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Research article

Backstroke-to-Breaststroke Turns Muscular Activity. A Study Conducted in Age Group Swimmers

Phornpot Chainok [1,2]✉, Jessy Lauer [2,3], Pedro Gonçalves [2,3], Karla de Jesus [2,3,4], Ricardo J. Fernandes [2,3] and Joao Paulo Vilas-Boas [2,3]

[1] Faculty of Sport, Burapha University, Chonburi, Thailand; [2] Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, Porto, Portugal; [3] Porto Biomechanics Laboratory, University of Porto, Portugal, [4] Faculty of Physical Education and Physiotherapy, Federal University of Amazonas, Manaus, Brazil

Abstract

The aims of this study were to compare surface electromyographic (EMG) activity and kinematic variables among open, somersault, bucket and crossover backstroke-to-breaststroke turning techniques, and identify relationships between the integrated electromyography (iEMG) and kinematics profile focusing on the rotation and push-off efficacy. Following a four-week of systematically increasing contextual interference intervention program, eight 12.38 ± 0.55 years old male swimmers randomly performed twelve repetitions (three in each technique) turns in and out of the wall at maximum speed until the 7.5 m reference mark. Surface EMG values of the right vastus lateralis, biceps femoris, tibialis anterior, gastrocnemius medialis, rectus abdominis, external oblique, erector spinae and latissimus dorsi were recorded and processed using the integrated electromyography (iEMG) and the total integrated electromyography (TiEMG) that was expressed as a percentage of iEMGmax to normalize per unit of time for each rotation and push-off phase. Complementarily, 2D sagittal views from an underwater video camera were digitized to determine rotation and push-off efficacy. The crossover turn presented the highest rotation and push-off iEMG values. Erector spinae and gastrocnemius medialis had the highest activity in the rotation and push-off phases (89 ± 10 and 98 ± 69%, respectively). TiEMG depicted a very high activity of lower limb muscles during push-off activity (222 ± 17 to 247 ± 16%). However, there were no relation between TiEMG and rotation and push-off time, tuck index and final push-off velocity during the rotation and the push-off phases across all the studied turning techniques. The rotation efficacy in age-group swimmers were dependent on rotation time ($p = 0.04$). The different turning techniques were not distinguishable regarding iEMG activity as a possible determinant of rotation and push-off efficacy. Our study has direct implications for selecting appropriate exercises and designing training programs for optimizing the rotation and push-off phases of backstroke-to-breaststroke turning at young ages.

Key words: Surface electromyography, turning techniques, individual medley, young swimmert.

Introduction

In competitive swimming the turning phase plays a critical role in determining the winners and the losers (Chow et al., 1984; Vilas-Boas et al., 2002; Prins and Patz, 2006) and should be a key factor of the training process (Blanksby et al., 1998; Faelli et al., 2021). Previously to the specialization training phase, when developing swimming fundamentals, coaches should include specific turns in their programs to enhance age-group swimmers effectiveness. Since there are different turning techniques, more than using subjective criteria, it is important to dispose of a deeper understanding of their particular demands, particularly regarding the execution and efficiency from the approach to the push-off phase.

The backstroke-to-breaststroke turn is, possibly, the most complex turning movement used in medley events (Gonjo and Olstad, 2020; Chainok et al., 2021) and its analysis is very difficult to carry out without appropriate technology (Vilas-Boas et al., 2002; Pereira et al., 2015; Chainok et al., 2016). In this specific turn, swimmers must touch the wall in a dorsal position and change the direction of motion using the open, somersault, bucket and crossover turning techniques (FINA swimming rules, SW 9.4 and 10.4; 2017-2021). Each one has different rotation mechanics and imposes different muscle recruitment and activation patterns, with the open turn being taught first due to its simplicity (Purdy et al., 2012; Gonjo and Olstad, 2020). Literature focusing on the biomechanical comparison of backstroke-to-breaststroke turning techniques is very scarce, probably due to the difficulties in analysing the integrated movement in different planes and axes, and the corresponding muscle activity (Blanksby et al., 1998; Veiga et al., 2014; Pereira et al., 2015).

The interest in muscle activity assessment during swimming is not new (Lewillie, 1971; Clarys, 1983), with surface electromyography (EMG) contributing decisively to the understanding of the technical actions when propelling through the water (Clarys and Rouard, 2011; Figueiredo et al., 2013; Martens et al, 2015). EMG analysis was also implemented for characterizing the starting phase (de Jesus et al., 2011) and for training optimization (Clarys and Cabri, 1993; Martens et al., 2016), but few studies analysed the muscular actions during the turning phase (Pereira et al., 2015). In fact, the analysis of the EMG activity of backstroke-to-breaststroke turning techniques was not yet done, not being known if technical variations (e.g. different body positions during the rotation and wall push off) could directly influence performance.

Although the muscle activity assessment during the turning phase is interesting, an observation of mastery technical capability should be taken into consideration since it could directly to robustness and reliability of the EMG results. Consistent with the aforementioned perspectives, facilitate learning to mastery the four backstroke-to-breaststroke turning techniques in age-group swimmers may be obtained from the level of the swimmers, past

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experience and scheduling of practice sessions (Seifert et al., 2016; Silva et al., 2019; Chainok et al., 2021). A practice schedule offering systematic increases in contextual interference which the blocked, serial and random trials scheduling have been very promising for established learning sports skills (Porter and Magill, 2010; Broadbent et al., 2015; Buszard et al., 2017) and beneficial for the key properties of continuous and complex skills (Porter and Magill, 2010; Porter and Beckerman, 2016).

Since there is no comprehensive understanding of the relative importance of the biomechanical determinants of different backstroke-to-breaststroke turning techniques, it was aimed to compare the EMG activity levels of four backstroke-to-breaststroke turns. In addition, it was proposed to observe the eventual relationships between the integrated electromyography (iEMG) and rotation and push-off time, tuck index and final push-off velocity. We hypothesized, that (1) the EMG response of lower limb and core muscles during the rotation and push-off phases would be sensitive to the different backstroke-to-breaststroke turning techniques, (2) the correlations and contributions of total iEMG activity and selected kinematics are expected to be evident in the rotation and push-off efficacy. Since these data are very important for age-group swimmers in particular in which young swimmers must build and consolidate a specific and detailed motor patterm of the turn (Faelli et al., 2021), we have centred our attention on evaluating 11 and 12-years-old swimmers engaged in systematic increases in contextual interference training.

