OBSERVATION AND TECHNICAL CHARACTERIZATION IN SWIMMING: 200 M BREASTSTROKE

LOCOMOTOR APPARATUS IN EXERCISE AND SPORTS

ORIGINAL ARTICLE

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ABSTRACT

Introduction: Characterization of the breaststroke technique, regarding the relationship between kinematic and neuromuscular parameters. Method: Surface electromyographic signals (EMG) were used to analyze the dynamics of neuromuscular activity of the muscles pectoralis major (PM), biceps brachii (BB), triceps brachii (TB) and anterior deltoid (AD), in twelve national elite swimmers. A couple of cameras (an underwater camera and an above the water surface camera) were used to provide a dual projection that permits analysis of kinematic variables (Speed, SF, SL) in the 200 m breaststroke event. Results: Swimming speed decreased from 1.41 (0.07) to 1.16 (0.09) $m.s^{-1}$($P<0.05$). Stroke length decreased from 2.32 (0.37) to 1.96 (0.24) m, while stroke frequency suffered decrease from 37.52 (5.16) to 34.40 (3.58) cycle/min of 1st lap 50 m until the 3rd lap of 50 m, slightly increasing in the last lap to 35.82 (3.39) cycle/min. Blood lactate increased from 1.12 (0.22) to 12.00 (3.23) $mmol.L^{-1}$. EMG results indicated increase in frequency concerning amplitude for all muscles studied: BB, PM and TB, except for the AD. Negative correlation between speed frequency, SF and SL was obtained, i.e. to the muscles BB, TB and PM there was a correlation between speed, SF and SL, meaning that as the kinematic variables increase, the frequency decreases. The correlations suggested that the neuromuscular activation presents a direct correlation with the kinematic variables, especially for frequency reduction in the BB, TB and PM muscles, and to a high extent and correlation with the kinematic variables in PM. Conclusion: The relationship between the kinematic variables and EMG is decisive in the swimming performance evaluation, in training exercises outside the pool to increase muscular endurance of muscles involved in the breaststroke technique.

Keywords: swimming, kinematics, EMG, amplitude, frequency.

INTRODUCTION

The breaststroke technique is considered one of the leas economical among the four swimming strokes[1]. The mechanical cause comes from its technical discontinuity and consequently, from the horizontal intracyclical velocity variety of the body mass center[2-4], which causes the need to perform complementary work to accelerate again the body mass center.

Over the last years, great part of the investigation about swimming has been dedicated to the kinematic analysis of the many strokes[5]. Being the breaststroke is the slowest[6] of the four strokes, some investigators have used the kinematic analysis to determine the swimming velocity (SV), since this parameter is very relevant to the sports performance access.

Concerning the variabls which describe the swimming velocity stroke lenght (SL) and stroke frequency (SF), it was verified that when swimming velocity is increased in breaststrokers, it is aassociated with increase in SF, but also to decrease in SL[7]. McMurray *et al.*[8] also verified that a reduced number of strokes for a given swimming velocity during a period of competition preparation, will be able to lead to increase of SL and consequently to improvement in sports performance. Thompson *et al.*[9] presented results which evidenced that both increase in SF and SL leads to increase in SV in national and international athletes in 200m breaststroke events.

According to the literature, in the 200m breaststroke events some athletes swim with high SF and reduced SL, while others swim with high SL and low SF; according to Maglisho[10], breaststrokers should choose to swim with long cycles and low frequency in the first half of the three fourths of their events in order to save energy, and immediately after they should increase their SF to keep their SV and delay fatigue in the final part of the event. Other authors[11,12] state that the SF and the SL can be correlated with breaststrokers' performance, possibly as consequence of their use of a ratio between SF and single SL[13].

Thus, the breaststroke technique has been studied through the observation of different physiological[14,15], energetic[16,17], kinematic and biomechanical parameters[18,19], such as in the injury rehabilitation diagnosis[20].

Since electromyography (EMG) is a study field which consists in the direct recording of the electrical potential of the active muscles and allows us obtain an expression. of the dynamic involvement of specific muscles in the body thrust in relation to the water[21], this study field will be crucial to the analysis and comprehension of the swimming movements.

