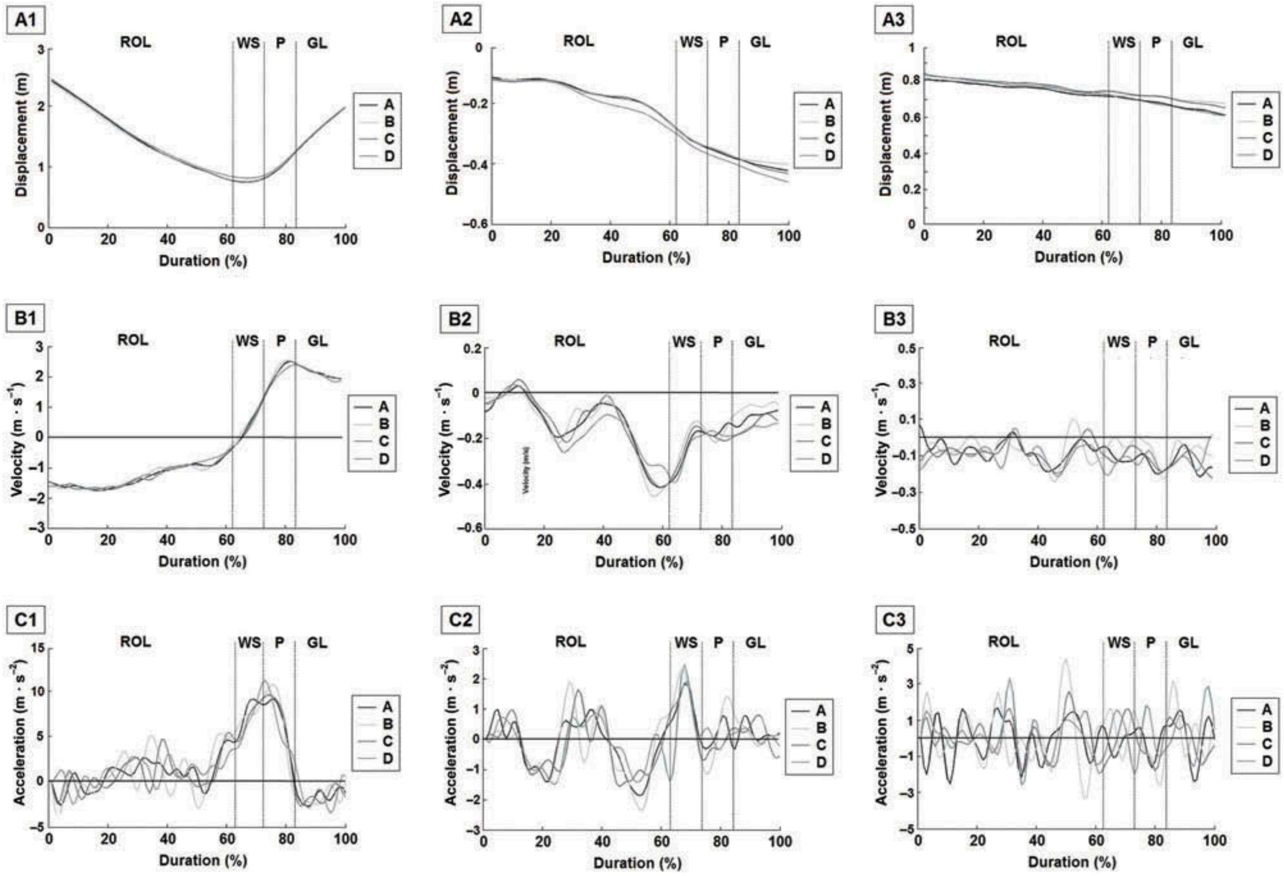


Figure 2. Mean curves of the displacement (A1 = *x* axis; A2 = *y* axis; A3 = *z* axis), velocity (B1 = *x* axis; B2 = *y* axis; B3 = *z* axis) and acceleration (C1 = *x* axis; C2 = *y* axis; C3 = *z* axis) of swimmers' centre of mass during the performance of the turn phases (ROL = rolling; WS = wall support; P = pushing; GL = gliding) in each flip turn variant (A, B, C or D). Data are normalised in the horizontal axes by the total turn time, considering the beginning of the rolling phase as "zero" and the gliding end as "100%".

kinematic parameters. Figure 3 was built to show the profiles of muscle activation for *Gastrocnemius Medialis, Tibialis Anterior, Biceps Femoris* and *Vastus Lateralis* in each flip turn variant.