Methods

Subjects

Eight young male swimmers (12.38 ± 0.55 years old, 1.55 ± 0.14 m of height, 44.6 ± 10.9 kg of body mass, 14.1 ± 5.3% of body fat, 18.8 ± 2.3 kg/m^2 of body mass index and 3.3 ± 0.7 of Tanner maturational status) volunteered to participate in the current study. Swimmers belong to the same swimming club, had 3.5 ± 1.4 years of competitive swimming experience and 178.3 ± 10.1 s of the best performance in the 200 m short-course individual medley (corresponding to 62.3 ± 6.8 % of the world junior record). The local ethics committee approved the experimental procedures and the swimmers parents provided written informed consent.

Training protocol

Swimmers had a 2 h theoretical-practical lesson to perfect each turning technique, with video and verbal descriptive/prescriptive feedbacks being given to correct eventual technical errors (Pereira et al., 2015). Afterwards, a systematically increasing contextual interference intervention program took place (40 min per session four times a week during one month). The difficulty level progressively increased, with appropriate challenges based on skill level (Jefferys, 2006), facilitating learning and improving performance (Guadagnoli and Lee, 2004). Swimmers followed a block schedule on the first fourth sessions (each one focusing on the open, somersault, bucket and crossover turns). Then, a serial schedule was implemented from the fifth to the eighth and from the ninth to the twelfth sessions (respectively 10 and 5 min per turning technique, with the later one repeating twice). A random schedule was followed in the last four sessions, with an equal number of trials per turning technique.

Testing procedures

Following the intervention period, and after a usual warm-up, swimmers randomly performed 12 maximal 25 m repetitions (c.f. Chainok et al., 2021; Gonjo and Olstad, 2020; 12.5 m swimming to the wall, turning, gliding and resuming swimming until the 12.5 mark). Each backstroke-to-breaststroke turning technique was repeated three times (with a 3 min interval in-between) and the corresponding average was taken for posterior analysis. An experienced researcher observed each repetition and, if not completed properly, the swimmer was asked to repeat after resting.

Data collection

EMG activity was recorded from the body right side by using bipolar EMG with an eight-channel device (Figueiredo et al., 2013; de Jesus et al., 2016). It were selected the muscles that play a dominant role on lower limbs action (Pereira et al., 2015), trunk motion and core stabilizing action (Marras et al., 1998; Kumar, 2010): vastus lateralis, biceps femoris long head, tibialis anterior, gastrocnemius medialis, rectus abdominis, external oblique, erector spinae and latissimus dorsi. Swimmers skin was shaved and cleaned to reduce skin impedance (Figueiredo et al., 2013; Martens et al., 2016). Active silver chloride surface electrodes (Dormo, Telic, S.A., Spain) with preamplifiers (AD621BNZ; Analog Devices, Norwood, MA, USA) were placed in accordance with the European Recommendations for Surface Electromyography (Hermens et al., 2000) and were waterproofed using an adhesive bandage (Rouard and Clarys, 1995; Lauer et al., 2013; Pereira et al., 2015).

Each swimmer performed three dry land maximal voluntary isometric contractions for each muscle studied, which were held 5 s (followed by 5 min rest) and verbal encouragement was given to the subjects. The maximal value of three measurements was defined for normalization (cf. Pereira et al., 2015; de Jesus et al., 2016). Swimmers wore a complete Fast Skin swimsuit (Speedo, Nottingham, UK) and the EMG cables come out from the lateral malleolus (with the ground electrode being positioned over the patella). The total gain of the amplifier was set at 1100, with a common mode rejection ratio of 110 dB, with the EMG signals being stored at a 1000 Hz sampling frequency on an acquisition card with a 16-bit analog-to-digital converter (BIOPAC Systems, Goleta, CA, USA).

Kinematic variables were recorded using an underwater digital video camera (HDR CX160E; Sony Electronics Inc., Japan) placed inside a waterproof housing (Sony SPK-HCH; Sony Electronics Inc., Japan) and operating at a 50 Hz sampling frequency and 1/250 digital shutter speed. It was fixed on a specially designed support at 5 m from the turning wall and 6.50 m from the swimmers sagittal plane, with the optical axis aligned perpendicularly to the sagittal plane (Araujo et al., 2010). To calibrate the performance space, a 4 m long, 1.5 m high and 2 m wide (horizontal, vertical and lateral axes) quadrangular frame was used (de Jesus et al., 2015). The swimming biomechanical

model comprised four rigid linked segments identified as lower limbs, head, arms and trunk). The video images and the EMG signal were synchronized through a visible-light trigger (Pereira et al., 2015; de Jesus et al., 2016).

Data treatment

MATLAB 2008a software (Math Works, Natick, MA, USA) was used for EMG signal processing, with raw EMG signals filtered using a fourth-order Butterworth band-pass filter (bandwidth 20 - 450 Hz), rectified and averaged to obtain the full-wave signals. The rectified EMG integration was calculated per unit of time (iEMG/T) for each turning phase to eliminate the phase duration effect and EMG signals were partitioned in 40 ms windows to find the maximal iEMG values ($iEMG_{max}$) for all studied muscles. iEMG/T was expressed as a percentage of $iEMG_{max}$ to normalize the results (Clarys, 2000) and calculated per phase (Lauer et al, 2013; Martens et al., 2015). Moreover, to obtain a more comprehensive understanding of the EMG activity and kinematic variables relative contributions in determining rotation and push-off efficacy, it was summed the normalized muscle activity of the core muscles ($TiEMG_{CBRO}$ and $TiEMG_{CBPO}$) and of the lower limbs ($TiEMG_{LLRO}$ and $TiEMG_{LLPO}$) during those phases (Feger et al., 2014; Figueiredo et al., 2013).