The EMG investigation in competitive swimming has been focused in establishing relations between the neuromuscular activity and kinematics (e.g stroke lenght, stroke rate, swimming velocity) and some physiological parameters; however, the majority of the studies have been developed with the crawl stroke[22-26], demonstrating hence a study gap in the breaststroke.

Since alterations of kinematic parameters are related to the muscular activity, Aujoannet *et al*.[25] verified that the EMG presents great individual variations; however, the fingers trajectory and SL were unchangeable during a 4 x 50m crawl test, while Figueiredo[27] presented fatigue indicators in a maximum 200m crawl test, in which the decrease in the hand velocity and the propulsive efficiency of the stroke occurred. In the amplitude domain, many studies presented amplitude increase of the neuromuscular activity[27-30]. In the frequency domain, decrease in the neuromuscular activity was observed as presented by Stirn *et al*.[26] in which 20-25% reduction of frequency and increase of amplitude of the triceps brachii and pectoralis major dorsal have occurred.

According to the literature, the most used and important muscles in the breaststroke technique are the biceps brachii, triceps brachii[31], supraspinatus, teres minor, trapezius and deltoid[32], biceps brachii, subscapular, teres major, pectoralis major, supraspinatus, infraspinatus, serratus anterior and deltoid[33].

Therefore, through the existing scientific grounding it is determinant to perceive the correlation between the neuromuscular and kinematic parameters in the breaststroke technique so that we can come to some conclusions about the characterization of the breaststroke technique, namely in 200m events and having elite swimmers as the sample.

The aim of this study was to observe and characterize the breaststroke technique concerning the correlation between kinematic and neuromuscular parameters in a 200m breaststroke event.

METHODS

Sample

Twelve male swimmers (age 22.3 ± 2.9 years; height 180.5 ± 0.5cm; weight 73.60 ± 3.82kg; mean ± SD) voluntarily participated in this study and signed a Free and Clarified Consent Form for participation in this study. All the swimmers from the sample are national swimmers, com mean of best result in the 200m breaststroke of 2.27.65 ± 0.04 seconds, corresponding, respectively to 643.75 ± 53.77 *FINA ranking points*. All measurements followed the guidelines by Harris and Atkinson[34] concerning ethical aspects.

Test procedures

The tests were performed in an indoors 50 m swimming pool, with water temperature of 27.5°C.

After placement of the equipment, the subjects performed 800 m of crawl general warm-up and specific 200 m of breasstroke at mean level of effort and afterwards, they performed a maximum 200 m breaststroke test.

Due to the measurement equipment attached to the swimmer, they initiated the test exiting from below and they were not allowed to perform the subaquatic distance after exiting the lap.

Data acquisition

Blood samples were taken from the earlobe at rest and immediately after the swimming test, and three, five and seven minutes after swimming. The blood concentrations were measured after the exercise using the *Lactate Pro Analyser*.

The swimming distances were filmed on the sagittal plane with a pair of cameras, providing double projection from a subaquatic camera (Sony Mini Dv DCR-HC42E, USA) and another one above the water surface (Sony Mini Dv DCR-HC42E, JVC, USA).

The cameras were placed steady at 25m from the upper wall, on a side wall of the pool, perpendicular to the dislocation lie and at 10m away from the swimmer. The images of both cameras were simultaneously recorded.

The study consisted in the kinematic analysis of swimming cycles (Ariel *Performance Analysis System, Ariel Dynamics Inc*., USA), at sampling rate of 50 Hz. The Zatsiorsky's model with adaptation to the DeLeva one[35] with trunk division in two articulated parts, divided in eight segments was used: 1) head, 2) trunk, 3) arm, 4) forearm, 5) hand, 6) thigh, 7) leg, 8) foot[36,37], from the mass center of the swimmer. The water surface was also digitalized using the light reaction on the water [38]. In order to create a single image from the double projection as previously described[1,2], the independent digitalization of both cameras was reconstructed with the help of a calibration volume (16 points) and a 2D DLT algorithm[39]. The mass center curve was kinematically analyzed using a filter with cutoff frequency of 5 Hz, as suggested by Winter[40].

The kinematic variables were measured by the period of the swimming cycle (P, s), stroke frequency (SF=cycle/min), stroke lenght (SL, m) and mean of swimming velocity of the entire cycle (SV=m s^{-1}).