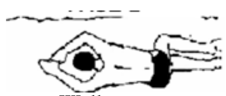
Discussion

This study aimed to describe and compare kinetic, kinematic and EMG characteristics of the four most used flip turn variants in international freestyle swimming events. None of the 80 variables studied showed significant differences between technical variants of the front crawl flip turn, not allowing to choose one as the more effective technical variant of the studied action. Although there were no statistical differences between the variants studied, some issues can be pointed out, considering that at a high or top competition level, very small differences of time – that might not be identified by statistical tests – could be decisive. Indeed, despite the inexistence of statistically significant differences between variants, the "group effect" might have "masked" individual beneficial effects of a particular variant regarding a specific swimmer, suggesting that swimmers and coaches should attentively analyse and train different technical alternatives to select, at least chronometrically, the best adapted to each case.

During the rolling phase, the D variant shows a macroscopically different global body movement, once in this variant the swimmer turns laterally, combining rotational movements both on horizontal anterior–posterior and medial–lateral axes, unlike in the other variants. Despite this clear technical difference, no statistical differences were observed in the rolling time with the A, B and C variants, all characterised by a dorsal rotation. Furthermore, Puel et al. (2012) showed that for elite swimmers the best 3-m turning performances are related with higher distances from the head of the swimmer to the wall before the starting of the turning action, but, in the current study, the rolling distance presented no differences between the four variants.

No difference was found when comparing the kinematic (wall support time, pushing time and centre of mass horizontal velocity at the end of the push-off) and kinetic (force peak and

Table II. Mean ± *s* (95% confidence interval) values of the average EMG signal amplitude, expressed as percentage of maximal isometric voluntary contraction, in each phase of the analysed flip turn variants (A, B, C and D); and results of the comparison between the variants (*P*-value and effect size).

Turning phase	Muscle	Turning variant					
		A	B	C	D	*P-value*	η_p^2
	GM	30.5 ± 37.4 (5.4–55.8)	34.0 ± 48.3 (1.6–66.5)	31.0 ± 39.0 (4.9–57.3)	29.9 ± 40.2 (2.9–56.9)	0.999	0.001
	TA	21.1 ± 9.3 (14.9–27.5)	20.7 ± 8.6 (15.0–26.6)	19.8 ± 7.4 (14.8–24.9)	21.5 ± 8.3 (15.9–27.1)	0.990	0.003
	BF	9.6 ± 7.4 (4.6–14.2)	10.0 ± 5.0 (6.6–13.4)	15.6 ± 26.6 (2.3–33.6)	8.0 ± 3.4 (5.8–10.3)	0.791	0.028
Rolling	VL	15.7 ± 9.4 (9.3–22.1)	18.3 ± 9.9 (11.6–25.0)	16.3 ± 8.7 (10.4–22.2)	17.9 ± 12.9 (9.2–26.6)	0.962	0.008
	GM	68.9 ± 98.4 (2.8–135.1)	100.6 ± 109.1 (27.3–173.9)	70.2 ± 76.2 (19.0–121.5)	115.7 ± 184.6 (8.3–239.8)	0.864	0.020
	TA	33.2 ± 18.4 (20.9–45.6)	36.2 ± 17.7 (24.3–48.1)	33.7 ± 17.6 (21.8–45.6)	41.2 ± 19.7 (28.0–54.6)	0.679	0.041
	BF	18.1 ± 14.4 (8.4–27.8)	20.0 ± 14.2 (10.5–29.7)	27.2 ± 43.9 (2.2–56.8)	22.7 ± 20.9 (8.7–36.8)	0.941	0.011
Wall support	VL	80.5 ± 45.0 (50.3–110.7)	81.7 ± 44.1 (52.1–111.4)	75.1 ± 45.5 (44.5–105.7)	85.8 ± 59.9 (45.6–126.2)	0.982	0.005
	GM	152.5 ± 119.0 (72.6–232.6)	167.6 ± 152.3 (65.2–270.0)	142.3 ± 117.0 (63.7–221.0)	143.5 ± 116.1 (65.5–221.6)	0.989	0.003
	TA	22.6 ± 10.8 (15.3–29.9)	24.1 ± 13.3 (15.2–33.1)	21.1 ± 8.6 (15.4–27.0)	22.6 ± 10.8 (15.4–30.0)	0.909	0.015
	BF	16.5 ± 7.6 (11.4–21.7)	17.2 ± 11.4 (9.6–24.9)	22.5 ± 9.1 (16.4–28.8)	20.4 ± 9.0 (14.3–26.5)	0.600	0.050
Pushing	VL	63.6 ± 31.9 (42.1–85.1)	61.6 ± 24.1 (45.5–77.8)	57.3 ± 27.1 (39.1–75.6)	68.7 ± 37.2 (43.7–93.8)	0.861	0.020
	GM	40.4 ± 30.3 (20.1–60.8)	37.5 ± 28.5 (18.3–56.7)	39.9 ± 28.2 (21.0–59.0)	38.1 ± 29.1 (18.6–57.8)	0.983	0.004
	TA	7.7 ± 3.0 (5.7–9.8)	8.0 ± 3.4 (5.7–10.3)	9.4 ± 3.3 (7.2–11.7)	7.3 ± 3.7 (4.8–9.9)	0.544	0.057
	BF	16.3 ± 11.4 (8.6–24.0)	16.5 ± 14.3 (6.9–26.2)	25.2 ± 25.6 (8.0–42.5)	16.6 ± 11.9 (8.6–24.7)	0.697	0.039
Gliding	VL	27.7 ± 11.5 (20.0–35.4)	26.9 ± 12.3 (18.7–35.2)	29.9 ± 13.9 (20.6–39.4)	28.2 ± 15.7 (17.7–38.8)	0.974	0.006