Kinematic analyses comprised two intermediate phases of the backstroke-to-breaststroke turn (Pereira et al., 2015): (i) rotation, starting immediately before the hand entry during the last upper limbs cycle before turning and ending before the feet touch the wall and (ii) push-off, starting on the initial feet-wall contact and ending before the feet push-off the wall. The anatomical landmarks were manually digitized frame by frame using the Ariel Performance Analysis System (Ariel Dynamics, San Diego, USA), with the image coordinates transformed to 2D object-space coordinates using the Direct Linear Transformation algorithm (Abdel-Aziz et al., 2015). After a 6 Hz low-pass Butterworth image filtering, it was analysed the rotation and push-off durations, the tuck index (the ratio between the distance of the femur greater trochanter from the wall at foot contact and the actual trochanteric height; Prins and Patz, 2006) and the final push-off velocity (the hips displacement at the last frame when leaving the wall; Prins and Patz, 2006).

Statistical analysis

Statistics were performed in SPSS for Windows version 24 (SPSS, Chicago, IL, USA), with the significance level being set at 0.05. Since an iEMG data normal distribution could not be assumed due to the sample size (checked using the Shapiro–Wilk W test), the non-parametric Kruskal–Wallis H test was used to compare the differences of iEMG and selected kinematic variables among four backstroke to breaststroke turning techniques. In addition, the Mann–Whitney U test was used for pairwise comparisons and the Spearman correlation analysis was conducted to verify the existence of relationships between rotation and push-off iEMG and kinematic variables. Intraclass correlation coefficient (≥ 0.75, 0.40 - 0.75 and < 0.40 expressing good, moderate and poor reproducibility, respectively; van Asseldonk et al., 2014) was determined by comparing the core and lower limbs muscles iEMG and relative activation time in each turning phase.

Results

Fair to good iEMG and relative activation time reproducibility values were achieved between trials per turning phase for open, somersault, bucket and crossover turning techniques (ICC = 0.43 - 0.97, 0.59 - 0.97, 0.44 - 0.95 and 0.42 - 0.97, respectively). Data regarding the EMG activity during the rotation phase are shown in Table 1, with differences among the turning techniques being observed for all muscles (except for rectus abdominis) and with the erector spinae revealing greater activity than the other muscles ($\chi^2(7) = 350.546$, $p < 0.001$). Figure 1 displays the median iEMG values during the rotation phase for the four turning techniques, with differences displayed for all muscles (except for the vastus lateralis).

Table 1. The integrated electromyography (iEMG) mean ± SD, median and interquartile range (IQR) of the rectus abdominis (RA), external oblique (EO), latissimus dorsi (LD), erector spinae (ES), biceps femoris (BF), vastus lateralis (VL), tibialis anterior (TA) and gastrocnemius medialis (GM) in the rotation phase for each studied backstroke-to-breaststroke turning technique and respective of χ^2 and p-values of the comparisons among techniques.

iEMG (%)	Turning techniques												χ^2	P<
	Open			Somersault			Bucket			Crossover				
														
	Mean±SD	Median	IQR	Mean±SD	Median	IQR	Mean± SD	Median	IQR	Mean±SD	Median	IQR		
RA	43.37±23.37	49.60	31.15	32.12±15.01	25.20	19.93	48.51±19.75	50.30	18.35	41.19±15.08	41.00	14.25	6.41	0.09
EO	11.62±6.26	11.60	11.63	11.26±11.57	9.60	24.30	2.69±2.67	2.55	2.85	31.25±11.17	31.00	10.25	36.74	**0.001**
LD	7.91±5.22	7.90	8.45	8.41±5.26	8.40	3.15	7.89±4.41	7.90	1.68	50.88±22.42	51.00	37.75	37.33	**0.001**
ES	52.50 ±19.39	52.50	0.00	48.18±30.83	48.20	23.00	77.70±11.91	77.70	0.00	89.10±10.00	89.00	0.00	30.04	**0.001**
BF	48.47±18.67	48.50	29.48	33.11±22.53	29.15	29.80	43.96±17.76	44.00	10.73	42.00±18.68	41.00	14.75	7.312	**0.001**
VL	36.29±14.94	36.30	12.78	41.98±20.20	42.00	33.25	37.37±26.20	37.40	27.38	41.94±11.86	42.00	0.00	4.174	**0.001**
TA	9.59±6.21	8.45	3.58	23.89±14.50	23.90	12.45	12.91±4.63	12.90	2.03	36.19±12.35	36.00	0.00	35.30	**0.001**
GM	8.29±3.05	8.30	0.00	31.63±15.11	38.80	24.30	29.22±8.62	29.20	5.18	45.88±15.99	46.00	5.00	40.44	**0.001**