Surface EMG signals were analyzed from four muscles: pectoralis major (PM), biceps brachii (BB), triceps brachii (TB) and anterior deltoid (AD) on the right side of the swimmers' body. These muscles were selected due to their importance in the breaststroke technique[31-33].

Bipolar surface electrodes (10 mm diameter, Plux, Lisbon, Portugal) were used with distance between electrodes of 20 mm. The electrodes on the upper part of the PM were placed on the mean line which connects the acromion to the manubrium (externum), two fingers below the clavicle[26]. The electrodes on the long part of the TB, BB and AD were laced according to the SENIAM recommendations[41].

Initially, the swimmer's skin was shaved to the muscle's surface where the electrodes were going to be placed. Subsequently, the dead skin surface was removed by abrasion and detection surface was cleaned with ethyl alcohol to remove the oily layer and consequently decrease resistance between the electrodes and not exceed 5 KOhm[42].

Reference electrode (ground) was placed on the cervical vertebra (C7). Transparent stickers were used (Hydrofilm®, 10cm x 12.5cm, USA) to protect and isolate the swimmer from the water [43]. All cables were attached to the skin by adhesives on many sites in order to minimize its movement and consequently inference to the signal. Additionally, to have the cables immobilized, the swimmers wore a complete swim suit (FastskinSpeedo®).

The EMG equipment the swimmer had attached to his body was very light and was only composed of electrodes, its corresponding cables and the entire adhesive isolation. The *wireless* EMG (BioPLUX. research, Lisbon, Portugal; eight analog channels (12 *bit*), sampling frequency 1,000 Hz; 86g, with compact dimensions: 84 x 53 x 18mm) system was placed in a bag and placed below the swimming cap. The data were recorded through the Plux Monitor (Plux, Lisbon, Portugal) at 1,000 Hz frequency.

The EMG signal was processed through the total automatic analysis, with no manual intervention and with automatic instruments through the MATLAB software (Mathworks, Inc. Natick MA, USA).

Our EMG analysis was centered in the determination of the neighboring muscular activity. It was calculated through the segmentation of the energy present in the signal. The DC component was removed and filtered from the raw signal, using 5th order *butterwoth* low-pass filter (10 at 500 Hz), respectively. The signal energy was determined along time using a 250ms window.

The process of determination of the muscular activity threshold consisted in finding the neighboring points in which the the maximum peak energy is of 30%. However, even with the use of a 250 ms window, the energy of the muscular activity presented too much noise. In order to surpass this difficulty, the real maximum energy peaks were determined; that is to say, each cycle produced by the swimmer produces a pattern in the EMG signal, these patterns consist in the cycles periodicity. Thus, in an attempt to determine the maximum energy peaks, first the mean of the cycle period was determined, which was done through the self-correlation method, which determines the instant of the spectrum frequency of the signal energy.

Subsequently, a maximum filter with length equal to two times the mean of the cycle period was applied so that the peaks with higher energy could be determined and which were close to the mean of the cycle period. For each neuromuscular activation, an active phase corresponding to one part of the EMG signal was defined, for which the energy was at least 30% of the maximum value of energy obtained. The EMG segments from the active phases were extracted and used for calculation of the duration of the active phases and for analysis of the EMG amplitude and frequency. The non-active phase was defined as the interval between the two successive active phases (figure 1).

The amplitude of the EMG signal for each active phase was estimated using the mean of the EMG adjusted value, according to the SENIAM recommendations[41] and presented in relation to time. The linear regression curve was performed and the EMG

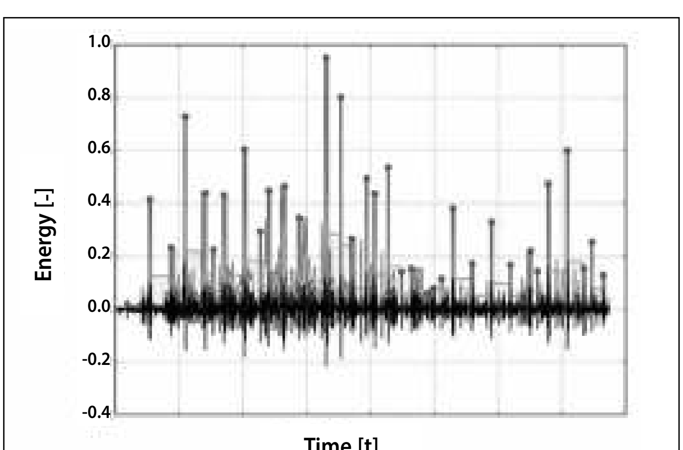

Figure 1. Maximum energy peaks of the EMG signals obtained in the biceps brachii muscle (BB).

amplitude values were presented and compared from the beginning of the first cycle until the last cycle.