Note: BF: *Biceps Femoris*; GM: *Gastrocnemius Medialis*; TA: *Tibialis Anterior*; VL: *Vastus Lateralis*; η_p^2: partial eta squared.

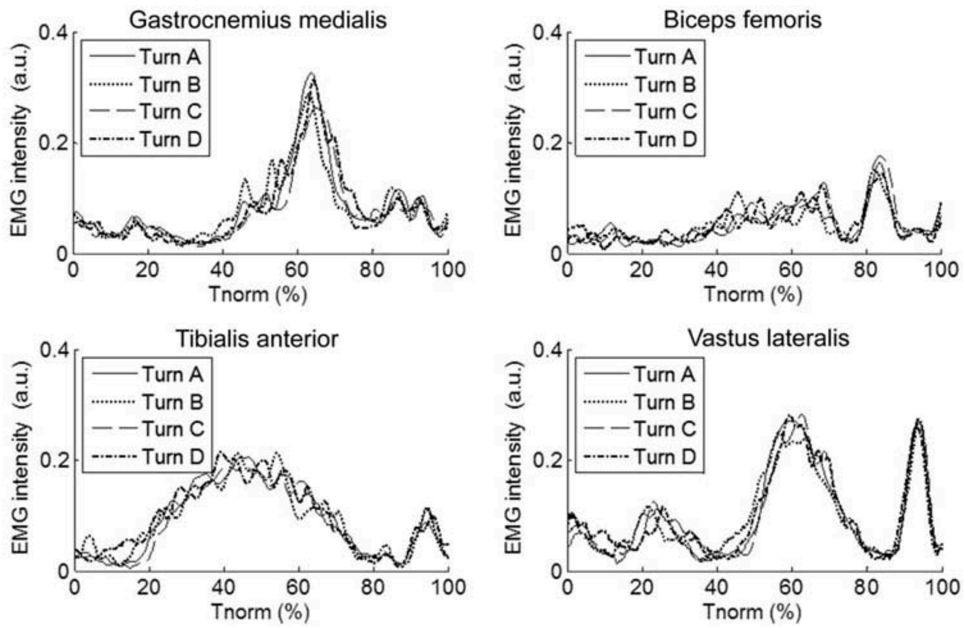


Figure 3. Mean typical curves presented by the swimmers for the activity of *Gastrocnemius Medialis, Tibialis Anterior, Biceps Femoris* and *Vastus Lateralis* in each flip turn variant (A, B, C or D). Data are expressed as arbitrary units (a.u.) and are normalised in the horizontal axes by the total turn time, considering the beginning of the rolling phase as "zero" and the gliding end as "100%".