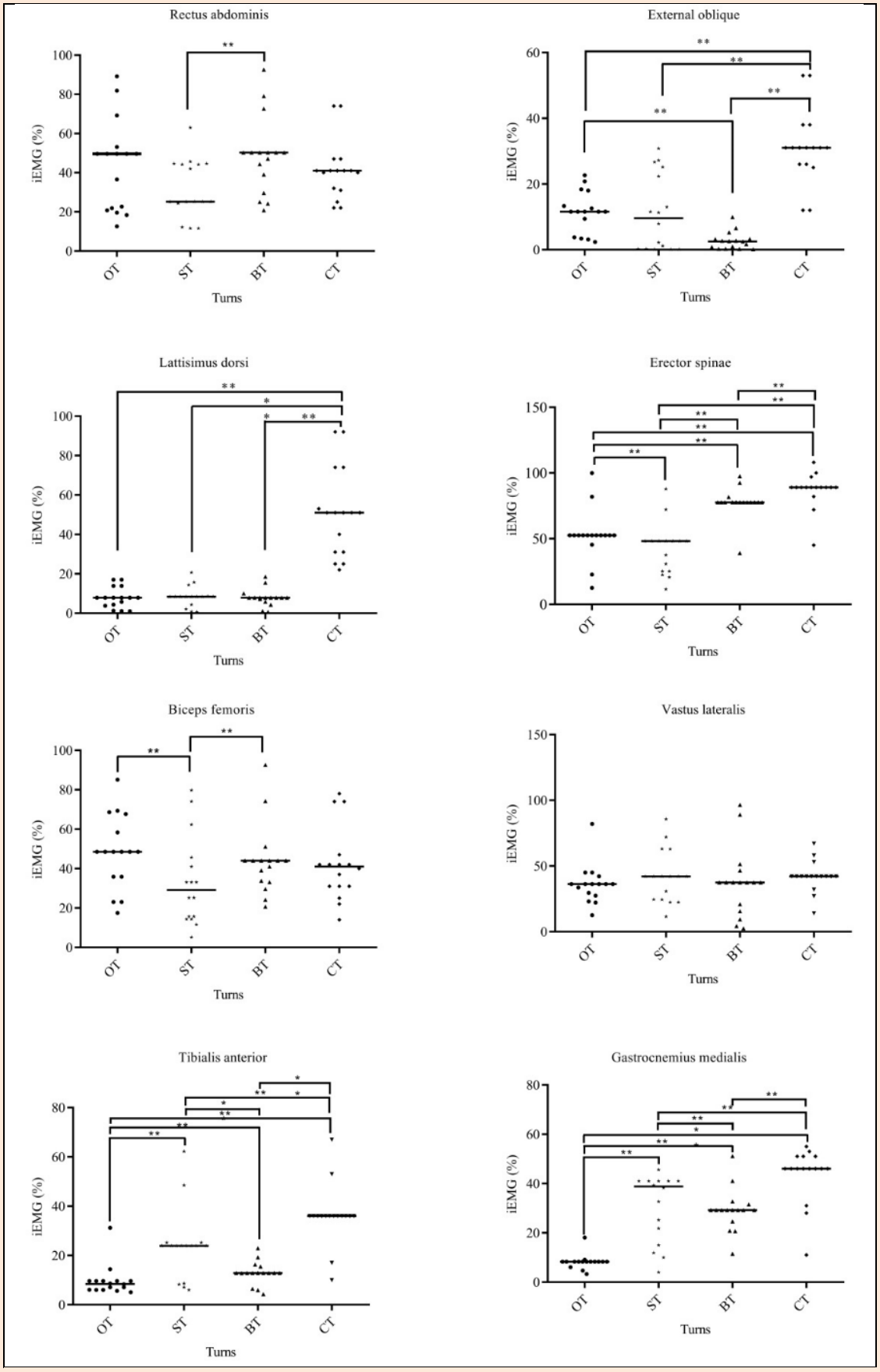

Figure 1. Median values of the normalized integrated EMG (iEMG; %) per phase of each muscle during the rotation phase of the open (OT), somersault (ST), bucket (BT) and cross-over (CT) backstroke-to-breaststroke turns. * and ** significant at $p < 0.05$ and 0.001 (respectively).

Regarding the push-off phase, differences in the EMG activity were found in-between the studied turns when comparing the external oblique, latissimus dorsi, erector spinae, biceps femoris and vastus lateralis (Table 2), with the gastrocnemius medialis exhibiting higher activity than the other muscles ($\chi2(7) = 266.437$, $p < 0.001$). Figure 2 shows the median iEMG values during the push-off phase for the four turning techniques, evidencing differences between all muscles (except for the tibialis anterior and gastrocnemius medialis).

Regarding the total muscle activation and selected kinematics during the rotation phase, we have observed differences among the four turning techniques in $TiEMG_{CBRO}$, $TiEMG_{LLRO}$ and $TiEMG_{CBPO}$ and rotation time (Table 3). The crossover turn displayed the highest $TiEMG_{CBRO}$, $TiEMG_{LLRO}$ and $TiEMG_{CBPO}$ values among the evaluated turns, and the somersault turn presented the highest $TiEMG_{LLPO}$ value. Complementarily, $TiEMG_{CBRO}$, $TiEMG_{LLRO}$ and $TiEMG_{CBPO}$ were higher in the crossover technique than in the other turns ($p < 0.001$), while $TiEMG_{LLRO}$ was higher in the somersault than in the open turn ($p < 0.001$). The studied turning techniques differed regarding the average rotation times, with the fastest being the open and bucket comparing to the crossover and somersault techniques, but no differences were observed regarding the push-off time, tuck index and final push-off velocity. The tuck index was higher in the open than in the somersault turn, while the final push-off velocity did not differ among four turning techniques (Table 4).

Table 2. The integrated electromyography (iEMG) mean ± SD, median and interquartile range (IQR) of the rectus abdominis (RA), external oblique (EO), latissimus dorsi (LD), erector spinae (ES), biceps femoris (BF), vastus lateralis (VL), tibialis anterior (TA) and gastrocnemius medialis (GM) in the push-off phase for each studied backstroke-to-breaststroke turning technique and respective of χ^2 and p-values of the comparisons among techniques.

iEMG (%)	Turning techniques: Open			Somersault			Bucket			Crossover			$\chi 2$	P<
														
	Mean±SD	Median	IQR	Mean±SD	Median	IQR	Mean±SD	Median	IQR	Mean±SD	Median	IQR		
RA	22.39±15.25	22.40	20.45	22.42±19.31	22.20	32.83	19.83±18.65	16.90	22.05	28.81±12.96	28.80	6.98	4.72	0.19
EO	3.30±4.36	0.80	5.43	2.89±4.60	0.45	2.70	2.93±4.80	0.60	2.63	4.32±1.99	4.30	2.10	9.19	0.03
LD	18.49±15.35	15.25	4.08	1.57±1.03	1.60	0.63	3.39±1.42	3.40	0.35	32.42±11.87	32.40	0.83	43.28	**0.001**
ES	42.78±15.35	42.80	1.95	32.41±16.08	32.40	13.05	54.88±21.73	54.90	13.12	63.89±16.14	63.90	10.50	24.55	**0.001**
BF	29.81±15.85	29.80	11.4	48.81±16.08	48.80	34.65	43.51± 5.47	43.50	32.60	35.80±19.41	35.80	9.83	9.27	**0.03**
VL	60.72±12.98	60.70	9.60	60.40±34.88	60.40	66.13	48.49± 5.55	32.30	37.47	39.28±22.80	39.30	25.90	11.16	**0.001**
TA	62.61±30.70	62.60	21.75	66.09±27.75	66.10	42.95	67.18± 6.42	67.20	99.70	55.23±29.59	55.20	41.15	1.94	0.59
GM	77.12±38.96	77.70	67.61	71.78±27.75	92.70	80.73	77.76± 5.74	76.05	92.50	91.38±48.40	98.25	69.55	1.88	0.61

