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NEUROMUSCULAR FATIGUE DURING 200 M BREASTSTROKE

Authors

Ana Conceição [1,3]

António Silva [2,3]

Tiago Barbosa [4,3]

István Karsai [5]

Hugo Louro [1,3]

[1] Sport Sciences School of Rio Maior - Polytechnic Institute of Santarém, Rio Maior, Portugal;

[2] University of Trás-os-Montes and Alto Douro, Vila Real, Portugal;

[3] Research Center in Sports Science, Health and Human Development, Vila Real, Portugal;

[4] Nanyang Technological University, Singapore;

[5] University of Pécs, Pécs, Hungary;

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RESUMO

O objetivo deste estudo foi: i) analisar os padrões de ativação dos músculos dos membros superiores (duração da fase ativa e não ativa) durante cada percurso dos 200m bruços, ii) quantificar a fadiga neuromuscular, através das variáveis cinemáticas e fisiológicas. Os dados electromiográficos (EMG) de superficie foram recolhidos nos músculos bíceps brachii (BB), deltoid anterior (DA), pectoralis major (PM) e tríceps brachii (TB) de nove nadadores masculinos durante 200m bruços á máxima intensidade. Os valores de lactacto sanguíneo registaram um aumento de 13.02 ± 1.72 mmol l-1 3 minutos após teste. A velocidade de nado (v) decresceu de 1.38 ± 0.09 ms-1 no 1º percurso de nado para 1.14 ± 0.08 ms-1 no 4º percurso, a distância de ciclo (DC) decresceu de 2.23 ± 0.18 m no 1º percurso para 1.92 ± 0.15 m no 4º percurso, FG decresceu de 37.58 ± 4.90 ciclo/min-1 no 1º percurso para 34.80 ± 2.83 ciclo/min-1 no 3º percurso e aumentou no 4º percurso (35.91 ± 2.99 ciclo/min-1); e o índice de nado (IN) demonstrou que a eficiência de nado foi superior no 1º percurso, decrescendo desde o início (3.07±0.25 m2/c/s) para o último percurso (2.19±0.29 m2/c/s). A amplitude do sinal EMG providenciado pelo ARV demonstrou um aumento no final do percurso para todos os músculos em estudo, à exceção do DA e PM no 1º percurso e para o BB, DA e TB no 4º percurso. A frequência média do PSD (MNF) diminui no final do nado no 4º percurso em relação ao 1º percurso para todos os músculos em estudo. Concluiu-se que, todos os parâmetros EMG não indicaram diferenças significativas nos músculos analisados na prova de 200m bruços, mas alguns indicadores da fadiga neuromuscular apontam para um aparecimento inicial no 2º percurso, mas mais evidente no 3º percurso. Existe uma tendência para o estado de fadiga de uma forma não linear.

Palavras-chave: natação; cinemática; EMG; frequência média

ABSTRACT

The aims of this study were: i) to analyze activation patterns of four upper limb muscles (duration of the active and non-active phase) in each lap of 200m breaststroke, ii) quantify neuromuscular fatigue, with kinematics and physiologic assessment. Surface electromyogram was collected for the biceps brachii, deltoid anterior, pectoralis major and triceps brachii of nine male swimmers performing a maximal 200m breaststroke trial. Swimming speed, SL, SR, SI decreased from the 1st to the 3rd lap. SR increased on the 4th lap (35.91 ± 2.99 stroke·min^{-1}). Peak blood lactate was 13.02 ± 1.72 mmol·l^{-1} three minutes after the maximal trial. The EMG average rectified value (ARV) increased at the end of the race for all selected muscles, but the deltoid anterior and pectoralis major in the 1st lap and for biceps brachii, deltoid anterior and triceps brachii in the 4th lap. The mean frequency of the power spectral density (MNF) decreased at the 4th lap for all muscles. These findings suggest the occur- rence of fatigue at the beginning of the 2nd lap in the 200m breaststroke trial, characterized by changes in kinematic parameters and selective changes in upper limb muscle action. There was a trend towards a non-linear fatigue state.

Key words: Swimming; Kinematics; EMG; Mean frequency.

INTRODUCTION

The breaststroke technique is considered one of the least economic of the four swimming styles (Barbosa et al., 2006), which can lead to early fatigue while swimming. Neuromuscular fatigue can be defined as: (i) the failure to maintain the required or expected force, accompanied by changes in muscular activity (Dimitrova et al., 2003); and (ii) the inability of skeletal muscle to generate high levels of muscular strength or maintain these levels over time (Enoka and Stuart, 1992). Additionally, the manifestations of fatigue have been associated with (Allen et al., 1995; Pagala et al., 1994): (i) a decline in muscle tension produced during and after submaximal and maximal exercise; (ii) an inability to maintain a given exercise intensity over time, reducing the speed of contraction and increased muscle relaxation time, as well as; (iii) the variation of intra and extracellular concentrations of certain metabolites and ions.

Neuromuscular fatigue can be divided into central and peripheral fatigue. Central fatigue comprises of decreases in the voluntary activation of the muscle, which is due to decreases in the number of recruited motor units and their discharge rate (González et al., 2012). Peripheral fatigue involves changes in neuromuscular transmission, muscle action potential propagation and decreases in the contractile tension of the muscle fibers (Boyas and Guevel, 2011). Peripheral fatigue during exercise is considered an impairment of the peripheral mechanisms from excitation to muscle contraction. Peripheral regulation is, therefore, related to a perturbation of calcium ion movements, an accumulation of phosphate, and/or a decrease of adenosine triphosphate stores (Boyas and Guevel, 2011).

Some studies attempted to relate the onset of fatigue with the execution of various sport techniques (Camata et al., 2011; Giangarra et al., 1993; Pink et al., 1993; Robineau et al., 2012). While swimming, neuromuscular mechanisms related to fatigue remain unclear, and the few studies which carried out research, focused mainly on the front-crawl technique (Caty et al., 2006; Figueiredo et al., 2011; Ikuta et al., 2012; Stirn et al., 2011).

Caty et al. (2006) observed a decrease in the instantaneous mean frequency in the extensor carpi ulnaris muscles (11.4% and 8.5%, respectively) after a 4x50m high intensity front crawl. Stirn et al. (2011) reported that at the end of a 100m front crawl at a maximal effort, the mean power frequency decreased by 20-25%. Ikuta et al. (2012) suggested that the decrease in swimming velocity was related to a decrease in the activity of several muscles coordinated with each other, and that a compensating strategy was involved between the pectoralis major and other muscles during the last lap of a 4x50m front crawl test.

Important muscles activated in breaststroke swimming seem to be the biceps brachii, triceps brachii, subscapularis, latissimus dorsi, pectoralis major, supraspi- natus, infraspinatus, serratus anterior, and deltoid anterior, teres minor and trapezio) for the upper limbs (Conceição et al., 2010; Nuber et al., 1986; Ruwe et al., 1994; Yoshizawa et al., 1976). While gluteus maximus, vastus medialis, rectus femoris, biceps femoris, abductor magnus, quadriceps, gastrocnemius, tibialis anterior, abductor hallucius, abductor digiti minimi, flexor digitorum brevis are for the lower limbs (Mcleod, 2010; Yoshizawa et al., 1976).

It is clear that EMG can be useful in tracking muscle fatigue for many reasons (the relationships found between sEMG features and muscle fatigue, and the possibility of recording them in almost any type of situation). Therefore, some studies have examined the relationship between muscle fatigue and EMG variables and, consequently, the possibility of using EMG models to accurately track muscle fatigue (González-Izal et al., 2012).

The linear techniques that are used to estimate muscle fatigue are based on linear regression, which relates changes in EMG parameters to changes in power loss (as a direct measurement of muscle fatigue). The non-linear techniques that are used to estimate muscle fatigue are based on neural networks to relate EMG parameters to muscle fatigue. Both linear and non-linear techniques provided good results for mapping changes in power or force loss during dynamic exercises based on sets of EMG parameters (González-Izal et al., 2012).

Apart from this, however, we have no idea of the appearance of fatigue of the upper limbs in breaststroke. Since there is a lack of studies to quantify the neuromuscular fatigue in the upper limbs, using spectral parameters, we believe that this research would have the potential to make a contribution to the limited body of knowledge in this field. The main aim for swimming coaches and researchers relies on the identification of the factors that might predict performance with higher validity and accuracy.

The aims of this study were: i) to analyze the activation patterns (duration of active and non-active phase) of the upper limbs four muscles during each lap for 200m breaststroke, ii) quantify neuromuscular fatigue, through kinematics and physiologic assessment. It was hypothesized that an increase in signal amplitude and a decrease in spectral parameters due to repetitive sub-maximal contractions, characterized a non-linear fatigue process. Also considered was that the fatigue process occurs differently for each of the muscles studied.

METHODS

Subjects

Nine male swimmers (age: 22.3 ± 2.9 years; height: 1.81 ± 0.05 m; body mass: 73.60 ± 3.82 kg; mean ±SD) volunteered to participate in this study and provided written consent. They were all swimmers competing at the national level with an average personal best result for 200m breaststroke (149.44 ± 6.59 s, corresponding respectively to 643.75 ± 53.77 FINA ranking points). All the procedures were approved by the institutional Ethics Committee and carried out according to the Helsinki Declaration.

Testing procedure

The experiments were performed in a 50m indoor swimming pool at a water temperature of 27.5 ° C and 75% humidity. Subjects performed a standard warm-up of 800m front crawl, and a specific warm-up of 200m breaststroke at a medium level of effort. After a twenty minute rest subjects performed a maximal 200m breaststroke trial with a push off start.

Data acquisition

EMG data collection

Surface EMG signals from the biceps brachii (BB), deltoid anterior (DA), pectoralis major (PM) and triceps brachii (TB) on the right side of the body were collected. These muscles were selected according to their importance in breaststroke (Conceição et al., 2010; Nuber et al., 1986; Ruwe et al., 1994; Yoshizawa et al., 1976).

Bipolar surface electrodes were used (10mm diameter discs, Plux, Lisbon, Portugal) with an interelectrode distance of 20mm. Electrodes on the upper part of the PM were placed in the middle of the line that connects the acromion process and the manubrium (sternum) two fingers below the clavicle (Stirn et al., 2011). The electrodes on the long head of the BB, DA and TB were placed in accordance with SENIAM recommendations (Herrmens and Freriks, 1999).

The skin was shaved, rubbed with sandpaper and cleaned with alcohol so that the inter-electrode resistance did not exceed 5 KOhm (Basmajian and De Luca, 1985). The ground electrode was positioned over the cervical vertebrae. Transparent dressings with labels (Hydrofilm®, 10 cm x 12,5 cm, USA) were used to cover the electrodes to isolate them from the water (Hohmann et al., 2006). All cables were fixed to the skin by adhesive tape in several places to minimize their movement and any signal interference. Swimmers wore a full body swimming suit to further immobilize the cables (Fastskin Speedo®, Speedo Aqualab, USA).

The wireless EMG device (BioPLUX.research, Lisbon, Portugal) with 8 analog channels (12bit), sampling rate at 1 kHz, was put in a waterproof bag (84x53x18mm) and placed inside the swimmer´s cap. Data was transmitted to the PC in real time via Bluetooth.

The EMG and video data were recorded simultaneously and were not synchronized with video recording, because the aim of this study was to understand the appearance of fatigue in relation to race parameters rather than detailed within cycle swimming kinematics.

All EMG analysis was conducted with a MATLAB routine (Mathworks, Inc., Natick MA, USA). The process of determining the muscle activity boundaries consists of finding the neighborhood points, where the energy was 30% of muscle activation maximum peak within a stroke (Stirn et al., 2011). These were calculated by segmenting the muscle input signal energy according to the same criteria described in Stirn et al. (2011). Starting from the raw signal, DC components were removed and thereafter filtered with a fifth-order Butterworth band pass filter where the lower and upper cut-off frequencies were set to 10 and 500Hz respectively. The signal energy was then determined with a 250 ms sliding window (Stirn et al., 2011) and according to:

$$E(t_0) = \int_{t_0+125\text{ms}}^{t_0+125\text{ms}} x^2\ (t)\,dt$$

Even though the high frequencies of the input signal were filtered with a Butterworth filter, muscle energy is very noisy and presents several local maximum peaks that didn´t correspond to the muscle active window center, as shown in Figure 2. To overcome this difficulty, a strategy to determine the muscle's "true" maximum energy peaks was devised. Each stroke taken by a swimmer produces patterns in the signal, these patterns are mainly translated by a periodicity in EMG energy, see Figure 1.

By defining the signal mean period, one can use this information to determine the maximum peak candidates with the highest and with minimal differences between two maximum candidates and the expected period.

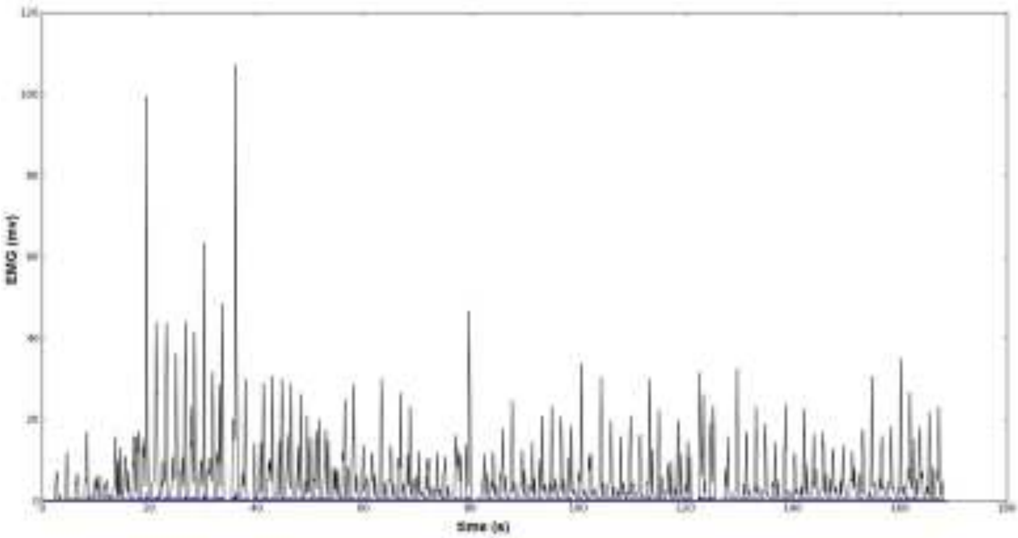

***Figure 1**. Energy envelope of EMG signal segment.*

Once the maximum candidates have been determined, the muscle activity boundaries were then selected by determining the neighborhood points where the energy is 30% of the determined maximum peaks. For each muscle activation, the active phase was defined as the part of the EMG signal for which the energy was at least 30% of the local maximum energy value, for each particular muscle activation. The raw EMG segments belonging to the active phases were extracted and used in the calculation of the active phase duration and the amplitude frequency analysis. The non-active phase was defined as the time interval between the two consecutives active phases as shown in Figure 2.

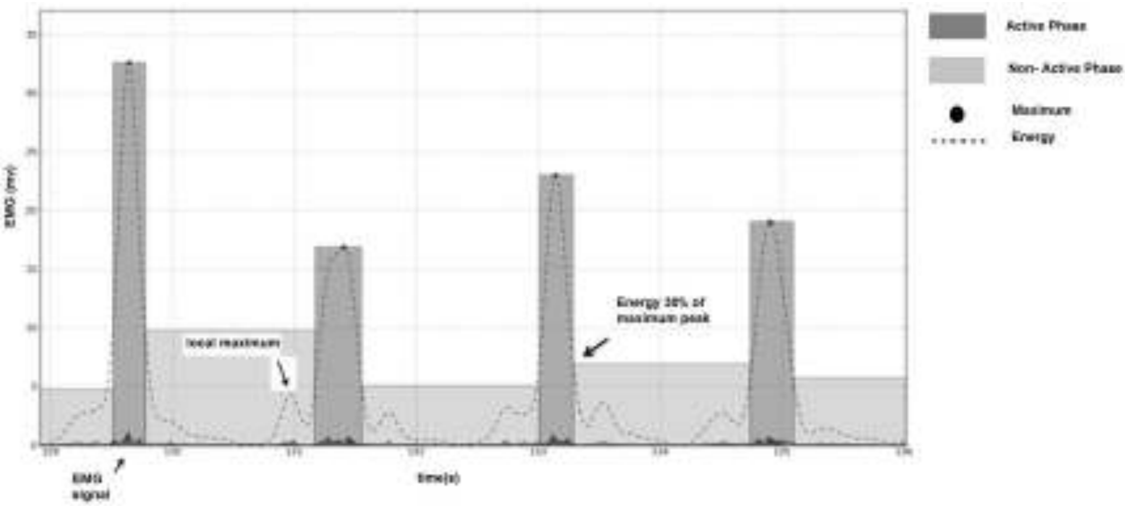

Figure 2*. Segment of non-active phase and active phase of the EMG signal.*

The temporal evolution of the active and non-active phases average durations during stroke were calculated for each muscle for the entire 200m. Linear regression curves were fitted to the data and the durations of the fitted curves at the beginning and completion of the swim were compared. The comparisons of the durations of the active and non-active phases of each muscle during the stroke were made to detect changes that might occur due to fatigue.

The average amplitude of EMG of each active phase was estimated using the average rectified value (ARV) of the EMG. ARV was calculated in accordance with SENIAM recommendations (Herrmens and Freriks 1999) and plotted as a function of time. A linear regression curve was fitted to the data and the ARV values of the curve at the time of commencement and the end of the swimming bout were compared (Figure 3).

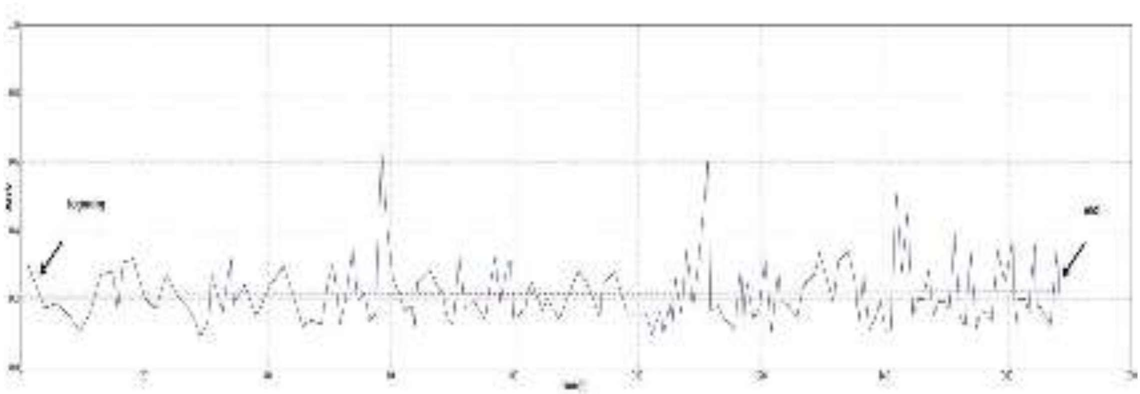

Figure 3. *Example of a linear regression of the tríceps brachii of one swimmer, of the ARV values in the beginning and the end of the swimming bout.*

For the frequency analysis, each extracted segment was zero-padded to the total length of 1s (i.e., 1,000 samples). In this way, a uniform frequency resolution (the frequency sampling interval) was used for all signal segments. The power spectral density (PSD) for each segment was estimated using the periodogram method (Proakis and Manolakis, 1996). The periodogram of a continuous signal segment x(t) of length T is defined as:

$$\boldsymbol{x}(\boldsymbol{f}) = \frac{1}{T} |X(f)|^2$$

Even though the periodogram is a non-consistent estimate of PSD (its variance is large and does not become zero with increasing length of the signal), it was demonstrated that using more sophisticated methods for PSD estimation, does not significantly improve the estimation of power spectrum central frequency measures (the mean or the median frequency) (Farina and Merletti, 2000).

Since the differences were insignificant, we decided to use the periodogram estimate in our study. As a measure of the central tendency of PSD we used the mean frequency of the PSD (MNF). MNF is defined as the first moment of the PSD and was developed by Kwatny et al., (1970). For the continuous spectrum spanning the frequencies between 0 and fMAX is defined as:

$$\mathbf{MNF} = \frac{\int_0^{fMAX} f.Px(f)df}{\int_0^{fMAX} .Px(f)df}$$

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

The values of MNF belonging to each muscle were plotted as a function of time. Since all data exhibited a trend toward linear decrease with time, a linear model was fitted to all MNF data sets to the initial MNF value (the value of MNF at the time of the first stroke) and the final MNF value (the value of MNF at the time of the last stroke) and labeled as MNFbeg and MNFend, respectively. To normalize results between subjects, the final MNF values were expressed as a percentage of the initial values and labeled MNFn as:

$$\mathbf{MNF_n} = \frac{\mathrm{MNF_{end}}}{\mathrm{MNF_{beg}}} \text{x } 100$$

The slope of the regression line was also calculated as an estimate of the rate of change over time.

Physiological data collection

Blood samples were collected from the earlobe at 3, 5, 7 minutes after the bout. Post exercise blood lactate concentrations were measured using a hand held portable apparatus (Lactate Pro AnalyserTM, Arkay, Kyoto, Japan). According Pyne et al., (2001) this equipment exhibits a high accuracy compared with other lactate analyzers and high degree of versatility under a variety of testing conditions.

Kinematic data collection

The swims were videotaped simultaneously on sagittal plane with a pair of cameras providing a dual projection from both underwater (Sony Mini Dv DCR-HC42E, EUA) and above (Sony Mini Dv DCR-HC42E, EUA) the water surface. The cameras were placed stationary at 25m of the headwall, on a lateral wall, perpendicular to the swimmer's trajectory and 10m away. The study comprised the kinematic analysis of stroke cycles (Ariel Per- formance Analysis System, Ariel Dynamics Inc., USA) at a sample rate of 50Hz. Zatsiorsky's model with an adaptation by de Leva (1996) was used with 8 anatomical landmarks and a trunk division in two articulated parts (Barbosa et al., 2010; Hirata and Duarte, 2007; Lafond et al., 2004; Pavol et al., 2002). To create a single image of dual projection as described previously (Barbosa et al. 2006; 2010), the independent digitalization from both cameras was reconstructed with the support of a calibration volume (16 point) and a 2D-DLT algorithm (Abdel-Aziz and Karara, 1971).

The stroke cycle was measured between the 18th m and 22th m, and identified at the end of the leg´s recovery (i.e., when the knees were in full flexion and feet on eversion).

Stroke mechanics were measured by the stroke cycle period (P, s), the stroke rate (SR = 1/P, Hz), the stroke length (SL, m) and the mean swimming speed of the full stroke (v, $m \cdot s^{-1}$). Finally, the swimming efficiency was estimated using the stroke index (SI = v SL, $m^2 \cdot c^{-1} \cdot s^{-1}$) as suggested by Costill et al. (1985). This index assumes that, at a given v, the swimmer with greater SL has the most efficient swimming technique.

Statistical procedures

The assumptions of normality of data (Kolmogorov–Smirnov test) and homogeneity of variance (Levene's test) were both confirmed for all parameters. All results are reported as the mean values along with standard deviation values. The repeated measures ANOVA, with subsequent Tukey's test as post hoc analysis where applicable, were used for multiple comparisons between the laps ($p < 0.05$).

RESULTS

Kinematics data

Figure 4 presents the mean and SD of the kinematics parameters (Swimming Speed, SL, SR, SI) in the 4th lap of the 200m breaststroke. Swimming speed decreased from 1.38 ± 0.09 $m \cdot s^{-1}$ in the 1st lap to 1.14 ± 0.08 $m \cdot s^{-1}$ in the 4 th lap. Significant variations were observed on swimming speed between the 1st lap and 2nd lap, and between the 1st lap and 3rd lap [$F = 21.27$, $p < 0.05$]. SL decreased from 2.23± 0.18 m in the 1st lap to 1.92 ± 0.15 m in 4th lap. Significant variations were observed on the SL between the 1st lap and 3rd lap, and between the 1st lap and 4th lap [$F = 4.41$, $p < 0.05$].

SR decreased from 37.58± 4.90 stroke min^{-1} in the 1st lap to 34.80±2.83 stroke min^{-1} in 3rd lap and then increased in the 4th lap (35.91 ± 2.99 stroke·min^{-1}). No significant variations were observed between laps [$F = 0.92$, $p > 0.05$]. Lastly, the SI was higher in the 1st lap, and decreasing from the 1st (3.07 ± 0.25 m2·s^{-1}) to the last lap (2.19 ± 0.29 m2·s^{-1}). Significant variations were observed on the SI between the 1st lap and 2nd lap, between the 1st lap and 3rd lap and between the 1st lap and 4th lap, [$F = 16.94$, $p < 0.05$].

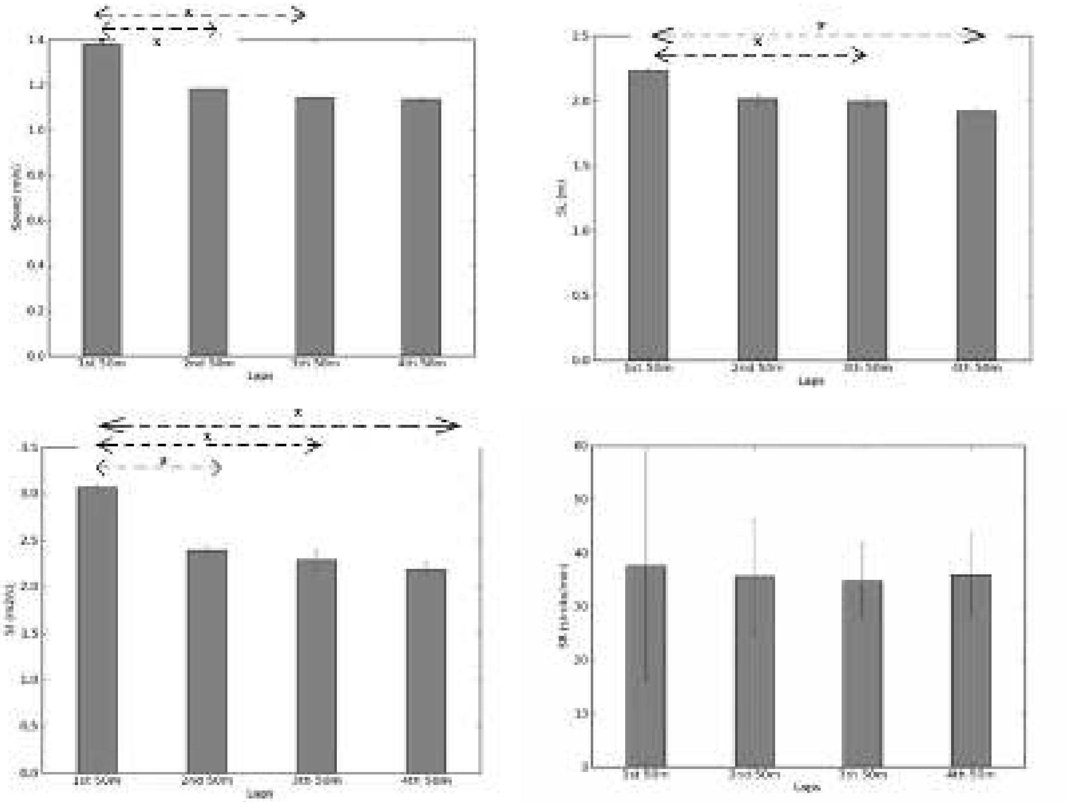

Figure 4. *Mean and SD of Swimming Speed (m·s^{-1}); Stroke length (SL) m; Stroke index (SI) $m^2 \cdot c^{-1} \cdot s^{-1}$ and Stroke rate (SR) stroke min^{-1} in the four 50m lap of a 200-m breaststroke. * $p< 0.05$.*

Physiology

The means and standard deviations in blood lactate concentration (La) measured after the 200 m breaststroke are shown in the Figure 5. The highest value (13.02 ± 1.72mmol·l^{-1}) was observed at the 3rd minute after the trial. Significant variations were observed in La between the 1st minute and 3rd minute, and between the 1st minute and the 5th minute [$F = 2.47$, $p < 0.05$].