horizontal impulse) variables during the wall contact (wall support and pushing phases) between the flip turn variants. Counsilman (1984) suggested that the lateral positioning of the body during the wall contact favours an effective push-off. However, Teel (1998) referred that the turn could be faster when using the dorsal support. It is assumed that when the swimmer touches the wall with his/her feet pointing to the water's surface – as in variant B – even though he/she is able to roll faster, more time should be spent to adjust the body in a suitable position to perform the subsequent impulse. Force peak and impulse values found in the present study were similar to those presented in previous studies which analysed swimmers with comparable age and technical level (Hubert et al., 2003; Lyttle & Mason, 1997).

The terminal velocity of the pushing action has been considered by different authors (Blanksby, Skender, Elliott, McElroy, & Landers, 2004; Clothier, 2004; Lyttle, 1999) as one of the most performance influencing variables of the flip front crawl turning technique. This variable depends on an optimal combination between the generated push-off force and the reduction of the drag force, searching for the most aligned and hydrodynamic position. According to Costill, Maglischo, and Richardson (1992), during the gliding phase a ventral position should be maintained in a hydrodynamic condition until the swimming speed is reached. From the work of Lyttle, Blanksby, Elliott, and Lloyd (2000), it seems that there is no difference between the lateral and ventral gliding techniques. However, Marinho, Barbosa, Rouboa, and Silva (2011) have recently showed, through a computational fluid dynamics analysis, that the lateral position was the one in which the drag is lower and authors suggest it seems to be the one that should be adopted during the gliding after starts and turns. Although the difference between variants was not significant in this study, we observed slightly higher values for the centre of mass horizontal average velocity during gliding and for the centre of mass instantaneous velocity at the end of gliding when swimmers performed the lateral gliding without executing a rotation during the push-off (variant C). However, we agree if there is a supposed advantage in doing that, it might be compensated after gliding, because the swimmers still need to rotate their bodies to get in to the proper swimming position. Thus, no differences would occur in the overall turn performance, as we observed in this study when comparing the 5 m round trip time between the variants.

Still considering the kinematical variables, it is possible to observe a high similarity between variants regarding the distance from the swimmer's centre of mass at the end of the gliding and the pool wall and the total turn time, suggesting that swimmers were able to cover the same distance in the same time period, irrespectively of the flip turn variant used. Curves of the displacement, velocity and acceleration of the centre of mass during the turning action (Figure 2) showed, again, a high similarity between flip turning variants, particularly over the anteroposterior horizontal axis, over which most of the turning actions occur.

Regarding the electromyographic activity in swimming, there are a few studies analysing the upper and/or lower limb muscles in front crawl (Caty et al., 2007; Figueiredo, Sanders, Gorski, Vilas-Boas, & Fernandes, 2013; Stirn, Jarm, Kapus, & Strojnik, 2011) and in backstroke (de Jesus et al., 2011; Hohmann, Fehr, Kirsten, & Krueger, 2008) and front crawl (Krüger, Wick, Hohmann, El-Bahrawi, & Koth, 2003) starts. However, this is the first study to investigate the EMG characteristics during the front crawl flip turn. Observing Figure 3, it is possible to perceive that the neuromuscular behaviour of the muscles selected for EMG analysis was very similar between the flip turn variants. This similarity was confirmed by the statistical analysis for all EMG parameters measured in this study. It is possible that future analysis of other muscle groups involved in the rolling and pushing actions, namely the lateral muscles of the trunk and those of the upper limbs, may show differences in the activation pattern when considering different variants of the flip turn technique. By analysing the average EMG values presented in Table II, it is possible to observe that *Gastrocnemius Medialis* and *Vastus Lateralis* are mainly active during the wall support and pushing phases, which could be expected because of their main role as ankle and knee extensors, respectively. The mean levels of activation of *Tibialis Anterior* were very similar during the rolling, wall support and pushing phases, and its activity decreases during the gliding, once the swimmers adopt a plantarflexed position at this phase. The *Biceps Femoris* had a more subtle participation during the whole turn, regardless of the variant used.

