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Kinematic and Electromyographic Changes During 200 m Front Crawl at Race Pace

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Key words
- swimming
- technique
- front crawl
- segmental kinematics
- muscle activity
- blood lactate

Abstract

The purpose of this study was to analyse eventual kinematic and electromyographic changes during a maximal 200 m front crawl at race pace. 10 male international level swimmers performed a 200 m maximal front crawl test. Images were recorded by 2 above and 4 under water cameras, and electromyographic signals (EMG) of 7 upper and lower limbs muscles were analysed for 1 stroke cycle in each 50 m lap. Capillary blood lactate concentrations were collected before and after the test. The variables of interest were: swimming speed, stroke length, stroke and kick frequency, hand angular velocity, upper limb and foot displacement, elbow angle, shoulder and roll angle, duration of stroke phases, and EMG for each muscle in each stroke phase. Generally, the kinematic parameters decreased, and a relative duration increased for the entry and pull phases and decreased for the recovery phase. Muscle activation of flexor carpi radialis, biceps brachii, triceps brachii, peitoral major and upper trapezius increased during specific stroke phases over the test. Blood lactate concentration increased significantly after the test. These findings suggest the occurrence of fatigue, characterised by changes in kinematic parameters and selective changes in upper limbs muscle activation according to muscle action.

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Introduction

In front crawl swimming, the production of propulsive forces to overcome a velocity-dependent water resistance (i.e., hydrodynamic drag force) is mainly generated by the arm stroke motion. The contribution of the arm action to the total front crawl propulsion generated in front crawl is estimated to be about 85 % [17,23]. Nevertheless, propulsion generation in swimming is not yet fully understood [35,40], it is know that propelling forces are strongly linked to kinematic hand parameters, as observed in different models of hand force calculation [7,20,35,41]. It was also suggested that swimming speed (v) could be partly explained by hand displacements in the horizontal (aligned with the direction of the motion) and vertical axes during the arm stroke [17], with hand speed being one of the main factors predicting swimming speed [39].

Studies regarding the effect of fatigue on the arm stroke kinematics during high intensity swimming are limited. Deschodt [17] reported a significant decrease in horizontal wrist displacement in a 6×50 m front crawl set at maximal speed. In addition, Suito et al. [39] showed that hand speed and peak angular velocity of shoulder adduction were significantly reduced from the first to the second half of an all-out 100 m front crawl, in agreement with the reports of Toussaint et al. [40]. On the other hand, Aujouannet et al. [5] found unchanged spatial fingertip's trajectory, despite the occurrence of fatigue, during a protocol of 4×50 m front crawl at maximal intensity.

These alterations in kinematic parameters due to fatigue may be associated with eventual changes in muscle activation. For instance, an increase in the average muscular activity was found after an exhaustive 400 yards front crawl test for the shoulder external rotators (supraspinatus, infraspinatus, and teres minor), and internal rotators (subscapularis) muscles [27]. Furthermore, some authors found increases in the integrated EMG of the deltoid muscle during swimming at a speed of 1.3 and 1.4 $m.s^{-1}$ in a swimming flume [43], and of the flexor carpi ulnaris (considering the whole stroke cycle) and triceps brachii (during the insweep and outsweep phases) over a 4×100 m protocol conducted at 85 % of the 100 m front crawl speed [32]. More recently, Stirn et al.

[38] evaluated muscle fatigue in upper body muscles during a 100 m all-out front crawl; although no changes in EMG amplitude of the pectoralis major, latissimus dorsi and triceps brachii muscles were found, it increased for the triceps brachii and the lower part of the latissimus dorsi.
Although the contribution of the lower limbs to the total propulsion in front crawl is known to be low [16, 23], the kick plays an important role in providing stability for the whole stroke by facilitation of body position, optimizing propulsion and minimizing resistance [24], as well as in assisting an economical body roll, as it is linked to the hydrodynamic forces [45], implying physiological changes (e.g., oxygen consumption) [28]. In addition, proper kicking is required as a foundation for development of good coordination in the global front crawl technique [36]. In this way, the changes that might occur in the lower limbs actions during high-intensity swim should be taken into account.
In spite of the above-mentioned findings, to the best of our knowledge, no studies have been conducted to analyse the changes of such kinematic and electromyographic parameters during a high intensity swim competition distance. The present study aimed to investigate kinematic and electromyographic changes during a maximal 200 m front crawl at race pace, as it is described that fatigue evolves during this event. Changes on general stroke parameters, with the decrease of the velocity and stroke length and increase of the stroke frequency [2, 13], on bioenergetics, with the increase of energy cost [19], along the effort were reported.

