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MUSCULAR FATIGUE DURING 200 M FRONT CRAWL

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The purpose of this study was to evaluate muscle fatigue in upper and lower limbs as well as trunk muscles during a 200 m all-out front crawl effort. Surface electromyogram was collected from the flexor carpi radialis, biceps brachii, triceps brachii, pectoralis major, trapezius pars superior, rectus femoris, biceps femoris and tibialis anterior of 13 international level male swimmers. Velocity, stroke frequency and stroke length were calculated based on 3D video analysis. Spectral Indices of Muscle Fatigue (IMF) were calculated for each stroke of the each 25 m lap. During the 200 m, the rate of IMF changed against the first lap and increased gradually across successive laps, reflecting the evolvement of muscle fatigue for all studied muscles.

KEY WORDS: swimming, front crawl, EMG, fatigue, performance.

INTRODUCTION: Muscle fatigue represents a complex phenomenon encompassing various causes, mechanisms and forms of manifestation, and is described as an acute impairment of performance (Enoka & Stuart, 1992). It can be continuously monitored during performance by measuring myoelectric activity using surface electromyography (EMG). As fatigue evolves, the amplitude of the EMG signal increase due to synchronization and recruitment of motor units and the mean or median frequency of the power spectrum is shown to shift to lower frequencies, due most of it to the diminished muscular fiber conduction velocity as a consequence of local metabolic changes in working muscle (Basmajian & DeLuca, 1985). Though, the diagnostic value of time domain methods in muscle fatigue evaluation is considered to be more limited than the frequency domain methods (Merletti et al., 2004).
Few studies focused on the effect of fatigue on the EMG in swimming and manly used amplitude analysis. Caty et al. (2006) observed decrease of instantaneous mean frequency in the extensor carpi ulnaris and flexor carpi ulnaris muscles (11.4% and 8.5%, respectively) during the 4 x 50 m high intensity front crawl. More recently, Stirn et al. (2010) evaluated muscle fatigue in the upper body muscles (pectoralis major, latissimus dorsi and triceps brachii) during a 100 m all-out front crawl effort, having the mean power frequency of all muscles significantly decreased by 20–25%. The purpose of this study was to evaluate muscle fatigue in upper and lower limbs and trunk muscles by analysing EMG signals during a 200 m all-out front crawl performance. In order to better understand and interpret results, some kinematic (velocity, stroke length and stroke rate) and physiological (lactate concentration) data were obtained as well.

METHODS: Ten highly trained male swimmers (average ± SD: aged 21.6 ± 2.4 yrs; height 185.2 ± 6.8 cm; arm span 188.7 ± 8.4 cm; body mass 76.4 ± 6.1 kg), involved in competitive swimming for 11.9 ± 3.5 yr with an average personal best performance in 200 m front crawl (short course) of 109.3 ± 2.1 s, participated in the study. The measurements were performed in a 25 m indoor swimming pool. After an individual warm-up, totaling 1000 m, subjects performed a 200 m all-out front crawl swim. Because of the measurement equipment it was used a push off start and flip turns were not allowed.
The kinematic performance of each swimmer was recorded with a total of six stationary (four below and two above water) and synchronized video cameras (Sony® DCR-HC42E). Twenty-one landmarks that define the three-dimensional position and orientation of the rigid segments were manually digitized using APAS software (Ariel Dynamics, Inc.). Kinematic