In spite of the novelty and relevance of data presented in this article, limitations should be addressed. The authors recognise that the statistical power and the generalisation of main findings are dependent upon a large number of observations. Due to the technical issues that have been previously described, different sample sizes were used for centred approaches in each type of variables. Yet, considering the complexity of the methodology and data collection, the results should be considered preliminary, although important, and used with caution.

Conclusion

This study is the first to investigate combined biomechanical parameters in different variants for the front crawl flip turn technique. The four analysed turning variants were not distinguishable in terms of kinematical, kinetic and EMG parameters during the rolling, wall support, pushing and gliding phases. Apparently, the choice of any of the flip turning variant can be made accordingly to the swimmer's subjective preference, if supported by chronometric validation. The authors believe that further analyses considering the relationship between variables and turn performance can provide a better support for the determination of the most efficient flip turn variant.

Funding

This work was supported by the Fundação para a Ciência e a Tecnologia, Portugal [grant number BD31854/2006].

References

Abdel-Aziz, Y., & Karara, H. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. In: *Proceedings of the American Society of Photogrammetry Symposium on Close Range Photogrammetry* (pp. 1–18). Falls Church, VA: American Society of Photogrammetry.

Blanksby, B., Gathercole, D., & Marshall, R. (1996). Force plate and video analysis of the tumble turn by age-group swimmers. *Journal of Swimming Research*, *11*, 40–45.

Blanksby, B., Skender, S., Elliott, B., McElroy, K., & Landers, G. (2004). An analysis of rollover backstroke turn by age-group swimmers. *Sports Biomechanics*, *3*, 1–14. doi:10.1080/14763140408522826

Caty, V., Aujouannet, Y., Hintzy, F., Bonifazi, M., Clarys, J., & Rouard, A. (2007). Wrist stabilisation and forearm muscle coactivation during freestyle swimming. *Journal of Electromyography and Kinesiology*, *17*(3), 285–291. doi:10.1016/j.jelekin.2006.02.005

Chow, J., Hay, J., Wilson, B., & Imel, C. (1984). Turning techniques of elite swimmers. *Journal of Sports Sciences*, *2*, 241–255. doi:10.1080/02640418408729720

Clarys, J., & Cabri, J. (1993). Eletromyography and the study of sports movements: A review. *Journal of Sports Sciences*, *11*, 379–448. doi:10.1080/02640419308730010

Clothier, J. (2004). *Underwater kicking following the freestyle tumble turn* (Unpublished doctoral thesis). University of Ballarat, Ballatat, Victoria, Australia.

Costill, D., Maglischo, E., & Richardson, A. (1992). *Swimming*. Oxford: Blackwell Scientific Publications.

Counsilman, J. (1984). *The swimming: Science and technique for champions*. Rio de Janeiro: Interamericana.

de Jesus, K., de Jesus, K., Figueiredo, P., Gonçalves, P., Pereira, S., Vilas-Boas, J. P., & Fernandes, R. J. (2011). Biomechanical analysis of backstroke swimming starts. *International Journal of Sports Medicine*, *32*, 546–551. doi:10.1055/s-0031-1273688

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics*, *29*, 1223–1230. doi:10.1016/0021-9290(95)00178-6

Figueiredo, P., Sanders, R., Gorski, T., Vilas-Boas, J. P., & Fernandes, R. J. (2013). Kinematic and electromyographic changes during 200 m front crawl at race pace. *International Journal of Sports Medicine*, *34*(1), 49–55. doi:10.1055/s-0032-1321889

Haljand, R. (1998). *Technical preparation of swimming starts turns and stroke*. Tallin: Tallin University of Education Sciences.

Hohmann, A., Fehr, U., Kirsten, R., & Krueger, T. (2008). Biomechanical analysis of the backstroke start technique in swimming. *E-Journal Bewegung Und Training*, *2*, 28–33.

Hubert, M., Roesler, H., Araujo, L., Pereira, S., Santos, L., & Schütz, G. (2003). Influence of the dynamic variables in the time of execution to crawl swim turn. In H.-J. Menzel, M. Chagas, L. Salmela, & S. Fonseca (Eds.), *Proceedings of the X Brazilian biomechanics conference* (pp. 207–210). Ouro Preto: Universidade Federal de Minas Gerais.

Konrad, P. (2006). *The ABC of EMG: A practical introduction to kinesiological electromyography*. Scottsdale: Noraxon USA.