Methods
▼

Participants

10 international level male front crawl swimmers (mean ± SD of 21.6 ± 2.4 years old; 76.4 ± 6.1 kg of body mass; 1.85 ± 0.07 m of height; 1.89 ± 0.08 m of arm span), 200 m specialists (91.6 ± 2.1 % of the 25 m pool world record average speed), volunteered to participate in the study. All procedures were performed in accordance with the ethical standards proposed by Harriss and Atkinson [21] and the local ethics committee approved the study. All swimmers provided written informed consent.
Swimmers were marked with white half spheres attached to a black complete swimsuit, allowing manual digitisation for further 3-dimensional reconstruction. 21 anatomical landmarks were used: the vertex of the head, 7th cervical vertebra, mandible (mental protuberance), and the right and left tip of the third distal phalanx of the finger, wrist axis, elbow axis, shoulder axis, hip axis, knee axis, ankle axis, fifth metatarsophalangeal joint, and the tip of the first phalanx.

Data collection

After a moderate intensity individual warm-up totalling 1000 m, subjects underwent a 200 m maximal front crawl test, using a push off start and open turns to eliminate the influence of the dive in the analysis of the first stroke cycle and due to the EMG apparatus. One complete non-breathing stroke cycle, at mid-pool, was recorded for each 50 m of the 200 m front crawl. The stroke cycle was defined as the period between 2 consecutive hand entries of the right hand. Swimmers were instructed to avoid breathing while swimming through the calibrated space. The swimming test was recorded by 6 synchronised video cameras (Sony® DCR-HC42E) 4 under and 2 above the water. All cameras recorded the motion of the swimmer at a sampling frequency set at 50 fields per second and an electronic shutter speed of 1/250 s. The recorded swimming space was calibrated using a frame of the following dimensions: 3.0 m length (x), 2.0 m height (y), and 3.0 m (z) width (accuracy and reliability established by Figueiredo et al. [18]). 3-dimensional reconstruction of the 21 body landmarks, digitised manually and frame by frame using APAS (Ariel Dynamics Inc), was computed using DLT [1], Zatsiorsky anatomical model adapted by de Leva [15], and a 6 Hz low pass digital filter. Tests were conducted in a 25-m indoor swimming pool (27.5 °C).
The EMG activity was measured at a sampling frequency of 1 000 Hz, with a 16-bit analogue to digital conversion (BIOPAC System, Inc). The EMG signal of 7 muscles (flexor carpi radialis, FCR; biceps brachii, BB; triceps brachii, TB; pectoralis major, PM; upper trapezius, UT; biceps femoris, BF; and rectus femoris, RF), which have been shown to have high activity during front crawl swimming (for review see Clarys and Cabri [11]), was recorded from the right side of the body using bipolar (inter-electrode distance of 2 cm) Ag–AgCl circular surface electrodes, with preamplifiers (AD 621 BN). The electrodes were placed parallel to the direction of muscle fibres on the surface of the muscle belly according to international standards [21]. Before electrode fixation, the skin surface was shaved, abraded, and cleaned with alcohol. Afterwards, electrodes were covered with an adhesive bandage (Opsite Flexifix®) to avoid contact with water [14, 33]. All cables were fixed to the skin by adhesive tape to minimise the perturbation of the natural movement and interference with the signal. In addition, swimmers wore a complete swimsuit (Fastskin, Speedo®) 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 corresponding to each one of the electrodes were fixed. A reference electrode was attached to the skin of the patella. The total gain of the amplifier was set at 1 100 with a common mode rejection ratio of 110 dB [14]. To synchronise EMG and video, an electronic flashlight signal/ electronic trigger was marked simultaneously on the video and EMG recordings.
Capillary blood samples (5 µl) were collected from the ear lobe to assess rest and post exercise blood lactate by means of a portable lactate analyser (Lactate Pro, Arkray, Inc.). Blood lactate was measured before and at 1, 3, 5, and 7 min after the test; the peak value was used for further analysis as an indicator of exercise intensity.