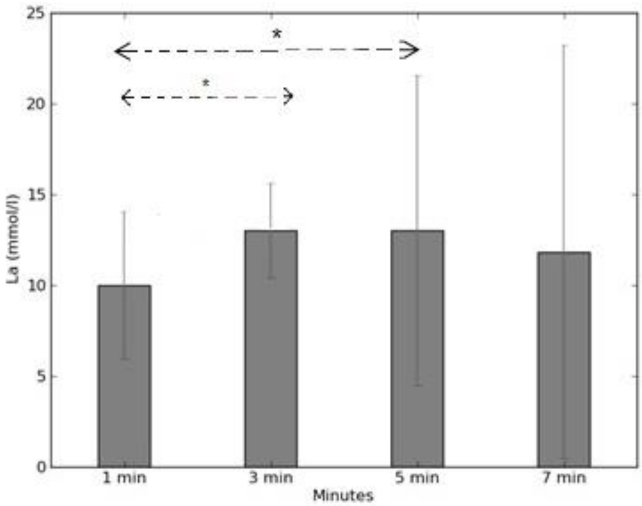

Figure 5. *Blood lactate concentration after swim 1, 3, 5 and 7 min. * p < 0.05.*

Neuromuscular

The duration of the active phase (Table 1) was, for the BB muscle, higher in the beginning phase compared to the end phase of the swim for all four laps. The DA muscle presented a higher value in the beginning phase in the 1st lap and 3rd lap, but exhibited a higher value in the end phase for the 2nd and 4th lap. The PM muscle demonstrated a higher duration of active phase at the end for all laps with the exception of the 3rd lap (PMbeg: 0.69 ± 0.62 s and PMend: 0.55 ± 0.33 s) where the active phase was higher at the beginning than the end of the session. The TB muscle showed a higher active phase at the beginning in the 1st and 3rd lap, and higher values in the end in the 2nd and 4th lap.

The long duration of active phase was shown in BB at the beginning of the swim in the 1st lap (0.99 ± 0.78 s) and the shorter for the TB at the end of swimming the 3rd lap (0.52 ± 0.15 s). Moreover, for all the muscles, the active phase showed the same trend in the 3rd lap. The duration was higher in the beginning compared to the end of the swim. The differences between beginning and the end for each muscle were not statistically significant for $p < 0.05$.

Table 1. *Mean (±SD) duration of active phase for active phasebeg and active phaseend four all the muscles (BB- bíceps brachii; DA- deltoid anterior; PM- pectoralis major and TB- triceps brachii), over the four laps of the 200 m breaststroke maximal effort.*

Laps	1st lap		2nd lap		3rd Lap		4th Lap	
	Active $phase_{beg}$ (s)	Active $phase_{end}$ (s)	Active $phase_{beg}$ (s)	Active $phase_{end}$ (s)	Active $phase_{beg}$ (s)	Active $phase_{end}$ (s)	Active $phase_{beg}$ (s)	Active $phase_{end}$ (s)
BB	.99 (.78)	.98 (.90)	.73 (.26)	.58 (.14)	.68 (.27)	.56 (.20)	.70 (.24)	.63 (.10)
DA	.78 (.30)	.64 (.17)	.63 (.14)	.72 (.14)	.87 (.67)	.58 (.25)	.82 (.38)	.93 (.58)
PM	.61 (.18)	.71 (.32)	.64 (.17)	.88 (.48)	.69 (.62)	.55 (.33)	.62 (.35)	.79 (.63)
TB	.71 (.21)	.69 (.25)	.54 (.14)	.58 (.14)	.54 (.22)	.52 (.15)	.84 (.74)	.85 (.76)

Table 2. *Mean (±SD) duration of non-active phase for non- active phasebeg and non- active phaseend for all the muscles (BB- biceps brachii; DA- deltoid anterior; PM- pectoralis major and TB- triceps brachii), over the four laps of the 200 m breast- stroke maximal effort.*

Laps	1st lap		2nd lap		3rd Lap		4th Lap	
	Non-Active $phase_{beg}$ (s)	Non-Active $phase_{end}$ (s)	Non-Active $phase_{beg}$ (s)	Non-Active $phase_{end}$ (s)	Non-Active $phase_{beg}$ (s)	Non-Active $phase_{end}$ (s)	Non-Active $phase_{beg}$ (s)	Non-Active $phase_{end}$ (s)
BB	.76 (.24)	.80 (.24)	.81 (.21)	.72 (.22)	.77 (.20)	.81 (.28)	.79 (.26)	.78 (.17)
DA	.66 (.16)	.71 (.14)	.79 (.15)	.69 (.17)	.70 (.16)	.75 (.19)	.70 (.24)	.68 (.26)
PM	.60 (.18)	.60 (.13)	.70 (.24)	.68 (.32)	.63 (.21)	.65 (.17)	.72 (.20)	.68 (.16)
TB	.63 (.27)	.62 (.18)	.55 (.17)	.67 (.26)	.59 (.17)	.64 (.29)	.61 (.18)	.53 (.22)

The non-active phase in Table 2, showed an increase in the end of the test for all the muscles in the 3rd lap and a decrease in the 4th lap. The muscles BB, DA and PM demonstrated the same behavior in the relative duration of the non-active phase for each lap of the 200m breaststroke, that is, in the 1st and 3rd lap they had a longer duration at the end compared to the beginning of the swim, unlike in the 2nd and 4th lap where the higher duration was observed in the beginning of the swim.

The TB showed a different behavior compared to the other muscles studied, which presented a higher duration in the non-active phase in the beginning compared to the end of the swimming the 1st and 4th lap, and in the end for the 2nd and 3rd laps, moreover for all the muscles under study the non-active phase showed the same behavior in the 3rd lap, where the duration was higher in the beginning which also happened in the active phase. The differences between the beginning and the end for each muscle were not statistically significant for $p < 0.05$.

The relative duration of activation (RAF) in Figure 6, decreases at the beginning phase in the 1st and 3rd lap for the DA and PM, whereas for the 2nd and 4th lap it was higher in the end for both the DA and PM. The BB demonstrated a RAF higher in the end phase in the 1st and 2nd lap, and the reverse in the 3rd and 4th lap. The TB decreased at the beginning phase over the first three laps, in contrast to the 4th lap where the value was higher in the end. The differences between the beginning and the end for each muscle were not statistically significant for $p < 0.05$.

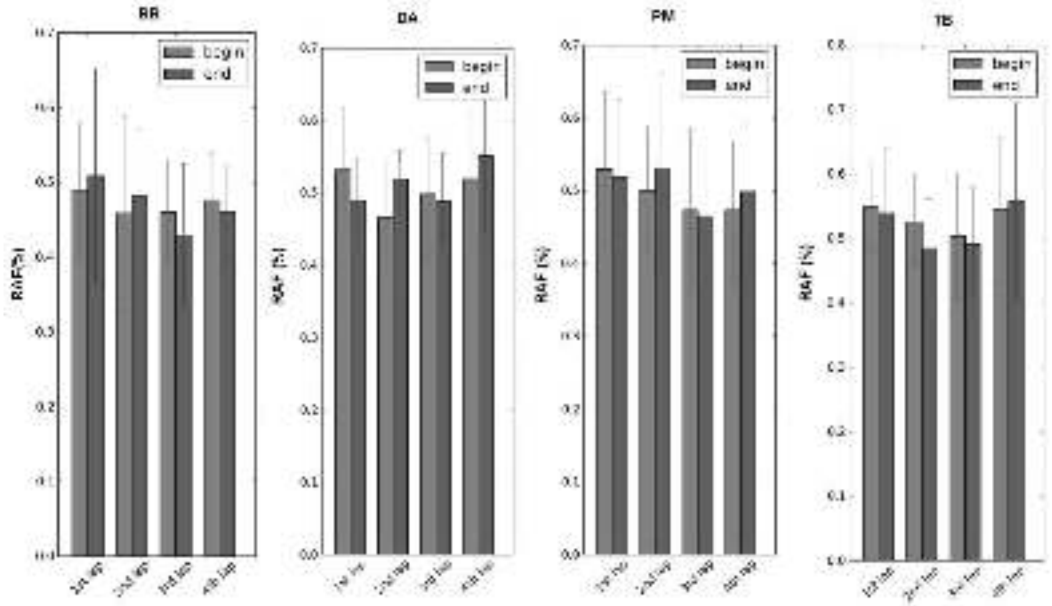

Figure 6. *Comparison of the mean relative duration of activation value with SD for RAFbeg (gray bars) and RAFend (black bars) four all the muscles (BB- bíceps brachii; DA- deltoid anterior; PM - pectoralis major and TB- triceps brachii), over the four laps of the 200 m breaststroke maximal effort.*

Figure 7 demonstrated that the average rectified value increases at the end phase compared to the beginning phase for all muscles comparing the 1st lap with the 4th lap, except for the DA (DAbeg:0.42 ± 0.13; DAend: 0.42 ± 0.10) that demonstrated higher values in the beginning phase. The BB and TB muscles have similarities throughout the laps, that is, in the first three laps (1st, 2nd and 3rd laps) the ARV was higher in the end compared to the beginning and in the 4th lap the reverse was observed. The PM showed similarities in the 1st and 3rd lap which had higher values in the beginning, and in the 2nd and 4th lap had higher values at the end.

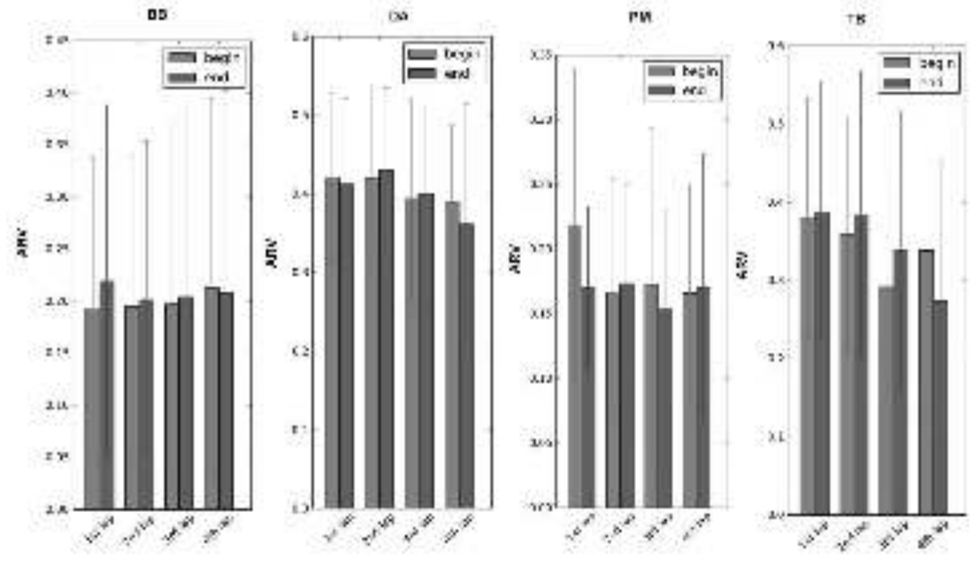

Figure 7. *Mean ARV value with SD for ARVbeg (gray bars) and ARVend (black bars) four all the muscles (BB - bíceps brachii; DA- deltoid anterior; PM - pectoralis major and TB- triceps brachii), over the four laps of the 200 m breaststroke maximal effort.*

In Figure 8, the mean MNF value for the BB increased in all the laps at the end except the 3rd lap (BBend: 82.47 ± 16.20 Hz BBbeg: 86.15 ± 11.72 Hz). DA decreases in all the laps at the beginning except in the 3rd lap (DAend: 77.38 ± 13.68 Hz, DAbeg: 74.54 ± 15.52 Hz). The PM decreases at the beginning in the 1st lap (PMbeg: 89.65 ± 23.61 Hz; PMend: 89.53 ± 17.74 Hz) and 3rd lap (PMbeg: 79.37 ± 10.58 Hz; PMend: 76.16 ± 16.92 Hz), and increases at the beginning in the 2nd lap (PMbeg: 82.13 ± 15.33 Hz; PMend: 86.11 ± 18.12 Hz) and 4th lap (PMbeg: 74.33 ± 14.61 Hz; PMend: 75.18 ± 13.92 Hz). TB decreases at the beginning in the 1st lap (TBbeg: 78.17 ± 10.83 Hz; TBend: 74.79 ± 16.37 Hz) and in the 4th lap (TBbeg: 72.45 ± 11.83 Hz; TBend: 65.72 ± 12.94 Hz), whereas in the 2nd (TBend: 73.72 ± 13.68 Hz; TBbeg: 72.41 ± 12.65 Hz) and 3rd lap (TBend: 71.32 ± 11.26 Hz; TBbeg: 68.78 ± 11.03 Hz) we can observe an increase at the end phase compared to the beginning. Moreover, the MNF decreases at the end of swimming the 4th lap relative to the 1st lap for all muscles under observation for the 200m breaststroke. Note that the differences between the beginning and the end for each muscle were not statistically significant for $p < 0.05$.

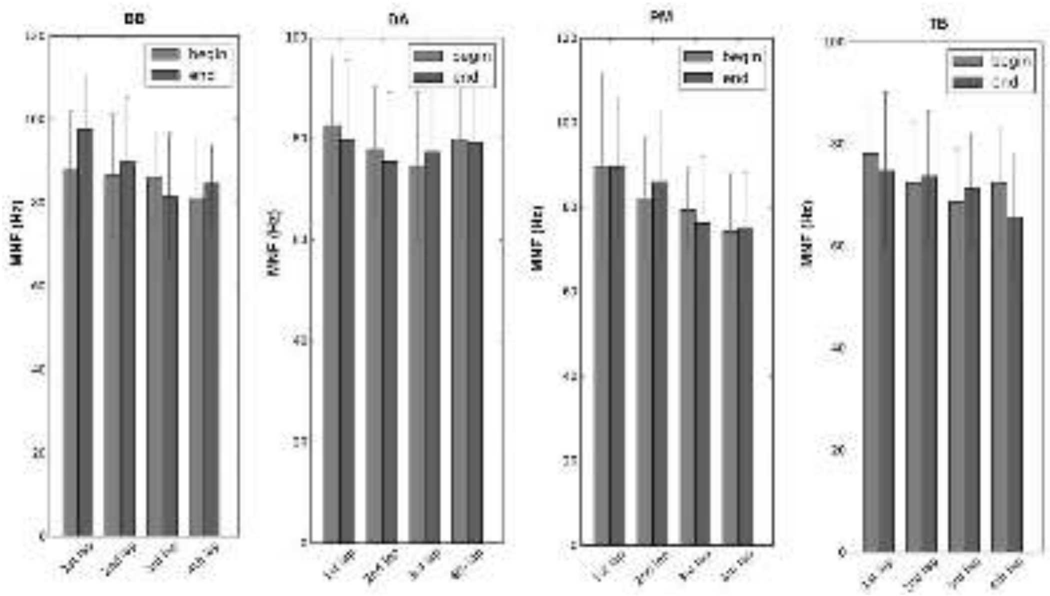

Figure 8. *Mean MNF value with SD for MNFbeg (black bars) and MNFend (gray bars) four all the muscles (BB- bíceps brachii; DA- deltoid anterior; PM- pectoralis major and TB- triceps brachii) and swimming bouts, over the four laps of the 200 m breaststroke maximal effort.*

DISCUSSION

The aims of this study were: i) to analyze four muscle activation patterns (duration of active and non-active phases) of the upper limbs during each lap for the 200m breaststroke, ii) quantify neuromuscular fatigue, through kinematics and physiologic assessment. The main findings were that some indicators of neuromuscular fatigue begin to appear shortly into the 2nd lap, but are more evident in the 3rd lap (i.e amplitudes increase and spectral variables decrease) in a non-linear fashion.

Kinematics

The average decrease in the swimming speed from the 1st lap to the 4th lap shows a much greater decline in speed compared to the results of similar studies (Takagi et al., 2004; Thompson et al., 2000; 2004). In breaststroke, an increase in swimming speed is associated with an increase in SR, but has a decline more in SL relative to the other swimming strokes (Thompson et al., 2004), supporting the changes in the swimming technique under the 200m breaststroke (Takagi et al., 2004). In this study SL suffered a decrease in the 1st lap to the 4th lap, whereas the SR decreased from the 1st lap to the 3rd lap and then increased in the 4th lap.

As swimming speed decreased, different SR and SL combinations were observed, giving the best performance in the face of the fatigue task constraints, and decreasing the swimmer's ability to maintain a constant SL. Increasing SR in the last 50m lap is due to the inability to generate sufficient extra effort to overcome high drag. The decrease in the swimming speed SL, SI and the increase of SR in the last lap suggested a trend for the inability to generate sufficient extra effort needed to overcome high drag throughout the test (Craig and Pendergast, 1979; Chatard et al., 2003; Thompson et al., 2004). This change in the stroke kinematics due to a decrease in the power output can be a consequence of peripherical fatigue phenomena (Ikuta et al., 2012; Stirn et al., 2011).

Physiology

The blood lactate concentration levels after the test reached values that would be expected after a 200m breaststroke race and are in agreement with the results in other studies in which similar tests were performed with swimmers of the same or similar competitive level (e.g., Capelli et al., 1998; Lomax and Castle, 2011). These results suggest that the swimmers performed the swimming test very close to their maximum effort level. The average blood lactate concentration measured after 3 minutes was 13.2 ± 1.72 mmol·l -1, representing the highest values. Increases of lactate concentration are responsible for fatigue by changes in the intracellular pH. As a result, muscle fiber conduction velocity decreases and changes the shape of the motor unit action potential waveform (Cifrek et al., 2009).

Neuromuscular

The amplitude of EMG signals is influenced by the number of active motor units (Moritani et al., 1986), their discharge rates, and the shape and propagation velocity of the intracellular action potentials (Dimitrova and Dimitrov, 2002).

The amplitude signal of EMG provided by the ARV demonstrated an increase and maintenance at the end phase compared to the beginning for BB and PM, comparing the 1st lap with the 4th lap, and a small decrease for DA and TB that demonstrated higher values in the beginning phase compared to the end phase. The swimmers, during the end of the swim, increase the period in the recovery phase, decreasing the amplitude of the EMG signal for DA and TB. These muscles are responsible for the movement of antepulsion of the arms up to the point where it is stretched in front.

EMG amplitude has been observed to increase during submaximal dynamic exercise (Tesch et al., 1990) and to decrease during exercises at maximal levels of voluntary contraction (Komi and Tesch, 1979). An increase of the EMG amplitude during swimming has already been observed in previous studies (Rouard and Clarys, 1995; Rouard et al, 1997; Stirn et al., 2011; Wakayoshi et al., 1994). Ikuta et al., (2012) noted that the mean amplitude value of the PM was significantly higher for the 4th lap than for the 2nd and 3rd laps in 4x50 m front crawl. The authors noted that the increase activity of the PM may have been a compensatory strategy to maintain swimming speed during the test swim. Moreover, Nuber et al. (1986) verified that the PM continued to activate through recovery in the breaststroke.

So, it seems that a decrease in the active phase duration and the increase in the non-active phase on the 3rd lap, with all the muscles monitored, reveal that in this lap muscles start to display the onset of neuromuscular fatigue indicating that this is a milestone of the 200m breaststroke race.

The MNF decreases at the 4th lap in comparison to the 1st lap for all muscles. Dynamic fatiguing tasks have been found to show a decrease in the mean power frequency (Tesch et al., 1990). A number of authors reported similar data in several other human muscles (Basmajian and De Luca, 1985; De Luca, 1984). The same is also apparent for swimming, or at least for front-crawl (Figueredo et al., 2011; Stirn et al., 2011). The reduction of muscle fiber conduction velocity is one of the causes of signal power spectrum shift toward lower frequencies, and also of the increase in the EMG signal amplitude because of a spatial low-pass filtering effect of tissue as a volume conductor (De Luca, 1984).

However, during a fatiguing exercise, two oppositing effects might occur (Petrofsky and Lind, 1980): (i) a decrease in the mean frequency as discussed above and; (ii) increase in intramuscular temperature due to the exercise, which causes an increase in the mean frequency. So it is possible that during some types of exercise, the two effects compensate each other, and the decrements found in the mean frequency can be small or non-significant.

Associations

A decrease in swimming speed, SL, SI and an increase in the SR in the last lap, can be associated to the higher La after the test, to a non-significant increase of the amplitude and a non-significant decrease in the spectral variables. These suggest that the presence of fatigue in the upper limbs occurs in a different way for the different muscles studied, by a non-linear process. However, more investigation in order to better understand this phenomenon is required in the near future.

As blood flow is restricted, at a certain level of contraction, by intramuscular pressure, muscle becomes ischemic. Myoelectric manifestations of muscle fatigue might be affected by this event (Merletti et al., 1984). However, these are evidences for land based exercises, and to the best of our knowledge none of this data has been collected during swimming.

The shape of the ARV during the four laps represent the increased activation patterns in the 2nd and 3th lap in accordance with the normal adaptation and the tactic to use the remaining capacity in the final lap to achieve the best result. The higher activation by DA and TB showed that these muscles play a significant role in this event (Yoshizawa et al., 1976; Conceição et al., 2010).

With this research we can provide quick practical information for swimmers and coaches to adjust training methods.

CONCLUSION

This study showed a trend for a neuromuscular fatigue state in a non-linear fashion, with the 2nd and 3rd lap being the critical moments of a 200m breaststroke race. Decreases in swimming speed are related to SL, SI, and increases of the SR in the last lap, increases in the blood lactate concentration after the test, and a non-significant increase of the amplitude and non-significant decrease in the spectral parameters.

Both the technical and physiologic training in breaststroke swimmers should take into account the onset of fatigue in a non-linear fashion, including specific training to prevent sharp falls in the 2nd and 3rd laps of competitive racing.

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OBSERVATION AND TECHNICAL CHARACTERIZATION IN SWIMMING: 200 M BREASTSTROKE

Authors

Ana Conceição [1,3]

António Silva [2,3]

Tiago Barbosa [3,4]

Hugo Louro [1,3]

[1] *Sport Sciences School of Rio Maior - Polytechnic Institute of Santarém, Rio Maior, Portugal;*
[2] *University of Trás-os-Montes and Alto Douro, Vila Real, Portugal;*
[3] *Research Center in Sports Science, Health and Human Development, Vila Real, Portugal;*
[4] *Nanyang Technological University, Singapore;*

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RESUMO

Introdução: Caracterização da técnica de bruços na relação entre os parâmetros cinemáticos e neuromusculares. **Métodos**: A eletromiografia de superfície (EMG) foi utilizada para analisar a dinâmica da atividade neuromuscular nos músculos biceps brachii (BB), triceps brachii (TB) e anterior deltoid (DA), em doze nadadores de elite nacional. Foram utilizadas um par de câmaras, fornecendo uma projeção dupla a partir de uma câmara subaquática e outra acima da superfície da água, para análise das variáveis cinemáticas: velocidade de nado (v), frequência gestual (FG) e distância de ciclo (DC) em 200m bruços. **Resultados**: A v diminui de 1.41 (0.07) para 1.16 (0.09) m.s-1 ($p<0.05$). A DC diminuiu de 2.32 (0.37) para 1.96 (0.24) m, enquanto a FG sofreu um decréscimo de 37.52 (5.16) para 34.40 (3.58) ciclo/min do 1º percurso de 50m até ao 3º percurso de 50m, aumentando ligeiramente no último percurso para 35.82 (3.39) ciclo/min. O lactato sanguíneo aumentou de repouso para o pico de lactato sanguíneo de 1.12 (0.22) para 12.00 (3.23) mmol.L-1. Os resultados de EMG indicaram um aumento da frequência em relação à amplitude para todos os músculos em estudo, exceto para o DA. Correlações negativas foram obtidas entre a frequência e a v, FG e DC, ou seja, para os músculos BB, TB e PM, verificou-se uma correlação forte entre v, FG e DC, isto é, á medida que as variáveis cinemáticas aumentam a frequência diminui. As correlações sugerem que a ativação neuromuscular apresenta relação direta com as variáveis cinemáticas, nomeadamente para uma diminuição da frequência, nos músculos BB, TB e PM, e para uma elevada amplitude e forte correlação com as variáveis cinemáticas em PM. **Conclusões:** A relação entre as variáveis cinemáticas e EMG são determinantes na avaliação da performance em natação pura desportiva, nomeadamente, no suporte para a prescrição de exercícios para o aumento da resistência muscular dos músculos envolvidos na técnica de bruços.

Palavras-Chave: natação, cinemática, EMG, amplitude, frequência

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.

Key words: 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 described1,2, 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 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).

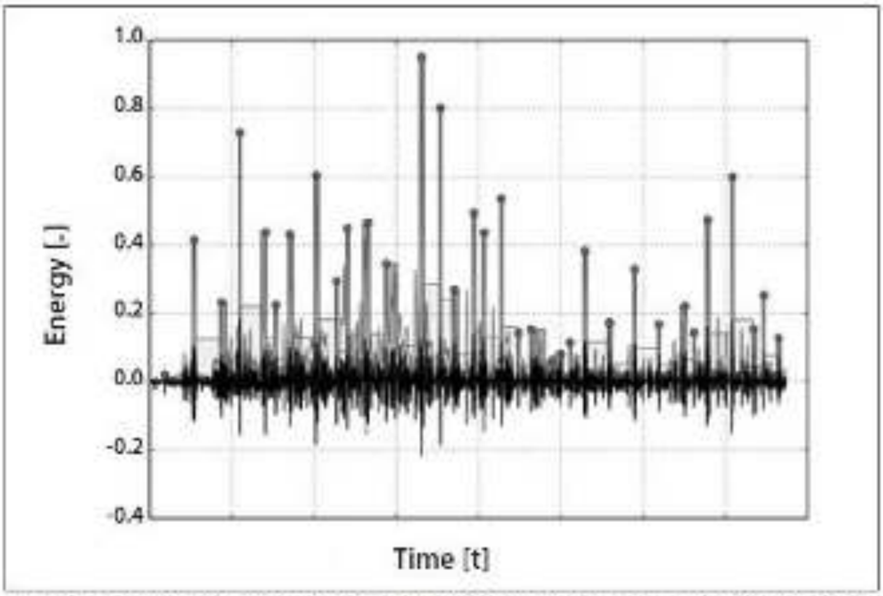

Figure 1. Maximum energy peaks of the EMG signals obtained in the biceps brachii muscle (BB).

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 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:

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

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:

$$\mathbf{MNF} = \frac{\int_0^{fMAX} f.Px(f)df}{\int_0^{fMAX} .Px(f)df}$$

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}.

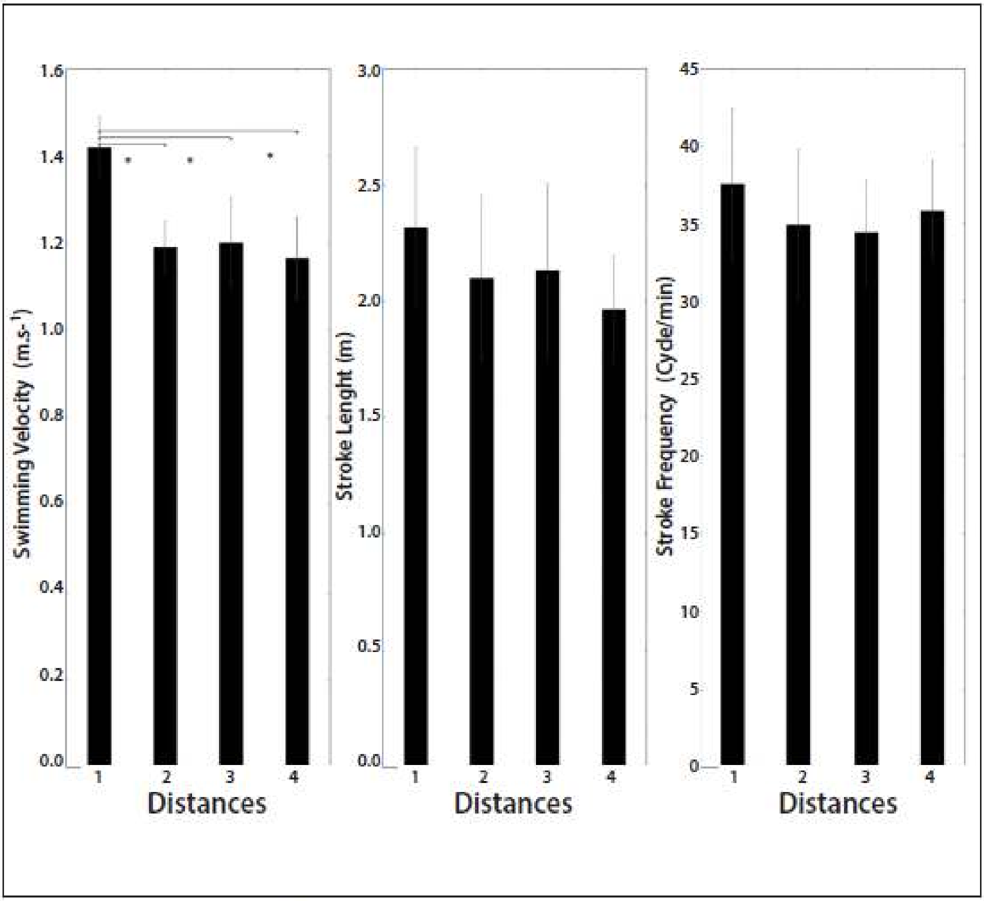

Figure 2. Mean (SD) of the swimming velocity (SV), stroke lenght (SL) and stroke frequency (SF) for the four swimming distances of 50m of the 200m breaststroke *P < 0.05.

Table 1 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 $p < 0.05$).

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.

Sl demonstrated strong correlation with SF, when Sl increases, SF decreases (r=-0.78, for $p < 0.05$) (figure 3).