Krüger, T., Wick, D., Hohmann, A., El-Bahrawi, M., & Koth, A. (2003). Biomechanics of the grab and track start technique. In J.-C. Chatard (Ed.), *Biomechanics and medicine in swimming IX* (pp. 219–223). Saint-Étienne: Publications de l'Université de Saint-Étienne.

Lyttle, A. (1999). *Hydrodynamics of the human body during the freestyle tumble turn* (Unpublished doctoral thesis). The University of Western Australia, Nedlands, Australia.

Lyttle, A., & Benjanuvatra, N. (2004). Optimising swim turn performance. Retrieved from http://www.coachesinfo.com/article/281

Lyttle, A., Blanksby, B., Elliott, B., & Lloyd, D. (1999). Investigating kinetics in the freestyle flip turn push-off. *Journal of Applied Biomechanics*, *15*, 242–252.

Lyttle, A., Blanksby, B., Elliott, B., & Lloyd, D. (2000). Net forces during tethered simulation of underwater streamlined gliding and kicking techniques of the freestyle turn. *Journal of Sports Sciences*, *18*, 801–807. doi:10.1080/026404100419856

Lyttle, A., & Mason, B. (1997). A kinematic and kinetic analysis of the freestyle and butterfly turns. *Journal of Swimming Research*, *12*, 7–11.

Maglischo, E. W. (2003). *Swimming fastest: The essential reference on technique, training and program design* (3rd ed.). Champaign, IL: Human Kinetics.

Marinho, D., Barbosa, T. M., Rouboa, A. I., & Silva, A. J. (2011). The hydrodynamic study of the swimming gliding: A two-dimensional computational fluid dynamics (CFD) analysis. *Journal of Human Kinetics*, *29*, 49–57. doi:10.2478/v10078-011-0039-4

Mason, B., & Cossor, J. (2001). Swim turn performances at the Sydney 2000 Olympic Games. In: *Proceedings of XIX International Symposium on Biomechanics in Sports* (pp. 65–69). San Francisco: University of California at San Francisco.

Pereira, S., Gonçalves, P., Fernandes, R., Machado, L., Roesler, H., & Vilas-Boas, J. (2010). Graphic removal of water wave impact in the pool wall during the flip turn. In P.-L. Kjendlie, R. Stallman, & J. Cabri (Eds.), *Biomechanics and medicine in swimming XI* (pp. 148–150). Oslo: Norwegian School of Sport Science.

Pereira, S., Ruschel, C., Souza, T., Araujo, L., Gonçalves, P., Fernandes, R., … Vilas-Boas, J. P. (2011). Comparative analysis of temporal parameters of different techniques of the freestyle flip turn. *Portuguese Journal of Sport Sciences*, *11*(supp. 2), 359–362.

Puel, F., Morlier, J., Avalos, M., Mesnard, M., Cid, M., & Hellard, P. (2012). 3D kinematic and dynamic analysis of the front crawl tumble turn in elite male swimmers. *Journal of Biomechanics*, *45*(3), 510–515. doi:10.1016/j.jbiomech.2011.11.043

Roesler, H. (2003). Turning force measurement in swimming using underwater force platform. In J. Chatard (Ed.), *Biomechanics and medicine in swimming IX* (pp. 243–248). Saint-Étienne: Publications de l'Universite de Saint-Étienne.

Stirn, I., Jarm, T., Kapus, V., & Strojnik, V. (2011). Evaluation of muscle fatigue during 100-m front crawl. *European Journal of Applied Physiology*, *111*(1), 101–113. doi:10.1007/s00421-010-1624-2

Teel, D. (1998). *Biomechanical analysis of the freestyle flip turn* (Unpublished master's thesis). Southern Connecticut State University, New Haven, Connecticut, USA.

Vilas-Boas, J., & Fernandes, R. (2003). Swimming starts and turns: Determinant factors of swimming performance. In P. Pelayo & M. Sydney (Eds.), *Proceedings des 3èmes Journées Spécialisées en Natation* (pp. 84–95). Lille: Faculté des Sciences du Sport et de l'Education Physique de l'Université de Lille.

Wu, G., & Cavanagh, P. R. (1995). ISB recommendations for standardization in the reporting of kinematic data. *Journal of Biomechanics*, *28*(10), 1257–1261. doi:10.1016/0021-9290(95)00017-C