Frequency was analyzed with each segment extracted being zero for a total of 1 s (2,000 samples). Thus, a uniform resolution frequency was used for all the signals segments. The spectrum density (PSD) for each segment was performed using the periodogram method[44]. The periodogram for a continuous signal x(t) of T length was defined as:

$$\boxed{Px(f) = \frac{1}{T}|X(f)|^2}$$

As measurement of central tendency of PSD, we used the mean of the PSD frequency (MNF), defined as the first PSD moment. For a continuous spectrum, we included the frequencies between zero and and fMax defined as:

$$\boxed{\mathrm{MNF} = \frac{\int_0^{f\max} f.Px(f)df}{\int_0^{f\max} .Px(f)df}}$$

The MNF value was calculated for segment and used as a frequency parameter for each studied muscle.

Mean and standard deviation (SD) for descriptive analysis were used for all the study variables. In order to verify the data normality, the Kolmogorov-Smirnov test and variance homogeneity (Levene test) were used. Two-way ANOVA for repeated measures with Tukey test was applied for comparison between distances. The differences were considered significant for $P < 0.05$.

RESULTS

Figure 2 presents the mean values (SD) of the kinematic parameters for each 50m distance of the 200m breaststroke. The SV decreased from 1.41 (0.07) to 1.16 (0.09) $m.s^{-1}$ with significant differences from the first 50m distance and for the remaining 50m distances ($P < 0.05$). SL decreased from 2.32 (0.37) to 1.96 (0.24) m from the first 50m distance to the fourth 50m distance. SF suffered decrease from 37.52 (5.16) to 34.40 (3.58) cycle/min from the first 50m distance to the third 50m distance, slightly increasing in the last distance to 35.82 (3.39) cycle/min. Significant difference has not been verified in the many swimming distances during the 200m breaststroke neither in SL nor SF. Concomitant to the decrease previously indicated of swimming velocity, the lactate concentrations increased from rest to the blood lactate peak after the 200 m breaststroke from 1.12 (0.22) to 12.00 (3.23) $mmol.L^{-1}$.

Table 1 demonstrates that the SV was correlated with lactate, presenting strong correlation between the two, that is to say, when the swimming velocity decreases, lactate increases ($r=-0.61$, for $p < 0.05$). SF and SV also present strong correlation, that is, when the SV increases, the SL increases as well ($r=0.71$, for $p < 0.05$). SL demonstrated strong correlation with SF, when SL increases, SF decreases ($r=-0.78$, for $p < 0.05$) (figure 3).

The EMG results indicate increase of frequency concerning amplitude for all the studied muscles, except for AD. In decreasing order, the muscles which presented greater amplitude were AD (103.62 (2.09)%), followed by PM (99.51 (3.47)%), TB (98.40 (7.89)%)