Data analysis

Kinematical data analysis was done using APAS (Arial Dynamics, Inc.). The mean horizontal speed was calculated by dividing the swimmer's mean whole-body centre of mass (CM) horizontal displacement by the time spent to complete 1 stroke cycle. Stroke frequency (SF) was the inverse of the time to complete 1 stroke cycle. Stroke length (SL) was the horizontal displacement of the CM during 1 stroke cycle. Angular speed of the hand was derived through a digitising procedure and considered to be the mean angular speed of the line from the midpoint of the wrist to the fingertip projected onto the xy plane of the external reference system. Kick frequency (KF) was the inverse of the time to complete 1 kick cycle, defined as the period between 2 consecutive maximum vertical coordinates of the right foot.
The backward displacement amplitude and slip amplitude were calculated through the difference between the coordinates of the most forward point and the most backward position of the

fingertip, and of the entry and exit of the fingertip, respectively (◉ **Fig. 1**). The vertical motion of the upper limb was represented by displacements of the fingertip, wrist, and elbow. The y displacement of the first phalanx tip was representative of the foot's vertical motion. Both the y direction motion of the upper limb and foot were referenced to an external point. The lateral motion of the upper limb was calculated as the absolute z displacement, referenced to the swimmer's CM.

Shoulder roll angle was determined by the arc-tangent (Sy/Sz), where Sy and Sz are the y and z components of the shoulder unit vector, i.e., the angle between the unit vector of the line joining the shoulders, projected onto the yz plane (the plane perpendicular to the swimming direction) and the horizontal.

The 3-dimensional elbow angle was calculated in 4 time moments within the underwater stroke cycle (◉ **Fig. 1**): (i) entry of the hand in the water (A – entry); (ii) beginning of finger backward movement (B – first back); (iii) finger vertically aligned with the shoulder (C – shoulder x); (iv) end of backward movement (D – end back). These time moments were calculated based on the horizontal displacement of the finger and shoulder during the stroke cycle. The elbow angle range during the pull and push phases was calculated as: C–B and D–C, respectively.

4 separate phases were identified within every stroke cycle (◉ **Fig. 1**), from the swimmer's (3-dimensional model) horizontal (x) and vertical displacement (y) of the digitized finger coordinates and noting the time corresponding to these displacements using APAS (Arial Dynamics, Inc.): entry, pull, push, and recovery [10,36]. Time was expressed in seconds and as a percentage of the stroke cycle. Kick cycle phases were calculated based on the vertical displacement of the foot: the downbeat, from the maximal to minimum vertical coordinates; and, the upbeat, from the minimum to maximal vertical coordinates.

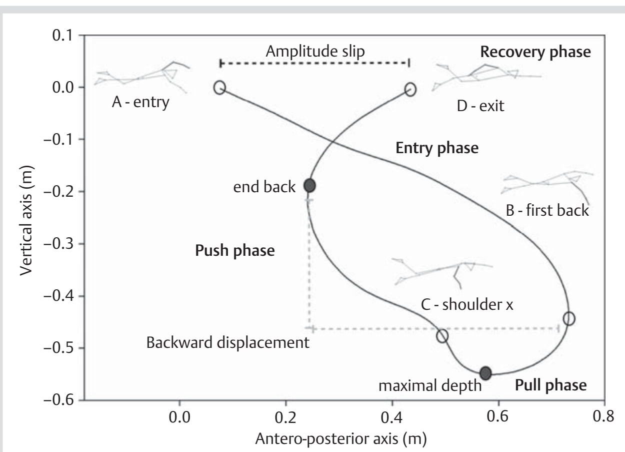

Fig. 1 Example of the underwater trajectory of the right hand.

