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Caros leitores

As neurociências sempre constituíram um desafio na minha vida profissional. Estando ligado ao ensino das profissões do desporto com especial incidência na área psicológica, tive oportunidade de privar com os autores sobre vários temas e tarefas que fazem parte deste mundo fascinante que é o desporto. O conhecimento no desporto está cada vez mais centrado na otimização do rendimento. Não falamos apenas de rendimento virado para a competição desportiva, mas também do rendimento inerente à melhoria da qualidade de vida do ser humano.

O estudo das Adaptações Neuromusculares no Desporto é um dos temas desenvolvidos pelos autores e que se enquadra no estudo do organismo humano, com base nos conhecimentos neurofisiológicos. Salientamos a análise do funcionamento das sequências motoras complexas e o seu reflexo na aprendizagem das mesmas. Os trabalhos apresentados demonstram a grande adaptabilidade deste sistema e a sua elevada relação com o treino desportivo.

Em simultâneo, os autores procuram proporcionar ao seu leitor, ferramentas de estudo no âmbito da observação e análise da técnica desportiva que que permitem responder aos desafios evolutivos de conhecimento que devem caraterizar os estudantes do ensino superior.

Professor Doutor Carlos Silva

Capitulo I

Effect of glide on neuromuscular adaptation in breaststroke swimming: a case study of an elite swimmer

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Effect of glide on neuromuscular adaptation in breaststroke swimming: a case study of an elite swimmer

ABSTRACT:

The aim of this case study was to examine the upper and lower limbs muscular responses of one elite, breaststroke swimmer at three different glide and speed conditions, to understand how strength and condition could be optimized during training.

Surface electromyograms (SEMG) were collected in biceps brachii (BB), biceps femoris (BF), deltoid anterior (DA), gastrocnemius medialis (GM), pectoralis major (PM) rectus femoris (RF), tibialis anterior (TA), and tríceps brachii (TB) during 18 x 25 m breaststroke trials performed at three different glide (normal, maximal, minimal) and speed (70, 80 and 90% of maximal speed) conditions. Each trial required an individually imposed swimming speed corresponding to 70, 80 and 90% of the swimmer maximal speed and a specific glide condition: minimal glide, normal glide and maximal glide. In maximal glide, higher participation of TB and DA and TA, RF, and GM muscles. In normal glide, a significant higher participation of all the muscles occurred, except for GM. In minimal glide, a significant higher participation of all the muscles occurred, except for the PM. We have also found that swimming at 90% of maximal speed led to significant higher use of the BB and PM muscles, for the upper limbs and BF and TA muscles for the lower limbs. In conclusion, the swimmer recruited different muscles as increasing his swimming speed and when gliding differently than normally. It suggested that strength and condition should be trained for various swimming speeds associated to various conditions of glide to ensure behavioral adaptability in competition.

Keywords: Swimming; Breaststroke; Glide effect; EMG

INTRODUCTION

The breaststroke technique is one of the least economic of the four swimming techniques[1] and its relationship with the physical performance of the swimmers seems obvious as in no other swimming technique, effort is devoted not only to the production of propulsion, but also in overcoming the active drag during the recovery phases of upper and lower limbs [2]. Indeed, Gatta et al. [3] suggested that the average frontal area and the estimated active drag values are largest in breaststroke compared to the other techniques. This economy issue can lead to early fatigue in breaststroke swimming.