data were processed with a low-pass filter at 6 Hz and one stroke cycle for 50 m lap was analyzed. The average horizontal swimming velocity (v) was calculated by dividing the swimmer's mean center of mass horizontal displacement by the time to complete one stroke cycle. Stroke frequency was the inverse of the time to complete one stroke cycle. Stroke length was the horizontal displacement of the centre of mass during one stroke cycle.
EMG data was collected from the flexor carpi radialis (FCR), biceps brachii (BB), triceps brachii (TB), pectoralis major (PM), trapezius superior (TS), rectus femoris (RF), biceps femoris (BF) and tibialis anterior (TA) muscles. These muscles were selected according to their importance during propulsion and stabilisation of the front crawl swimming technique (cf. Clarys & Cabri, 1993). The skin of the swimmer was shaved and rubbed with an alcohol solution. Recordings of the muscle activity were unilateral using disposable Ag–AgCl circular surface electrodes, with preamplifiers (An AD621 BN), placed in a bipolar configuration with 2.0 cm inter-electrodes distance, in line with the muscle's fibre orientation (Basmajian & DeLuca, 1985). Electrodes were placed in the midpoint of the contracted muscle belly and covered with an adhesive bandage (Opsite Flexifix) to avoid contact with water. A reference electrode was attached to a body area remote from the studied muscles (patella). The total gain of the amplifier was set at 1100 with a common mode rejection ratio of 110 dB. The data were sampled at 1000 Hz with a 16-bit analog to digital converter (BIOPAC System, Inc). To synchronise EMG and video it was used an electronic flashlight trigger. The EMG data analysis was performed using the MATLAB 2008a software environment (MathWorks Inc., Natick, Massachusetts, USA). A new highly sensitive spectral index of muscular fatigue (IMF; equation 1), proposed by Dimitrov et al. (2006), was calculated for each stroke of each 25 m mid-pool section. The mean IMF was calculated for each 25 m.

$$IMF = \frac{\int_{f1}^{f2} f^{-1} \cdot PS(f) \cdot df}{\int_{f1}^{f2} f^{k} \cdot PS(f) \cdot df} \qquad (1)$$

where k was 5, PS(f) was the spectral power for the current frequency f and f1 = 8 Hz and f2 = 500 Hz were the high and low-pass frequencies of the amplifier filter. The relative changes in values of the IMF, for different repetitions were calculated against the first repetition of the corresponding set. Fatigue criterion was the increase of IMF. The final IMF values expressed as a percentage of the initial values were labeled IMF_n.
In addition, capillary blood samples (5μl) were collected from the ear lobe, at rest, as well as at 1, 3, 5, and 7 min of recovery, to assess rest and post exercise peak blood lactate concentrations (Lactate Pro, Arkray, Inc.) in order to evaluate a physiological marker of exercise intensity.
Mean (SD) computations for descriptive analysis were obtained for all variables (normal Gaussian distribution of the data was verified by the Shapiro–Wilk's test). A one-way repeated measure ANOVA with Bonferroni post hoc was used to compare the kinematical parameters along the 200 m and a paired sample t-test to determine differences between the first and last 25 m laps. To analyze the relationship between muscles IMF and laps across the 200 m front crawl a within subjects correlation coefficient was reported (Bland and Altman, 1995). Statistical analysis was performed using STATA 10.1 (StataCorp, USA) and $p<0.05$ accepted as significant.

RESULTS: Swimming v decreased significantly from 1.54 $m.s^{-1}$ in the first to 1.35 $m.s^{-1}$ in the last lap ($F_{3,27} = 24.6$, $P < 0.001$, $f = 1.26$). SL showed a tendency to decrease in the first three laps, however without statistical significance (2.29 m, 2.21 m, 2.19 m, respectively); a decrease was observed in the final lap (2.12 m) comparing to the previous ones ($F_{3,27} = 4.6$, $P = 0.01$, $f = 0.32$). Concomitant with the decrease in swimming v, a significant reduction in SF was found from 0.68 Hz in lap 1 to the other laps (0.63 Hz, 0.61 Hz, 0.64 Hz, respectively) ($F_{3,27} = 5.1$, $P = 0.01$, $f = 0.39$). To further study the changes in the in SL, SF, and v, each parameter value was expressed as a percentage of the value observed in the first lap (Figure 1).