The EMG data analysis was performed using the MATLAB 2008a software environment (MathWorks Inc., Natick, Massachusetts, USA). The raw EMG signals were band-passed filtered (8–500 Hz), full-wave rectified and smoothed with a 4th order Butterworth filter (10 Hz) for the linear envelope. The integration of the rectified EMG (iEMG) was calculated, per unit of time, to eliminate the stroke phases duration effect (iEMG/t). The signal was partitioned in 40 ms windows to find the maximal iEMG value for each swimmer over every stroke cycle in the mid-pool. To normalise the results, iEMG/t was expressed as a percentage of iEMG maximum value obtained during the 200 m [9].

Statistical analysis

All data were checked for normality and expressed as means and SD. The compound symmetry, or sphericity, was checked using the Mauchley test [44]. A 1-way repeated measures analysis of variance (ANOVA) was used to assess changes in the measured variables over the 4 laps during the race. When significance was determined, post-hoc comparisons were conducted with Bonferroni analysis. A repeated measures t-test was used to compare blood lactate concentration between the beginning and end of the effort. Statistical significance was set at $p \leq 0.05$. All statistical tests were performed using STATA 10.1 software (StataCorp, Inc.). Effect size between laps and between beginning and end of the 200 m were computed with Cohen's f and Cohen's d, respectively. The criteria for interpreting the effect size were based on Cohen's [12] suggestion that f effect sizes of 0.1 are small, 0.25 moderate, and 0.4 large and d effect sizes of 0.2 are small, 0.5 moderate, and 0.8 large.

Results

Mean ± SD, p, f and F values of the repeated measures ANOVA are displayed in ◉ **Table 1** for the general biomechanical parameters, hand angular v and KF, in ◉ **Table 2** for the arm and foot lengths, and in ◉ **Table 3** for the angle variables computed. Changes in race parameters were observed as denoted by the significance level and large effect sizes. Swimming speed, hand angular v, SL, SF, maximal depths of finger, wrist and elbow, elbow angle at the end back, shoulder roll and KF significantly diminished along the 200 m. Whereas, maximal elbow width showed a significant increase.

Mean ± SD relative and absolute durations of stroke phases for each lap, as well as the propulsion/non-propulsion ratio, are presented in ◉ **Fig. 2** (left and right panel, respectively). The entry and pull phases presented an increase of the relative duration along the 200 m ($F_{3,27}=5.25$, $p=0.005$, $f=0.23$; $F_{3,27}=3.37$, $p=0.03$, $f=0.36$, respectively), while a decrease was observed for the recovery phase ($F_{3,27}=9.08$, $p<0.001$, $f=0.37$). Absolute durations of the entry phase increased progressively from the

Table 1 Mean ± SD data and statistical comparisons between the laps across the 200 m front crawl for the general biomechanical parameters, hand angular velocity (v) and kick frequency.

Parameter	Lap 1	Lap 2	Lap 3	Lap 4	$F_{3,27}$	*P*	*f*
speed ($m.s^{-1}$)	1.57 ± 0.08	1.39 ± 0.06[a]	1.34 ± 0.07[a]	1.35 ± 0.06[a]	24.58	< 0.001	1.26
stroke length (m)	2.29 ± 0.23	2.21 ± 0.17	2.19 ± 0.13	2.12 ± 0.13[a,b,c]	4.55	0.01	0.32
stroke frequency (Hz)	0.68 ± 0.09	0.63 ± 0.06	0.61 ± 0.05 [a]	0.64 ± 0.05	5.08	0.006	0.39
hand angular v ($rad.s^{-1}$)	0.048 ± 0.007	0.044 ± 0.005	0.042[a] ± 0.005	0.042 ± 0.004[a]	5.18	0.006	0.40
kick frequency (Hz)	2.02 ± 0.21	1.87 ± 0.21	1.85 ± 0.20[a]	1.91 ± 0.22	2.80	0.05	0.26

[a,b,c] Significantly different from the first, second and third lap, respectively. *P* < 0.05

Table 2 Mean ± SD data and statistical comparisons between the laps across the 200 m front crawl for the arm and foot lengths.