Table 3. The total integrated electromyography (TiEMG) mean±SD, median and interquartile range (IQR) and selected kinematic for each studied backstroke-to-breaststroke turning technique and respective of χ^2 and *p*-values of the comparisons among techniques.

iEMG (%)	Turning techniques: Open			Somersault			Bucket			Crossover			$\chi 2$	P<
	Mean±SD	Median	IQR	Mean±SD	Median	IQR	Mean±SD	Median	IQR	Mean±SD	Median	IQR		
$TiEMG_{CBRO}$ (%)	115.4±7.0	116.50	39.85	106.2±12.7	100.3	62.1	136.8±5.2	136.9	32.4	212.3±7.0	210.0	48.5	32.95	**0.001**
$TiEMG_{LLRO}$ (%)	102.6±6.8	98.70	35.03	130.6±6.6	139.2	44.5	123.5±9.0	123.5	30.3	166.0±8.6	166.0	45.0	22.18	**0.001**
$TiEMG_{CBPO}$ (%)	87.0±9.3	86.05	46.53	59.0±6.2	60.9	39.8	81.0±7.8	80.7	33.4	129.4±7.2	125.8	13.4	27.72	**0.001**
$TiEMG_{LLPO}$ (%)	230.9±10.9	224.4	71.6	247.1±16.1	239.3	101.4	236.9±16.7	231.5	105.0	221.7±16.7	220.8	41.1	1.54	0.67
Rotation time (s)	1.31±0.05	1.32	0.35	1.56±0.07	1.58	0.37	1.36±0.07	1.29	0.39	1.44±0.07	1.48	0.41	8.57	**0.04**
Push-off time (s)	0.29±0.018	0.27	0.14	0.32±0.02	0.32	0.11	0.28±0.01	0.28	0.01	0.32±0.17	0.27	0.14	2.98	0.39
Tuck index	0.64±0.032	0.64	0.21	0.54±0.03	0.54	0.10	0.58±0.03	0.58	0.12	0.56±0.02	0.56	0.06	4.73	0.19
Final push-off velocity (m/s)	1.68±0.035	1.65	0.22	1.66±0.05	1.65	0.28	1.64±0.06	1.59	0.29	1.74±0.05	1.75	0.34	2.79	0.43

$TiEMG_{CBRO}$: total iEMG of core body muscles during rotation; $TiEMG_{LLRO}$: total iEMG of lower limbs during rotation; $TiEMG_{CBPO}$: total iEMG of core body muscles during push-off; $TiEMG_{LLPO}$: total iEMG of lower limbs during push-off.

Table 4. The post-hoc comparisons of the total integrated electromyography (TiEMG) and selected kinematic variables among four different backstroke-to-breaststroke turns.

Variables	Kruskal-Wallis H test		Mann-Whitney U test: Open vs. somersault		Open vs. bucket		Open vs. crossover		Somersault vs. bucket		Somersault vs. crossover		Bucket vs. crossover	
	H	Sig.	Z	Sig.	Z	Sig.	Z	Sig.	Z	Sig.	Z	Sig.	Z	Sig.
$TiEMG_{CBRO}$ (%)	32.95	0.001	98.00	0.26	72.00	**0.04**	10.00	**0.001**	61.00	0.01	15.50	**0.001**	15.00	**0.001**
$TiEMG_{LLRO}$ (%)	22.18	0.001	53.00	**0.001**	70.00	**0.03**	19.00	**0.001**	120.0	0.76	57.00	**0.001**	55.50	**0.001**
$TiEMG_{CBPO}$ (%)	27.72	0.001	66.00	**0.02**	109.50	0.49	40.00	**0.001**	74.00	0.04	11.00	**0.001**	25.00	**0.001**
$TiEMG_{LLPO}$ (%)	1.54	0.67	110.00	0.49	124.00	0.88	114.00	0.59	119.00	0.73	96.00	0.23	105.50	0.40
Rotation time (s)	8.57	0.04	59.00	**0.001**	126.0	0.94	88.00	0.13	69.00	0.03	98.00	0.26	94.00	0.20
Push-off time (s)	2.98	0.39	98.50	0.26	126.50	0.96	96.00	0.22	97.50	0.25	122.50	0.84	93.00	0.18
Tuck index	4.73	0.19	74.00	**0.001**	96.00	0.23	82.50	0.09	114.00	0.60	112.00	0.55	115.50	0.64
Final push-off velocity (m/s)	2.79	0.43	122.00	0.82	103.50	0.36	105.00	0.39	116.50	0.67	98.50	0.27	86.50	0.12

$TiEMG_{CBRO}$: total iEMG of core body muscles during rotation; $TiEMG_{LLRO}$: total iEMG of lower limbs during rotation; $TiEMG_{CBPO}$: total iEMG of core body muscles during push-off; $TiEMG_{LLPO}$: total iEMG of lower limbs during push-off.