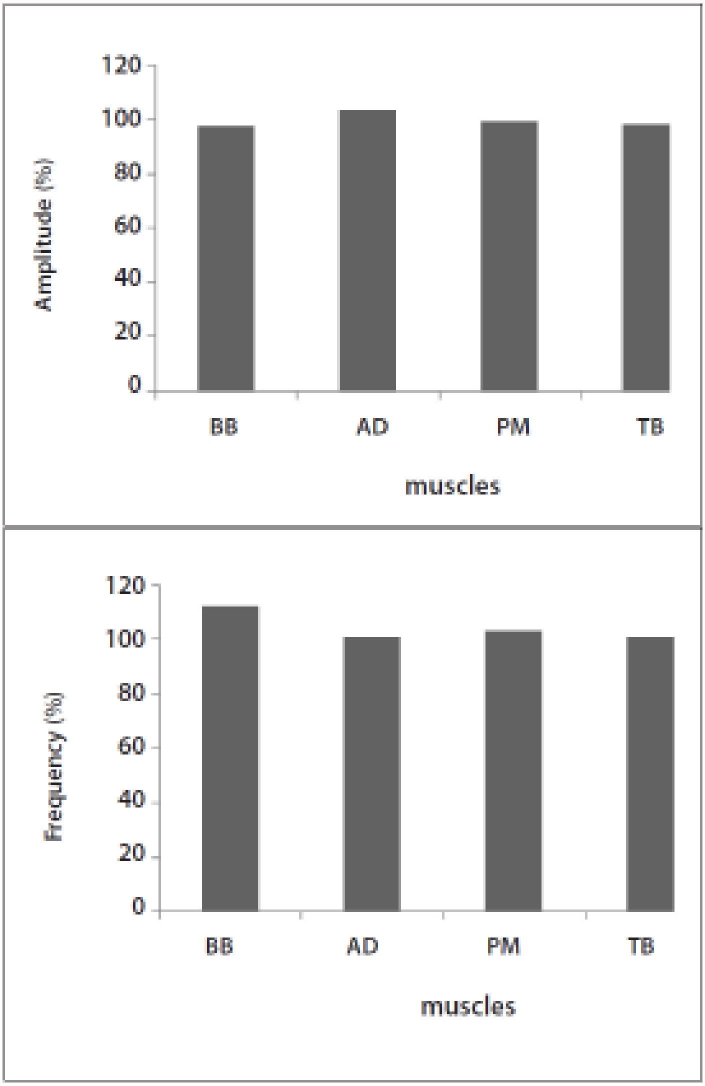

Figure 3. Mean (SD) of the amplitude and frequency between the first and fourth swimming distances for all the studied muscles during the 200m breaststroke (pectoralis major (PM), biceps brachii (BB), triceps brachii (TB) and anterior deltoids (AD).

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)%) 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

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.

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WAVE CHARACTERISTICS IN BREASTSTROKE TECHNIQUE WITH AND WITHOUT SNORKEL USE

Authors

Ana Conceição [1,3]

António Silva [2,3]

José Boaventura [4]

Daniel Marinho [3,5]

Hugo Louro [1,3]

[1] *Sport Sciences School of Rio Maior - Polytechnic Institute of Santarém, Rio Maior, Portugal;*

[2] *University of Trás-os-Montes and Alto Douro, Vila Real, Portugal;*

[3] *Research Center in Sports Science, Health and Human Development, Vila Real, Portugal;*

[4] *INESC TEC - INESC Technology and Science (formerly INESC Porto) and ECT - School of Science and Technology, University of Trás-os-Montes e Alto Douro, Portugal;*

[5] *University of Beira-Interior, Covilhã, Portugal;*

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RESUMO

O objetivo deste estudo consistiu em analisar as características das ondas geradas durante o nado, com e sem a utilização do snorkel Aquatrainer®. Oito nadadores masculinos realizaram duas séries de 25 m bruços, o primeiro sem a utilização do snorkel (condição normal) e o segundo com a utilização do snorkel (condição com snorkel). Os pontos anatómicos, a velocidade do centro de massa, a frequência gestual, a distância de ciclo, o número de Strouhal (St) foram quantificados. A análise de Fourier foi utilizada com o objetivo de determinar a frequência, amplitude, e as fases características das ondulações verticais. Também foi determinado a ondulação do período, a percentagem do primeiro e segundo harmónico da onda, e a contribuição de cada uma dessas componentes para a energia contida para cada um dos sinais de onda. A primeira onda obteve uma frequência de 0.76 Hz (condição normal) e 0.78 Hz (condição com snorkel), e ao segundo harmónico da onda obteve uma frequência de 1.52 Hz (condição normal) e 1.56 Hz (condição com snorkel). Nas condições normais, a amplitude da onda foi superior ao vertex (0.72 m) e cervical (0.32 m) depois nas condições com snorkel (0.71 m e 0.28 m, respetivamente). Os valores mais baixos foram encontrados na bacia (0.03 m na condição normal, e 0.02 m na condição com snorkel). Podemos concluir que a utilização do snorkel leva a alterações no padrão biomecânico na velocidade de nado, bem como em algumas variáveis mecânicas da braçada.

Palavras-chave: Natação Pura Desportiva, frequência gestural, distância de ciclo, snorkel, onda, análise de Fourier

Abstract

The purpose of this paper was to examine the characteristics of waves generated when swimming with and without the use of Aquatrainer® snorkels. Eight male swimmers performed two maximal bouts of 25 m breaststroke, first without the use of a snorkel (normal condition) and then using a snorkel (snorkel condition). The body landmarks, centre of the mass velocity, stroke rate, stroke length, stroke index, and Strouhal number (St) were quantified. Fourier analysis was conducted to determine the frequency, amplitude, and phase characteristics of the vertical undulations. We also determined the undulation period, the first and second harmonic wave percentage, and the contribution of these components to the power of each of the wave signals. The first wave harmonics had a frequency of 0.76 Hz (normal condition) and 0.78 Hz (snorkel condition), and the second wave harmonics had a frequency of 1.52 Hz (normal condition) and 1.56 Hz (snorkel condition). Under the normal conditions, the wave amplitude was higher on the vertex (0.72 m) and cervical (0.32 m) than that produced under snorkel conditions (0.71 m and 0.28 m, respectively). The lowest values were found in the hip (0.03 m in normal conditions, and 0.02 m in snorkel conditions) and in the trunk (0.06 m in normal conditions, and 0.04 m in snorkel conditions). It can be concluded that snorkel use seems to lead to slight changes in the biomechanical pattern in swimming velocity, as well as several stroke mechanical variables.

Key words: Competitive swimming, stroke rate, stroke length, swimming snorkel, wave motion, Fourier analysis.

INTRODUCTION

The wave motion is evident in elite breaststroke swimmers, whose movements have been observed to be similar to those of aquatic mammals. The propulsive movements of dolphins have been studied by Videler and Kamermans (1985), who suggested differences between the upward and downward movements of dolphins. Specifically, they stressed that the downward movement causes more thrust than the upward movement, which can be explained by an increase in drag during upward action.

Ungerechts et al. (1998) found that while the swimming velocity of dolphins increases with kick frequency, amplitude and kick frequency are independent. Moreover, Hochtsein and Blickhan (2010) recently suggested that although the human body is limited by the asymmetry of its movement, it possesses as high flexibility as a body of a fish, allowing high-level swimmers to mimic the locomotion strategies of fish. They also discovered that several of the behaviours of aquatic animals could be mimicked to enhance the performance of swimmers.

Over the years, researchers have sought to identify various technical indicators that can improve swimming performance. Accordingly, researchers have developed studies to produce relevant information that can help swimmers and coaches to apply practical decisions with regard to the technical model that is used. Movement has commonly been regarded as comprising of sinusoids of a particular frequency and phase characteristics of the swimming stroke, generating the hypothesis that movement is controlled by “oscillator-like mechanisms” (Kelso et al., 1980; 1981). Thus, it is possible that an objective measure of the differences between movement patterns could be achieved by quantifying the fundamental waveforms and its frequency harmonics.

The study of the cephalous-caudal wave was started by Sanders et al. (1995; 1998), who used Fourier analysis to quantify the amplitude and phase of the vertical undulations of butterfly stroke swimmers. Sanders et al. (1995) showed that the vertical displacement-time profiles of the body parts of skilled butterfly swimmers are characterised by low frequency waveforms. These phase relationships result in a caudal wave traveling along the body during the stroke cycle. Sanders et al. (1998) also reported that the percentage of power contained in the fundamental frequency of the vertex, head and shoulder vertical undulations causes the swimmer to modify his technique from a conventional (flat) style to wave action. In other studies, the Strouhal number has been shown to be an indicator of efficiency that relates beat frequency and amplitude to swimming velocity (Triantafyllou and Triantafyllou, 1995; Fish and Ror, 1999; Arrelano et al., 2002).

While there have been numerous recent reports about the breaststroke swimming technique, there has been a lack of detailed studies examining the wave motions in breaststroke with the use of equipment such as a snorkel. The Aquatrainer® snorkel (K4 b2, Rome, Italy) allows the measurement of ventilation and oxygen uptake during swimming, and several studies have shown that this equipment recorded the cardiorespiratory parameters of swimmers with validity and accuracy (Toussaint et al., 1987;

Keskinen et al., 2003; Rodriguez et al., 2008). Therefore, it is relevant to analyse the effects of snorkel use and its contribution and suitability as a training device. Barbosa et al. (2010) reported that the Aquatrainer® snorkel affected the normal biomechanical pattern of the breaststroke stroke. However, only a few studies have focused on the effect of the use of the snorkel on the wave characteristics of breaststroke.

Hence, the aim of the present study was to determine the effect of using a snorkel on the frequency, amplitude and phase characteristics of breaststroke using Fourier analysis and the calculation of the Strouhal number.

The objectives of this study were as follows: to determine and verify the home advantage in soccer in the UEFA zone in the first decade of the 21st century and its evolution during this time. We evaluated the behaviour of home advantage taking into account the UEFA ranking and described home advantage in the most powerful leagues of Europe.

MATERIAL AND METHODS

Participants

Eight national-level, male Portuguese swimmers who are experts in the breaststroke technique volunteered to participate in this study. The subjects average (SD) age, body height, body mass, arm span and FINA points for 100 m breaststroke were 21.25 ± 6.73

years, 1.77 ± 0.03 m, 71.14 ± 12.39 kg, 1.84 ± 0.03 m and 483.125 ± 118.38 points, respectively. All subjects gave their written informed consent before data collection, which was approved by a local ethics committee and performed according to the declaration of Helsinki.

Measures Procedures

The measures were performed in a 50 m indoor swimming pool. All subjects performed a warm-up of 400 m at medium intensity. After the warm-up, the subjects were instructed to perform two bouts of 25 m breaststroke swims at maximum intensity, one bout in a "normal condition" and another in the "snorkel condition", using the Aquatrainer designed by COSMED®. The sequence for the implementation of the two conditions was randomly defined. Full recovery was allowed.

The subjects were used to training with snorkel devices. However, the subjects only started to use the Aquatrainer snorkel two weeks before the experiments.

Data collection

The swimmers were videotaped in the sagittal plane in one cycle with a pair of cameras that provided both underwater projection (Sony Mini-DV, 50 Hz) and projection above the water surface (Sony Mini-DV, 50 Hz). The cameras were placed stationary at 25 m from the headwall, in a lateral wall of the swimming pool, perpendicular to the line of motion and 10 m away from the swimmer (Barbosa et al., 2010). The study comprised the kinematical analysis of one stroke cycle, where the frames were scanned manually using the APAS System (Ariel Dynamics, USA) at a frequency of 50 Hz.

The digitised images incorporated the definition of the anthropometric spatial model from Zatsiorsky-Seluyanov, adapted by de Leva (1996), in which the body is divided into the eight following segments: 1 - head, 2 – trunk, 3 – arm, 4 - forearm, 5 - hand, 6 – thigh, 7 - leg, 8 - foot (Pavol et al., 2002; Lafond et al., 2004; Hirata and Duarte, 2007; Barbosa et al., 2010). This was done using data of the mass and relative locations of the centres of mass of the different segments, allowing the calculation of the location of the swimmer's centre of mass

(Colman et al., 1998). The stroke cycle was measured between the 18 and 22 m and identified at the end of the leg recovery when the legs were in flexion and the orientation of the toes had returned to the starting position.

A two-dimensional analysis was conducted by creating a single image of a dual projection, as described previously (Barbosa et al., 2005; Vilas-Boas et al., 1997). The independent digitalisation from both cameras was reconstructed with the help of a calibration volume (cube with 12 calibration points) and a 2D DLT algorithm (Abdel-Aziz and Karara, 1971; Wilson et al., 1997). For the analysis of the centre of mass kinematics, a filter with a cut-off frequency of 5 Hz was used, as suggested by Winter (1990). Stroke mechanics were assessed by the stroke rate (SR = 1/P, Hz), the stroke length (SL, m) and the average swimming velocity of the centre of mass (m/s). The swimming efficiency was estimated by the stroke index (SI = velocity x stroke length), as suggested by Costill et al. (1985). The Strouhal number is a dimensionless number that represents the ratio of unsteady and steady motion (Fish and Rohr, 1999). The Strouhal number (St) can be defined by the following equation (1):

$$St = \frac{A_{p-p} f}{U} \qquad (1)$$

where: A p-p is the tail-beat peak-to-peak amplitude (the distance from the peak of the tail fluke upstroke to the peak of the tail fluke downstroke), ƒ is the tail-beat frequency and U is the average body velocity. It can also be interpreted as a reduced frequency that provides the ratio between the motion caused by the tail oscillation and that due to the forward motion of the swimmer. In such cases, it is an estimate of the unsteadiness in the fluid-body interaction relative to the overall fluid structure. The practical use of this number is to adjust its variables, in this case with frequency and amplitude values modifications, to bring its value closer to the more efficient range, without decreasing the swimmer's speed. As such, it is an indicator of the efficiency in the aforementioned energy transfer mechanism.

The amplitude of the harmonics was analysed by the peak-to-peak amplitude. Fourier analysis was used to quantify the amplitude and phase of the vertical undulations of butterfly swimmers (Sanders et al., 1995). The FFT function was applied to the acquired time series containing the whole number of periods to generate an accurate frequency response. As an example, Figure 2 shows the plots of one period of one acquired signal and the 2 major harmonics computed and their sums (H1+H2). As shown, in this case, the reconstructed signal (H1+H2) is very close to the acquired one, and this procedure has produced results similar to the other processed signals.

To estimate the frequency spectrum, H (f), of a given continuous signal in time domain, h (t), the Fourier transform defined in the equation 2 can be used (Brigham, 1974):

$$\mathrm{H(f)} = \int_{-\infty}^{+\infty} \mathrm{h(t)e^{-j2\pi ft}dt} \qquad (2)$$

However, in our study, as a result of the sampling process, the measured signals were not in continuous time. Instead, they were measured and recorded periodically in time with an interval of time between the data records designated by the sampling period (T). In this case, the signal, h(t), was represented by the discrete signal, h(KT), with N samples resulting from sampling the continuous signal, h(t), with a sampling frequency, fs, resulting in a sampling period of T=1/fs. In this work, the sampling period used was T = 0.02 s (Sanders et al., 1995; 1998). To estimate the frequency spectrum of the discrete signals in the time domain, h (kT), the DFT - Discrete Fourier transform algorithm was used (Brigham, 1974) defined by the equation 3:

$$\mathrm{H(n)} = \sum_{k=0}^{N-1} \mathrm{h(kt)e^{-\frac{j2\pi nk}{N}}} \qquad (3)$$

where: the discrete Fourier transform H(n), with the range from 0 to N-1, is a discrete function to approximate H (f), where N is the number of signal samples and T is the sampling period. Note that H(0),…, H(f), corresponds to the harmonics amplitudes at f=0 Hz,…, f=fs/N. In this work, the DFT of the studied signals was computed to determine the main components in frequency, i.e., the relevant harmonics, of various signals collected from a number (n=8) of swimmers. The DFTs were calculated using the fft function of the programming language, Matlab (MathWorks). This function implements the algorithm FFT - Fast Fourier Transform, which is a faster way to determine the discrete Fourier transform given in the previous expression (Brigham, 1974; Nussbaumer, 1981; Elliot and Rao, 1982). The analysis described above was previously used in other swimming investigations (Sanders et al., 1995; 1998).

The spectral power density, Phd, of the signal h(KT) between harmonics was calculated as described in equation 4:

$$P_{hd} = H(n).^{*}\,\mathrm{conj}\big(H(n)\big),\ P_{hd} = \mathrm{fft}(h).^{*}\,\mathrm{conj}\big(\mathrm{fft}(h)\big) \qquad (4)$$

where: H(n), which is a vector of complex numbers, representing the temporal DFT of the signal h(KT), conj is the conjugate of a complex number and the operator (.*) denotes the element- by-element product of the considered vectors. To obtain the amplitude of each harmonic, equation 5 was employed:

$$P_{ha} = \mathrm{abs}\,\big(\mathrm{fft}(h)\big) * 2/N \qquad (5)$$

In this study, the power of the original signals was also determined and some of each of the relevant harmonics used to describe the original signals. In this case, the 2 major harmonics components are H1 and H2, as shown in the results section, Figures 1 and 2. The signal strength, Pot, provides a measure of its power and was determined by equation 6:

$$\mathrm{Pot} = \frac{1}{N}\sum_{0}^{N} y^2 \qquad (6)$$

We also calculated the percentages with which each body segment accounted for the power corresponding to the two most important harmonics presented in each of the original signals.

Statistical Analysis

Statistical analyses were performed using SPSS 20.0 for Windows® (Chicago, IL). The variables were expressed as the means and standard deviations (SD). Normality and homoscedasticity assumptions were checked by Shapiro-Wilk and Levene tests, respectively. Data variation was analysed with the Wilcoxon Signed- Rank Test to assess differences between the two conditions (normal and snorkel). The Pearson correlation coefficient (r) was used to assess the association between variables to analyse the expected and unexpected associations between variables and to eliminate and / or confirm any unlawful associations between all the variables studied. The level of significance was set at $p \leq 0.05$.

RESULTS

Table 1 presents the mean (SD) values of the assessed stroke mechanics in the 25 m breaststroke in both swimming conditions. The swimming velocity was significantly higher in the normal condition, 1.01(0.29) m/s, when compared to the snorkel condition, 0.91(0.30) m/s (p= 0.02). The stroke length had a tendency to decrease with the use of the snorkel and was 1.22(0.40) m/cycle, compared to 1.47(0.44) m/cycle in the normal condition. The stroke rate increased in the snorkel condition (0.76(0.11) Hz) when compared to the normal condition (0.71(0.15) Hz). The stroke index showed that the swimming efficiency was significantly higher in the normal condition (1.56(0.78) m2/c/s) than in the snorkel condition (1.19(0.74) m2/c/s), and (p=0.05).

Table 1 shows that the average frequency values of the first and second harmonic were similar in the two conditions and that the wave period in the normal condition in first harmonic varied slightly among swimmers. Furthermore, it was observed that the normal condition had higher values in the first and second harmonic compared with those in the snorkel condition. Additionally, the normal condition provided a slower wave formation compared to that in the snorkel condition. The wave period provided in SNK of the first harmonic varied slightly among swimmers.

Table 1

Summary of stroke mechanics, frequencies, and period of undulations (n=8)

	Normal condition	Snorkel condition	*p*
Velocity (m/s)	1.01(0.29)	0.91(0.30)	0.02
SL (m/cycle)	1.47(0.44)	1.22(0.40)	0.23
SR (Hz)	0.71(0.15)	0.76(0.11)	0.55
SI (m^2/c/s)	1.56(0.78)	1.19(0.74)	0.05
Frequency (Hz) First Harmonic	0.76(0.06)	0.78(0.07)	0.15
Frequency (Hz) Second Harmonic	1.52(0.11)	1.56(0.15)	0.18
Period (s) First Harmonic	1.33(0.11)	1.29(0.12)	0.15
Period (s) Second Harmonic	0.66(0.05)	0.65(0.06)	0.17

Notes: SL= stroke length, SR= stroke rate, SI= stroke index.

Table 2 presents the average (SD) amplitude of the segments for all the swimmers in the normal condition and snorkel condition. The Fourier oscillation amplitudes were higher in the normal condition, except for the toe (0.14 m in the normal condition and 0.15 m in the snorkel condition). In the normal condition, the average amplitude values were higher on the vertex (0.72 m) and cervical (0.32 m) in comparison to those provided for the snorkel condition (vertex (0.71 m) and cervical (0.28 m)). In the two conditions, the lowest values were observed in the hip (0.03 m in the normal condition and 0.02 m in the snorkel condition) and trunk (0.06 m in the normal condition and 0.04 m in the snorkel condition).

Table 2

Summary of the amplitude of the first and second harmonic for all the segments in both swimming conditions

Body segments	Normal condition	Snorkel condition
Vertex	0.72(0.24)	0.71(0.22)
Cervical	0.32(0.19)	0.28(0.15)
Shoulder	0.18(0.08)	0.17(0.07)
Trunk	0.06(0.03)	0.04(0.01)
Hip	0.03(0.01)	0.02(0.01)
Knee	0.10(0.02)	0.10(0.03)
Ankle	0.12(0.03)	0.12(0.02)
Toe	0.14(0.04)	0.15(0.04)

By correlating the amplitude of the first harmonic in the normal condition and snorkel condition, we verified a correlation between the average of the amplitude for the first harmonic in the snorkel condition with that in the normal condition. This did not occur in the second harmonic ($r=0.894$; $p= 0.03$). Figure 1 illustrates the amplitudes of the harmonics 1 to 8 in the normal condition of the vertex signal for the SW1. The 2 relevant harmonics (first and second harmonics) were located near 0.78 Hz and 1.56 Hz, with maximal peak-to-peak amplitudes of 0.22 m and 0.04 m, respectively.

Figure 2 shows the plots of the measured signal and the first and second harmonic waves, as well as the sum of these two harmonics for the normal condition for the vertex of the SW1. As shown, the reconstructed signal, or the sum of first and second harmonics, is very close to the measured signal.

Considering that the signal power is 100 percent, it was found that the contribution of each of the two major harmonics, i.e., the first and second harmonics, to the signal power were 83% and 8.5%, respectively. This means that these two major harmonic components can describe approximately 92 percent of the original wave characteristics.

By correlating the centre of mass velocity with the Fourier waves amplitudes for all the body segments in the two fundamental frequencies (first and second harmonics) in the normal condition, significant values were only observed in the second harmonic. There was a negative correlation between the centre of mass velocity and the knee amplitude, which means that a lower knee amplitude corresponds to a greater velocity of the centre of mass. By correlating velocity with the amplitude of Fourier undulations for all the body segments in both fundamental frequencies (first harmonics) in the snorkel condition, we found that there was a correlation between the shoulder amplitude and the velocity. Additionally, in the second harmonic, there was a correlation with the knee extent.

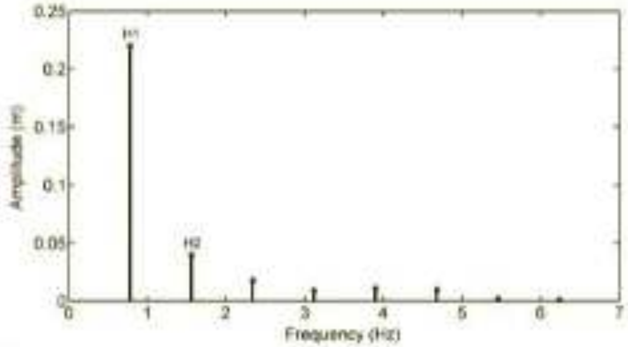

Figure 1

The amplitude signal (m) of the first to eighth harmonics of the vertex of subject 1 in the normal condition

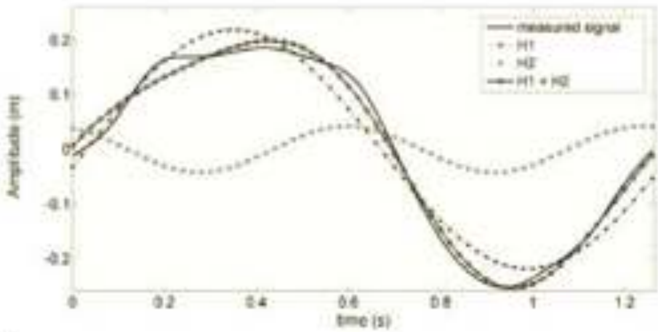

Figure 2

A plot of the measured signal (normal condition for the vertex of subject 1) and the computed harmonics (first and second harmonics). The signal sum of the first and second harmonics denotes the approximation to the measured signal when they are considered as the 2 more relevant harmonics

From Table 3, it can be observed that the high percentage of the total wave power is contained in the Fourier Fundamental Frequency (first harmonics) of the shoulder, cervical, knee and trunk in the normal condition, and the cervical, shoulder and knee condition in the snorkel condition. This means that the vertical motions of the cervical and knee were simply particular phases of a sinusoid oscillation (Sanders et al., 1995; Sanders, 1995).

Table 3

Summary of the percentage power contributions of the total power wave signals of the body segments.

	First harmonic component		Second harmonic component	
Body segments	Normal condition	Snorkel condition	Normal condition	Snorkel condition
Vertex	51.58(0.42)	64.42(0.41)	9.97(0.10)	10.53(0.06)
Cervical	84.40(0.11)	87.74(0.05)	8.03(0.05)	8.07(0.04)
Shoulder	91.64(0.31)	87.30(0.11)	2.91(0.03)	3.20(0.03)
Trunk	82.70(0.14)	64.14(0.31)	5.65(0.07)	9.05(0.10)
Hip	81.03(0.29)	61.80(0.30)	9.21(0.07)	15.77(0.10)
Knee	85.49(0.29)	74.95(0.31)	11.64(0.06)	10.59(0.07)
Ankle	69.34(0.09)	61.46(0.26)	19.77(0.10)	16.31(0.13)
Toe	65.57(0.11)	59.87(0.28)	20.53(0.12)	17.47(0.14)

The fundamental frequency of Fourier (H2) had higher values in both conditions in the toe, rather than in the ankle, knee (normal condition), and hip (snorkel condition). The correlation of the Fourier frequency (H2) with the velocity showed a correlation between the velocity and the knee, with a significance level of 0.01. This suggests that the power percentage contained in the knee is a crucial factor affecting the swimming velocity.

With respect to the correlation between the percentages of power contained in each body segment, for the Fourier frequency (first harmonics) and the velocity provided by the snorkel condition, there was a correlation between the velocity and shoulder, with a significance level of 0.01. As such, it seems that the percentage of power contained in the shoulder significantly affected the velocity, while the Fourier frequency (H2) did not.

On average, the Strouhal number (St) was equal to 0.41 in the normal condition and 0.53 in the snorkel condition, with an average amplitude of 0.12 m in the normal condition and 0.08 to 0.18 m in the snorkel condition. By correlating the St in the normal condition and snorkel condition with the amplitude, kick frequency and velocity, we found a negative correlation between the velocity and St in the normal condition ($r = -0.783$, $p = 0.021$) and in the snorkel condition ($r = -0.830$, $p = 0.011$), indicating that the most efficient swimmer presents the lowest St and consequently, the greatest velocity.

DISCUSSION

The aim of the present study was to determine the effect of using a snorkel on the frequency, amplitude and phase characteristics of breaststroke swimming using Fourier analysis and the calculation of the Strouhal number. The main finding of this study was that the use of a snorkel affects breaststroke swimming efficiency, which may involve motions that are characterised by a small number of composite waves that may be transmitted in a cephalous-caudal direction along the body to conserve mechanical energy.

It should be noted that in stroke mechanics, an increase in the stroke rate will cause the normal biomechanical pattern between velocity, stroke rate, and stroke length to be higher, while stroke length will tend to decrease (Barbosa et al., 2010). In this study, the normal behaviour was altered in the snorkel condition, as seen by the decrease in velocity and the increase in stroke length and stroke rate compared to the normal swimming condition. There was also a change in velocity in favour of the normal condition, which was expected. However, in the normal condition, the stroke rate decreases as the velocity increases. The decreased velocity observed during the snorkel condition can be attributed to a higher active drag (Barbosa et al., 2010). This means that in snorkel swimming, swimmers must perform relatively more work in terms of the stroke rate to obtain lower velocity compared to normal swimming. These results are similar to that reported by Kjendlie et al. (2003). Nevertheless, there was a tendency for a change in those variables when all the subjects were swimming with the snorkel. High stroke index values are inversely associated with the energy cost of swimming (Costill et al., 1985). As such, the lower stroke index in snorkel swimming must be related to the lower velocity that swimmers could achieve when swimming in this condition. However, in the normal condition, swimmers achieved a slightly higher velocity and therefore a greater speed.

In both swimming conditions, the pattern of the vertical movement of the body segments of the swimmers was almost entirely comprised of two low-frequency waveforms throughout the body. This suggests that these swimmers performed the breaststroke in a harmonic or wave-like pattern, as suggested by Ungerechts (1982), Thornton (1984) and Sanders et al. (1995). In this study, the amplitude undulation of the hip, knee, ankle and toe was small compared to the vertex, cervical and shoulder, contrary to that suggested by Thornton (1984) and Sanders et al.