Parameter	Lap 1	Lap 2	Lap 3	Lap 4	$F_{3,27}$	*P*	*f*
backward amplitude (m)	1.62 ± 0.12	1.57 ± 0.14	1.59 ± 0.11	1.59 ± 0.11	0.96	0.43	0.00
backward amplitude/ SL (m)	0.71 ± 0.06	0.71 ± 0.08	0.73 ± 0.07	0.75 ± 0.07[a,b]	4.50	0.01	0.18
amplitude slip (m)	0.56 ± 0.27	0.57 ± 0.32	0.56 ± 0.33	0.58 ± 0.31	0.06	0.98	0.00
max. finger depth (m)	0.72 ± 0.06	0.71 ± 0.06	0.70 ± 0.05	0.69 ± 0.06[a]	4.90	0.008	0.17
max. wrist depth (m)	0.57 ± 0.06	0.56 ± 0.06	0.55 ± 0.05	0.54 ± 0.06 [a]	4.50	0.001	0.18
max. elbow depth (m)	0.36 ± 0.04	0.35 ± 0.04	0.34 ± 0.04	0.33 ± 0.06 [a,b]	6.98	0.001	0.21
max. finger width (m)	0.34 ± 0.05	0.35 ± 0.09	0.35 ± 0.09	0.38 ± 0.07	1.13	0.35	0.07
max. wrist width (m)	0.33 ± 0.04	0.34 ± 0.06	0.33 ± 0.07	0.34 ± 0.04	0.41	0.75	0.00
max. elbow width (m)	0.31 ± 0.05	0.33 ± 0.06	0.34 ± 0.05	0.35 ± 0.05[a]	4.79	0.008	0.23
finger width range (m)	0.35 ± 0.08	0.35 ± 0.10	0.33 ± 0.10	0.35 ± 0.05	0.75	0.53	0.00
wrist width range (m)	0.29 ± 0.05	0.30 ± 0.08	0.27 ± 0.08	0.27 ± 0.06	1.30	0.29	0.09
elbow width range (m)	0.22 ± 0.05	0.23 ± 0.05	0.23 ± 0.05	0.23 ± 0.05	1.03	0.39	0.03
depth right foot (m)	0.47 ± 0.03	0.47 ± 0.05	0.48 ± 0.03	0.48 ± 0.04	0.11	0.96	0.00

[a,b] Significantly different from the first, second and third lap, respectively. $P<0.05$

Table 3 Mean ± SD data and statistical comparisons between the laps across the 200 m front crawl for the computed angles.

Parameter	Lap 1	Lap 2	Lap 3	Lap 4	$F_{3,27}$	*P*	*f*
elbow angle: entry (°)	149.4 ± 12.1	145.1 ± 14.0	149.1 ± 11.4	146.0 ± 12.8	1.61	0.21	0.10
elbow angle: first back (°)	149.7 ± 11.2	152.9 ± 6.8	148.4 ± 10.6	149.0 ± 8.1	1.85	0.16	0.13
elbow angle: shoulder x (°)	102.2 ± 13.4	101.2 ± 15.5	96.8 ± 12.5	95.9 ± 10.7	2.24	0.11	0.16
elbow angle: end back (°)	143.0 ± 3.3	142.6 ± 7.6	141.3 ± 6.6	136.3 ± 4.8 [a,b]	5.57	0.004	0.43
elbow angle: range of pull (°)	47.6 ± 14.7	51.7 ± 14.9	51.6 ± 17.5	53.0 ± 14.4	1.06	0.38	0.03
elbow angle: range of push (°)	40.8 ± 14.9	41.4 ± 19.1	44.4 ± 14.8	40.3 ± 12.6	0.56	0.64	0.00
shoulder roll (°)	107.6 ± 15.8	114.2 ± 13.2	118.9 ± 9.4[a]	114.1 ± 15.7	3.12	0.04	0.25

[a,b] Significantly different from the first, second and third lap, respectively. $P<0.05$