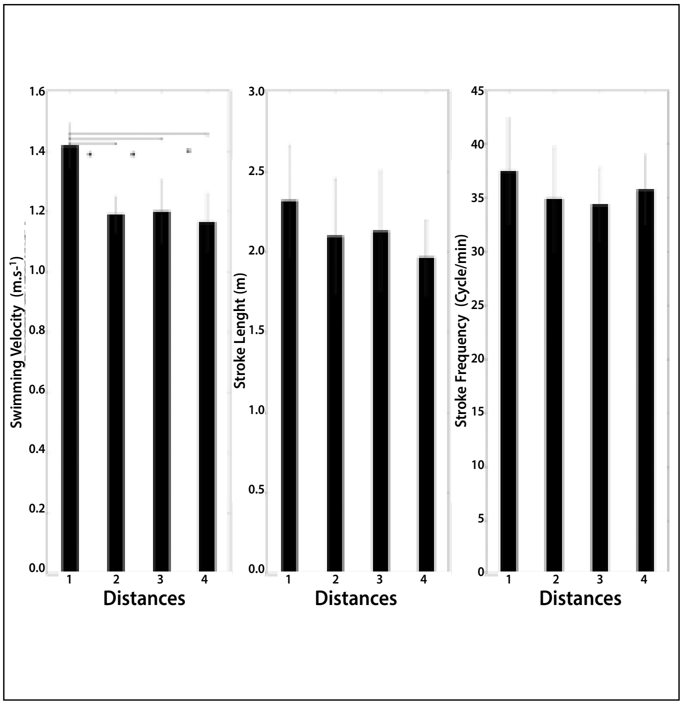

Figure 2. Mean (SD) of the swimming velocity (SV), stroke lenght (SL) and stroke frequency (SF) for the four swimming distances of 50m of the 200m breaststroke *P < 0.05.

Table 1. Correlation between the swimming velocity (ΔSV), cycle distance (ΔSL), gesture frequency (ΔSF) and blood lactate (ΔLa) alterations from the beginning until the end of the 200m breaststroke.

	ΔSV	ΔSL	ΔSF	ΔLa
ΔSV	–			
ΔSL	–0.19	–		
ΔSF	0.71*	–0.78	–	
ΔLa	–0.61*	0.09*	–0.44	–

*P < 0.05.

and BB (97.69 (2.33)%), while the muscles which presented higher frequency were BB (112.85 (12.11)%), PM (103.48 (12.52)%), TB (101.27 (6.15)%) and AD (101.52 (6.55)%).

In order to complete the kinematic and muscular activity during the 200m breaststroke, correlation between frequency and amplitude was performed for the studied muscles with the kinematic variables (SV, SF and SL) (table 2).

Table 2. Correlation coefficients between the muscular parameters: frequency and amplitude with kinematic, swimming velocity (SV), stroke lenght (SL) and stroke frequency (SF) variables.

	Frequency			Amplitude		
Muscles	SV	SL	SF	SV	SL	SF
BB	–0.77*	–0.71*	–0.88*	–0.32*	–0.22*	–0.49*
AD	–0.03*	–0.13*	0.16*	0.36*	0.26*	0.53*
TB	–0.74*	–0.66*	–0.85*	–0.56*	–0.48*	–0.72*
PM	–0.76*	–0.69*	–0.87*	0.81*	0.75*	0.91*

BB – biceps brachii; AD – anterior deltoid; TB – triceps brachii and PM – pectoralis major. *P < 0.05.