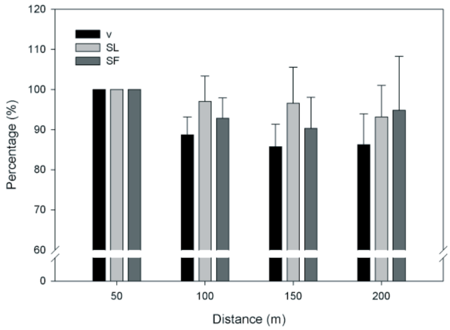

Figure 1: Averaged values and standard deviations expressed as percentage of the first 50 m lap value for stroke length (SL), stroke rate (SF), and swimming velocity (v) for the 200 m all-out performance.

Significant differences were found in normalized IMF_n between the first and the last lap of the 200 m (Figure 2) accomplished through a significant increase of the rate of change across the eight 25 m laps for all muscles studied (Table 1). In the beginning of the effort blood lactate was 1.07 ± 0.21 mmol.l^{-1} and by the end it was 11.12 ± 1.65 mmol.l^{-1}.

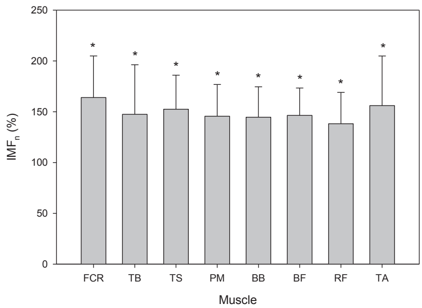

Figure 2: Normalised IMF_n (%) at the end of the 200 m. *p<0.05.

Table 1
Correlation coefficients and statistical significance

Variable	Within subject correlation with Lap (p-value)
Flexor carpi radialis	0.60 (0.001)
Triceps brachii	0.57 (0.007)
Trapezius superior	0.75 (0.001)
Pectoralis major	0.64 (0.001)
Biceps brachii	0.55 (0.001)
Biceps femoris	0.67 (0.001)
Rectus femoris	0.65 (0.004)
Tibialis anterior	0.54 (0.005)

DISCUSSION: In the present study fatigue was estimated analyzing some physiological, kinematic and EMG parameters. The blood lactate concentrations values achieved at the end of the test were similar to those obtained for the same event by Bonifazi et al. (1993) and Alberty et al. (2005), indicating that maximal effort was carried out by the swimmers.
Changes in the studied kinematical parameters were in accordance with the literature (Craig et al., 1985; Alberty et al., 2005). Simultaneously with the v decrease, different SF and SL

combinations were observed yielding the best performance in face of the fatigue task constraint, causing the lack of capability in maintaining a constant SL, increasing SF in the last 50 m lap, which is attributable to the inability to generate sufficient power output.
The EMG parameters obtained showed the overall compression of the spectral parameters, inducing an increase in the IMF calculated, as described previously under dynamic contractions (Dimitrov et al., 2006). The results are in line with the ones found by Caty et al. (2006) and Stirn et al. (2010) for 4 x 50 m and 100 m front crawl, respectively. In spite of the increased IMF in the final 25 m lap of the effort, the correlations coefficients obtained, showed a medium increase of the rate of change of the IMF across the 200 m. Such results could reflect a different evolvement of fatigue in the different muscles, depending of their function, as FCR showed the highest percentage of change, because it works as a stability muscle of the wrist, the highly propulsion muscles of the upper limbs, the TS that more linearly change across the effort (R=0.75) showing the effect caused by the cyclic recovery phase of the stroke, and the lower limbs propulsive muscles where the RF and BF, important in the downward and upward motion of the leg kick, changed less, probably because of the lower decrement of the power output of the legs comparing to the arms during front crawl swimming (Swain, 1999). Additionally, intramuscular coordination changes, inter-subject variability, but also the changes that occur as the power output (v) decreases influence the evolvement of the fatigue in each muscle. So, it would be of great interest to analyse the pattern of IMF during the effort in futures studies.

CONCLUSION: The kinematic and physiological parameters suggested that fatigue was attained within the effort. EMG parameters confirmed the fatigue state caused by the 200 m front crawl, and the significant involvement of the studied muscles in this specific swimming technique.

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