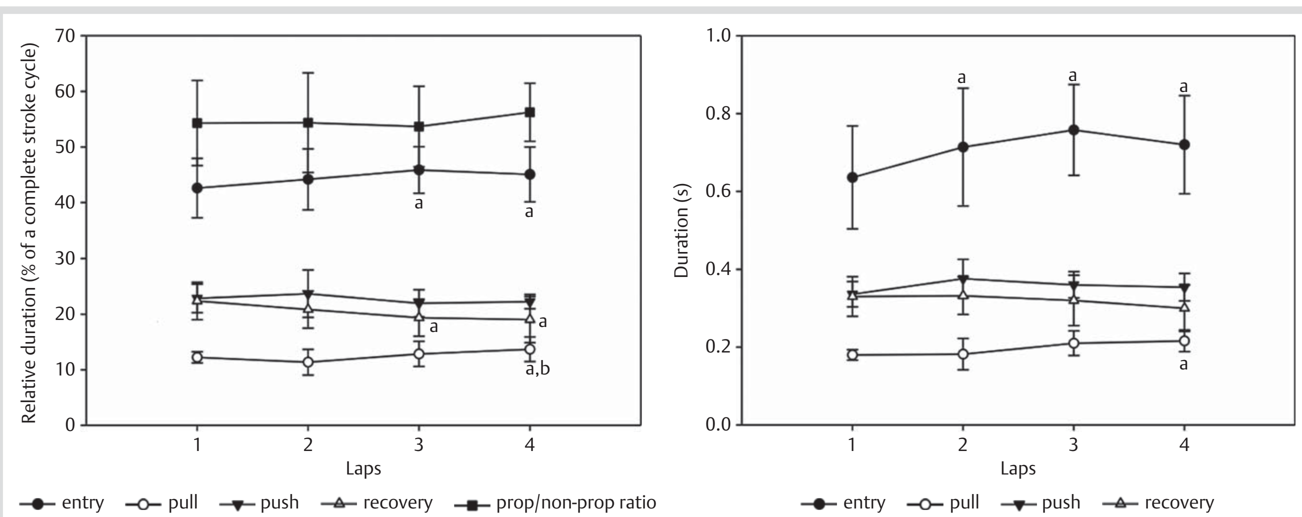

Fig. 2 Stroke phase relative durations and propulsion/non-propulsion ratio (left panel), and stroke phase absolute durations (right panel). Mean ± SD values are indicated over the 200 m front crawl. [a, b] Significantly different from the first and second lap, respectively. $p<0.05$.

first lap ($F_{3,27}=7.56$, $p<0.001$, $f=0.33$), whereas an increase in the push phase was observed only in the last 50 m ($F_{3,27}=4.13$, $p=0.02$, $f=0.47$). Although the push and recovery phases did not present significant differences ($F_{3,27}=2.37$, $p=0.09$, $f=0.29$; $F_{3,27}=2.67$, $p=0.07$, $f=0.19$, respectively) p-values were lower than 0.10 and the effect size was medium.

Fig. 3 shows upper body muscles activation (FCR, BB, TB, PM, and UT) separated by phase and lap.

FCR presented differences during the entry, pull and push phases between the second and the fourth lap and the third and the fourth lap ($F_{3,27}=7.14$, $p=0.001$, $f=0.42$; $F_{3,27}=9.01$, $p<0.001$, $f=0.43$; $F_{3,27}=3.32$, $p=0.04$, $f=0.32$, respectively); BB for the pull phase between the third and fourth lap ($F_{3,27}=3.30$, $p=0.04$, $f=0.27$); TB for the push phase between the first and fourth lap ($F_{3,27}=3.21$, $p=0.04$, $f=0.16$); PM for the pull phase between the third and fourth lap ($F_{3,27}=4.60$, $p=0.01$, $f=0.30$); and UT for the recovery phase between the first and fourth lap and the second and fourth lap ($F_{3,27}=5.19$, $p=0.01$, $f=0.29$). iEMG mean ± SD values of lower limbs muscles activation (BF and RF) are presented in **Fig. 4**; no statistical significant differences were found along the 200 m effort.

Blood lactate increased from 1.07 ± 0.21 $mmol.L^{-1}$ at rest to 11.12 ± 1.65 $mmol.L^{-1}$ after the test ($t=-21.27$, $p<0.001$, $d=-9.01$).