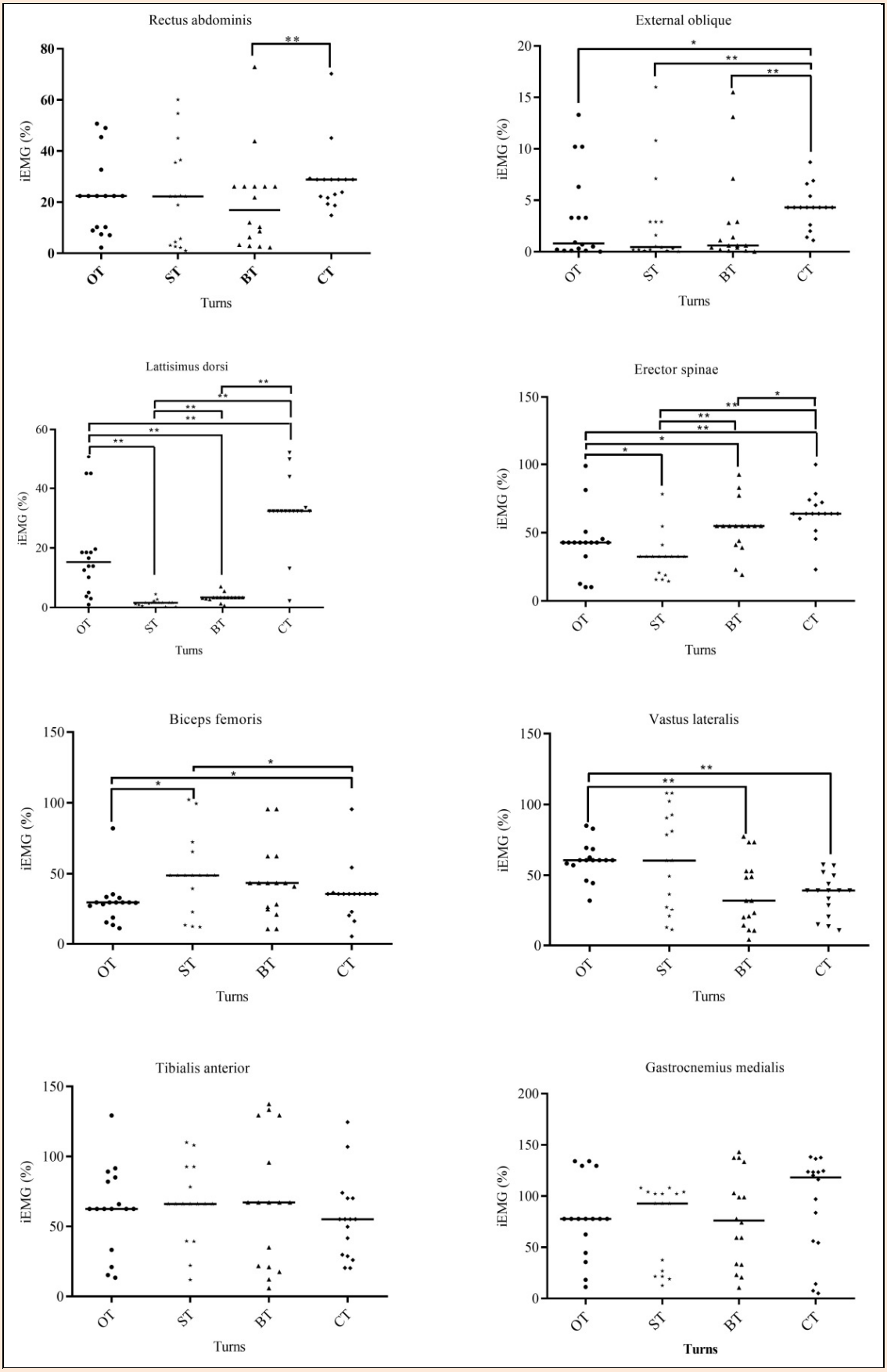

Figure 2. Median values for the normalized integrated EMG (iEMG; %) per phase of each muscle during the push-off phase of the open (OT), somersault (ST), bucket (BT) and cross-over (CT) backstroke-to-breaststroke turns. * and ** significant at $p < 0.05$ and 0.001 (respectively).

Table 5. Correlation coefficients between the total integrated electromyography (TiEMG) and selected kinematics variables in the rotation and push-off phase of each studied backstroke-to-breaststroke turning technique.

Turns	Statistical analysis values		Rotation phase			Push-off phase			
			TiEMG CBRO (%)	TiEMG LLRO (%)		TiEMG CBPO (%)	TiEMG LLPO (%)	Push-off time (s)	Tuck index
Open	Spearman rho	Rotation time (s)	-0.11	0.20	Final push-off velocity (m/s)	0.08	-0.23	0.01	0.32
	p-value		0.60	0.46		0.78	0.40	0.98	0.22
Somersault	Spearman rho		-0.18	-0.27		-0.50	0.20	0.33	-0.32
	p-value		0.51	0.31		**0.04***	0.66	0.22	0.23
Bucket	Spearman rho		0.33	-0.01		-0.30	0.16	-0.03	0.15
	p-value		0.21	0.99		0.26	0.56	0.92	0.59
Crossover	Spearman rho		-0.19	-0.20		0.18	-0.19	-0.01	-0.14
	p-value		0.47	0.45		0.50	0.49	0.98	0.60

$TiEMG_{CBRO}$: total iEMG of core body muscles during rotation; $TiEMG_{LLRO}$: total iEMG of lower limbs during rotation; $TiEMG_{CBPO}$: total iEMG of core body muscles during push-off; $TiEMG_{LLPO}$: total iEMG of lower limbs during push-off. * significant at $p < 0.05$.

Total muscle activation was not related to selected kinematic variables during the rotation and the push-off phases across all the studied turning techniques (Table 5). When analysing the contribution of iEMG activity and kinematics to rotation and push-off efficacy, it was only observed an inverse relationship between $TiEMG_{CBPO}$ and final push-off velocity in the somersault turn with all the other results not being statistically relevant.

Discussion

The current study is the first that measured and compared muscular activity among open, somersault, bucket and crossover backstroke-to-breaststroke turning techniques and was pioneer in assessing the relationships between EMG activity and selected kinematic variables regarding the rotation and push-off actions efficacy. Overall, the crossover turn presented the highest rotation and push-off iEMG values and erector spinae and gastrocnemius medialis had the highest activity in the rotation and push-off phases.TiEMG depicted a very high activity of lower limb muscles during push-off activity and there were no relation between TiEMG and selected kinematic variables during the rotation and the push-off phases across all turning techniques. In addition, the rotation efficacy in age-group swimmers were dependent on rotation time.