After limbs recovery, the glide and relaxation time occur within each cycle, however long glide duration may be inefficient due to the increase of the intra-cyclic speed variations [4]. These intra-cyclic speed variations decreased in sprint as the propulsive and recovery phases occur almost continuously (i.e. without gliding) or with an overlap [4].
However, breaststroke swimming remained the technique with the highest active drag due to a less economicunderwater recovery of arms and legs [5, 6]. Higher resistive recovery forces during recovery in conjunction with cyclical changes of trunk angle attack on incoming mass of water increase neuromuscular fatigue [7].
Some studies also suggested that style differences (e.g., flat, undulating) are more important in breaststroke than in other strokes by observing larger average of the coefficient of variation in frontal area, trunk inclination and dorsal camber in breaststroke [3,8,9].
Swimming at different speeds led in changes of trunk inclination and dorsal camber, arm-leg coordination [5,10] and muscular responses [11,12]. Seifert et al. [9] observed that for different imposed swim speeds, swimmers adapted the glide duration, in accordance with Chollet et al. [5] who differentiated between 'glide', 'continuous' and 'superposition' breaststroke techniques. However, when specific glide conditions are imposed (e.g., maximal or minimal glide), swimmers changed glide duration as well as arm propulsion, leg propulsion and arm to leg coordination during propulsive phase, showing that a complete reorganization of the technique occurred. Martens & Daly [13] suggested that during the propulsive phases of the arms, the swimmer changes body position from an optimal streamline during the glide to the least streamlined position during breathing. The glide refers to phases in swimming techniques during which the swimmer attempts to "maintain speed" without actions to propel the body in order to minimize resistive forces [14]. According to Newton's second law of motion, there is an inevitable deceleration during a glide that depends on the resistive forces applied to his body, almost exclusively to its immersed part. The glide phases could be improved (trying to maintain speed) by minimizing the resistive forces and could also be optimized by adapting the relative duration to the entire stroke cycle.
The change in glide duration is correlated to stroking parameters (stroke rate and stroke length) [5]. However, Invernizzi et al. [15] stated that, in breaststroke, the same distance can

be covered at similar speeds with different stroke rate (SR) and thus, that breaststrokers can use different styles to achieve their goals. These authors analyzed the effect of SR style (low or high-SR) on upper and lower limbs strength in national-level swimmers and showed that low-SR had significant lower chin-up results and up and down trunk movement than swimmers with high-SR. In sum, changes in glide are linked to swimming speed, stroke rate strategy and have an impact on kinematics (arm and leg stroke phase duration, arm to leg coordination, intra-cyclic speed variations); however, less information are available regarding the influence of glide on muscular activity.

At high skill level, some important upper limbs muscles are recruited in breaststroke swimming, namely: the biceps brachii (BB), triceps brachii (TB), latissimus dorsi (LD) [12,16], deltoid anterior (DA)[16] , LD and pectoralis major (PM)[11] for the arm pull-phase, deltoid posterior[12] for the shoulder elevation during the arm pull, LD and PM[11] for the pull-through phases, and supraspinatus, infraspinatus, middle deltoid, and serratus anterior[11] during the recovery phase. With regard to the lower limbs the rectus femoris (RF), biceps femoris (BF), gastrocnemius medialis (GM) and tibialis anterior (TA)
were the most recruited regarding the breaststroke kick[17]. Concerning the lower limbs, Yoshizawa et al. [12] reported that RF, TA, vastus medialis (VM), and BF had a role in the pelvis stabilization during the kick, that VM and RF stabilize the knee joint and that BF is involved in the recovery phase of the kick. In another point of view, Guignard et al.[18] described that the RF muscle was responsible for the hip flexion, the GM for the knee joint and TA for the ankle joint. Although these previous studies provided useful knowledge concerning the muscular activity in breaststroke, this body of literature remained insufficient to understand the effect of glide on the muscular organization of limbs in order to support the work of researchers, coaches and swimmers. Therefore, the aims of this study was to examine the upper and lower limbs muscular responses of one elite breaststroke swimmer at three different glide and speed conditions, to understand how strength and condition could be optimized during training.

Through a case study, we sought to highlight how the swimmer adapts his muscular participation when he is instructed to swim at different glide and speed conditions, because it might reflect his behavioral ability to face to various constraints during competition.

We hypothesized that (i) the swimmer muscular participation is destabilized and requested adaptations when gliding differently than normally, (ii) the higher swimming speed leads to a minimal glide condition and higher muscular participation.