(1995). In the snorkel condition, the correlation between the velocity and the amplitude (H2) with the amplitude of the knee seems to indicate that a higher amplitude in the knee during snorkel swimming will lead to a higher swimming velocity. The evidence of wave motion travelling around the body (cephalous-caudal wave) is very important as according to Sanders et al. (1995), the waves transmit energy. This supports the idea that energy accrued by raising the upper body was reused to aid propulsion or reduce drag. The results showed that a wave with a frequency equivalent to the first harmonic is higher in the snorkel condition than in the normal conditions. The same occurs for the second harmonic, which may be explained by the constrains of the equipment used by the swimmers (Aquatrainer® snorkel).

As observed from positive correlation between the total power contribution percentage with the velocity and the shoulder of snorkel swimming in first harmonic, the power contribution of the shoulder determines increases or maintenance of velocity, and contributes to the propulsion of the swimmer. The Strouhal number is an integral part of the fundamentals of fluid mechanics and a dimensionless number that describes the oscillation. Differences in St were observed in the two conditions, with higher values in the snorkel condition. The values found in this study (mean of St = 0.41 for normal condition, and St = 0.53 for snorkel condition) are far from those achieved by efficient animals, such as fish and dolphins (between St = 0.25 and St = 0.35), as presented by Triantafyllou and Triantafyllou (1995), but close to the result obtained with top swimmers (St=0.80) as presented by Arrelano et al. (2002; 2003).

The practical use of this number is adjusted to its contributing variables to bring its value closer to a more efficient range without decreasing the swimmer's speed. In this case, by introducing modifications in frequency and amplitude values, we can observe that with the use of a snorkel, the movement of a swimmer is very different from the excellent efficiency achieved during the normal pattern of swimming. Normal condition values are more similar to the values obtained by fish and dolphins. The significant changes in the amplitudes of the vertical undulations, the frequency and the power contribution indicated that swimmers with well established movement patterns will adopt a new movement patterns with the use of the snorkel. These changes in wave motion may impose considerable demands on the sensorimotor system of the swimmers (Sanders et al., 1995).

In conclusion, the use of the Aquatrainer® snorkel in the breaststroke leads to slight changes in the biomechanical pattern in swimming velocity and in several stroke mechanical variables. However, more data and a possible comparison with wave and conventional breaststroke will be required to confirm these findings. Therefore, some caution should be used when analysing data of breaststroke technique involving the use of a snorkel.

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FORCE PRODUCTION AND SPATIAL ARM COORDINATION PROFILE IN ARM CRAWL SWIMMING IN A FIXED POSITION

Authors

Istvan Karsai [1]

Nuno Garrido [2,3]

Hugo Louro [3,4]

Luis Leitão [3,4]

F Magyar [1]

Francisco Alves [5]

António Silva [2,3]

[1] Institute of PE and Sport Sciences, University of Pécs, Pécs, Hungary,

[2] Department of PE and Sport, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

[3] Research Center For Sport Sciences, Health and Human Development, Portugal

[4] Sport Sciences School of Rio Maior - Polytechnic Institute of Santarém, Rio Maior, Portugal

[5] Faculty of Human Movement Kinetics, Technical University of Lisbon, Portugal

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RESUMO

Este estudo analisou a relação entre a produção de força mecânica e posição espacial do braço do movimento de natação para cada lado do nadador. Oito nadadores masculinos reconhecidos internacionalmente realizaram na posição fixa do braço o nado com um dinamômetro sincronizado com câmaras subaquáticas.

As posições de braço (α no lado, β em vista frontal) e os ângulos do cotovelo (γ em 3D) foram determinados no momento em que a produção de força atingiu o pico (Fmax) e os valores máximos de taxa de desenvolvimento de força (RFDmax). (RFDmax) e os valores de α mostraram diferenças significativas entre os lados ($p < 0,05$). Para mostrar a estrutura de integração movimento do desempenho, foi utilizada análise de regressão múltipla (ARM) separadamente para ambos os lados. Para a variável critério, o impulso de força (ImpF50 %) foi calculado. Foram utilizados os parâmetros definidos como o sistema preditor mecânico e espacial para o modelo. Os resultados da MRA mostrou que o sistema de prognóstico proporcionou o modelo de estrutura das variáveis que explicam as variáveis de critério para ImpF50 % pelo lado dominante ($P = 0,007$) e pelo lado não dominante ($P = 0,001$) , respetivamente . A contribuição alternativa das variáveis para os modelos expressa objetivamente a diferença de desempenho entre os dois lados do nadador.

Palvras-chave: Posição fixa de nado, tempo-força, posição espacial, diferença de lado, modelo.

Abstract

This study analyzed the relationship between mechanical force production and spatial arm position of the swimming movement for each side of the swimmer. Eight internationally recognized male swimmers performed fix positioned arm only swimming with a dynamometer synchronized with underwater cameras. The upper arm positions (α in side, β in frontal view) and the elbow angles (γ in 3D) were determined at the moment where the force production reached the peak (Fmax) and the maximal values of rate of force development (RFDmax). (RFDmax) and α values showed significant differences between the sides ($P<0.05$). To show the motion integration structure of the performance, Multiple Regression Analysis (MRA) was employed separately for both sides. For the criterion variable, the impulse of force (ImpF50%) was calculated. The defined parameters as the mechanical and spatial predictor system were used for the model. The results of the MRA showed that the predictor system yielded the model structure of the variables that explain the criterion variables for ImpF50% by the dominant ($P=0.007$) and by the nondominant side ($P=0.001$) respectively. The alternate contribution of the variables to the models can objectively express the performance difference between the two sides of the swimmer.

Key words: Fix positioned swimming, force-time, spatial position, side difference, model.

INTRODUCTION

Swimming performance depends mostly on the optimization of propulsive force production (2, 7, 10, 14, 15). Description of the human swimming movement is difficult while the direct force measurement during free swimming is impossible, and the mechanism of the interaction between the hand, and arm complex and water molecules are not fully understood (3, 8, 18). Several experimental and analytical investigations tried to determine the optimal movement structure of the crawl stroke (1, 5, 13), but the diversity in anthropometrical characteristics and the complexity of the movement hindered the definition of the general model and find to the relevant parameters for the diagnosis of performance in crawl swimming.

It is reasonable to measure pulling force by tethered swimming methods fixing the swimmers to the edge of the pool or in a stable position that allows them to move their arms freely. Alley (2) and Counsilman (7) measured force developed in crawl arm stroke as a function of velocity using the partially tethered method. They revealed the basic force patterns for tethered crawl swimming. Yeater et al. (21) investigated the tether force for the crawl, back, and breast strokes and found that the two sides of the swimmer show differences regarding the cross cyclical movement observable by the force time curve.

Previously, the researchers focused mainly on the value of a given peak force (Fmax) or on the average of some peak values (avgFmax) on the force time curve, and used the mean force value of the time interval (Fmean). Moreover they tried to find a relationship between sprint swimming velocity (Vmax) and the defined variables. Other researchers developed mathematical models to find the connection between tethered force and force computed by the models. It was established that the models with some modifications, namely taking into account the overlapping effect and adjusting the hydrodynamic coefficients, are valid tools to detect the swimmers actual performance capacity (1, 12). Another method to estimate force production and analyze swimming performance is to record their movement using underwater cameras (4, 15). The limitation of the method was that the unsteady effects were not taking into account (9, 14, 19, 20). Seifert et al. (16) investigated the influence of the arm coordination asymmetry in crawl swimming using the index of coordination (IdC) developed by Chollet et al. (6). They found that elite swimmers tended to use the overlapping variation of the basic technique in addition there were differences between the values of IdC between the two sides. The effects depend mainly on the motor laterality and the breathing technique utilized. Based on these findings, there is a need to investigate the movement of both arms separately to have a deeper understanding of the technique and the role of the inter-limb coordination during crawl swimming.

In addition to the widely used parameters; Fmax and Fmean of the force time curve to examine tethered force production, there are more specific forms of strength expressions, which can give further information about the quality of movements and their effects in the water. The avgFmax expresses the maximum strength of the involved muscles, and the Fmean the average of the force exertion during a series of cyclic movements, independent from the side differences and overlapping effects. The rate of the force development curve and its maximum value (RFD) expresses the explosive force production of an athlete (17). Evaluating these parameters separately in each stroke they can be used for determining the specific strength. Furthermore the investigation of the spatial positions of the arms at the above-mentioned points of the force time curve can provide important information about arm coordination to diagnose swimming performance. The impulse of force in the essential part of the pulling pattern, between the 50 % values of the Fmax at the ascending and descending slopes of the force time curve (ImpF50%) expresses the ability of the single arm working potential value in a given period and is an indicator of the propelling force produced by the swimmer. This approach enables the investigation of the difference between the dominant and nondominant sides by avoiding the overlapping effect.

Based on this overview, in this work we investigated the fix positioned crawl arm swimming from two different aspects: to compare the performance of both sides using the selected variables; and to define the relationship between the criterion variable (ImpF50% as an indicator of propelling potential) and the different dimensions of parameters such as spatial arm position and mechanical force characteristics.

MATERIALS AND METHODS

Sample was composed by eight Portuguese National level swimmers (19.8 ±0.9 age; BM= 73.9 ±6.0 kg; BH=1.81 ±0.055 m). After completing the written consent form, the swimmers performed fix positioned, only arm crawl, swimming tests with a special water resistant dynamometer (TENZI TNF 06, TENZI Kft., Budapest; Hungary) in the push mode (200 Hz) (Fig. 1.). The dynamometer was connected to a PC and the data was recorded by the TENZI 3.0 program (TENZI Kft., Budapest; Hungary). The test was similar to the fully tethered swimming test used by Yeater et al., (21) and Martin et al., (13) with some modifications. The swimmer was connected to the measurement gage using a helmet instead of wearing a harness around the hip. Previous tests confirmed that the difference between the pull and push mode of the fix positioned swimming was less than 3.5 %, and there is no complaints in the neck region during or after performing the push mode test. While the test was being carried out four underwater synchronized cameras (50 Hz) recorded the motion.

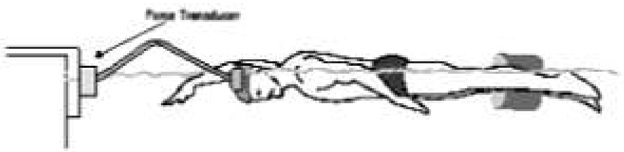

Fig. 1. Fix positioned swimming test, push mode with the water resistant dynamometer

In order to synchronize the kinetic and kinematic data, a control lamp was lit at the moment the force recording started. After a warm up exercise to get familiar with the device, the swimmer started swimming at a low frequency rhythm (0.41 Hz); the rhythm of a metronome was transmitted using a water resistant earphone. The swimmers were instructed to perform the swimming movement without breathing, one series lasted 20 seconds. The legs were tied and supported during the test and 20 N forces were applied as a pre-tension force to fix the swimmer in the helmet in order to maintain constant contact with the device. The frequency of strokes was increased gradually (0.08 Hz) inserting a 1 minute rest between each series. The test was stopped when the swimmer was not able to further increase the frequency of strokes. For the analysis, the averaged results of three whole cycles were used from the series where the highest Fmain was recorded. The kinematic data analysis was performed using the APAS system, according to the spatial position of the center of the shoulder, elbow and wrist joints.To differentiate between the dominant (stronger) and nondominant (weaker) sides, the values of the Fmax of the single strokes were used.

The criterion variable as the time dependent mechanical character of the force production (ImpF50%) was calculated (Fig. 2.) between the 50 % values of the Fmax at the ascending and descending slopes of the force time curve (ImpF50%= $\int_{n=0}^{n} F_n * t_n$).

To predict the criterion variable, a two dimensional system was applied where the momentary mechanical and spatial values of the arm movements were determined. For the dominant and nondominant sides (Figs 2 and 3). i: average of Fmax and the RFDmax of the three whole cycles chosen for the analysis ii: the momentary spatial positions as a characteristic of arm coordination during stroking maneuvers α (side view), β (frontal view) and γ (3D) (Fig. 3.)

After performing the descriptive statistics to determine the side differences the Wilcoxon Signed Rank test and the Paired Sample T test were used for distribution of the data. The Multiple Regression Analysis (MRA) was used to establish the relationship between the criterion variable and the predictor system for both sides. The analysis was performed using the SPSS v13 for Windows statistical packages.

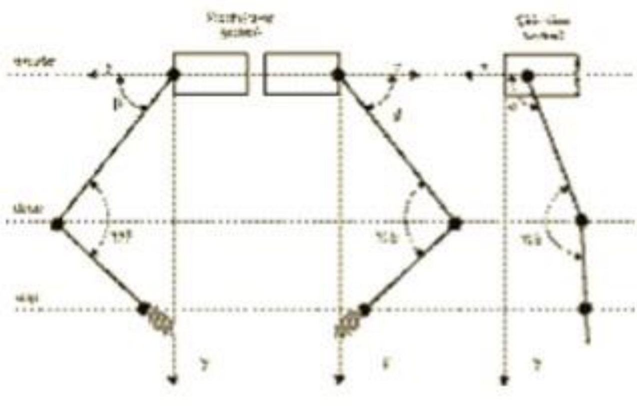

Fig. 2. Force time curve (solid line) and the first derivative of the function (dashed line) to assess the mechanical characteristics of two consecutive arm strokes measured from a representative swimmer. The peaks represent the maximal force production (Fmax) and the maximal rate of force development (RFDmax) for the dominant (stronger) and nondominant (weaker) sides. The filled areas under the force time curve represent the impulse of force (ImpF50%) determined according to 50% of Fmax

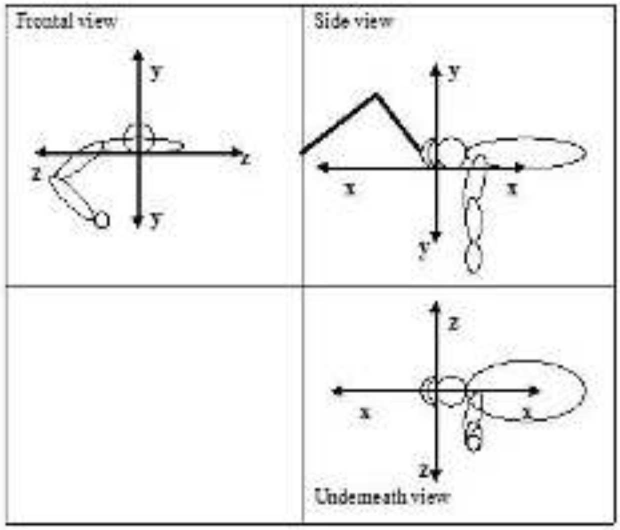

Fig. 3. The spatial positions of the upper arm from a frontal view (yz plane) and side view (xy plane) and the determination of the elbow angle in 3D

RESULTS

The swimmers (n=8) performed the highest Fmean =80.42 N at averaged frequency (avgFr) 0.651 Hz. These results are close to the measured values of the other investigators Akis and Orcan (1) and Yeater et al. (21). The variation coefficients of the Fmean and avgFr; were 12.85 % and 25.82 % respectively. This measurement fits the requirement to use the data as real and valid.

The results obtained from statistical analysis showed significant difference between the dominant and non-dominant sides for two mechanical parameters of the measured force production: Fmax (z=2.511, N-Ties=8, P=.012, one-tailed) and RFDmax (z=2.028, N-Ties=8, P=0.043). Furthermore, for one of the spatial arm coordination characters: αFmax (z=0.224, N-Ties=8, P=0.025). (Tables I and II).

The results of ANOVA regression indicates that the system of two dimensional predictor variables fits the model of predictors that describe the criterion variables statistically with high level of significance for the dominant (F=148.803, df=5,2, P=0.007) and nondominant sides (F=198.463, df=4,3, P=0.001). The model determines the criterion variable by the dominant side 99.7 % and the nondominant side 99.6 % of common variance (R square =0.997 and 0.996). Results of the MRA reveal (Table IV) a difference between the performance structures of the two sides, and describe the different predictor variables that contribute to the models. (Tables III and IV).

Table I. Description of the general variables of the fixed position only arm crawl swimming test

	Mean	Min	Max	SD	cV (%)
avgFr (Hz)	0.65	0.51	0.71	0.08	12.85
Fmean (N)	80.42	51.80	103.37	20.77	25.82

Table II. Descriptive statistics and results of the Wilcoxon Signed Rank test / Paired Samples test for the specified criterion and predictor variables

	Dominant side		Nondominant side		
	Mean	SD	Mean	SD	P
ImpF50% (Ns)	54.67	10.42	57.24	17.11	NS
Fmax (N)	275.10	61.42	212.51	43.10	0.012
RFDmax (N/s)	20.92	15.82	10.18	4.84	0.043
αFmax (deg)	88.53	25.89	114.88	24.17	0.025
βFmax (deg)	49.31	24.17	55.69	15.03	NS
γ Fmax (deg)	117.04	9.37	110.18	21.82	NS
αRFDmax (deg)	61.99	26.31	84.17	24.28	NS
βRFDmax (deg)	52.35	26.99	69.05	15.10	NS
γRFDmax (deg)	133.71	8.76	129.71	17.21	NS

Table III. Results of ANOVA of regression of the models for the Dominant and Nondominat sides

	Sum of Squares	df	Mean Square	F ratio	P
Model for the Dominant side	1383.36	5	276.673	148.80	0.007
Residual	3.719	2	1.859		
Total(Corr.)	1387.08	7			
Model for the Nondominant side	1445.52	4	361.380	198.46	0.001
Residual	3	1.82			
Total (Corr.)	1450.98	7			

Table IV. The parameters of the models (Multiple Regression Analysis – Enter method)

	Unstandardized Coeff.		Standardized Coeff.	t	P
	B	Std. Err	Beta		
Model for the Dominant side					
(Constant)	247.394	9.738		25.404	0.002
Fmax	–0.220	0.19	–1.042	–11.770	0.007
αFmax	0.381	0.037	0.665	10.441	0.009
βFmax	0.883	0.038	1.465	23.467	0.002
γ Fmax	–2.045	0.092	–1.625	–22.310	0.002
RFDmax	2.00	0.170	1.215	11.773	0.007
Model for the Nondominant side					
(Constant)	–157.625	15.867		–9.928	0.002
αFmax	0.311	0.047	0.632	6.629	0.007
RFDmax	1.883	0.255	0.699	7.390	0.005
γRFDmax	1.085	0.052	1.298	20.750	0.001
βFmax	0.329	0.070	0.375	4.706	0.018

DISCUSSION

The results obtained provided two groups of findings related to the specific aims of the present study. On one hand, in some cases significant differences exist among the examined variables between the two sides, on the other hand the ANOVA regression model provided a statistically high level of significance for the criterion variables for both sides and the structures of the models differ from each other.

Asymmetry between the sides

The asymmetric pulling patterns between the two arms during tethered swimming were observed by Yeater et al. (21) and Rushall et al. (14). They concluded that there were differences between the peak forces (Fmax) of the two sides. Seifert et al. (16) observed changes between the dominant and nondominant sides using the index of coordination (IdC) method. Our results, utilizing another point of view, underpin the previous findings. The Fmax and RFDmax differ as mechanical characteristics vary significantly between the sides. The notably different results of αFmax as the spatial coordination parameter indicates, that the dominant hand reaches Fmax at the mechanically optimalized position near 90 degrees in the xy plane of the shoulder position to the horizontal plane as was demonstrated by Lauder and Dabnichki (11). The nondominant side produced its RFDmax close to the mechanically optimal position regarding the α value and reaches its Fmax with 26.7 % lower values than the dominant side and 24.4 degrees behind the vertical projection of the shoulder joint center. The mean elbow angle at the examined points on either side showed almost constant values, the means ranged between 110.18 and 133.71 degrees in our study. The favorable elbow flexion angle between free swimming and fix positioned swimming should differ, but according to our study, the elbow joint position remains constant with both sides. The upper arm position in the yz plane did not show considerable difference between the two sides.

Comparison of the MRA results

The model includes parameters that predict the impulse force (ImpF50%) in different ways which is representative of the working potential of the moving arms in the fix positioned swimming test. Despite the finding that the ImpF50% values are almost the same in both cases (diff. 4.49 %) for the dominant and nondominant side, the model structure differs by the t value of the constants (25.4 and –9.92). While the results of the models with the reliability rate of 99.6 % and 99.6 % show dependence, the contribution of the different parameters of the structures, we can assume that the difference exists because of the way the motion is organized. The model for the dominant side consists of five parameters, four of them related to the maximal force achievement of one side (Fmax, αFmax, βFmax, γFmax) and RFDmax. The model shows that the motion is structured to produce a higher force during the stroke. The force peak (Fmax) is reached earlier than the peak by the nondominant side and the time duration is shorter during the essential part of the stroke. The model for the nondominant side consists of two parameters associated with the RFDmax and two components associated with Fmax. The lower Beta values and the selected parameters for the model, provide evidence that none of the pre-determined characters play a leading role in the organization to build the structure. We assume that during a longer period of moderate force production, the required force impulse is produced without attempting to reach a high value of Fmax or RFDmax. From these findings arises the question whether it is the complicated hydro dynamical circumstances or and a lack of the neuromuscular system liable for the asymmetry, or rather, when the ImpF50% does not differ considerably (diff4.49%) an existent compensatory system which regulates the reconsiliation between the sides is shown.

In conclusion, the results of this study suggest that under the investigated circumstances, in addition to the Fmax, the side difference is present in two other parameters in RFDmax and αFmax. Furthermore, by applying the used method to evaluate the kinetic and kinematic characteristics of the cross cyclical crawl swimming movement together provides meaningful information from the performance structure. The trainers and athletes are able to handle the problems which may arise from the difference in sides of the swimmer.

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MOTOR AND NEUROMUSCULAR PATTERNS DURING MAXIMAL IN BREASTSTROKE PACE

Authors

Ana Conceição [1,3]

António Silva [2,3]

Tiago Barbosa [3,4]

Jorge Campaniço [2,3]

Hugo Louro [1,3]

[1] *Sport Sciences School of Rio Maior - Polytechnic Institute of Santarém, Rio Maior, Portugal;*

[2] *University of Trás-os-Montes and Alto Douro, Vila Real, Portugal;*

[3] *Research Center in Sports Science, Health and Human Development, Vila Real, Portugal;*

[4] *Nanyang Technological University, Singapore;*

Publication

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RESUMO

O objetivo deste estudo consistiu em analisar os padrões neuromusculares e padrões motores temporais na técnica de bruços. Cinco nadadores de elite nacional realizaram 200m bruços à máxima intensidade, sendo-lhes recolhidos dados electromiográficos (EMG) respeitantes aos músculos bíceps brachii (BB), pectoralis major (PM), deltoid anterior (DA) e tríceps brachii (TB). Registou-se a duração relativa à fase ativa e não-ativa dos padrões neuromusculares bem como o valor médio retificado (ARV). Os percursos de nado foram gravados no plano sagital com um par de câmaras com recurso ao software THÉME 5.0 para analisar os padrões detetados em cada nadador. O padrão neuromuscular revelou que através do ARV, quer o BB quer o TB aumentaram no final do teste para o nadador 1 e 5, enquanto o BB, DA e PM para o nadador 2 e 4. Observaram-se diferentes padrões motores não só entre ciclos, mas também entre nadadores, sugerindo que existem semelhanças entre eles, ajustando cada nadador o seu estilo de nado ao modelo técnico. A ausência de um padrão neuromuscular comum a todos os nadadores pode estar relacionado com o facto de cada um deles usar diferentes modelos técnicos, repercurtindo-se igualmente na falta de homogenidade nos padrões motores. Assim sendo, estes dados sugerem que cada nadador adapta o seu padrão motor e neuromuscular numa forma única e distinta.

Palavras-chave: natação, biomecânica, EMG, atividade muscular, metodologia da observação, T-Patterns

ABSTRACT

The purpose of this study was analyzing the inter-temporal neuromuscular and motor patterns in Breaststroke technique. Five national level male swimmers performed 200m breaststroke at maximal effort.

Electromyographic data of biceps brachii, deltoid anterior, pectoralis major and triceps brachii were analyzed. The relative duration of active and non-active phase and the average rectified value for the neuromuscular patterns were recorded. The swim bouts were videotaped in sagittal plane with a pair of cameras and the THÉME software 5.0 was used to analyze the detect patterns in each swimmer.

The neuromuscular pattern revealed that by the average rectified value the biceps brachii and triceps brachii increased at the end of the test for swimmer 1 and 5, and biceps brachii, deltoid anterior and pectoralis major for swimmer 2 and 4. Different motor patterns between cycles and between swimmers were observed, it seems that they have similarities between them, adjusting his style to the technical model.

The absence of a neuromuscular pattern for all swimmers could be related to different technical models used for each swimmer, as presented in the motor patterns. These findings, suggested that each swimmer adapted their motor pattern and their neuromuscular pattern in a unique and distinct way.

Key words: Swimming, biomechanics, EMG, muscular activity, T-patterns.

INTRODUCTION

The ability to maintain high intensity work is dependent on a high capacity of providing the working muscles with sufficient energy (1). The muscular pattern of one movement in swimming are very important element, this information cannot be obtained through anatomical functional deductions, like has been demonstrated by Duchenne in the mid of XIX century, through the stimulation of muscles and observation of partially of paralyzed subjects (2). The neuromuscular activity are usually examined by the electromyography (EMG) to analyze the direct recording of electric potentials of the muscles active in the case of movements in swimming, that allows us to obtain an expression of the dynamic involvement of specific muscles involved in propulsion of the body in relation to water. Therefore, neuromuscular activity during swimming must be examined during experiments that reproduce the conditions of an actual race, because of the rules of swimming competitions and the constraints arising from the need to wear experimental equipment (3). Qualitative EMG relies on judgment of wave form patterns from neuromuscular activity in graphical demonstration. Based on the visual interpretation of the gross EMG signal it is possible to describe the neuromuscular activation according to the temporal domain (4). The research of EMG in competitive swimming, has focused in order to make relationship between neuromuscular activity with kinematics (e.g., stroke length, stroke rate, speed) and some physiological parameters (e.g., blood lactate, oxygen uptake), but most have been study the front crawl (5, 6, 7), thus verifying a lack of research in breaststroke. Nuber et al. (8) conducted a study, where they observed high activation of the supraspinatus, infraspinatus, middle deltoid, and serratus anterior during the recovery phases of front crawl, breaststroke and butterfly, and that latissimus dorsi and pectoralis major were predominately pull-through phase muscles.

In a study with breaststrokers Ruwe et al. (9) described and compared the patterns of electrical activity of the muscles of the shoulder, demonstrated a consistently activation for the serratus anterior and teres minor muscles in through the stroke cycle. Recently, Conceição et al. (10) compared the average pattern of muscle activation with snorkel and without snorkel in breaststroke, in biceps brachii and triceps brachii, they observed that the muscle activation was higher with snorkel, and that biceps brachii had higher values of activation in both conditions.

To analyze the sport movements of a swimmer, the level of swimming in a kinematic perspective and in terms of technical effectiveness should be carried out (11,12). The observational methodology is used to analyze the behavior situation, involves the fulfillment of an ordered series of tasks to collect and process data (13) and also presented a great importance in various scientific procedures in the study of technical performance. In competitive swimming there are some studies that used these procedures (12, 13, 14). According to Anguera et al. (15) there are advantages in using this method because not only can the user take the procedures of the laboratory into the field, but also can provide data without interfering with or manipulating the behavior of the observed subjects.

Among these we highlight to analysis of T-patterns, which allows the detection of hidden patterns of behavior, and the sequential analysis, as well as the demand for significant association relationship between behaviors recorded during these sequences. In this paper, through the existing science base we introduce the analysis of the neuromuscular patterns and the technical patterns in the breaststroke to make a significant contribution to analyses in swimming performance.

The aim of this study was to analyze the neuromuscular patterns in breaststroke through the support of the description of the detection patterns, with the introduction of a method to examine the data and to analyze the inter-temporal relationship between the structures of events.

MATERIAL AND METHODS

Subjects

Five national male swimmers (age 23.8 ± 2.6 years; height 178.6 ± 0.6 cm; weight 73.04 ± 3.32 kg; mean ± SD) volunteer to participate in this study and provided written inform consent. They were all national level swimmers with an average personal best result over 200 m breaststroke long course was 147.6 ± 0.041 s corresponding, respectively, to 630.75 ±

69.25 FINA ranking points. All subjects gave their written informed consent before participation.

Measures

Emg data collection

Surface EMG signals from the biceps brachii (BB), deltoid anterior (DA), pectoralis major (PM) and triceps brachii (TB) muscles on the right side of the body were measured. These muscles were selected based on the previous studies for their main function in swimming propulsion and in breaststroke (8,9,10). Bipolar surface electrodes were used (10 mm diameter discs, Plux, Lisbon, Portugal) with the inter-electrode distance of 20 mm. Electrodes on the upper part of the PM were placed in the middle of the line that connects the acromion process and the manubrium (sternum) two fingers below the clavicle (7). The electrodes on the long head of the TB, BB and DA were placed in accordance with SENIAM recommendations (16).