The orientation of the backstroke-to-breaststroke turns during the rotation phase may be described by the variations in the longitudinal rotation (Chainok et al., 2021), which relates to muscular activation and affects the rotation efficacy. The rotation phase execution is initiated by plantar flexion of the ankle, followed by knee and hip flexion, allowing the knees to be brought up to the chest, reducing the moment of inertia about the axis of rotation (Webster et al., 2011). Most of the selected lower and upper limb muscles were highly recruited in the crossover turn, which involves complex whole-body movements by combining twisting and rotational asymmetrical movements on both horizontal anterior-posterior and medial-lateral axes.

In the current study, the upper limb muscles (external oblique, lattisimus dorsi and erector spinae) were mainly activated during combined asymmetrical twisting and rotational movements, probably because torso dynamics is influenced by co-contraction recruitment, increasing trunk stiffness and resulting in greater muscle activity (Lee et al., 2006). Therefore, our hypothesis was partly supported. Notably, biceps femoris and rectus abdominis were the most active muscles in the open turn, acting as prime movers of the tucked position to facilitate knee flexion and assist hip flexion in the succeeding phases of rotation (respectively). The greater biceps femoris and rectus abdominis activation observed during the rotation phase could be related to the synergistic activation of the muscles crossing the knee and hip to provide a mechanical advantage in trunk to lower limbs coordination within posture and rotation movement (Mathiyakom et al., 2006; Yeadon and Hiley, 2014).

It was observed a high activation of vastus lateralis during somersault and crossover rotation, probably because it is the prime responsible for hip flexion. Vastus lateralis mainly contributes to the net joint moment and work done at the joints crossed while doing a reverse somersault (Mathiyakom et al., 2006). Interestingly, the gastrocnemius medialis was highly recruited when swimmers strongly swung backward to switch direction, meaning that age-group swimmers attempted to avoid excess drag and increased angular momentum by performing knee flexion and ankle plantar flexion while ultimate twist of the asymmetric hip movement. In this way, the net joint moment acting at the distal joint (ankle) is expected to be relatively large and, then, a relatively small action at the proximal joint (hip) is required to control the observed motion (Mathiyakom et al., 2006).

Integrated EMG interpretation becomes more complex when movements of large amplitude are involved, particularly regarding the core body muscles. As the swimmer initiates rolling in the bucket, open and somersault turns, lower limbs are brought up to the chest in a tight tuck, by co-activation of the hips and abdominal muscles (Chainok et al., 2016). The erector spinae and rectus abdominis were the main muscles activated during the rotation phase and the initiation of the hip flexion in a rotated posture is achieved by the activities of the contralateral external oblique and ipsilateral latissimus dorsi, followed by the erector spinae (Kumar et al., 1996; Kumar et al., 2002).

In fact, the erector spinae is one of the strongest muscles (most often recruited in bending movements) and is capable of producing more of a twisting moment when the torso is flexed (Marras et al., 1998). Its activity is highest at 40° of knee flexion due to greater mechanical disad-

vantage and having not reached the state of flexion–relaxation (Kumar, 2010). In contrast, the latissimus dorsi and external oblique muscles reduce their activity when the twisting motion is performed in an asymmetric posture (Marras et al., 1998), as it occurs in swimming turns. In the crossover turn, the erector spinae and latissimus dorsi were mainly activated during combined asymmetrical twisting and rotational movements, probably because torso dynamics is influenced by co-contraction recruitment, increasing trunk stiffness and resulting in greater muscle activity (Lee et al., 2006).

As expected, the main gastrocnemius medialis and tibialis anterior activities were observed during the push-off probably due to their role during the explosive lower limbs extension (Pereira et al., 2015). This high activation can be explained by the muscular co-contraction contribution (Lyttle et al., 1999) and the kinetic link of the mono-articular and biarticular muscles contributing from the proximal (hip) to distal (ankle) joints (Putnam, 1993; Jacobs et al., 1996). In fact, close kinetic chain movement involves multi-joint action developing mainly in biarticular muscle groups (Prokopy et al., 2008), with the closed kinetic chain of the lower limb extensors being directly related with jumping performance (Blackburn and Morrissey, 1998).

The stretch shortening cycle during the push-off consists on an eccentric contraction, mainly in biarticular muscles (quadriceps and gastrocnemius), while contact is followed by a concentric contraction producing an explosive movement while pushing off (Komi, 2000; Prins and Patz, 2006; Sousa et al., 2007). Therefore, it seems that a suitable contact time spent in the active phase and maximizing the use of elastic energy involved in the stretch shortening cycle for young swimmers can be used effectively during the push-off phase (Faelli et al., 2021).

Rotation and push-off efficacy have been accomplished using key kinematic, kinetic and hydrodynamic variables (e.g.Veiga et al., 2014). Nonetheless, comprehensive analysis of neuromuscular activation and selected kinematic factors including rotation time, push-off time, tuck index and final push-off velocity would provide a better understanding of those variables on backstroke-to-breaststroke turns. The slowest rotation time was found in the somersault turn that was lower than previously found for backstroke and breaststroke turns performed by age-group swimmers (Blanksby et al., 1998; Blanksby et al., 2004). It is also known that the rotation time varies widely among turning techniques regarding the degree of longitudinal rotation and different global body movement (Prins and Patz, 2006) and that task difficulty and learner past experiences could have a meaningful influence on the ability to learn dynamic movements (Guadagnoli and Lee, 2004).

No differences were found when comparing push-off time and final push-off velocity among the four studied backstroke-to-breaststroke turns. The influence of biomechanical variables linked to the contact phase on the final push-off velocity has been one of the most critical determinants of the flip and rollover backstroke turns (Blanksby et al., 2004; Prins and Patz, 2006; Pereira et al., 2015). The push-off time of the four different backstroke to breaststroke turns was relatively higher compared to data previously published regarding the flip turn (Lyttle et al., 1999). The wall contact time spent in the "active" push-off phase was likely to result in faster push-off velocities due to the mechanical and neuromuscular benefits of stretch shortening cycle (Prins and Patz, 2006; Faelli et al., 2021).