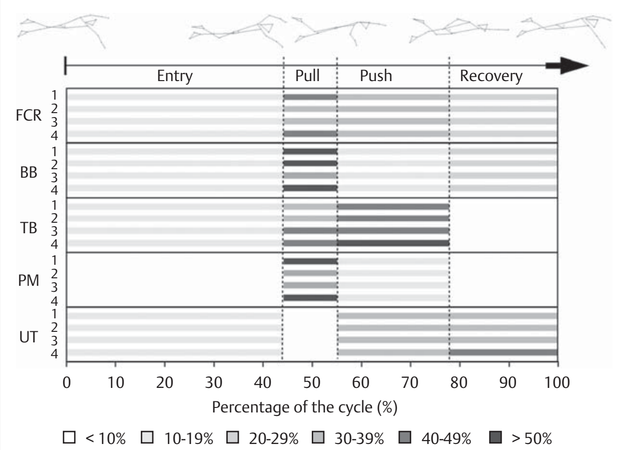

Fig. 3 Upper limb muscles iEMG during each stroke phase across the 200 m front crawl. FCR – flexor carpi radialis, BB – biceps brachii, TB – triceps brachii, PM – pectoralis major, and UT – upper trapezius. The stick figure represents the key points that define the phases.

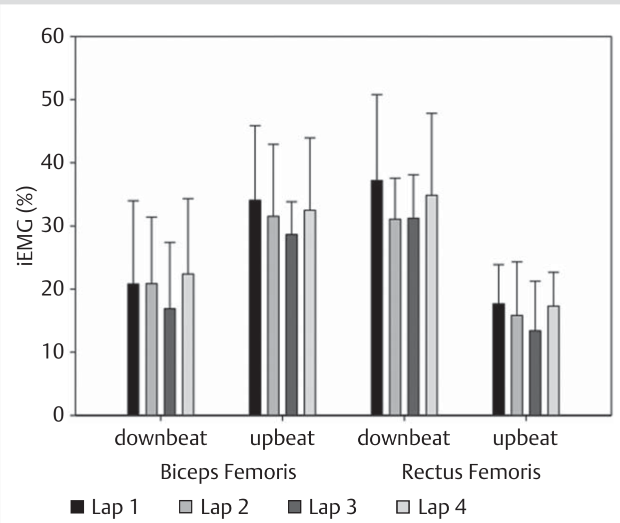

Fig. 4 Mean ± SD values of the lower limb muscles iEMG during downbeat and upbeat phases of the kick over the 4 laps of the 200 m front crawl maximal effort.

Discussion

This study aimed to analyse if the changes in kinematic variables and muscle activity in response to a high-intensity swimming test would reflect evidence of fatigue, as high blood lactate values were measured after the 200 m, confirming the high-intensity of the effort and glycolytic participation.

Stroke parameters management changed along the 200 m front crawl event as expected, as in the literature [3, 13, 30]. SL decreased along the test with statistical meaning in the last 50 m lap, and SF decreased in the third lap in comparison to the first, and augmented at the end of the effort to compensate the decrease in the SL (allowing maintenance of speed) [2, 3, 13].

Concomitant with velocity decrease, angular velocity of the hand diminished along the 200 m; once the upper limb is assumed to be the main generator of propulsive force, therefore decreases in swimming velocity are likely to be caused by reduced hand velocity, as found for the 100 m front crawl [39, 40]. This change of hand angular velocity has implications on the time duration of the stroke phases, as the pull phase is increased in relative and absolute values, but without higher propulsive force generation. The increase in relative duration of the pull phase, and the decrease in relative duration of the recovery phase, is in agreement with the results of Alberty et al. [3] also during a 200 m test.

Backward amplitude was higher than the value reported by Deschodt et al. [16], probably because of the different protocol velocities, as it changes the SR-SL relationship [13], and lower velocities are associated with higher SL [6]. However, backward amplitude remained statistically stable, suggesting that the most forward point augmented, possibly due to a higher glide, in accordance with the increase in relative and absolute duration of the entry phase. When backward amplitude was normalised to SL, an increase in the last lap was observed, suggesting a decrease of the propelling efficiency [19], as a higher relative duration of the pull phase as hand angular velocity decreased, but with lower propulsive impulses as SF increased [4].