The skin under the electrodes was shaved, rubbed with sandpaper and cleaned with alcohol so that the interelectrode resistance did not exceed 5 kOhm (17). The ground electrode was positioned over the cervical vertebrae. Transparent 10 cm x 12.5 cm dressings (Hydrofilm®, USA) were used to cover the electrodes and isolate it from the water. All cables were fixed to the skin by adhesive tape in several places to minimize their movement and consequently their interference with the signal. Additionally to immobilize the cables, the swimmers wore a thin long sleeved custom made swimming suit (Fastskin Speedo®, Speedo Aqualab, USA).

The EMG equipment carried by the swimmer was very light composed only the electrodes, the corresponding cables and the transparent dressings. The wireless EMG device (BioPLUX.research, Lisbon, Portugal) it is an eight analog channels(12 bit), sampling rate at 1kHz; 86 g, and a compact dimensions; 0.84 cm x 0.53 cm x 0.18 cm.

The device was fixed in a waterproof bag and put inside the cap of the swimmer. The data were recorded using the Monitor Plux (Plux, Lisbon, Portugal) at a simple frequency of 1 kHz.

All EMG analysis was conducted with automatic tools developed under MATLAB software (Mathworks, Inc., Natick MA, USA). It was determinate the EMG boundary´s, the process of determining the muscle activity boundary´s consists on finding the neighborhood points, where the energy is 30% of the maximum peak. These are calculated by segmenting the muscle input signal energy according to the same criteria described in Stirn et al. (7). Starting from the raw signal, DC components where removed and afterword's filtered using fifth-order Butterworth band-pass filter with the lower and upper cut-off frequencies set within 10 and 500 Hz respectively. The signal energy was determined over time using a 250 ms sliding window. However, even with a 250 ms sliding window, muscle activity energy is very noisy and presents several local maximums peaks that do not correspond to the muscle active window center and therefore making automation hard. To overcome this difficulty, a strategy to determine the muscle "true" maximum energy peaks was devised.

Each stroke taken by a swimmer produces patterns in the signal, these patterns consists mainly in a periodicity of the strokes. After determining the mean period, a maximum filter, with a length equal to twice the mean stroke period, is used to determine the peaks with the highest energy and closest to the stroke mean period.

The muscle activity boundaries are then selected by finding the neighborhood points where the energy is 30% of the determined maximum peaks. Muscle activation within each stroke results in a local maximum in the energy envelope. For each muscle activation, we defined its ''active'' phase as the part of the EMG signal for which the energy of the EMG was at least 30% of the local maximum energy value for the particular muscle activation. The non-active phase was defined as the time interval between the two successive active phases.

The temporal evolution of the active and non-active phase's average durations, during stroke, were calculated for each muscle for the entire swimming time. Linear regression curve were fitted to the data and the durations of the fitted curves at the time of the first and last stroke were compared.

The average amplitude of EMG of each active phase was estimated using the average rectified value (ARV) of the EMG. ARV was calculated in accordance with SENIAM recommendations (16) and plotted as a function of time. Linear regression curve was fitted to the data and the ARV values of the fitted curve at the time of the first and last stroke were compared.

T-Pattern data collection

The swims were videotaped on sagittal plane with a pair of cameras providing a dual-media frames from both underwater (SONY D8, EUA, 50 frames*s^{-1}) and above (Sony Mini Dv DCR-HC42E, EUA, 50 frames*s^{-1}) the water surface and an periscope Coach Scope (Delphis Swim products). The cameras were placed at 25 m of the headwall, in a lateral wall of the pool, perpendicular to the line of motion and 6 m away from the swimmer displacement trajectory. One of the cameras were at 30 cm of depth the other 10cm above the water level. The images of both cameras were recorded simultaneously and it was possible to follow the swimmers trajectory and visualize five swimming strokes for each lap.

T-Patterns assessment

We used an Ad-hoc reference (18). The instrument has been configured by the nature of research: (i) criteria, (ii) system of codes and, (iii) units of coding. The structure of the observation was taken a individual events at the description of time and order (19), representing one or more specific technical behavior of a hand cycle.

The instrument emerged by the software Theme 5.0 of temporal patterns analysis, reproducing a lot of different patterns, which take to a variety of conducts and also a reconfiguration of the codification system. The adaptation of the Observing System

Performance in Breaststroke Technique (OSPBT) was conducted based on five core criteria: FPAA, SPAA, FPAL, SPAL and R, as Table 1, characterizing the conduct considered critical in the cycle of the breaststroke swim.

Table 1. Moments of observation and description of observation instrument used in hoc – OSPBT.

FPAA	First propulsive action of arms	Focuses on aspects of the connection from one cycle to another, particular in the moment that correspond to the beginning of flexion until the most deepest point that the hands reach.
SPAA	Second propulsive action of arms	Focuses on critical aspects of the second propulsive support of the arms, moment that finish with the extension of the arms.
FPAL	First propulsive action of legs	The transitional approach criteria is the maximal flexion of the knees, that the terminus it's the moment in which the angle of the hip/leg it's 45º.
SPAL	Second propulsive action of legs	Focuses on the moment that start with the angle hip/leg at 45º and finish with the full extension of the same
R	Recovery	Focuses on the moment correspond to the end of the cycle. Recovery moment that start with full extension of the legs away until the junction of them.

For this study the instrument was set with 431 alphanumeric codes, with a total of 44 configurations at long of 20 hand cycles. Each criterion represents a stage of a complete cycle gesture, adding movements and actions that represent the technical conduct, independent of any existing variant. The conduct was in accordance with the temporal characterization delimiting the beginning and end of each stage. In each of these stages a list of key points were defined, being critical to the implementation in the exploratory phase. To each of them an alphanumeric code was assigned (Table 2, 3).

Table 2. Observation criterion for the first propulsive action of arms (FPAA), second propulsive action of the arms (SPAA) and for the recovery (R).

Criteria of observation 1st Moment -First Propulsive Action of arms (FPAA)				
Behaviorcriteria(*FPAA*)				
Legs *FPAAL*	P1 Position of the legs 1P1 Extension 1P2 Flexion	P2 Relationship: ankle - hip 1P3 Above the hip 1P4 Below the hip/an extension	P3 Position of the feet in relation to the legs 1P5 Flexion 1P6Extension	P4 Inclination of the legs in relation to the water line 1P7 tilted up 1P8 downward / parallel to the waterline
Aggregatedcriteria(*FPAA*)				
Trunk *FPAAT*	T1 Head position according to the trunk 1T1 Above/ in line 1T2 Below	T2 Position of the trunk 1T3 Flexion 1T4 Extension 1T5Dorsi-flexion	T3 Inclination of the trunk (shoulders / mid-point of the trunk) in relation to the waterline 1T6 Tilted upward/ parallel to the waterline 1T7 Tilted down	
Head *FPAAH*	C1Vision guidance 1C1 Front 1C2 Diagonal / down	C2Head position relative to the waterline 1C3Above waterline 1C4Below waterline/ intermediate		
Arms *FPAAA*	B1 Horizontal relationship: hand- shoulder 1B1Above the shoulders 1B2Below the shoulders / an extension			
Criteria of observation 2nd Moment -Second Propulsive Action of arms (SPAA)				
Behaviorcriteria(*SPAA*)				
Legs *SPAAL*	P5 Position of the legs 2P1 Extension 2P2 Flexion	P6 Inclination of the legs in relation to the water line 2P3 tilted up 2P4 downward / parallel to the waterline	P7 Position of the feet 2P5 Parallel 2P6 Discontinuous (one above the other)	P8 Relationship: ankle - hip 2P7 Above the hip 2P8 Below the hip/ an extension
Aggregatedcriteria(*SPAA*))				
Trunk *SPAAT*	T4 Position of the trunk 2T1 Flexion 2T2 Extension 2T3 Dorsi-flexion	T5 Inclination of the trunk (shoulders / mid-point of the trunk) in relation to the waterline 2T4 Tilted upward/ parallel to the waterline 2T5 Tilted down	T6 Position of the gluteus in relation to the waterline 2T6 Above the waterline / intermediate 2T7 Below the waterline	
Head *SPAAH*	C3 Vision guidance 2C1 Front 2C2 Diagonal / down	C4 Head position relative to the waterline 2C3 Above the waterline / intermediate 2C4 Below the waterline		
Arms *SPAAA*	B2 Orientation of the finger 2B1 Pointed at the bottom of the pool 2B2 Pointed to the back and front	B3 Vertical relationship: hand-shoulder 2B3 In front of the shoulders/no extension 2B4 Behind the shoulders		

Table 3. Observation criterion for the first propulsive action of legs (FPAL), second propulsive action of the legs (SPAL) and for the recovery (R).

Criteria of observation 3rd Moment -First Propulsive Action of legs (FPAL)			
Behaviorcriteria*(FPAL)*			
Legs *FPAL*	P9 Relationship between the feet 3P1 Away 3P2 Together	P10 Relationship between the knees 3P3 Away 3P4 Together	P11 Relationship: feet - leg 3P5 Foot rectum back 3P6 Foot rectum out
Aggregated criteria *(FPAL)*			
Trunk *FPALT*	T7 Position of the trunk 3T1 Flexion 3T2 Extension 3T3 Dorsi-flexion	T8 Inclination of the trunk (shoulders / mid-point of the trunk) in relation to the waterline 3T4 Tilted upward/ parallel to the waterline 3T5 Tilted down	
Head *FPALH*	C5 Head position relative to the waterline 3C1 Above the waterline / intermediate 3C2 Below the waterline		
Arms *FPALA*	B4 Position of the forearm with respect to the waterline 3D1 Tilted upward/ parallel to the waterline 3B2 Tilted down	B5 Position of the hands with respect to the waterline 3B3 Tilted upward/ parallel to the waterline 3B4 Tilted down	B6 Relationship on horizontal: hand-shoulder 3B5 Above the shoulders 3B6 Below the shoulders / in extension
Criteria of observation 4rd Moment –Second Propulsive Action of legs (SPAL)			
Behaviorcriteria*(SPAL)*			
Legs *SPALL*	P12 Relationship between knee 4P1 Away 4P2 Together	P13 Relationship knee-hip 4P3 Above hip 4P4 Below the hip/ an extension	P14 Angle: down-leg 4P5 Acute angle 4P6 Rectum angle 4P7 Obtuse angle
Aggregatedcriteria*(SPAL)*			
Trunk *SPALT*	T9 Position of the gluteus in relation to the waterline 4T1 Above the waterline 4T2 Below the waterline/intermediate	T10 Position of the trunk 4T3 Flexion 4T4 Extension 4T5 Dorsi-Flexion	T11 Inclination of the trunk (shoulders / mid-point of the trunk) in relation to the waterline 4T6 Tilted upward/ parallel to the waterline 4T7 Tilted down
Head *SPALH*	C6 Head position relative to the waterline 4C1 Above the waterline / intermediate 4C2 Above the waterline		
Arms *SPALA*	B7 Position of the forearm with respect to the waterline 4B1 Tilted upward/ parallel to the waterline 4B2 Tilted down	B8 Relationship: elbow-shoulder 4B3 Above the shoulders 4B4 Above the shoulders / In extension	

Criteria of observation 5th Moment – Recovery (R)				
	Behavior criteria (R)			
Legs RL	P15 Relationship: ankles - hip SP1 Above the hip SP2 Below the hip/ an extension	P16 Orientation of the foot SP3 Down and back SP4 Pronounced back	P17 Angle: mid-point of the trunk – hip – knee SP5 Obtuse angle SP6 Shallow angle	P18 Inclination of the legs in relation to the waterline SP7 Tilted upward/ parallel to the waterline SP8 Tilted down
	Aggregated criteria (R)			
Trunk RT	T12 Position of the shoulders in relation to the waterline ST1 Above the waterline / intermediate ST2 Below the waterline	T13 Position of the gluteus in relation to the waterline ST3 Above the waterline ST4 Below the waterline/ intermediate	T14 Inclination of the trunk (shoulders / mid-point of the trunk) in relation to the waterline ST5 Tilted upward/ parallel to the waterline ST6 Tilted down	
Head RH	C7 Position of the head in relation to the waterline SC1 Above the waterline SC2 Below the waterline / intermediate			
Arms RA	B9 Position of the forearm with respect to the waterline SB1 Tilted upward SB2 Tilted down / parallel to the waterline			

For the detection of temporal patterns, we used the software THÉME 5.0 since the algorithm of T-patterns developed by Magnusson (20), which is the detection of temporal patterns based on a binominal probability theory that allows the identification of sequential and temporal systems of data.

Procedures

Measures were performed in a 50 m indoor swimming pool at a temperature of 27.5 ºC and 75% of humidity. Subjects performed a standard warm-up of 800 m front crawl at a medium level of effort, after a twenty minutes passive rest, the subjects were submitted to a maximal 200 m breaststroke bout. The bout started with the subjects pushing off the head-wall of the pool and was also advised to perform to reduce the underwater glides after turns.

Statistical Analysis

Statistical analysis was performed using statistical packages SPSS for Windows and Microsoft Office Excel 2007. The arithmetical means of the indices and standard deviation were calculated.

RESULTS

Figure 1 show in absolute time units the duration of active phase and non-active phase at the beginning end at the end of swimming for the four muscles under observation, for the five swimmers. Swimmer 1 presents a higher active phase in the TB muscle (0.33 ± 0.07 seconds) in the beginning than the BB, PM and DA. The BB (0.17 ± 0.01 s) and the DA (0.23 ± 0.09 s) muscles had a higher relative duration of the active phase in the end of the test compared with the beginning, unlike the PM (0.26 ± 0.05 s) and the TB (0.33 ± 0.07 s) that this higher relative duration was presented in the beginning. The duration of non-active phase reached had higher values in the BB (1.96 ± 0.12 s) in the beginning of the test than the TB, PM and DA. The BB (1.96 ± 0.12 s) and the PM (1.47 ± 0.60 s) reached higher duration of non-active phase in the beginning of the test, unlike the DA (1.62 ± 0.34 s) and the TB (0.92 ± 0.15 s) in the end of the test.

Summary the swimmer 1 had for the BB a higher relative duration of the active phase in the end of the swimming bout, whereas for the non-active phase the duration was higher in the beginning of the swimming bout. Already the TB achieved the opposite behavior, i.e.: higher relative duration of the active phase in the beginning of the swimming bout and non-active phase duration higher in the end of the swimming bout.

The DA and PM presented similarities in their behavior, because they had higher relative duration of the active and non-active phase in the end of the bout for the DA, and in the beginning of the bout for the PM.

In swimmer 2, DA (0.27 ± 0.03 s) was activated for a higher period in the beginning than the BB, TB and PM. Only the BB (0.26 ± 0.02 s) had a higher duration in the active phase on the end of the test, unlike the DA (0.27 ± 0.03 s), PM (0.20 ± 0.02 s), TB (0.23 ± 0.05 s) had the higher values in beginning. The duration of non-active phase reached had higher values in the PM (1.53±0.31 s) in the end of the test than the other muscles. All the muscles had higher duration in non-active phase in the beginning of the test BB (1.46 ± 0.32 s), DA (1.43 ± 0.09 s), TB (0.80 ± 0.07 s), excepted for the PM (1.53 ± 0.31 s) that was in end of the test.

Under synthesis, the swimmer 2 obtained a behavior characterized by a similar behavior for the DA and TB, because both had a higher relative duration in active phase in the beginning of the swimming bout and the same in the non-active phase, unlike the BB and PM that had a different behavior.

Swimmer 3, presented had a higher period for the TB (0.26 ± 0.03 s) in the end of the test, than BB, DA and PM muscles, and unlike the other swimmers the relative duration of active phase for the swimmer 3 was for all the muscles higher in the end of the test compared with the beginning, BB (0.19 ± 0.03 s), DA (0.25 ± 0.03 seconds), PM (0.18±0.02 s). The duration of non-active phase reached had higher values in the DA (1.48 ± 0.19 s) in the beginning of the test than BB, TB and PM muscles. All the muscles had higher duration in non-active phase in the beginning of the test BB (1.34 ± 0.04 s), DA (1.48 ± 0.19 s), PM (1.31 ± 0.04 s), excepted for the TB (1.04 ± 0.40 s) that was in end of the test.

The current swimmer presented a very similar behavior for all the muscles in study for the active phase and non-active phase, excepted for the TB that presented a higher relative duration of the non-active phase in the end of the swimming bout.

Swimmer 4, demonstrated higher values of the relative duration of active phase in the TB (0.32 ± 0.04 s) in the end of the test, than the BB, PM and DA muscles. This swimmer showed higher values of activation in the end of the test for all muscles, excepted for the DA (0.27 ± 0.02 s) in the beginning. The duration of non-active phase reached had higher values in the DA (1.54 ± 0.18 s) in the beginning of the test than the BB, TB and PM muscles. All the muscles had higher duration in non-active phase in the beginning of the test DA (1.54 ± 0.18 s), PM (0.82 ± 0.29 s), TB (1.16 ± 0.12 s), excepted for the BB (1.52 ± 0.25 s) that was in end of the test.

So, the swimmer 4 demonstrated a behavior that in the active phase all the muscles had a higher duration in the end of the swimming bout, excepted for the DA that was in the beginning of the bout, as the non-active phase was higher for all muscles in the beginning except for the BB.

Lastly, the swimmer 5 had the DA (0.33 ± 0.03 s) at the muscle which had more duration in the active phase on the beginning of the test, than the BB, TB and PM muscles. The relative duration of the active phase was higher for DA (0.33 ± 0.03 s) and TB (0.29 ± 0.04 s) in the beginning, and for BB (0.23 ± 0.01 s) and PM (0.24 ± 0.03 s) on the end of the test. The duration of non-active phase reached had higher values in the BB (1.84 ± 0.34 s) in the end of the test than the TB, PM and DA muscles. All the muscles had higher duration in non-active phase in the end of the test.

This swimmer presented a distinct behavior in the muscles study in the duration of the active phases, namely two muscles had higher duration in the beginning (DA and TB) and the other two muscles in the end (BB and PM) of the swimming bout. In the non- active phases all the muscles presented the same behavior, in which all of them had a higher duration in the end of the swimming bout.

By the analysis relative duration of the active phase and non-active phase we can observe that all the swimmers under study had a different behavior, but we can note some similarities between them. As regards to the duration of the active phase, the main behavior was in the BB, that presented always a higher duration in the active phase in the end of the swimming bout for all the swimmers, the DA was very irregular behavior, because he had a higher active phase in swimmer 2, 4, 5 in the beginning of the swimming bout and for swimmer 1 and 3 in the end of the swimming bout, moreover the PM had a higher duration in the active phase mostly in the end of the swimming(swimmer 3, 4, 5), finally the TB had predominantly more duration in the active phase in the beginning of the swimming bout(swimmer 1, 2, 5).

The non-active phases demonstrated that the TB and DA had a higher duration in the non-active phase in the beginning of the swimming bout for all the swimmers, excepted for the swimmer 1, the BB had higher duration of non-active phases in the beginning for three swimmers (swimmer 1, 2, 3) and for two swimmers (swimmer 4 and 5) in the end of the swimming bout. DA had had a higher duration in the non-active phase in the beginning of the swimming bout for all the swimmers. The PM had a higher duration in the non-active phase in the beginning of the swimming bout for all the swimmers, excepted for the swimmer 2.

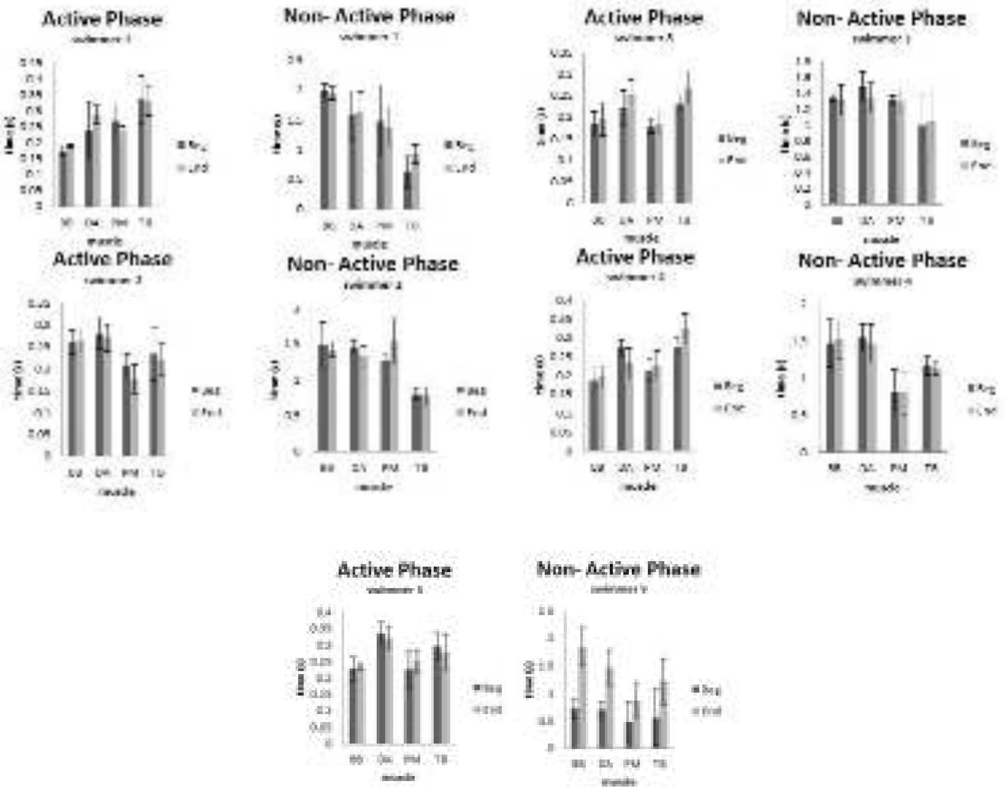

Figure 1: Mean and standard deviation of the duration of active and non-active phase at the beginning (dark gray) and end (gray) of the swimming bout for each swimmer. BB- biceps brachii; DA- deltoid anterior; PM- pectoralis major; TB- triceps brachii

In figure 2 shows the comparison of the average rectified value (ARV) for each muscle, in the beginning and the end for each swimmer. For the swimmer 1, the ARV increased for the BB (0.11 ± 0.01 v) and TB (0.60 ± 0.04 v) in the end with the respect to the beginning. Swimmer 2 also in the BB (0.26 ± 0.02 v) and in DA (0.82 ± 0.03 v).Swimmer 3 increased for all muscles at the beginning with respect to the end of the bout. The swimmer 4 increased for the DA (0.69 ± 0.05 v) and PM (0.13 ± 0.01 v) in the end with the respect to the beginning. Lastly, swimmer 5 had a similar ARV with the same muscles from the swimmer 1, that is an ARV increased for the BB (0.23 ± 0.03 v) and TB (0.22 ± 0.05 v) in the end with the respect to the beginning.

For all the swimmers, it can verify that the muscles who presented higher ARV where the TB and DA. The DA obtained higher ARV for all the swimmers in the beginning and in the end of the swimming bout, excepted for the swimmer 2 and 4. In the BB, PM and TB we can observe that predominantly they presented higher ARV values in the beginning of the swimming bouts: swimmer 1, 3 e 4, for BB, swimmer 1, 2, 3 e 5 for PM and swimmer 2, 3 e 4 for TB).

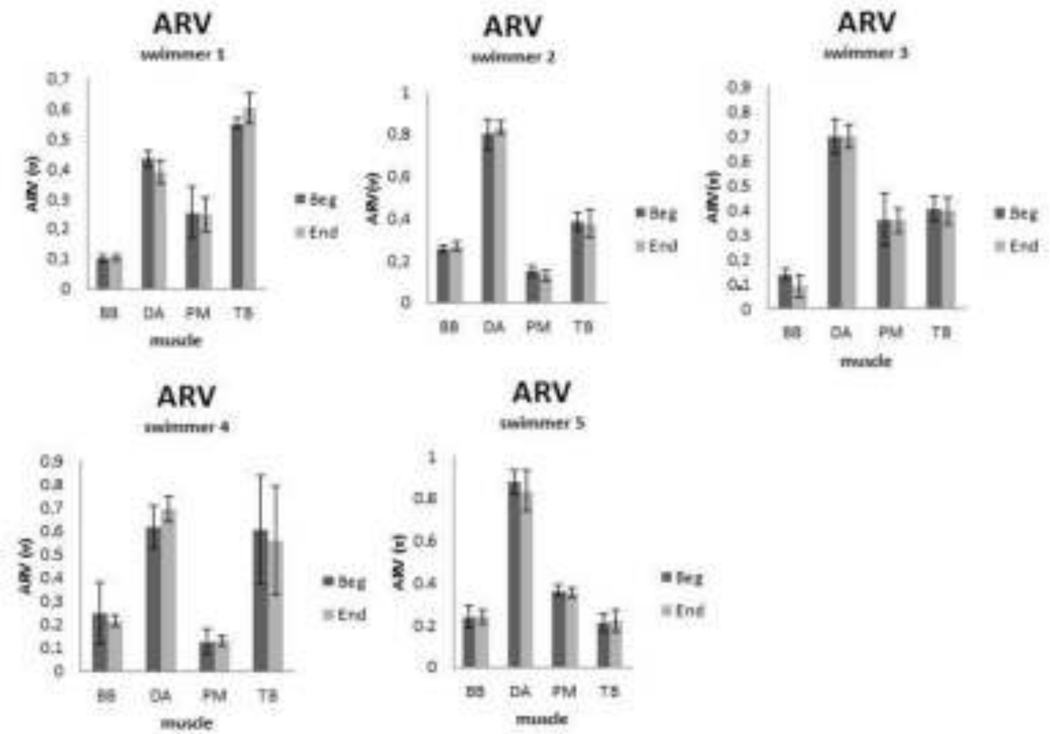

Figure 2. Comparison between the muscles of an average rectified value at the beginning(dark gray) and end (gray) of swimming bout for each swimmer, BB- *biceps brachii*, DA- *deltoid anterior*, PM- pectoralis major, TB- *triceps brachii*.

Figure 3, presents the motor pattern equivalent of five different events, corresponding to the five moments of observation made in each stroke, which was repeating in 10 cycles for each swimmer. The swimmer 1 and 4 had technical model of swimming is close to the variant “very wavy, arched” from Silva et al. (2002), and a motor pattern is characterized by the following settings: FPAA:1p1,1p3,1p6,1p7,1t1,1t5,1t6,1c2,1c4,1b1 which means legs in extension, ankle above hip, feet in extension in relation to legs and legs inclined upward(relationship with the water line). Head up according to the trunk, being in dorsi-flexion inclined for upward/parallel to the waterline.

Orientation of the vision to diagonal/lower, head below the water line/intermediate. Hands above the shoulder level (horizontal relationship). SPAA: 2p1,2p4,2p5,2p8,2t3,2t4,2t7,2c2,2c3,2b2,2b3 which means legs in extension inclined down/parallel to the water line, feet parallel and ankles below the hip/in prolonging.

Trunk in dorsi-flexion and inclined upward/parallel to the water line and gluteus below the water line, diagonally oriented view/down and head above the water line/intermediate. Finger pointed at the bottom and front hands in front of the shoulders /no extension (vertical relationship). The moment of observation FPAL was characterized by: 3p1,3p3,3p6,3t3,3t4,3c1,3b2,3b4, means knees and feet’s apart and standing straight out(ratio-foot-leg). Head up the water line /intermediate, forearms inclined down, hand below the water line/extension in the shoulders and below/in extension (horizontal ratio: hand-shoulder). SPAL: 4p1,4p3,4p6,4t2,4t5,4t6,4c1,4b2,4b4 which means knees apart and ankles above the hip (ratio: ankle-hip) and right angle between the foot and the leg. Gluteus below the water line/intermediate, trunk in dorsi-flexion and inclined to upward/parallel to the water line. Head up the water line/ intermediate, forearms inclined down and elbow below the shoulders/ in prolonging (relationship elbow-shoulder. R: 5p2, 5p3, 5p5, 5p8, 5t2, 5t4, 5t6, 5c2, 5b2, which means ankles below the hip/in the extension, toes directed downwards and backwards, midpoint trunk-hip-knee-ankle in obtuse angle and legs inclined down.