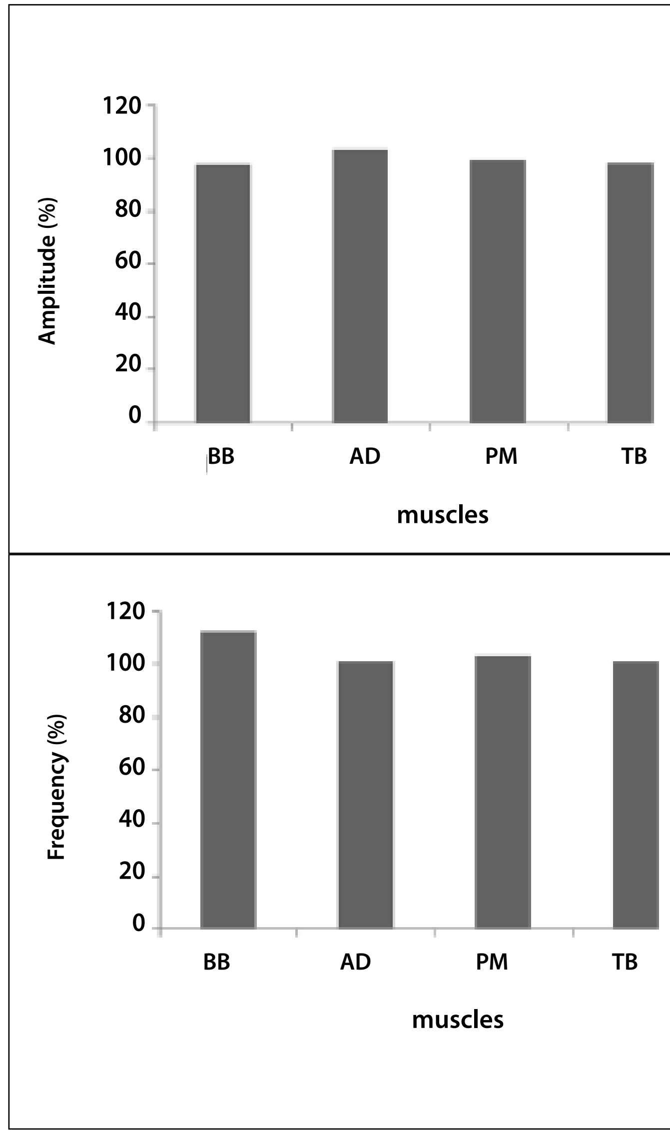

Figure 3. Mean (SD) of the amplitude and frequency between the first and fourth swimming distances for all the studied muscles during the 200m breaststroke (pectoralis major (PM), biceps brachii (BB), triceps brachii (TB) and anterior deltoids (AD).

Concerning amplitude, light correlation was obtained for the BB and TB muscles: as the SV, SF and SL variables increase, the amplitude decreases, while for the AD and PA muscles, the contrary was observed: as the SV, SF and SF variable increase, the amplitude also increases, where the on one side, the AD muscle presents light correlation, on the other side, the PM muscle presents strong correlation.

DISCUSSION

The aim of this study was to analyze and characterize the breaststroke technique during a 200m event, concerning the correlation between dynamics of the neuromuscular activity through analysis of the amplitude and frequency with the kinematic parameters (SV, SF and SL). High lactate concentrations, decrease of swimming velocity and alterations in SF and SL point to swimming performance during the 200m breaststroke.

The lactate concentrations obtained were similar to previous studies for 200 m distances[26,45-47], corroborating that the 200 m event presents significant anaerobic contribution. The decrease presented in SV, SF and SL agree with the results presented by previous studies [3,9,12,7,48], when refer that in the breaststroke technique there is increase in SV associated with increase in SF, but higher decrease in SL relatively to other swimming styles[9], corroborating alteration in the technique during the 200 m[3].

The correlation between *ΔSL and ΔSF* reflect the capacity of the swimmers to keep the SV during the 200 m[6], while the strong correlation between SV and SF suggests that SF is a determinant indicator in the motor organization in competitive swimming[9,49].

Thompson *et al.*[13] observed that the 200m breaststroke swimmers with better performance present great capacity to keep the swimming velocity in the mean of duration of laps and exits; however, not always in the articulation of the kinematic variables, to which they refer as being an unique factor to each swimmer.

Thus, though the presented results, we can indicate that the increase in SF and SL cause increase in SV in national elite swimmers in the 200 m breaststroke.

The kinematic variables and lactate concentration ratio was clearly associated with the alterations presented in the neuromuscular activity; therefore, increase in the EMG amplitude and frequency parameters confirm the high involvement of the studied muscles in the breaststroke technique, as well as its great contribution to the upper extremities thrust. This amplitude increase was also demosntrated in other types of maximum protocols used in swimming, namely in the crawl stroke [26,28,30].

Many negative correlations were obtained between frequency and SV, SF and SL; that is, for the BB, TB and PM muscles, strong correlation was verified among SV, SF and SL, meaning that as the kinematic variables increase, the frequency decreases, while for the AD muscle, the values are very close to zero in module, it is an indication that alterations in the kinematic variables do not reflect in the frequency of this muscle.

Therefore, the great correlations presented between the kinematic variables and the studied muscles suggest that the neuromuscular activation presents a direct relation with the kinematic variables, clearly in frequency decrease, in the BB, TB and PM muscles and for high amplitude and strong correlation with the kinematic variables in the PM muscle.

CONCLUSIONS

Based on these data, it can be concluded that through observation of high lactatemia values we obtained reduction of swimming velocity and neuromuscular activation, which allow us state that the correlation between kinematic variables and EMG are crucial in the performance observation and evaluation in sportive swimming. Moreover, it can be an important way in supporting strength training exercises prescription outside the pool for the increase of muscular resistance of the muscles involved in the breaststroke technique.

All authors have declared there is not any potential conflict of interests concerning this article.

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