The measured depths were similar to the values previously described for 25 m maximal intensity swimming [16, 25, 29]. A decrease of the depths was observed from the first to the last lap, resulting in a tendency for an absolute decrease in elbow angle at shoulder x point (not statistically different, but with a medium size effect). This occurred due to the increased elbow width, although with the same range. The values presented by the maximal finger width were in accordance with the literature [25, 29]. The observed changes in the depth could be due to changes in SF, as the shoulder roll presents the same pattern (significant decrease in the third lap), and have been linked to each other [8, 31, 45]. The magnitudes of shoulder roll in the present study were similar to those reported by Psycharakis and Sanders [30] and McCabe et al. [25], at least for the first lap, where the velocities were higher. However, the speed was constant during the last 3 laps, the shoulder roll increased in the last lap, and yet the depths decreased. In this phase (pull) the PM and BB showed a great importance and an increase of the activation as previously reported [32, 33], suggesting that the attained stability was done by increasing the muscle effort, based on the dominant contribution of shoulder adduction during this phase [39]. A high activation of the TB in this phase suggests the antagonist action to maintain joint stability and supplement prime movers action [32]. It would be of interest to understand if less skilled swimmers perform in the same way or have great kinematical changes.

In the push phase, the elbow angles at end back point values were slightly lower than the ones presented by McCabe et al. [25]; however the measurement protocols were different, as they implemented bouts of 25 m at maximum speed. The decrements in this parameter across the effort could lead to the speculation that a reduction of the power output [7, 20], and also a decrease in the propulsive forces produced in the push phase occurs. It is suggested that TB fatigues, although the push phase duration was stable, because of the decrease of angular hand velocity. TB activation during the push phase increased significantly along the 200 m, in agreement with the results of Aujouannet et al. [5]. The increase in EMG signal amplitude occurs in response to muscle fatigue to maintain the swimming speed through an additional recruitment of muscle fibres [26].

As SF increased in the last lap, changes occurred in the relative duration of the recovery phase, as previously observed [2, 37], but with a decrease (medium effect size) of the absolute duration [6]. Concomitant with these changes the activation of the

UT muscle occurred in the last lap, resulting from the successive sub-maximal repetitions (bringing the upper limb out of the water to the initial position to start a new stroke cycle), and decreasing the time between contraction and relaxation. The augmented activation of FCR during the catch, pull and push phases throughout the test is likely to confirm the important role of this muscle in stabilising the wrist during these phases, as previously reported for the wrist flexor muscles [9], since the higher load is underwater, presenting evidence of fatigue [32].
The deterioration of stroke mechanics is described in the literature, and was related to local fatigue due to several biochemical events, such as high blood lactate levels [19,40]. The observed post exercise blood lactate values were similar to those found by other authors after a 200 m front crawl swimming event [3,13,42], confirming the high intensity achieved by the participants during the test, and suggesting the appearance of fatigue.
Regarding the lower limbs, KF decreased in the third lap, as in the SF, suggesting that swimmers maintained the same arm-leg coordination. The lower limbs seem to follow the upper limbs frequency, as the first ones have a lower importance in the propulsion [17,23], which is reflected in the level of activation of both BF and RF muscles in comparison to the upper limb muscles in their main phases. As a consequence, BF and RF do not show electromyographic and kinematic evidences of fatigue, as their level of activation remained the same, predominantly in the downbeat (RF) and upbeat (BF) kick, as they are agonistic/antagonistic muscles; their depth remained also the same, in spite of changes in KF. Kick depth values were slightly higher than those presented by McCabe et al. [25], probably because in sprinting the KF is so much higher that it reduces the amplitude of the kick. In addition, the slightly higher activity of the BF and RF in the first lap of the upbeat and downbeat phase (respectively), suggested that the higher speed in the first lap could be associated with higher lower limbs use; this would lead to a higher body position, decreasing frontal drag, and consequently requiring less work for the upper limbs (as found by Rouard et al. [34]).

Conclusion

Changes in the spatial and temporal kinematics occurred during the 200 m front crawl. In addition, muscular activation of the upper limb muscles increased during the event in the phases in which they were required. These changes evidenced fatigue that was indicated by high blood lactate at the end of the event. The lower limb kinematics and muscle activity remained quite stable only changing their KF in response to SF changes, but not showing signs of fatigue.

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