For swimmer 2 and swimmer 5, we can noted that the technical model of swimming is close to the variant “very wavy, slightly arched” from Silva et al. (2002), and a motor pattern is characterized by, FPAA: 1p1,1p4,1p6,1p8,1t1,1t5,1t6,1c2,1c4,1b2;SPAA:2p1,2p4,2p5,2p8,2t3,2t4,2t7,2c1,2c3,2b2,2b3,FPAL:3p1,3p3,3p5,3t3,3t4,3c1,3b2,3b4,3b6,SPAL:4p1,4p4,4p6,4t2,4t5,4t6,4c1,4b2,4b4, R:

5p2,5p3,5p5,5p8,5t2,5t4,5t5,5c2,5b2. The swimmer 3 presented a technical model of swimming is close to the variant “very wavy, slightly arched” from Silva et al.(2002) and a motor pattern characterized by, FPAA: 1p1,1p4,1p6,1p8,1t1,1t5,1t6,1c2,1c4,1b2,SPAA:p2,2p4,2p5,2p8,2t3,2t4,2t7,2c1,2c3,2b1,2b3 ,FPAL:3p1,3p3,3p5,3t3,3t4,3c1,3b2,3b4,3b6,SPAL:4p1,4p4,4p6,4t2,4t5,4t6,4c2,4b2,4b4, R: p2,5p3,5p5,5p8,5t2,5t4,5t5,5c2,5b2. Consequently , in all the motor patterns completes of the five swimmers, there is swimmers that have a greater stability in stroke cycle, this greater stability comes from the more number of occurrences of the same cycle 5 events, 5 observation moments: FPAA, SPAA, FPAL, SPAL and R. The swimmer 1 was the swimmer with more stability behavior during swimming, because presented 10 cycles recurred(5 equal events), following by the swimmer, 5, 3, 2 and 4 that repeat the same cycle in 7 cycles, 6 cycles, 3 cycles and 3 cycles, respectively.

The behavioral variability occurred with higher frequency in the moments with higher propulsive force production (SPAA).

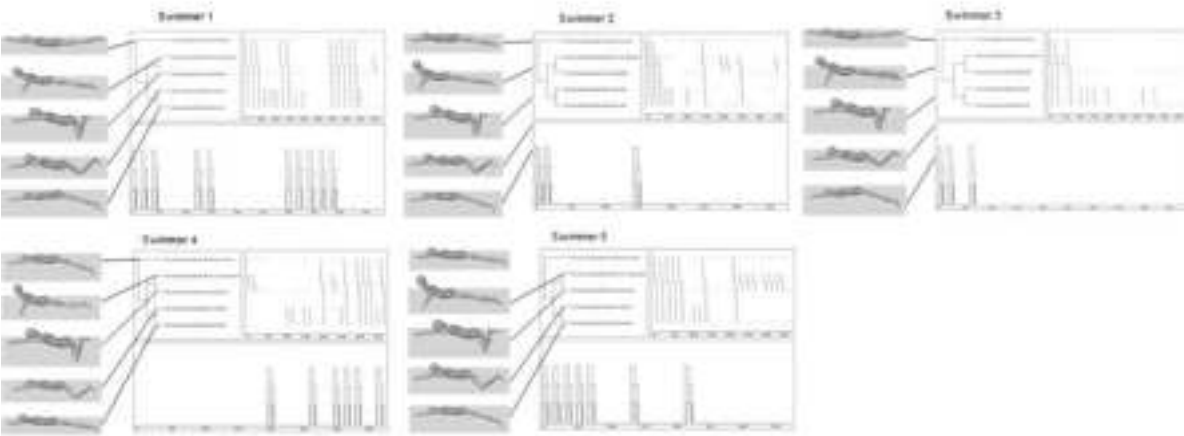

Figure 3. Schematic representation (left image) and complete behavior pattern with five observation moments (both images in the upper part of the figure) with the spatio-temporal reference of occurrence of the strokes (diagram in below part of the image), for all the swimmers.

DISCUSSION

The aim of this study was to analyze and characterize the neuromuscular patterns in breaststroke through the support of the description of the detection patterns, with the introduction of a method to examine the data and to analyze the inter-temporal relationship between the structures of events.

The main finding of this study was that each swimmer had their neuromuscular behavior, verifying some similarities in some swimmers and muscular patterns. The motor behavior pattern showed that each swimmer had also its own behavior pattern, since each adjusts its technical characteristics of swimming.

The methodology used in this study increased the capacity of access the neuromuscular and motor behavior of the swimmers and coaches in a view further. On the one hand, the wireless EMG device for data collection in the neuromuscular patterns, it´s a new approach since it allows to reduce the constraints on the swimmer during the swimming bout, and also as has been suggested by some previous studies with this device (21, 22), on the other hand, the construction of ad hoc instruments presented in this study to access the motor patterns had advantages in the flexibility, in the ability to adapt to very different behaviors and situations, in the rigor on the application of the various procedural operations in non-restrictive and unobtrusive nature of its appraisal of real situations (23).

Neuromuscular Patterns

In swimming analyzing the rectified EMG signal it is possible to observe very clearly the differences between the activation and the resting periods of the muscles. Following this, the relative duration of the active phase demonstrated a tendency of an increasing in TB muscle for all swimmers under study, excepted for the swimmer 2 and 5, where the DA had a higher duration, this tendency of the TB it´s similar with the 100m front crawl test at maximal intensity, developed by Stirn et al.(7).As regards to the non-active phase, we can´t state that there is a tendency relatively to the beginning and the end of the swimming, because each swimmer presented a different behavior for the muscles in study.

The neuromuscular pattern provided by the ARV demonstrated an increased at the end for BB and TB in swimmer 1 and 5, and for BB, DA and PM in swimmer 2 and 4,being in agreement with Conceição et al. (10) and in disagreement with the results achieved by Nuber et al. (8) where biceps firing was inconsistent. This outcomes in neuromuscular pattern were also according with study developed by Ikai et al. (24), that showed qualitatively that the BB,TB DA were highly activate during the strokes.
The absence of a neuromuscular pattern for all the swimmers could be related to different technical models used for each swimmer since the beginning to the end of the swimming bout.

Motor Patterns

The motor patterns results were in agreement with the results in other studies in which similar methodologies were used in simultaneous techniques (12, 13). Campaniço et al. (13) reported that compared male and female genders in butterfly technique, it wasn´t found any equal complex pattern between all swimmers, but in each intra-individual was found a complex pattern, demonstrating that all swimmer are totally different and that each individual has its own motor pattern. After Louro et al. (12) in four male butterfly swimmers, verify that each of the swimmers had their own behavioral pattern and each pattern was adjusted for individual characteristics.
Moreover, the behavioral patterns are different at both intra-individual and inter-individual because they are tailored to each specific need of different swimmers. Although, in our study different patterns between cycles and between swimmers were observed, it seems that they have similarities between them, adjusting his style to the technical model.
In our results relatively to the technical model presented, the swimmers 1 and 4 adopted the “very wavy, arched” variant, whereas the swimmers 3 and 5 used the variant “very wavy, slightly arched”, lastly the swimmer 2 chosen the “wavy, slightly arched” variant. According to Louro et al. (12) even though the standard model is a reference, each swimmer adapted their swimming pattern in a unique and distinct way, these behavior changes occur as each

swimmer has patterns with different complexities, because change existing settings by default.

Associations

This study is the first to report EMG and motor patterns in swimming. The amount of information to be removed through a qualitative observation, using observation instruments properly applied, is vast and varied, which we can verify the existence of different line of research using the same software and algorithm (19,20) although using different areas of technical performance.

By the characterization of the neuromuscular patterns and motor patterns in individual point, it seems that there is a relationship between them, although each swimmer adopt a distinct motor and neuromuscular pattern, but there were some similarities between them, i.e. the swimmers 1 and 4 showed similar neuromuscular pattern in the muscles DA e TB and adopt a “very wavy, arched” variant, while swimmers 3 and 5 showed similar in the muscle DA and adopt a variant “very wavy, slightly arched”.

The measurement of the neuromuscular and motor pattern has practical implications for the coaches, since thorough the knowledge of these two indicators the coaches may improve the training plan according to the technical model used by their swimmers, such as developed specific training exercises in water and dry land to optimize the neuromuscular patterns of the most prevalent muscles for each technical model. Based on our results using the known methods, we can state that there is a need of developing more advanced measurement systems for the breaststroke technique which allows us to have clear insight into the structure of the technical performance like has been developed by the front crawl.

CONCLUSION

As a conclusion, we noted that each swimmer adapted their motor pattern and their neuromuscular pattern in a unique in distinct way. Although different patterns between cycles and between swimmers were observed in motor and neuromuscular pattern, it seems that they have similarities between them, adjusting his style to the technical model.

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STATEMENT OF CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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STABILITY OF PATTERNS OF BEHAVIOR IN THE BUTTERFLY TECHNIQUE OF THE ELITE SWIMMERS

Authors

Hugo Louro [1,2]

António Silva [2,3]

Teresa Anguera [2,4]

Daniel Marinho [2,5]

Conceição Oliveira [2,4]

Ana Conceição [1,2]

Jorge Campaniço [2,3,4]

[1] *Sport Sciences School of Rio Maior - Polytechnic Institute of Santarém, Rio Maior, Portugal;*

[2] *Research Center in Sports Science, Health and Human Development, Vila Real, Portugal;*

[3] *University of Trás-os-Montes and Alto Douro, Vila Real, Portugal;*

[4] *University of Barcelona, Barcelona, Spain;*

[5] *University of Beira Interior, Department of Sport Sciences, Covilhã, Portugal*

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RESUMO

O objetivo deste estudo foi encontrar padrões na técnica de natação da mariposa, com uma adaptação do Sistema de Observação do Comportamento Tech. Sendo um instrumento para a análise qualitativa *ad-hoc,* permite o estudo da estabilidade da aplicação técnica. Quando usado no treino de nadadores, as análises podem reduzir a variabilidade comportamental da técnica de nado. Através da análise dos padrões temporais (*T- pattern*) foi estudado uma sequência de cinco ciclos à velocidade máxima, e o comportamento dos quatro nadadores de elite portugueses, com um registro de 259 códigos alfanuméricos e um total de 160 configurações. A estrutura original do instrumento, com base em um sistema misto de categorias e formatos de campo, regista as características técnicas, observados durante a execução de ciclos de braçada. A validade foi assegurada por meio do índice de confiabilidade intra-observador (95%) e exatidão inter- observador (96%). Para detetar padrões em cada nadador foi utilizado o software Théme 5.0, o que permitiu a identificação das estruturas estáveis de desempenho técnico dentro de um intervalo de tempo crítico ($p < 0,05$) *t-patterns* . Os padrões eram diferentes, adequando-se as características de execução técnica dos nadadores. Verificou-se que o nadador pode criar configurações com diferentes níveis de complexidade da estrutura, dependendo da implementação de mudanças no ciclo de mão. As variações dos códigos em cada configuração obtida usando o SOCTM, permitiu determinar as diferenças entre os nadadores. No entanto, os registros mostram uma semelhança comportamental clara quando se compara o resultado com um padrão geral da técnica de mariposa. A qualidade e o potencial deste instrumento parece ser determinante, devido aos padrões serem obtidos a partir de uma sequência temporal.

Palavras-chave: Análise técnica, padrões, mariposa, cronologia.

Abstract

The purpose of this study was to find patterns in the butterfly swimming technique, with an adaptation of the Behavioral Observation System Tech. This, as an instrument for ad-hoc qualitative analysis, enables the study of the stability of the technical implementation. When used in the training of swimmers, analysis can reduce the variability of behavioral tuning swimming technique. Through the analysis of temporal patterns (T-pattern) and a sequence of five cycles running at hand maximum speed, the behavior of four technical Portuguese elite swimmers, with a record of 259 alphanumeric codes and a total of 160 configurations, were studied. The structure of the original instrument, based on a mixed system of categories and formats Field, can record technical features, observed during the execu- tion of hand cycles. The validity was ensured through the index of intra-observer reliability (95%) and inter-observer accuracy (96%). To detect patterns in each swimmer, the Theme 5.0 software was used, which allowed to identify the stable structures of technical performance within a critical interval of time ($p < 0.05$) t-patterns. The patterns were different, adjusting to the characteristics of technical implementation of the swimmers. It was found that the swimmer can create settings with different levels of structure complexity, depending on the implementation of changes within the hand cycle. Variations of codes in each configuration obtained using the SOCTM, allowed determining the differences between swimmers. However, the records showed a clear behavioral similarity when comparing the result with a general pattern of the butterfly technique. The potential quality of this instrument seems to be important due to the patterns obtained from a temporal sequence.

Key words: Technical analysis, patterns, butterfly, chronology.

INTRODUCTION

The sports technique aimed to achieve an optimum resolution of the tasks of competition in a particular sport (Grosser and Neumaier, 1986). It is defined as a rational process, appropriate and economic, for a sport result (Bompa, 1983; 1990). Generally, it is described by a set of characteristics and dynamics of cinematic form: verbal, graphic design, mathematics, biomechanics, anatomy, functional, or other.

To analyze the sport movements of a swimmer, the level of swimming in a cinematic perspective and in terms of technical effectiveness should be carried-out (Barbosa et al., 2008; Marinho et al., 2009). Thus, we have to take into account the differences between the model and the individual response (Counsilman, 1968; Campaniço et al., 2006). In this context, we must also remember that the stagnation in technical (Knapp, 1980), stems from the acquisition of engines weak habits that the swimmer use to achieve the proposed objective in terms of efficiency, are not the most profitable and efficient.

The butterfly technique is characterized by models and variants identified (Colman and Persyn 1993; Persyn et al., 2000; Silva and Alves, 2000). These models can be observed, described and analyzed with high accuracy compared to existing technological resources. The demand of the particular hand champions, so often discussed in technical terms in the scientific community, is the main reason why the procedures used in this study can be used to know the actual reason for its success.

Persyn et al. (2000) compared and characterized the main variants of the butterfly technique in wave and flat styles, accurately defining the phases and sub-phases in each cycle of swimming. Silva and Alves (2000) reinforced some aspects of the new variants associated to wave criteria, focusing in particular on the importance of lumbar hyper-extension and torso arched position. Sanders et al. (1995), Sanders (1996), Scheihauf et al. (1988), Togashi and Nomura (1992), Mason et al. (1992), Maglischo (2003), Barbosa et al. (2003), Barbosa et al. (2005), Silva and Alves (2000), Platonov (2005), Chollet et al. (2005) confirm the technical standard as a typical set of actions: (i) position of the body wave, (ii) action of the upper limbs, (iii) ascending and descending action of the lower limbs, (iv) coordination between actions of the upper and lower limbs and, (v) coordination between these and the breathing action.

The observational methodology, particularly as a strategy of scientific method, used for analyzing the behaviour situation, involves the fulfilment of an ordered series of tasks to collect and process data (Sackett, 1978; Bakeman and Gottman, 1989; Anguera 1993; Anguera et al., 2001). In swimming, we can note the importance of such scientific procedures to study the technical performance (Campaniço et al., 2006; Oliveira et al., 2006; Cardoso et al., 2008; Louro et al., 2009a).

According to Anguera et al. (2001), there are advantages in using this method because not only can the user take the procedures of the laboratory into the field, but also can provide data without interfering with or manipulating the behaviour of the observed subjects. To examine the technical performance (Campaniço and Anguera, 2001), using the observation as a tool for coding (Anguera and Blanco-Villaseñor, 2003), one must: (i) isolate the object of observation, (ii) create a system suitable for the purpose of research, (iii) develop criteria and specifications in relation to the observed behaviour (categories and formats of the field), (iv) involve a process of rating and measurement and, (v) ensure and validate the instrument of observation.

In this context, the objective of this study was to introduce a method to examine the data and to analyse the inter-temporal relationship between the structures of events (movements) in the butterfly technique. This method of analysis is based on the detection of patterns using the software THEME, developed by Magnusson (1996; 2000). This instrument intend to identify consistent patterns that exist within a flow of conduct and thus to provide a different view of the complex relationships between movements. The detection of the pattern is based on the theory of probability and, more specifically, the binomial distribution (Magnusson, 2000). The major advantage of this software lies on the identification of hidden patterns allowing a different approach of the complex relationships continuously established during a sequence of actions. According to Magnusson (2000), the algorithm used in the detection of temporal patterns is based on a binominal theory of probabilities allowing identifying the sequential and temporal data systems. Hence, observational methods applied to sport are scientific procedures that reveal the occurrence of perceptible motor behaviours, allowing them to be formally recorded and quantified. In addition, they also allow the analysis of the relations between these behaviours, such as sequentiality, association and covariation. Theme software was used to determine behaviour patterns in sports, rendered precisely around the process of observation of sport events guided by ad-hoc instruments, answering to several problems, such as performance in collective sport games (e.g. Anguera and Jonsson, 2003; Anguera et al., 2003) or recording and reproduction of technical actions for visualization of flows of conduct in individual sports (e.g. Castañer et al., 2009; Louro et al., 2009a; Lyon et al., 1994).

METHODS

Our study was based on observational methodology. In this context the design of this study was classified as punctual, nomotetic, multidimensional (Anguera et al., 2001). Punctual, since the acquired data were obtained in a single moment, or a single session. Nomotetic, since our sample comprised four subjects with a common bond, cycles of the butterfly swim. It also seeks to investigate the conduct in which several dimensions of technical execution occur simultaneously (multidimensional character).

In the exploratory phase, we defined the behavior to be observed, based on deductive explanation. The units of measurements were defined as units of events, or events.

Participants

The sample comprised four international level swimmers, all with a male performance sports with more than 750 points in the table of FINA for 100m butterfly. The athletes involved were representative of the national team of Portugal in absolute Olympics in butterfly.

Instruments

Instrument for measurement For the record of the image a Sony Mini-DV Camera (50 Hz) was used, and recorded in real time, connected via Firewire to the hard disk of a laptop (Centrino Airis, 1700 Mhz). The camera had been protected by a sealed housing Ikelite. To perform the capture of the image to digital format the MovieMaker software was used and the display of images was carried out using Quintic Software. All procedures were conducted in an indoor 50m swimming pool.

Instruments of observation

We used an Ad-hoc reference (Anguera et al., 2000). The instrument has been configured by the nature of research: (i) criteria, (ii) system of codes and, (iii) units of coding. The structure of the observation was taken as individual events at the discretion of time and order (Anguera, 1990; Anguera and Blanco, 2003), representing one or more specific technical behavior of a hand cycle.

The adaptation of the Observing System Performance in Butterfly Technique (SOCTM) was conducted based on four core criteria: EMA, PAP, SAP and SMRB, as Table 1 (Louro et al., 2009a), characterizing the conduct considered critical in the cycle of the butterfly swim. Each criterion represents a stage of a complete cycle gesture, adding movements and actions that represent the technical conduct, independent of any existing variant. Each criterion is divided into two phases, comprising a few frames of video sequence.

Table 1. Moments of observation and description of observation instrument used in hoc – SOCTM.

EMA	Input your hand in the water	Focuses on aspects of the relationship cycle with another gesture, particularly when that occurs the entry of the hands in water, associated with the position of the head, torso and legs. The transitional approach is marked by the beginning of flexion of the arms and below the point of the leg. This is divided into two stages: Entry 1 of the hands in water, coinciding with the onset of action of the kick-down, 2 extending out of the arms and the end of the downward action of the legs.
PAP	First propulsive support	Focuses on critical aspects of the generation of propulsive support the arms as they performed in front of the line of the shoulders, associated with new positions of the head, trunk and legs during the movement. The transitional approach is the deepest point of the hands. It is divided into two stages: 1 Flexion of the forearm in relation to the long arm and onset of action upwards legs 2 The deepest point of the hands occurring in front of the head and shoulder line.
SAP	Second propul-sive support	Focuses on critical aspects of the second generation of the propulsive support of the arms as they planned for behind the line of the shoulders, associated with new positions of the head, trunk and legs during the movement. The criterion is the transition from hands on the vertical line of the thigh. It is divided into two stages: 1 The hands are on the vertical line of the shoulder, at the commencement of the action; 2 hands are on the vertical line of the thigh.
SMRB	Out of the hands and arms recovery	Focuses on critical aspects of the arms and out as they planned ahead for the recovery carrier. The transitional approach is the entry point of the hands in the water, which coincides with the moment of departure the effect of two-foot vertical climb of the legs. It is divided into two stages: 1 out of the hands in water and rising action of the legs, 2 during the immersion of the head and in the 2nd half (after the vertical shoulder) and recovery of arms.

The conduct was in accordance with the temporal characterization delimiting the beginning and end of each stage. In each of these stages a list of key points were defined, being critical to the implementation in the exploratory phase. To each of them an alphanumeric code was assigned.
In this context, the analysis of data was conducted based on the following settings on two occasions: (i) for the moment that determines the entry in the time period and, (ii) relating to the movement performed by the first moment that marks the entrance to the following criterion.
This means that we have a characterization of temporal sub-events, characterizing the technical achievement of the swimmer for a given time of the swimming cycle. Table 1 represents the four criteria. For this study the instrument was set with 83 alphanumeric codes. Each swimmer can get 40 different settings by examining a hand cycle, i.e., eight settings, or events, per cycle, making 40 in all the five cycles.

Observational Sample

The sample was represented by many observational records, 259 alphanumeric codes and a total of 160 configurations, or lines of code per event, used to catalog the performance of each swimmer during the five hand cycles.

Review procedures

Each subject performed the overall butterfly swimming technique in a distance of 25m. The filming was conducted in a sagital plane with rotation from right to left, following the motion of swimming, to permit the viewing of five complete cycles of swimming. The camcorder had been fixed, protected by a sealed housing and was placed perpendicular to the direction of displacement at a 6m distance from the swimmer and about 30cm deep, protected by a sealed housing.
Five cycles were extracted to ensure the behavioral sequence, taken from closer to the midline of the focal center, 8 to 10m after finishing between 18 and 20m.
The descriptive analysis was performed by the number of codes, settings and levels of stability (I) and variable (Iv). The stability is given by the ratio between the highest point on the frequency of

occurrence and the total on each moment of observation. The closer to 1, the greater the stability is and was used to interpret each of the moments in study, or parts of the movement. This index is important for analysis of a single subject, or several subjects. The variability was given by the ratio of n-frequency settings recorded and the maximum possible settings for time of observation. For all the swimmers analysis, n = 20 was performed. The lower the index, the more similarity between swimmers executions in each moment of observation is observed. To detect the patterns, the software first identifies the relationship between the two types of events and then detects the most complex patterns, using simple combinations. After detecting simple patterns, the user can then add up these patterns and simple patterns become more complex, since it combine with each other. Throughout the process of detection, a selection of models is done by deleting the less complete versions (Magnusson, 1996, 2000).

It is important to note that to interpret behavioral patterns hidden by the hierarchical structures of the graph obtained in the output, in this study it was defined that it would be only subjected to analysis the patterns whose events represent the four phases, regardless the use, or not, of the eight moments of integrated observation of the four criteria.

This filtering options selected in the software, also took into account the temporal distances of each event and the context of sequences during the swim.

The results of the patterns, that are found for the time period of five cycles and to find a pattern to the events, must occur at least twice during this period. Not all the events that occur are mentioned twice, because the software filters them and exposes only the events that have a higher chance, in the critical time.

The representation of this information differs from swimmer to swimmer; a type case study. Natural condition of implementation, the maximum speed, regardless of each swimmer, compels us to explore different types of settings.

RESULTS

The results that are presented refer to the table of frequency events, and analysis of the behaviour pattern of relationships through the sequential and critical intervals.

Descriptive analysis Noting, for example, the table of frequencies of a swimmer, representing a codification of the system of gestures over five cycles (Table 2). One can easily visualize the structure of the settings of each criterion and its variations in performance.

Table 2. Number of codes found by each swimmer and settings of each swimmer and the index of stability (IOS).

			Swimmer 1		Swimmer 2		Swimmer 3		Swimmer 4	
Quantity	Absolute (A)	IOS (i.e.)	A	I E	A	IE	A	IE	A	IE
Criteria recorded			67		69		64		59	
Diferents criteria recorded	30	1	38	.79	38	.79	35	.86	36	.83
Settings	8	1	16	.50	17	.47	15	.53	15	.53

In terms of technical description of the conduct, we can observe the conduct stable (I) and the overall implementation from the configurations obtained. Values less than or equal to 0.5 are considered weak, between 0.5 and 0.75 reasonable, less than 0.75 very reasonable, and 1.0 is considered excellent.

We can observe that the swimmers had a high stability. All values are above 0.79, i.e. very close to 1.

In Table 3 we can verify the events and changes occurred. At the entrance of the hand in the water (EMA) in the 1st time, there was a variation in the position of the hands relative to shoulders position being near (i.e. 0.40) or distant (i.e. 0.60), with variation of the heels being below the water line (i.e. 0.20) or above (i.e. 0.80). In the 2nd time the change happens in the path of the hands ranged from down (i.e. 0.40) and down and out (i.e. 0.60). During the first propulsive support (PAP), there were variations in the second swirl around the hand (i.e. 0.60) and vorticity (i.e. 0.40), and changes from below the knee (i.e. 0.80) or near the surface of the water (i.e. 0.20). During the second propulsive support (SAP), the behaviour change occurred between cycles, due to the position of the head for breathing, above (i.e. 0.40) and below (i.e.0.60) the waterline. We also found a variation in the position of the gluteus, near the waterline (i.e. 0.20) or below (i.e. 0.80). In the last criterion, on the output of the recovery of the arms and hands (SMRB), the variation was due to the head being above (i.e. 0.40) and below (i.e.

0.60) and in the 2nd time, due to the posture of the trunk, showing a dorsi-flexion (i.e. 0.40) or a flat position (i.e. 0.60).

Table 3. Characterization of the events and the occurrence frequency of swimmer 1 in the eight times of observation.

Criteria	Times of Observation	Settings(moles)	N	IE
EMA	1st time	1b2,1b4,1c3,1t2,1p4	3	,60
		1b1,1b4,1c3,1t2,1p4	1	,20
		1b1,1b4,1c3,1t2,**1p3**	1	,20
	2nd time	1b8,**1t5**,1t7	1	,20
		1b8,1t6,1t7	1	,20
		1b9,1t6,1t7	3	,60
PAP	1st time	2b2,2b5,2c2,2t1,2t4,2p4	5	1
	2nd time	**2b6**,2p9	1	,20
		2b6,2p8	1	,20
		2b7,2p9	3	,60
SAP	1st time	3b1,3b4,**3c1,3t2**,3p3	1	,20
		3b1,3b4,**3c1**,3t3,3p3	1	,20
		3b1,3b4,3c2,3t3,3p3	3	,60
	2nd time	3t5,3t8	5	1
SMRB	1st time	4b1,**4c1**,4t2,4t4,4p7	2	,40
		4b1,4c2,4t2,4t4,4p7	3	,60
	2nd time	4t7,4t12	3	,60
		4t8,4t12	2	,40

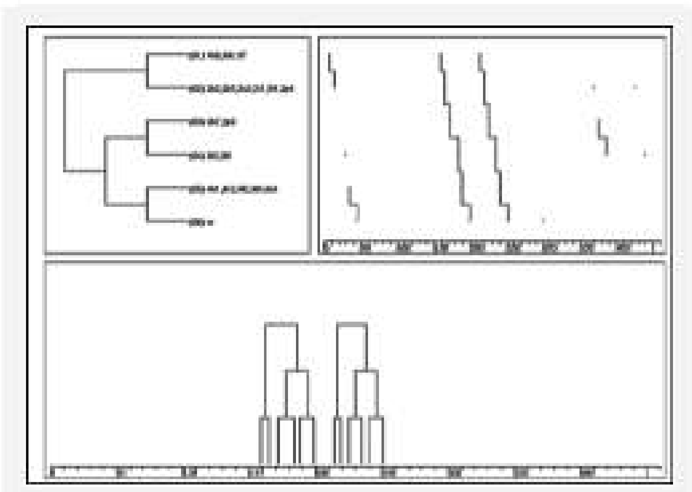

Figure 3. Swimmer 1 - Schematic representation of incomplete behavioural pattern, with five events in consecutive cycles 2 and 3.

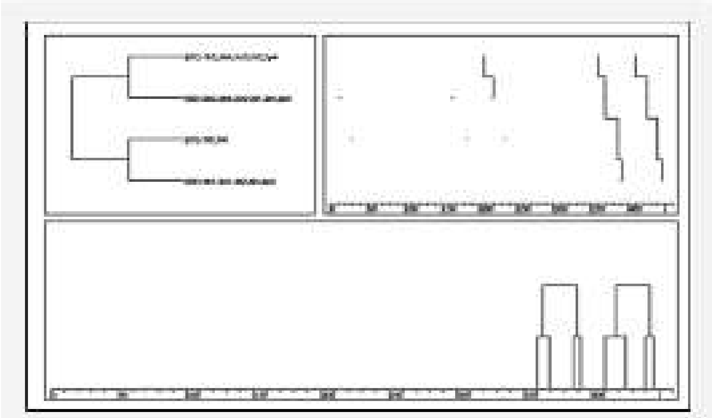

Figure 2. Swimmer 1 - Schematic representation of incomplete behavioural pattern, with four events in consecutive cycles with breathing.

The patterns displayed by the software Theme give us an overview of the behavioural interaction between times and between cycles. The output gives us three levels to view the same graph. The lower representation allows the visualization of time in which the default occurs, in the total sample time, and vertically, as characterized the diagram. The top right gives the relationship between time cycles. In the upper left corner we find the tree structures corresponding to the cycle times and the lines of events and their relationships within cyclical. In terms of data description in a swimmers' study, the pattern was classified as incomplete (five lines of events). In terms of general description of the technical conduct, interpreting Table 1, we can describe that we also obtained the settings, but now all related through a critical time interval (t-pattern) for the five cycles.