METHODS

2.1 Study design and subjects

This was a case of study performed on elite level male breaststroke swimmer (23 y; 180.5 m of body height; 80 kg; personal best time long course 100m breaststroke: 1:03.06) volunteered for this study. The subject was informed about the procedure and signed a consent approved by the local ethics committee. The experiment was performed in a 25-m indoor swimming pool at a water temperature of 28.5°C and 85% of humidity. After a standard warm-up of 800-m front crawl, and a specific warm-up of 200-m breaststroke at a medium level of effort, the swimmer performed 18 x 25-m breaststroke trials at different speeds and glide conditions with five minutes rest between trials. Each trial required an individually imposed swim speed corresponding to 70, 80 and 90% of his own maximal speed assessed during a previous all-out 25-m trial. The swimmer was also required to swim a specific glide condition: minimal glide, normal glide (i.e., preferential glide) and maximal glide.

The stroke rate was controlled for each trial. No underwater propulsion was permitted after the push-off that began each trial.

2.2 Data Collection

The Stroke Rate (SR/stroke.min^{-1}) was controlled for each trial (Seiko S141 stopwatch.).

SR is expressed in number of complete cycles per minute (stroke.min^{-1}). The three cycles that the experimenter timed were from 10 m after the push-off. SR was also *posteriori* assessed by the use of video recordings of the trials. Kinovea software (v.0.8.23) was used and the time to perform each cycle was computed. Mean and standard deviation of SR of all the cycles (except the two first and the two lasts) were assessed.

Surface EMG signals from the bíceps brachii (BB), biceps femoris (BF), deltoid anterior (DA), gastrocnemius medialis (GM), pectoralis major (PM), rectus femoris (RF), tibialis anterior (TA), and tríceps brachii (TB) were recorded at 1000 Hz, according to

International Society of Electrophysiology and Kinesiology placement recommendations. These muscles were selected according with their importance in breaststroke [11, 12, 16, 18].

Bipolar electrodes were used (10 mm diameter discs and diameter of 57 mm with snap connector of 3.9 mm diameter, Plux, Lisbon, Portugal) with an inter-electrode distance of 20 mm were waterproofed. Additionally, to immobilize the cables, the swimmer wore a full-body swimming suit (Fastskin Speedo®, USA).

All EMG was conducted with MATLAB (Mathworks Inc., Natick, USA) for determining the muscle activity by the neighborhood points, where the energy was 30% of muscle activation maximum peak within a stroke. These were calculated by segmenting the muscle input signal energy[19].

A Butterworth filter was used, but as muscle energy is very noisy and presents several peaks, activity boundaires were established an selected by finding the neighborhood point where the energy is 30% of the determined maximum peaks. For each muscle, it was defined its active phase as the part of the EMG signal for which the energy was at least 30% of the local maximum energy value, for particular muscle activation. The raw EMG segments belonging to the active phases were extracted and used in calculation of the active phase duration. The non-active phase was defined as the time interval between the two consecutives active phases.

The temporal evolution of the active and inactive phases average durations during stroke were calculated for each muscle for all swimming time. Linear regression curve were fitted to the data and the durations of the fitted curves at the time of the beginning and end of swimming bout were compared.

For matched-paired data (pre and post measurements), based on differences, in a non-normal difference's distribution, procedure of Wilcoxon Signed-Rank, Kruskall-Wallis H and t-Student paired test were applied. The assumptions were checked for each case. Statistical significance level was set at $P \leq 0.05$.

RESULTS

The SR increases from 70% to 90% of maximal velocity, and there were differences in SR between the three specific glide and speeds (Figure 1).