The final push-off velocities of the analysed turns were lower than those previously reported for age-group swimmers (Blanksby et al., 1996; Blanksby et al., 1998; Blanksby et al., 2004). It is possible that our young swimmers had not yet proper developed rotating and mechanical strategies to optimize the tuck index or the percentage of wall contact time spent in the active phase to maximize push-off efficacy. The tuck index in the open turn was higher than in the other turns, being known that higher tuck indexes lead to greater peak propulsive forces and lower wall contact times (Blanksby et al., 2004) However, the current study found that most tuck index values were closer to those previously reported for the breaststroke and the backstroke turns performed by age-group swimmers (Blanksby et al., 1998; Blanksby et al., 2004).

Following the previous studies that used the total EMG muscle activation as an analytical marker of task intensity and total muscle activation pattern for each extremity (Feger et al., 2014; Donnelly et al., 2015), our study provides a framework encouraging the use of EMG analysis for swimming training purposes. $TiEMG_{CBRO}$, $TiEMG_{LLRO}$ and $TiEMG_{CBPO}$ differed among turns due to the execution diversity and multi-link mechanism during rotation (in both lower limbs and core-body muscles). In addition, $TiEMG_{CBRO}$ and $TiEMG_{LLRO}$ exhibited the highest activation in the crossover turn. As expected, different turning technique rotation mechanics and strategies might directly reflected the increase of core body muscles co-activation to speed up the rotation time. During the push-off phase, $TiEMG_{LLPO}$ showed a very strong activity (with similar patterns among the four turning techniques), with gastrocnemius medialis being the main muscle activated during that phase in both age-group (Blanksby et al., 2004) and national level swimmers (Pereira et al., 2015). However, children maximal neuromuscular activation is generally lower than that of adults due to dimensionality, intramuscular synchronization and agonist–antagonist co-activation (Dotan et al., 2012).

Contrary to our expectations, selected kinematic variables and total muscle activation of iEMG did not presented strong relationships with rotation and push-off efficacy. However, a preliminary observation revealed an inverse relationship between $TiEMG_{CBPO}$ and final push-off velocity in the somersault turn, indicating that push-off performance should mainly activate co-contraction of muscles of the lower extremities. Interestingly, $TiEMG_{CBPO}$ showed greater activation in the crossover turn than in the other turns. The current results underline that muscular activation of the core body and lower extremities clearly exhibits the higher muscle activation in the crossover turn throughout the rotation and push-off phases. Data indicate that multiple factors (like differences in perceptual and cognitive skills, inherent variations and task difficulty) might account for these findings.

Conclusion

The current study allows concluding that: (i) the highest iEMG muscle activation occurred in the crossover turn throughout the rotation and push-off phases; (ii) the erector spinae revealed the highest activity during the rotation phase; (iii) biarticular gastrocnemius medialis and monoarticular tibialis anterior were mainly activated during the push-off phase; (iv) $TiEMG_{LLPO}$ showed very high activity with similar patterns in all turns during the push-off phase; and (v) selected kinematic variables and total iEMG muscle activation of iEMG did not influenced the rotation and push-off efficacy. These data provide valuable mechanistic insights into rotation and push-off phases of the most used backstroke-to-breaststroke turns, deepening the current understanding of the mechanical function and need for co-activation of the musculoskeletal system of age group swimmers. Moreover, the knowledge obtained from biomechanical analyses of the backstroke-to-breaststroke turn has direct implications for selecting appropriate exercises and designing training programs for optimizing this specific rotation and push-off phases at young ages. Future studies on this issue should reveal even more details of value for designing strength and conditioning training programs specialized in closed kinetic chain of the lower limb for "active" push-off phase, strengthening core muscles to improve the effectiveness of muscles co-activation to speed up the rotation.

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The experiments complied with the current laws of the country in which they were performed. The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study. The authors have no conflicts of interest to declare.

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Key points

- The orientation during rotation phase of the backstroke-to-breaststroke turns is related to difference core body and lower limb muscular activation that affects the rotation efficacy.
- Erector spinae revealed the highest activity during the rotation phase and gastrocnemius medialis and tibialis anterior were mainly activated during the push-off phase.
- The use of different core body and lower limb muscles showed promising evidence in the crossover turn throughout the rotation and push-off phases.
- Independent of the turning variant on the upper and lower limb muscles co-activation should be considered in specific closed kinetic chain of the lower limb for improving "active" push-off phase, strengthening core muscles to improve the effectiveness of muscles co-activation to speed up the rotation.

✉ **Phornpot Chainok**
Faculty of Sport Science, Burapha University, No. 169 Longhaad Bangsaen Road, Saensook, Mueang, ChonBuri 20131, Thailand

AUTHOR BIOGRAPHY

Phornpot CHAINOK
Employment
Lecturer at the Faculty of Sport Science - Burapha University.
Degree
PhD
Research interests
Sports biomechanics and biophysics in swimming
E-mail: phornpot@go.buu.ac.th

Jessy LAUER
Employment
Post-doctoral researcher at the Mathis lab Swiss Federal Institute of Technology
Degree
PhD
Research interests
Computer vision applied to behavior analysis and musculoskeletal simulations
E-mail: jessy.lauer@me.com

Pedro GONCALVE
Employment
Electro technical engineer at Faculty of Sport - University of Porto
Degree
MSc
Research interests
Biomechanic in swimming, sports training technology, sport performance
E-mail: pgoncalves@fade.up.pt

Ricardo J. FERNANDES
Employment
Associated professor 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

Karla DE JESUS
Employment
Lecturer at Faculty of Physical Education and Physiotherapy, Federal University of Amazonas
Degree
PhD
Research interests
Biomechanical research in swimming, sports training technology, sport performance
E-mail: karladejesus@ufam.edu.br

Joao Paulo VILAS-BOAS
Employment
Full professor at 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