Figure 1 the first class has two settings: 1b9, 1t6, 1t7 (Ic 0.60) for the 2nd time of EMA. These data give a trajectory of the hand downwards, with the trunk in flexion, tilted and below the hip. Its stability is considered reasonable. Regarding the second configuration, 2b2, 2b5, 2C2, 2t1, 2t4, 2p4 (Ic 1) refers to 1 when considered the PAP, indicating that the hands are in the extension of the shoulders, elbows away from the line of water (below this), head below the water line, gluteus above and below the trunk, tilted hip and heels above the water. These two events are crucial to the remaining structure. Its stability is excellent. The second branch corresponds to the event 2b7, 2p9 (Ic 0.60), for the 2nd time of PAP, characterized by a turbulent flow around the hand and knees below the waterline; reasonable stability. The second event 3T5, 3t8 (Ic 1) is the 2nd time of SAP, indicates that the trunk has a flat and inclined position above the hip; it has an excellent stability. Moreover, the third line shows only the configuration of the events 4B1, 4C2, 4t2, 4t4, 4p4 (Ic 0.60) which corresponds to 1 when the SMRB occurs, which reveals the hands out and behind the elbows; the head and shoulders are above the water line, close to the gluteus and well below the heel; its stability is reasonable. The pattern formed by the Sub 2 when EMA occurred and 1st when PAP is the triggering of other behaviour, consisting of a sub standard and a range of events, thus the standard of the swimmer but an incomplete one.

In Figure 2 one can observe the pattern corresponding to the inspiratory cycle which is the 4th and 5th cycle. Here is the relevant combination, the first branch of the 1st moment of EMA with the 1st PAP, first registered in the found patterns (1B2, 1b4, 1c3, 1t2, 1p4) (Ic 0.60), which means the hands from the extension of the shoulders, placing the hands before the elbow, guiding the vision down, gluteus near waterline and position of heels below the waterline, which seems to explain the association between the height of the body with the time of hands' entry; its stability is reasonable. The second branch, connecting the 2nd stage of the SAP with 1 out of hands, seems to explain the importance of acceleration of the arms in the output to compensate the breathing movement. We found that the behavioural patterns of the swimmer were incomplete, and five events were the most complete ones. The behavioural pattern of Figure 2, corresponding to the inspiratory cycle, is only the event corresponding to the time path of the SAP.

In Figure 3 the swimmer presents a stable technical execution. We can describe his technical side conduct using the In Table 4 configurations obtained in five cycles. In the first configuration, at the entrance of the hand in the water (EMA), there is a variation in the trunk, may be in dorsiflexion (i.e. 0.60) or flexion (i.e 0.40). In the second configuration, there is a support in the first propulsive variation between the head above (i.e. 0.20) or below (i.e. 0.80) the waterline, the gluteus above (i.e. 0.40) or near (i.e. 0.60) the water line. There is still variation between knees next (ie 0.20) or below (i.e. 0.80) the waterline. In the second propulsive support (third configuration), there is variability in the criteria when the head is above (i.e. 0.60) or below (i.e.

0.40) the waterline, and the heel is above (i.e. 0.40) or below (i.e. 0.60) the water. Even the trunk varies from plan (i.e. 0.80) to a dorsiflexion position (i.e. 0.20). In the fourth configuration, In and Out of the Hand and Arms Recovery, the change occurs in close heels (i.e. 0.20) or below (i.e. 0.80) the water line. There are two cycles' patterns where there is inspiration and a behaviour pattern not incomplete in inspiratory cycles.

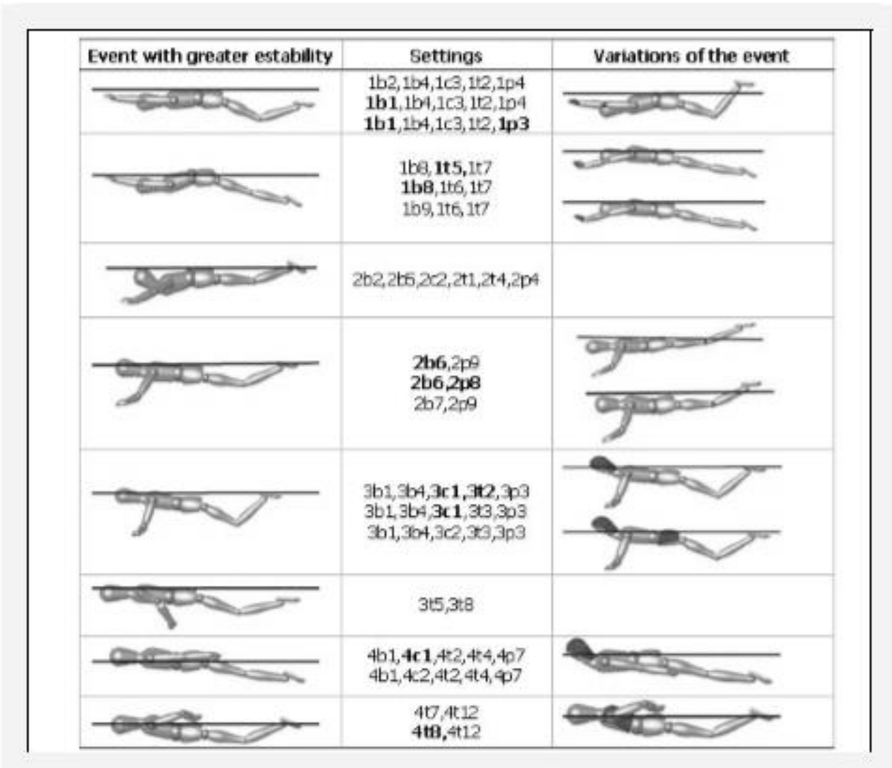

Figure 3. Schematic representation of events with greater stability and its variations in swimmer 1.

Table 4. Characterization of the events and the occurrence frequency of swimmer 2 in the eight times of observation.

Criteria	Times of Observation	Settings(modes)	N	IE
EMA	1st time	1b2,1b4,1c3,1t2,1p4	5	1
	2nd time	1b8,1t5,1t7	3	,60
		1b8,1t6,1t7	2	,60
PAP	1st time	2b3,2b4,2c1,2t2,2t4,2p4	1	,20
		2b3,2b4,2c2,2t1,2t4,2p4	2	,40
		2b3,2b4,2c2,2t2,2t4,2p4	2	,40
	2nd time	2b6,2p8	1	,20
		2b6,2p9	4	,80
SAP	1st time	3b1,3b4,3c1,3t3,3p3	1	,20
		3b1,3b4,3c1,3t3,3p4	2	,40
		3b1,3b4,3c2,3t3,3p3	1	,20
		3b1,3b4,3c2,3t3,3p4	1	,20
	2nd time	3t5,3t8	4	,80
		3t6,3t8	1	,20
SMRB	1st time	4b1,4c1,4t2,4t4,4p3	1	,20
		4b1,4c1,4t2,4t4,4p4	4	,80
	2nd time	4t7,4t12	5	1

This swimmer presents a complete pattern (eight events). He presents a great stability in swimming. The pattern of Figure 4 and 5 corresponds to two cycles (3 and 5), which are inspiratory ones, as verified by the code 3c1 where the head is above 2 during the propulsive support. In terms of technical description of the conduct, we can observe that the first branch presents a configuration relating to 1 when the EMA occurs: 1B2, 1b4, 1c3, 1t2, 1p4 (Ic 1) correspond to the behaviour of the swimmers' hands on the extension of the shoulders, elbows or before the hands' entering, guiding the vision down, legs bends heel and below the waterline; in this time an excellent stability was found. This event is crucial for the rest of the action. There is a link of this single event to the following event configurations, which constitute various sub-standards. In the following sub-standard we have two configurations: The first configuration corresponds to two events. The first, 1b8, 1t5, 1t7 (i.e. 0.60), corresponding to the 2nd time of EMA, when the swimmer displays a out and down trajectory of the hand, trunk in dorsi-flexion position and tilted down the hip; a reasonable stability.

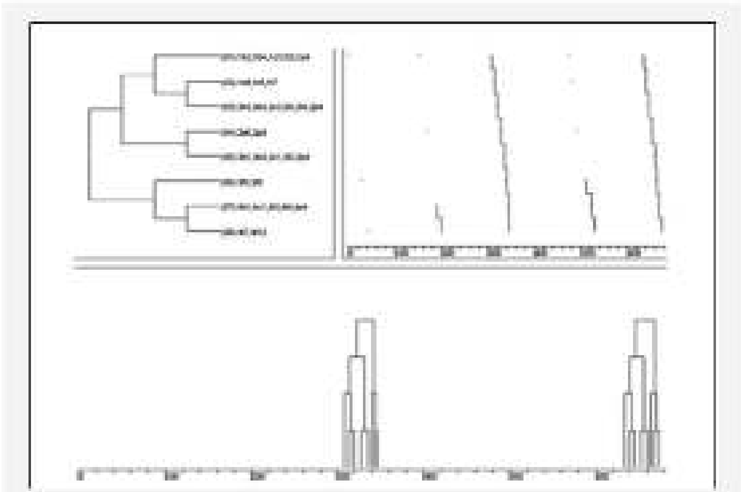

Figure 4. Swimmer 2 - Schematic representation of complete behavioural pattern. Pattern with eight events in alternating cycles.

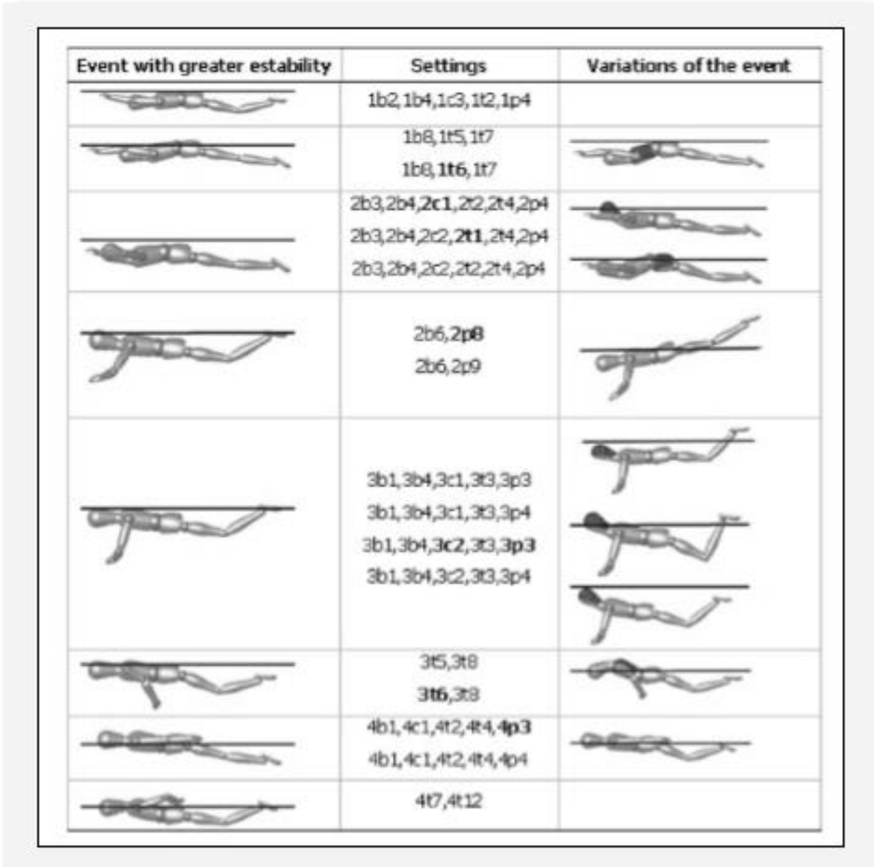

Figure 5. Schematic representation of events with greater stability and its variations in swimmer 2.

The second configuration, 2b3, 2b4, 2C2, 2T2, 2t4, 2p4, (i.e. 0.40), refers to the first of PAP, indicated that the hands are outside the extension of the shoulders, elbows close to the water line (below this), head below the water line, trunk tilted and below the hip and heels below the water line; the stability is poor.

This subdivision of the event is a crucial link to the next cycle of events. This subdivision consists of a substandard with two events for the 2nd time of PAP, 2b6, 2p9 (I 0.80), characterized by a flow of vortices around the hands and knees below the waterline, and a reasonable stability. In the 1st stage of the SAP, 3b1, 3b4, 3c1, 3T3, 3p4 (Ic 0.40), the swimmer presents the elbows close to the chest, the thumbs close, the head above, the gluteus above, the heels below the water line. In this stage the movement presents a low stability.

These two settings, plus the subdivisions that have previously mentioned, presented a strong relationship with the end of the observations of the cycle, thus creating a line of the event and a bunch of two configurations. The first corresponded to the 2nd time of SAP. The event 3T5, 3t8 (Ic 0.80) indicates that the trunk has a flat and inclined position above the hip, and a reasonable stability.

This event is related to the two configurations corresponding to the observed movements of the SMRB, being the configuration composed by the event.

The second configuration, 4B1, 4C1, 4t2, 4t4, 4p4 (Ic 0.40), corresponds to the 1st time of SMRB where the hands leave the water behind the elbows, the head and shoulders are above the water line, the gluteus close to the water line and the heels below. The second configuration corresponds to the moment when the hands leave the water and the arms recovery (4t7, 4t12), indicating that the trunk is flat and below the hip; this event has a low stability.

Table 5. Characterization of the events and the occurrence frequency of swimmer 3 in the eight times of observation.

Criteria	Times of Observation	Settings(moles)	N	IF
EMA	1st time	1b2,1b3,1c3,1t2,1p4	1	,20
		1b2,1b4,1c3,1t2,1p4	4	,80
	2nd time	1b8,1t5,1t7	5	1
PAP	1st time	2b3,2b4,2c2,2t1,2t4,2p4	4	,80
		2b3,2b4,2c2,2t2,2t4,2p4	1	,20
	2nd time	2b6,2p9	5	1
SAP	1st time	3b1,3b4,3c1,3t3,3p3	1	,20
		3b1,3b4,3c2,3t3,3p3	3	,60
		3b1,3b4,3c2,3t3,3p4	1	,20
	2nd time	3t5,3t8	4	,80
		3t6,3t8	1	,20
SMRB	1st time	4b1,4c1,4t2,4t4,4p3	1	,20
		4b1,4c1,4t2,4t4,4p4	2	,40
		4b1,4c2,4t2,4t4,4p4	2	,40
	2nd time	4t7,4t12	5	1

This swimmer presents stability between cycles. It is important to notice that he has two (in five) breathing cycles which are the 3rd and 5th cycles, respectively.

Examining the technical conduct in Table 5, minor changes and / or variations van be noticed, which correspond to: (i) at the entrance of water (EMA) the elbows can enter after the hands (i.e.

0.20), simultaneously or before (i.e. 0.80), (ii) in the PAP there is variation between the gluteus above (i.e. 0.80) or near (i.e. 0.20) the waterline, (iii) in the SAP there is variability in the head, being above (i.e. 0.20) or below (i.e. 0.80) the waterline, and with respect to the heels, they stay above (i.e. 0.80) or below (i.e. 0.20) the water. The trunk can change from plan (i.e. 0.80) to a dorsiflexion position (i.e. 0.20) and, (iv) in the SMRB there is variation in the heels position being close (i.e. 0.20) or below (i.e. 0.80) the water line.

The default behaviour of the swimmer is incomplete; there are 7 recordings of the event observation. The pattern indicated in Figure 6 and 8 occurred in consecutive cycles (3 and 4). It is important to stress that there is a breathing movement in the 3rd cycle.

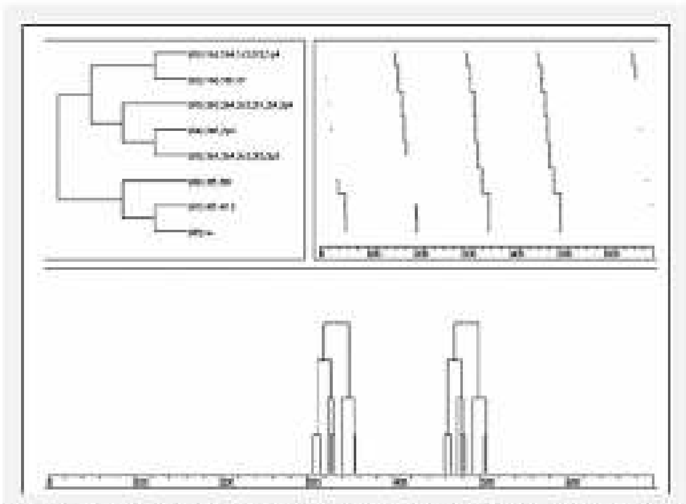

Figure 6. Swimmer 3 - Schematic representation of incomplete behavioural pattern. Pattern with seven events in consecutive cycles.

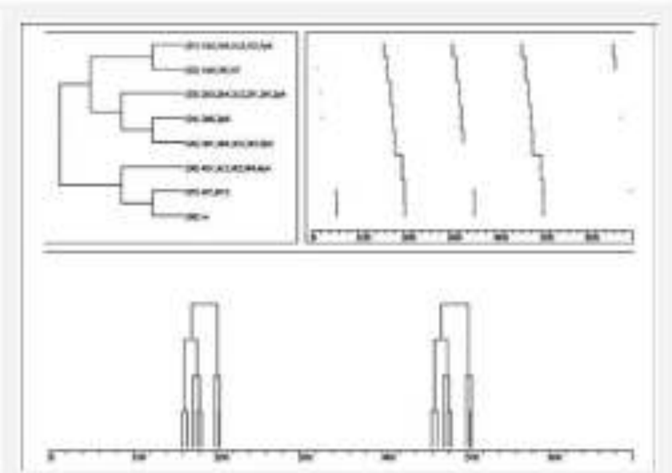

Figure 7. Swimmer 3 - Schematic representation of incomplete behavioural pattern. Pattern with seven events in alternating cycles.

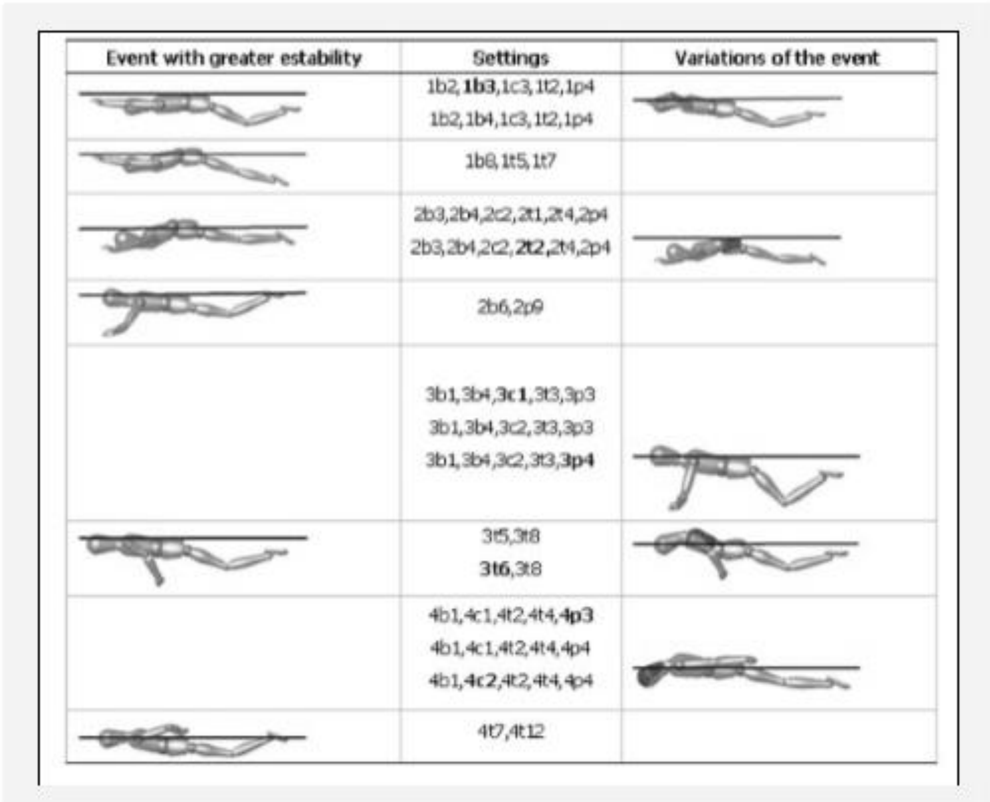

Figure 8. Schematic representation of events with greater stability and its variations in swimmer 3.

The technical description of the pipeline indicates that the swimmer has a sub-standard with two events corresponding to the entry of the hand. In the first event 1B2, 1b4, 1c3, 1t2, 1p4, (i.e. 0.80) the swimmer present the hands away from the extension of the shoulders, the elbows enter at the same time or before both hands, guiding the vision downwards and heels below the waterline; this time the stability is quite reasonable. In the second event 1b8, 1t6, 1t7 (i.e. 1) the swimmer presents a down and outsweep path of the hand, with the trunk in flexion, tilted and below the hip; there is an excellent stability.

This setting affects all the rest of the pattern because it is from this setting that the other sub-standard is created and gives us the pattern and their temporal relations. This configuration will connect with another configuration consisting of an event linked to two events.

The event 2b3, 2b4, 2C2, 2t1, 2t4, 2p4 (i.e. 0.80) is the 1st time of PAP and indicates that the hands are outside the extension of the shoulders, the elbows are close to the water line (below this line), the head is below the water line, the gluteus are above, the trunk is tilted and below the hip and the heels are below the waterline. The stability is quite reasonable. The second event has two settings.

The configuration of the two events is the 2nd time of PAP 2b6, 2p9 (i.e. 1), characterized by a flow of vortices around the hands and knees below the waterline; the stability is excellent. In the 1st stage of the SAP 3b1, 3b4, 3c2, 3T3, 3p3, (i.e. 0.60) the swimmer presented the elbows close to the chest, the thumbs close together, near the head, gluteus above, and the heels below the water line. The stability has a reasonable value. This subdivision in three events has a crucial link with the configuration described above.

Together they will influence the rest of the swimming cycle behaviour, being connected by two settings: (i) the connection time to the 2nd SAP 3T5, 3t8 (i.e. 0.80) indicates that the trunk has a flat and inclined position above the hip and a reasonable stability and, (ii) the 2nd time of SMRB corre- sponds to 4t7, 4t12 (i.e. 1) indicating that the trunk is flat and below the hip; excellent stability.

In Figure 7 it was found an incomplete pattern, where the eight observed moments are seven events that occur in at least two cycles of the five observed. We have a pattern that occurs in cycle 2 and 4 and they are not breathing cycles. The event 4B1, 4C1, 4t2, 4t4, 4p4, (i.e. 0.40) corresponds to 1 when the SMRB occurs. The hands leave the water behind the elbows, the head and shoulders are above the water line, the gluteus are close to this line and the heels are far from the water line; its stability is poor.

After the analysis of Table 6, we found some stability in the technical execution, but some changes oc- curred: (i) at EMA, we have variations of gluteus position, near (i.e. 0.80) or below (i.e. 0.20) the water surface, (ii) in the PAP a variation exists between the gluteus position above (i.e. 0.40) and near (i.e. 0.60) the water surface and, (iii) in the SAP there is variability in the head criterion, being above (i.e. 0.20) or below (i.e. 0.80) and the gluteus near (i.e. 0.20) or below (i.e. 0.80) the water line.

Table 6. Characterization of the events and the occurrence frequency of swimmer 4 in the eight times of observation.

Criteria	Times of Observation	Settings(moles)	N	IE
EMA	1st time	1b1,1b4,1c3,1t2,1p4	4	,80
		1b1,1b4,1c3,1t3,1p4	1	,20
	2nd time	1b8,1t6,1t7	5	1
PAP	1st time	2b3,2b4,2c2,2t1,2t4,2p4	2	,40
		2b3,2b4,2c2,2t2,2t4,2p4	3	,60
	2nd time	2b6,2p9	5	1
SAP	1st time	3b1,3b4,3c2,3t3,3p4	1	,20
		3b1,3b4,3c1,3t2,3p4	1	,20
		3b1,3b4,3c2,3t2,3p4	3	,60
	2nd time	3t5,3t8	5	1
SMRB	1st time	4b1,4c2,4t2,4t4,4p4	5	1
	2nd time	4t7,4t12	5	1

Analyzing the pattern behaviour of the swimmer it was found that it is a stable behaviour containing a line of events with frequencies higher than 4. There is less stability in the 1st observation time PAP and SAP, i.e., in moments of propulsive actions. We also note that this swimmer contains another technical indicator of stability, presenting 15 events during the course of five cycles.

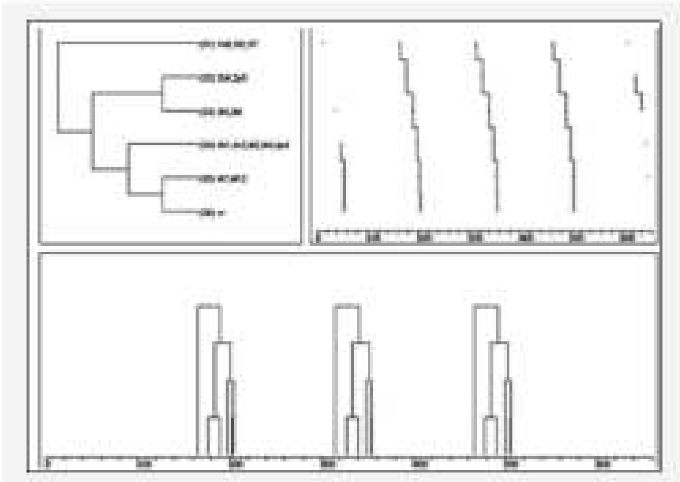

Figure 9. Swimmer 4 - Schematic representation of incomplete behavioural pattern. Pattern with five events in 5 consecutive cycles.

In Figure 9 and 10 The pattern is incomplete (five events) and their description is easily performed, where the first subdivision corresponds to the 2nd moment of EMA with the settings 1b8, 1t6, 1t7 (i.e. 1) corresponding to the behaviour of the swimmer's hand with a down and outsweep path, with the trunk in flexion, tilted and below the hip; the stability is excellent. This action is crucial to the performance of the swimmer in the cycle, because this action manages the entire behaviour pattern.

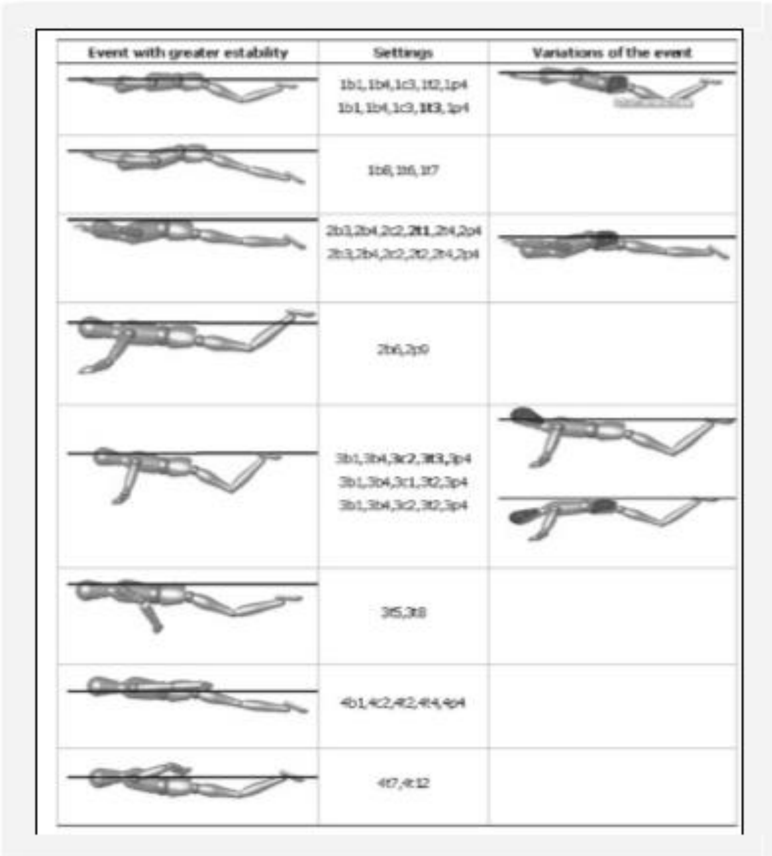

Figure 10. Schematic representation of events with greater stability and its variations in swimmer 4.

The event is connected to a configuration consisting of two more configurations separated by a bunch of events. The following substandard has two settings, with an event corresponding to the 2nd time of PAP 2b6, 2p9 (i.e. 1), characterized by a flow of vortices around the hands and knees below the waterline; reasonable stability. The second event is the 2nd time of SAP 3T5, 3t8 (i.e. 0.1) indicates that the trunk has a flat and inclined position above the hip, with an excellent stability. These two configurations are connected to other events that characterize the cycle.