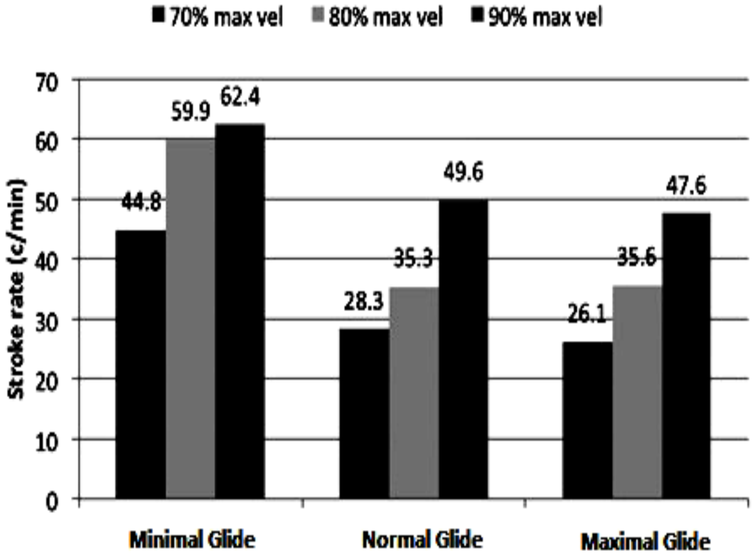

Figure. 1. Mean of the stroke rate (SR, stroke min^{-1}) for the three specific glide conditions (no-glide, normal glide and extra-glide) and the imposed swim speeds (70, 80 and 90% of maximal speed).

For active phase, at 70% the TB muscle presented higher in the end (0.99 s), followed by the TA (0.98 s). At 80% the TB presented higher in the end (1.43 s), and the TB (1.15 s). For inactive phase, at 70% and 90% the RF and TA presented differences between beginning and end ($p = 0.008$; $p = 0.026$ and $p = 0.015$; $p = 0.026$). For PM, DA and BF at 90% the behavior of the swimmer was different ($p = 0.026$; $p = 0.026$; $p = 0.023$).

The active and inactive phases showed differences at 90% for BB ($p = 0.036$), BF ($p = 0.017$), PM ($p = 0.05$) and TA ($p = 0.011$).

The duration of active phase (Table 1) was for TB higher in the end (3.37 s) with respect to the beginning at 90% in the minimal glide. The longest duration of active phase was in TB in the end of the swimming for the 90% and minimal glide (3.37 s) and the shortest for the BB in beginning for the 70% and maximal glide (0.12 s).

Table 1. Mean active phase value for Beg (beginning) and End four all eight muscles (BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii), for the three specific glide conditions (maximal glide, normal glide and minimal glide) and the imposed swim speeds (70, 80 and 90% of maximal speed).

	Active phase (s)															
	BB		BF		DA		GM		PM		RF		TA		TB	
	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End
Maximal Glide																
70%	0.12	0.65	0.37	0.38	0.97	1.05	0.31	0.79	0.26	0.35	0.9	0.66	0.83	1.1	0.43	1.04
80%	0.57	0.56	0.75	0.61	0.54	0.56	0.43	0.99	0.64	0.64	0.68	0.72	0.69	0.81	0.94	1.42
90%	0.63	0.54	0.64	0.62	1.01	0.75	1.24	1.06	0.65	0.67	0.68	0.67	0.71	0.7	0.98	1.31
Normal Glide																
70%	0.61	0.96	0.41	0.34	0.63	0.61	0.79	0.48	0.27	0.28	0.83	0.22	0.97	0.98	0.24	1.47
80%	0.62	0.58	0.53	0.58	0.35	0.56	0.44	0.47	0.68	0.64	0.73	0.85	0.47	0.41	0.75	1.47
90%	0.55	0.59	0.62	0.72	0.76	0.62	0.28	0.42	0.61	0.67	0.76	0.62	0.66	0.84	1.58	0.72
Minimal Glide																
70%	0.74	0.74	0.75	0.74	0.51	0.41	0.38	0.44	0.55	0.58	0.75	0.79	0.74	0.87	0.38	0.46
80%	0.63	0.59	0.64	0.57	0.58	0.54	0.57	1.99	0.57	0.58	0.68	0.73	0.74	0.66	0.83	1.41
90% *	0.56	0.57	0.53	0.53	0.38	0.69	0.34	0.89	0.52	0.55	0.56	0.57	0.59	0.64	2.10	3.37

Notes: With *, statistically significant at 5 % (-2.371; 0.018); BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii.

The glide effect showed at 90% of maximal velocity differences between different glides (p = 0.018). Those were noticed between normal and minimal glide, with a mean difference of -0.203 (p=0.030). For active and inactive phase the same glide condition presented differences on TA (p = 0.039).

For all muscles and in maximal glide, the inactive phase showed a decrease in the end at 70% and 80% and an increase in the end at 90% (Table 2).

Table 2. Mean inactive phase value for Beg (beginning) and End four all eight muscles (BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii), for the three specific glide conditions (maximal glide, normal glide and minimal glide) and the imposed swim speeds (70, 80 and 90% of maximal speed).

	Inactive phase (s)															
	BB		BF		DA		GM		PM		RF		TA		TB	
	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End	Beg	End
Maximal Glide																
70% *	0.55	0.26	1.87	1.86	1.12	0.64	1.28	0.84	1.28	0.55	0.74	0.94	1.43	1.03	0.44	0.38
80%	0.86	0.65	0.72	0.71	0.91	0.91	0.76	0.84	0.58	1.02	0.51	1.03	0.64	0.61	0.43	0.34
90%	0.61	0.62	0.56	0.67	0.44	0.69	0.29	0.63	0.86	0.41	0.56	0.61	0.53	0.57	0.41	0.27
Normal Glide																
70%	0.44	0.36	1.35	1.79	0.83	0.44	1.14	0.73	0.96	0.97	0.63	1.24	1.22	1.06	0.46	0.68
80%	1.06	1.02	1.18	0.93	1.11	0.88	1.35	0.94	1.31	1.01	0.78	0.88	0.98	1.38	0.76	0.81
90%	0.64	0.74	0.62	0.67	0.58	0.77	0.78	0.69	0.77	0.58	0.28	1.02	0.4	0.65	0.39	0.32
Minimal Glide																
70% **	0.97	0.95	0.95	0.85	0.84	0.95	0.98	1.29	0.9	1.38	0.66	1.62	0.88	0.79	1.07	1.16
80%	0.44	0.48	0.49	0.53	0.47	0.58	0.51	0.47	0.38	0.87	0.52	0.31	0.38	0.59	0.44	0.25
90%	0.35	0.45	0.44	0.73	0.46	0.41	0.56	0.42	0.84	0.46	0.41	0.53	0.25	0.48	0.22	0.29

Notes: With * and **, statistically significant at 5 % (3.800; 0.002 and -2.500; 0.025); BB- bíceps brachii; BF- biceps femoris; DA- deltoid anterior; GM- gastrocnemius medialis; PM- pectoralis major; RF- rectus femoris; TA- tibialis anterior; TB- tríceps brachii

Considering glide conditions and velocity's, at 70% the mean differences were reflected in BB, BF and TB, between maximal and minimal glide (BB: p=0.046; BF: p=0.031; TB: p=0.014), and normal and minimal glide (BB: p=0.045; TB: p=0.028). The BB, BF, DA and TB, showed statistical differences in normal and minimal glide (BB: p=0.017; BF: p=0.03; DA: p=0.046; TB: p=0.035). The BB presented variations at 90%, between normal and minimal glide (p = 0.035).

DISCUSSION

The aim of this study was to examine the upper and lower limbs muscular responses at three different glide and swimming speed conditions in breaststroke.

The main finding concerning the glide effect was that when swimmer swum with normal glide, higher participation of all the muscles, except GM, may be linked because the leg kick is the largest propulsive force and because the GM was responsible for the knee joint movement during the recovery phase of legs[18].

Conversely, the maximal glide were characterized by higher participation of TB and DA, that can be related to a higher streamline body position, supported by higher elbow extension [10] of TA, RF and, GM. Last, in minimal glide condition, all the muscles showed higher participation, except PM, this could be due to a compensatory strategy to maintain swimming speed in the end[16].

The main finding concerning the swimming speed effect, was that at 90% of the maximal speed, the swimmer mostly used the upper limbs (BB), called “arms propulsor” style, whereas 70% of the maximal speed he favored the lower limbs (RF) called “leg propulsors” style. We observed that at 90% of the maximal speed the muscular participation decrease, with the change from maximal to normal glide [5,10]. Indeed, at 70% of maximal speed, the swimmer recruited mostly the TB, DA, BB and TA, RF, and BF. At 80% of the maximal speed the TB, PM, and TA, RF, and GM were mostly recruited. Finally, at 90% of the maximal speed the DA, TB and TA, GM were mostly recruited, suggesting that, whenever the swimmer swims at 90%, he begun to use more the BB, PM and BF, TA.