The second subpattern consists of 2 branches, one corresponding to the configuration 4B1, 4C1, 4t2, 4t4, 4p4, (i.e. 1) which belongs to the 1st moment of SMRB, when the hands leave the water in a position behind the elbows, the head and shoulders are above the water line, the gluteus near the water line, and the heels below this line. The other branch corresponds to 4t7, 4t12 (i.e. 1) and corresponds to the 2nd time of SMRB, indicating that the trunk is flat and below the hip. It is important to stress that the 4th cycle is a breathing cycle.

This incomplete pattern of the swimmer has a triggering event for all the other events the 2nd time of EMA. From this event, a sub standard event take place composed of the 2nd time of PPA and the 2nd time of SAP, which will connect differently to the events of the 1st time of SMRB and the "Moment SMRB”. We only found one pattern in this swimmer; although we can point out that it happens in 3 of the 5 cycles.

Table 7. Index of variability and configurations carried out in greater number of times for moments of observation. Settings made by most swimmers in each moment.

Criteria	Times of Observation	Number of Settings Occurred	Variability Index
EMA	1st time	6	,30
	2nd time	3	,15
PAP	1st time	6	,30
	2nd time	4	,20
SAP	1st time	9	,45
	2ns time	2	,10
SMRB	1st time	9	,45
	2nd time	2	,10

When analysing Table 7 we can verify the index of variability of each event in the sample.

There is great variability in the 1st stage of the SAP and SMRB (0.45), corresponding to the most propulsive phases of the butterfly stroke. There is less variability is the 2nd time for each of these phases, because of the degree of freedom of each criterion and the small number of criteria observed.

DISCUSSION

The objective of this study was to introduce a method to examine the data and to analyse the inter-temporal relationship between the structures of events (movements) in the butterfly technique. Thus, the SOCTM instrument respects all the procedures of the observational method (Campaniço et al., 2006; Cardoso et al., 2008; Oliveira et al., 2001). This instrument allows us to collect data from temporal relations of sequences of events and, in particular with regard to our context, the way the technical characteristics of the swimming style are hierarchically related, represented in graph as a temporal pattern.

Methodologically, observation in sport is particularly suited to the implementation of unobtrusive procedures to appraise the behaviour of an individual. Amongst the observational methodology advantages are its flexibility, its ability to adapt to very different behaviours and situations, its rigor in the application of the various procedural operations and the non-restrictive and unobtrusive nature of its appraisal of real situations. In swimming analysis, observational methodology allows to explain the temporal relations, the relations between the technical components and the structure of a motor pattern (Louro et al., 2009b).

The performance in swimming is dependent on the swimmer's technique. Thus, the systematic observation and analysis during training and competition, seems to be a determinant procedure to the evaluation of the swimmer's performance. During several years, the qualitative observation in swimming was carried-out using list point methods, where the focus was based on the technical deviations from the model. However, this evaluation seems to be limited due to the onedimensional character of the analysis. Throughout the observational method, several behaviour patterns are presented, allowing observing relevant characteristics of the motor behaviour, especially its stability and variability during the actions. Moreover, this method can be applied in natural context, allowing the data collection in a simple and non-invasive way.

Therefore, this analysis leads us to attempt to identify patterns of implementation of a direct, but through the analysis of discrete data, it is only possible if we use the Theme software (hidden patterns between discrete data). Furthermore, we can verify the existence of different line of research using the same software and algorithm (Anguera and Jonsson 2003; Anguera et al., 2007; Borrie et al., 2002; Jonsson, 1998; Lyon et al. 1994; Magnusson, 1996, 2000), although using different areas of technical performance. For instance, Theme software was used to analyse technical patterns having for reference biomechanical criteria, in the consolidation of motor conducts in learning, in observational and cognitive expertise in the sport performance, in recording and reproduction of technical actions, oriented for the study of conducts in an interaction context.

The current study is based on the movement analysis, especially on the technical evaluation of the swimmer through the definition of specific motor patterns. Although the important data raised by this study, this study has some limitations. This kind of studies requires that the observer has a good knowledge of the swimmer's movement. The ad-hoc instrument used in this study needs to be adapted to other movements if one wants to apply this methodology into another context. During the imaging recording, we only used one underwater camera, which can limit the observation of the movement in all the space orientations. Therefore, in further analysis, this limitation should be corrected using more than one camera in different plans.

In the future, it seems also interesting to analyse the swimmers' patterns in a larger scale. Within this study, only four swimmers were evaluated. Thus, generalisations from a very limited sample size should always be presented with special careful. Furthermore, the analysis of swimmers of different performance level (Olympic finalist/medallist swimmers and non-expert swimmers) and female swimmers can improve the quality of this kind of evaluations.

CONCLUSION

We note that each of the swimmers have their own behavioral pattern, each pattern adjusted for individual characteristics. In each swimmer the criteria are observed from changes in each cycle on the adaptations and adjustments that the swimmer performs, which is shown with different events at the same time of observation, both with the same swimmer among the swimmers observed.

Moreover, the behavioral patterns are different at both intra-individual and inter-individual because they are tailored to each specific need of different swimmers.

Thus, each swimmer will have patterns with different complexities, because they change the number of events by pattern, depending on the changes and adjustments that the swimmer makes on their action.

Although different patterns between cycles and between swimmers were observed, it seems that they have similarities between them, adjusting his style to the technical model.

For the stability we observed that this behavior changes with the swimmer and also between phases and moments observed. We found higher values of stability in swimmers who presented the best times in butterfly technique. This fact seems to suggest that the swimmers who present greater stability of the swimming pattern could obtain the best performance results.

On the other hand, the variability is found in higher stages of acceleration of the swimming cycle, corresponding to phases of greatest propulsive force production.

We conclude that, although the standard model is a reference, each swimmer adapted their swimming pattern in a unique and distinct way.

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CAN THE CURRICULUM BE USED TO ESTIMATE CRITICAL VELOCITY IN YOUNG COMPETITIVE SWIMMERS?

Authors

Aldo Costa [1,2]

António Silva [2,3]

Hugo Louro [2,4]

Victor Reis [2,3]

Nuno Garrido [2,3]

Mário Marques [1,2]

Daniel Marinho [1,2]

[1] *University of Beira Interior, Department of Sport Sciences, Covilhã, Portugal*

[2] *Research Center in Sports Science, Health and Human Development, Vila Real, Portugal;*

[3] *University of Trás-os-Montes and Alto Douro, Vila Real, Portugal;*

[4] *Sport Sciences School of Rio Maior - Polytechnic Institute of Santarém, Rio Maior, Portugal;*

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RESUMO

Os objetivos do presente estudo foram avaliar a velocidade crítica usando o *currículo* do nadador em provas de crawl e comparar velocidade crítica para a velocidade correspondente a 4 mmol • L-1 de concentração de lactato sanguíneo e com a velocidade de um teste de 30 min. A amostra foi composta por 24 nadadores de alto nível masculino entre os 14 e 16 anos de idade. Para cada sujeito a velocidade crítica, a velocidade correspondente a 4 mmol • foram determinados l-1 de concentração de lactato sanguíneo e da velocidade média de um 30 min de teste. A velocidade crítica também foi estimada considerando-se o melhor desempenho de um nadador ao longo de várias distâncias baseado no *currículo* do nadador. Velocidade crítica incluindo provas de 100, 200 e 400 m não foi diferente da velocidade de 4 mmol • L-1 de concentração de lactato no sangue. A velocidade crítica incluindo todas as provas do nadador não foi diferente da velocidade do teste de 30 min. A avaliação da velocidade crítica com base no *currículo* nadador, parece ser um bom método para determinar a capacidade aeróbica de um nadador. A seleção das provas a serem incluídos na avaliação crítica velocidade deve ser a principal preocupação na avaliação do nadador.

Palavras-chave: Treino, avaliação, capacidade aeróbia, força critica.

ABSTRACT

The aims of the present study were to assess critical velocity using the swimmer *curriculum* in front crawl events and to compare critical velocity to the velocity corresponding to a 4 mmol·l^{-1} of blood lactate concentration and to the velocity of a 30 min test. The sample included 24 high level male swimmers ranged between 14 and 16 years old. For each subject the critical velocity, the velocity corresponding to a 4 mmol·l^{-1} of blood lactate concentration and the mean velocity of a 30 min test were determined. The critical velocity was also estimated by considering the best performance of a swimmer over several distances based on the swimmer *curriculum*. Critical velocity including 100, 200 and 400 m events was not different from the velocity of 4 mmol·l^{-1} of blood lactate concentration. Critical velocity including all the swimmer events was not different from the velocity of a 30 min test. The assessment of critical velocity based upon the swimmer *curriculum* would therefore seem to be a good approach to determine the aerobic ability of a swimmer. The selection of the events to be included in critical velocity assessment must be a main concern in the evaluation of the swimmer.

Key words: Training, evaluation, aerobic ability, critical power.

INTRODUCTION

A number of field tests have been developed to help swimming coaches monitoring their training. For instance, Smith et al. (2002) reported that the first level of evaluation should be the competitive performance itself. The use of the individualized swimming distance versus time performance curve, based on a series of criterion effort has appeared attractive and appealing for physiological assessment in swimming (Wakayoshi et al., 1992). The critical swimming velocity concept (CV) could provide the basis to analyze the effects and trends brought about through training, predict future competitive performance and provide recommendations for continued directional training (Dekerle, 2006).

The critical velocity concept is an extension of the critical power concept originally introduced by Monod and Scherrer (1965). Attempting to understand the local work capacity of one muscle or one muscle group, Monod and Scherer (1965) highlighted the fact that local work and time to exhaustion were linearly related. Further, the slope of the relationship, called critical power, was defined as a threshold of local fatigue, while the y-intercept value corresponded to a reserve of energy. Critical power was mathematically defined as the power that can be maintained indefinitely. A distance time relationship equivalent to the work time equation of Monod and Scherer (1965) was proposed by Hughson et al. (1984). The slope of the relationship (CV) was interpreted as a maximal rate of energy turnover by aerobic metabolism and was defined as the velocity that can be maintained indefinitely without exhaustion (Dekerle et al., 2005; Fernandes and Vilas-Boas, 1999; Wakayoshi et al., 1992).

Since Wakayoshi et al. (1992) have recovered the critical power concept for swimming, creating the CV concept (aerobic ability indicator), several distances have been used by several authors for its determination (Dekerle et al., 2002; Fernandes and Vilas-Boas, 1999; Soares et al., 2004; Wakayoshi et al., 1993). At a lower level, the y-intercept value (anaerobic swimming capacity indicator) was being similarly recuperated, though its informative usefulness related to anaerobic potential is still in discussion (e.g. Soares et al., 2004; Vilar et al., 2004). Recently, some authors (Abe et al., 2006; Fernandes et al., 2008) have introduced the concept of anaerobic critical velocity, based upon sprint swimming distances and the respective time durations. Anaerobic critical velocity seems to represent the functional anaerobic capacity of swimmers. However, this new concept is outside the main aim of the present paper and will not be considered. Critical velocity only will be analyzed as an aerobic ability indicator.

Wakayoshi et al. (1993) and Dekerle et al. (2002) have used 200 and 400 m distances in the determination of CV and Fernandes and Vilas-Boas (1999) have concluded that the distances of 200 and 800 m seem to be the best in enabling CV estimation. However, the use of only two performances to assess critical velocity would be unreliable (Dekerle, 2006). This concern has to be considered when using the distance – time relationship to predict performance or monitoring the effects of training. To enable the use of different distances in the determination of CV and in the subsequent comparison of results from different studies we must be sure that the results are sufficiently similar not to negatively influence training planning and not to lead to misinterpretations of science. It can be noticed that the determination of CV has been shown to be reliable if exhaustion times are variable and physiological responses at CV have also been shown to be reproducible (Hinckson and Hopkins, 2005; Vandewalle et al., 1997). Nevertheless, Wright and Smith (1994) established that a long swimming distance, of approximately 15 min duration, should be included as one of the distances used to compute CV, in order to avoid overestimation of this parameter.

The use of only two distances in the assessment of the CV is due, naturally, to worries related to swimmer evaluation by coaches. From a theoretical point of view, the more distances that are included the better, because this minimizes possible errors, increasing the strength of the regression line equation. However, it is not always possible to carry-out an experimental protocol to determine the CV including various distance bouts. This situation would require expensive time, which could be a main concern for coaches. An alternative approach is to apply the best performance of a swimmer in several distances using the same technique to assess CV based on the swimmer *curriculum*. With this approach, critical velocity may be assessed without additional experimental tests. It only requires the use of the best performance of a swimmer in competition in several distances, i.e., the swimmer *curriculum*. Fernandes and Vilas-Boas (1999) have already used this approach to assess critical velocity. However, Fernandes and Vilas-Boas (1999) used the competition distance and the correspondent official time on the distances of 50, 100, 200, 400, 800 and/or 1500 m. In the present study we aimed to determine CV including all the swimmer events but also to use different combinations of distance – time plots. Moreover, in the study of Fernandes and Vilas-Boas (1999) only the most recent times were analyzed and the authors did not refer to the time gap between all the events. In the present paper we wanted to investigate if the personal best times, independently of the moment when they took place, produced the same results in young swimmers.

The critical velocity assessment that was developed is a non-invasive test to evaluate the aerobic ability (Toussaint et al., 1998; Toubekis et al., 2006). Several authors attempted to associate this intensity to maximal lactate steady state and to the velocity corresponding to 4 $mmol{\cdot}l^{-1}$ of blood lactate concentration (V4) (e.g. Dekerle et al., 2005; Toubekis et al., 2006). Another test widely used in swimming to assess aerobic capacity is the 30 minutes test (t30) (Colantonio and Kiss, 2007; Olbrecht et al., 1985). Both CV and t30 are non-invasive tests and seem to be valid and practical methods for the evaluation of the endurance capacity of young swimmers (Toubekis et al., 2006).

Taking into account the above considerations, we hypothesized that CV can be estimated based only on swimmer best performances (*curriculum*). Further, it is suggested that CV based on the *curriculum* can be a good and time-saving approach to help coaches monitor training, namely to an understanding of whether critical velocity is related to V4 and velocity of t30, since these two parameters are widely used in swimming training.

Therefore, the aims of the present study were: to assess CV in young swimmers using the swimmer *curriculum* in front crawl events and to compare this *curriculum*-based CV to the velocity corresponding to a 4 $mmol{\cdot}l^{-1}$ of blood lactate concentration (V4) and to the velocity of a 30 min test (Vt30).

METHODS

Subject

A sample of 24 male swimmers of high national level was used in this study. The mean (± standard deviation) of their age, height and body mass were 15.04 ± 0.20 years, 1.71 ± 0.07 m and 64.81 ± 8.34 kg, respectively. Their mean (± standard deviation) best times for 50, 100, 200, 400, 800 and 1500 m freestyle were respectively: 26.65 ± 0.52, 56.64 ± 1.36, 243.03 ± 3.08, 258.71 ± 5.84, 548.36 ± 18.80, 1047.97 ± 37.51 seconds. The participants were age-group swimmers and were selected to join technical and conditional evaluation.

Technical information

The participants' parents and coaches provided their written informed consent and the procedures were approved by the institutional review board.

For each subject the CV, the V4 and the Vt30 were determined. The CV was assessed considering the best performance recorded in several distances, based on the swimmer *curriculum*. The personal best in the 50, 100, 200, 400, 800 and 1500 m freestyle was registered for each swimmer. The mean (± standard deviation) time gap between the swimmers personal records (the difference between the oldest and the most recent personal best) was 5.0 ± 1.2 months. The CV was calculated using the slope of the distance-time relationship, plotting the swimming performances over time (Wakayoshi et al., 1992) (Figure 1). The standard error of CV (slope of the equation line) was calculated to determine the strength of the regression line equation.

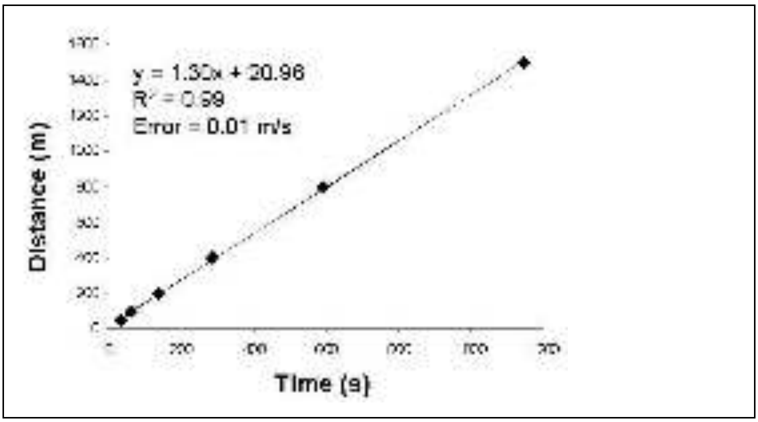

Figure 1*. An example of the assessment of CV50to1500 for one swimmer of the sample (CV50to1500 = 1.30 m/s). The regression equation, the R^2 value between the distance and the event time and the standard error of CV are also presented.*

We considered three critical velocities based on the swimmer *curriculum*: (i) the velocity corresponding to the regression of 50, 100 and 200 m (CV50/100/200), (ii) the velocity corresponding to the regression of 100, 200 and 400 m (CV100/200/400) and (iii) the velocity corresponding to the regression of 50, 100, 200, 400, 800 and 1500 m (CV50to1500).

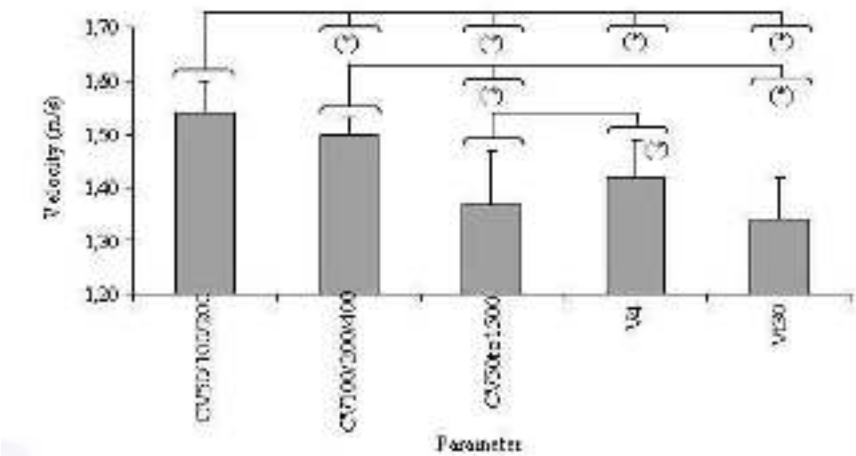

Figure 2. *Mean ± SD values for the velocities that were considered in the study and statistical differences between the values of each velocity. * $p \leq 0.05$.*

To determine the swim velocity at 4 mmol·l^{-1} of blood lactate concentration (V4), each subject performed 2x200 m front crawl, at 80% and at 100% of their maximum speed (according to their best time at 200 m front crawl), with 30 minutes of passive recovery between bouts (Mader et al., 1976; Michielon et al., 2006; Silva et al., 2007). One, three and five minutes after each bout, 32 micro-litres of capillary ear lobe blood samples were collected and analysed with an Accusport Lactate Analyser (Boehringer, Mannheim, Germany). The highest value of blood lactate concentration was used. Before each subject's test a calibration of the Accusport was performed with several YSI 1530 Standard Lactate Solutions (2.5, 5.0, 10.0 and 15.0 mmol·l^{-1}). V4 was determined by linear interpolation of the points relating blood lactate and swimming speed.

To determine the Vt30, each subject performed a 30 min all-out test in front crawl, trying to swim the greatest distance possible. The mean velocity during the 30 min test was considered to be the Vt30 (Colantonio and Kiss, 2007; Olbrecht et al., 1985). This test was carried out individually, i.e., each swimmer performed alone in a single lane.

Statistics

The normality and homocedasticity assumptions were checked respectively with the Shapiro-Wilk and the Levene Tests. A repeated-measures analysis of variance with Bonferroni adjustment was used to analyze the differences between the mean values of each velocity (CV50/100/200, CV100/200/400, CV50to1500, V4 and Vt30). The Spearman correlation coefficient was used to evaluate the associations between each velocity that was considered. The statistical significance was set to $p \leq 0.05$ for all analysis. Data are presented as mean and standard deviations (*SD*).

RESULTS

In Figure 2 the mean values of the CV50/100/200, CV100/200/400, CV50to1500, V4 and Vt30 are presented. One can note that the highest velocity was obtained using the CV with 50, 100 and 200 m personal best times. On the other hand, the velocity obtained during the 30 min all-out swimming presented the lowest value. When we compare the values for each velocity, it is possible to observe that only the CV including 100, 200 and 400 m was not different from the V4, and the CV including all the swimmer freestyle events was not different from the Vt30.

Mean (± standard deviation) error of CV50/100/200, CV100/200/400 and CV50to1500 were 0.04 ± 0.001, 0.03 ± 0.003 and 0.01 ± 0.001 m·s^{-1}, respectively.

In Table 1 the correlations between each velocity are presented. We can observe that there was no relationship between CV50/100/200, CV100/200/400 and CV50to1500. Moreover, CV100/200/400 was not related to V4 and Vt30. On the other hand, both CV50/100/200 and CV50to1500 were positively related to V4.

***Table 1**. Correlations between each of the velocity that were considered.*

	CV50/100/200	CV100/200/400	CV50 to 1500	V4	Vt30
CV50/100/200	----	.43	-.17	.73 *	.47
CV100/200/400		----	.61	.39	.07
CV50to1500			----	.72 *	.44
V4				----	.69 *
Vt30					----

* $p \leq 0.05$.

DISCUSSION

The aims of the present study were to assess critical velocity using the swimmer *curriculum* in front crawl events and to compare critical velocity to the velocity corresponding to a 4 mmol·l^{-1} of blood lactate concentration and to the velocity of a 30 min test in young swimmers.

The main finding of this work was that the CV using 100, 200 and 400 m was not different from V4 and that the CV including all the swimmer freestyle events was not different from Vt30. Moreover, CV50/100/200 and CV50to1500 presented a positive relationship with V4.

The critical velocity was at first thought to correspond to a sustainable intensity and has been compared to parameters such as the maximal lactate steady state (the highest intensity that can be maintained without any drift in the blood lactate concentration) and the onset of blood lactate accumulation (intensity corresponding to a 4 mmol·l^{-1} of blood lactate concentration during an incremental test) (Dekerle et al., 2006). However, swimmers can hardly maintain CV for longer than 30-40 min (Dekerle et al., 2006) and CV has been shown to be close to Vt30 (Colantonio and Kiss, 2007; Dekerle et al., 2002; Fernandes and Vilas-Boas, 1999) and higher than maximal lactate steady state and V4 (Dekerle et al., 2005; Denadai et al., 2000; Martin and Whyte, 2001; Rodriguez et al., 2003; Wakayoshi et al., 1992; 1993). All these data must be interpreted with care, since it does not seem possible that swimmers could sustain this intensity indefinitely. However, the studies cited above which argue that CV does not represent a steady state threshold were based on wrong assumptions, omitting the premise of always including a long distance in the CV assessment (Fernandes and Vilas-Boas, 1999; Wright and Smith, 1994). In fact, Fernandes and Vilas-Boas (1999) and Toubekis et al. (2006) reported CV values lower than V4 and Greco et al. (2007) reported that CV was significantly higher than Vt30 in males and females.

The present study showed CV values based on 50, 100 and 200 m higher than V4 and Vt30 and CV values based on 100, 200 and 400 m higher than Vt30 and similar to V4. Moreover, CV based on all the events presented similar values of Vt30 and lower values than V4. Thus, it seems important to note that the value of CV is dependent on the exhaustion times used to plot the relationship (Dekerle et al., 2006; di Prampero et al., 1999; Fernandes et al., 2008; Toubekis et al., 2006), considering the influence of energy cost in swimming. This phenomenon is noted in our study as well. It seems logical that critical velocity would decrease when including more long-distance events. When including the 1500 m the CV would decrease since the aerobic component is very high while at the 50 m this component is very low (Gastin, 2001). Further, Wright and Smith (1994) established the fact that a long swimming distance, of approximately 15 min duration, should be included as one of the distances used to compute CV, in order to avoid overestimation of this parameter. Therefore, the suggestion of Wakayoshi et al. (1993) and Dekerle et al. (2002) to use the distances of 200 and 400 m to assess CV should be treated with caution.

Additionally, according to the specialized literature (Jacobs, 1986; Stegmann et al., 1981; Urhausen et al., 1993), the V4 does not represent the individualized lactate threshold in trained swimmers, since those values are usually lower than 3 $mmol \cdot l^{-1}$. However, the velocity corresponding to 3.5 $mmol \cdot l^{-1}$ of blood lactate concentration could better be used in trained swimmers (Heck et al., 1985). Thus, the problem did not seem to be the low values of Vt30 (well related with the CV obtained with all competition distances) but the fact that both V4 and critical velocity assessments not including a long distance could overestimate the anaerobic threshold.

In an attempt to make the determination of CV quick and easy for coaches, the suggestion to base this assessment on only two performances seems pertinent (Wakayoshi et al., 1993; Fernandes and Vilas-Boas, 1999; Dekerle et al., 2002). However, including only two performances to determine CV would decrease its level of reliability, although the use of a long distance would help in correcting for this (Fernandes and Vilas-Boas, 1999; Wright and Smith, 1994). We were able to note that including more distance-time events would decrease the estimation error of critical velocity. Indeed, it was found an error of only 0.73% in the CV50to1500 whereas CV50/100/200 and CV100/200/400 presented an error of 2.60% and 2.00%, respectively. This situation has to be considered when using the distance-time relationship to predict the performance or monitoring effects of periods of training. This point of view reinforces the main concern of the present study. An alternative approach to the assessment of CV based on experimental tests is to use the swimmer *curriculum* to determine CV. Using this methodology one can assess CV based on all the performances that are available for a given swimmer.

It seems that CV50to1500 is a good approach to determine Vt30, which has been shown to be close to CV obtained using experimental tests during training sessions (Dekerle et al., 2002). This tendency was already confirmed using competition times by Fernandes and Vilas-Boas (1999). CV50/100/200 and CV100/200/400 presented significantly higher values than CV50to1500. Therefore, these values must be used carefully when designing training sets (Wright and Smith (1994). Although CV100/200/400 was not different from V4, CV100/200/400 was not related to this velocity.

Furthermore, we observed that there was no relationship between CV50/100/200, CV100/200/400 and CV50to1500. Once again one must take into account that the inclusion of different distance-time events could produce very diverse CV results. The CV was found to vary according to different distances. For instance, the change of 50 to 400 m (CV50/100/200 *vs.* CV100/200/400) was sufficient to produce different values of critical velocity.

The CV has been shown in swimming to be a good indicator of the capacity of the aerobic energy system (Toussaint et al., 1998). Greco and Denadai (2005) and Toubekis et al. (2005) confirmed this finding in young swimmers. CV is lower than the end velocity of an incremental test, traditionally associated to maximal aerobic velocity and it is highly related to V4 (Wakayoshi et al., 1992; 1993) and maximal lactate steady state (Dekerle et al., 2005). Altimari et al. (2007) suggested that anaerobic threshold velocity obtained from fixed lactate blood concentration of

3.5 mmol·l^{-1}, as well as the critical velocity obtained through larger distances seems to be the most reliable indices of prediction of the aerobic performance in the adolescent swimmers. In the present study we found that CV50/100/200 was related to V4, presenting a positive relationship between each parameter ($r = 0.73$). The same relationship occurred between CV50to1500 and V4 ($r = 0.72$), indicating that the swimmers with higher CV50to1500 presented higher V4 values. This assumption could be important in designing training sets in swimming teams, where the individuals are usually divided into training groups of similar level.

However, should personal best times be used to design training sets, some concerns must be emphasized. The first is related to the selection of the events to be analyzed and the second is related to the chosen technique. Freestyle may comprise events from 50 to 1500 m but the other strokes are limited to 50, 100 and 200 m. events. It would be interesting therefore to conduct this study assessing CV in relation to different stroke techniques, rather than only in front crawl. The third concern is related to the data available for each swimmer because sometimes swimmers do not compete in all the events. On the other hand, some of the performances must be updated, which should be considered during the assessment of CV. In the present study the mean time gap between events personal records was 5.0 ± 1.2 months. In further investigations, it would be interesting to relate this time gap and critical velocity. However, in this study we analyzed only young swimmers and usually their personal best times correspond to the most recent official times. Thus, future analysis should extend the scope of this study to adult swimmers to test for significant similarities or differences. Moreover, it seems pertinent to compare CV for given distances obtained in competition and training contexts.

CONCLUSION

We have found that the assessment of CV based upon the swimmer *curriculum* seems to be a good approach to determine aerobic ability in young swimmers. Using personal best times was shown to be an alternative method to circumvent the difficulties of conducting experimental tests during training sessions. It also permitted the obtaining of accurate values with which to design training intensity sets. The assessment of CV based on the entire swimmer events presented the best way to predict the velocity of a 30 min all out swim, while the CV based on the 100, 200 and 400 m events was shown to be similar to the V4. Therefore, the decision over the selection of events to be included in the estimation of critical velocity must be a main concern in the evaluation of the swimmer.

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