Yoshizawa et al. [12] reported muscular differences in lower limbs (GM, TA, BF and RF), and in upper limbs (TB), and for deltoid muscles linked to different recovery. When the swimmer was instructed to use different glide conditions, we observed more behavioral adaptations at 70 and 90% of the maximal speed than at 80% of the maximal speed. At 70% of the maximal speed, the muscular participation showed differences in BB, BF and TB, between maximal and minimal glide, with an increase in BF, and decrease in BB and TB. This could mean that he did a muscular adaptation as he changed the glide condition at the lowest speed, performing a transition from “arm propulsors” (maximal glide) to “leg propulsor” (minimal glide). At 90% he showed an increase in BB, when he modifies glide between normal and minimal, supporting the importance of the “arm propulsors”, and a consequence of increase the speed and SR, the decrease of SL, and also changes in arm-leg coordination [20].

PRACTICAL APPLICATIONS

This study emphasized how this elite swimmer was able to switch between “arm propulsor” and “leg propulsor” in order to adjust is glide. The main practical application is to train strength and condition of the swimmers, in order to help the swimmer to adapt various durations of glide and respective neuromuscular recruitment and coordination. In other words, our study contributes to inform coaches and swimmers to get more efficient muscle recruitment, save energy, and develop the core body strength as a pre-condition for efficient transfer of propelling forces generated by limbs.

Instructing swimmers to use maximal and minimal glide appeared as a fruitful way to assess their behavioral adaptability, because these conditions caused whole behavioral reorganization that could be useful during competition.

CONCLUSIONS

Our findings suggested that the swimmer recruited different muscles when swimming speed was increased and regarding different glide conditions. Thus, swimmers should carefully choose how they glide so it does not alter their established muscular recruitment. The examination of the muscular adaptability by manipulating constraints such as glide duration is a promising way to understand (i) how swimmers may adapt their swimming skills in competition, and (ii) how to train their strength and condition.

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Neuromuscular and motor patterns in breastroke technique

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ABSTRACT

Objective: The aim of this study was to analyse the inter-temporal neuromuscular and motor patterns in breaststroke technique. Methods: Five national level male swimmers performed 200m breaststroke at maximal effort. Electromyography data on biceps brachii, deltoid anterior, pectoralis major and triceps brachii were analysed. 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 Theme software 5.0 was used to analyse the detected patterns in each swimmer. Results: The neuromuscular pattern revealed that by the average rectified value the biceps brachii and triceps brachii were increased at the end of the test for swimmers 1 and 5, while biceps brachii, deltoid anterior and pectoralis major were increased for swimmers 2 and 4. Different motor patterns between cycles, and between swimmers were observed. We found similarities between the swimmers, adjusting their style to the technical model. The absence of a neuromuscular pattern for all swimmers could be related to different technical models used by each swimmer, as presented in the motor patterns. Conclusions: These findings suggested that each swimmers adapted their own motor and neuromuscular pattern in a unique and distinct way.

Keywords: 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 is a very important element, and this information cannot be obtained through anatomical functional deductions was demonstrated by Duchenne in the mid of XIX century, through the stimulation of muscles and observation of partially paralysed subjects [2] . The neuromuscular activity is usually examined by electromyography (EMG), via direct recording of electric potentials of the muscles active, which for our study, are the movements in swimming [2] . EMG allows us to obtain an expression of the dynamic involvement of specific muscles involved in the propulsion of the body in relation to water. Therefore, neuromuscular activity of swimming must be assessed during experiments that reproduce the conditions of an actual race, and, due to the regulations of sports competitions, take into account the constraints that arise from the use of the required equipment [3].

Qualitative EMG relies on judgement 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 been focused in the relationship between neuromuscular activity and kinematics (e.g., stroke length, stroke rate, speed) and some physiological parameters (e.g., blood lactate, oxygen uptake), wherein most studied the front crawl [5, 6, 7] . 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 shoulder muscles, and demonstrated a consistent activation of the serratus anterior and teres minor muscles through the stroke cycle. Recently,

Conceição et al.[10] compared the average pattern of muscle activation with and without snorkel in breaststroke. In the 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 analyse 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 analyse the behaviour situation, involve the fulfilment of an ordered series of tasks to collect and process data [13] , and present great importance in various scientific procedures in the study of technical performances. In competitive swimming, there are some studies that use these procedures [11,13,14] .

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 behaviour of the observed subjects.

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

The aims of this study were to analyse the neuromuscular patterns in breaststroke, through the support of the description of the detection patterns, and introduct a method to examine the data and analyse the inter-temporal relationship between the structures of events.

METHODS

Participants

Five national male swimmers (age 23.8 ± 2.6 years; height 1.786 ± 0.6 meters; total body mass 73.04 ± 3.32 kg; mean ± standard deviation (SD)) volunteered to participate in this study and were provided with written informed consent. They were all national level swimmers with an average personal best result over 200 m breaststroke long course of 147.60 ± 0.04 s corresponding, respectively, to 630.75 ± 69.25 in FINA ranking points. The participants were informed about the procedure and signed a consent approved by the local ethics committee.

PROTOCOL

Measures were performed in a 50m indoor swimming pool at a temperature of 27.5 ºC and 75% humidity. Subjects performed a standard warm-up of 800m front crawl at a medium level of effort followed by 200 m breaststroke. After a twenty minutes of 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. Additionaly, each swimmer was instructed to swim in order to reduce the underwater glides after the turns.

EMG

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 previous studies and for their main function in swimming propulsion in breaststroke [8,9,10] . Bipolar surface electrodes were used (10 mm diameter discs, Plux, Lisbon, Portugal) with 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 with 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 (C7). Transparent 10.0 cm x 12.5 cm dressings (Hydrofilm®, USA) were used to cover the electrodes and isolate them from the water. All cables were fixed to the skin by adhesive tape in several places to minimise their movement and consequently their interference with the signal.

Additionally, to immobilise 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 of electrodes, cables and the transparent dressings. The wireless EMG device (BioPLUX.research, Lisbon, Portugal) had eight analogue channels (12 bit), sampling rate of 1kHz; weight of 86 g, and a compact dimensions of 0.84 cm x 0.53 cm x 0.18 cm. The device was fixed in a waterproof bag and placed inside the cap of the swimmer. Data were recorded using the Monitor Plux (Plux, Lisbon, Portugal) at a sample frequency of 1 kHz.

All EMG analyses were conducted using 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 boundaries consists of finding the neighbourhood 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 by Stirn et al. [7] . Starting from the raw signal, DC components were removed and filtered afterwards 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 this sliding window, muscle activity energy is very noisy and presents several local maximums peaks that do not correspond to the muscle active window centre, and therefore making automation hard. To overcome this difficulty, a strategy to determine the muscle “true” maximum energy peaks was devised.

Neuromuscular and motor patterns in breastroke technique

Each stroke taken by a swimmer produces patterns in the signal. These patterns consist mainly of periods of 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 mean stroke period. The muscle activity boundaries are then selected by finding the neighbourhood 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 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 was 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 trials were videotaped on sagittal plane with a pair of cameras providing a dual-media frames from both underwater (SONY D8, EUA, 50 Hz) and above (Sony Mini Dv DCR-HC42E, EUA, 50 Hz) the water surface, and with a periscopic Coach Scope (Delphis Swim products). The cameras were placed at 25 m of the headwall, in the lateral wall of the pool, perpendicular to the line of motion and 6 m away from the swimmer displacement trajectory. One of the cameras was at 30 cm below the water surface, and the other at 10 cm above. The images from both cameras were recorded simultaneously, and it was possible to follow the swimmers trajectory and visualise five swimming strokes for each lap.

T- PATTERNS ASSESSMENTS

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

The instrument, as evaluated by the temporal pattern analysis software (Theme 5.0), reproduced many different patterns, which take to a variety of conducts and a reconfiguration of the codification system. The adaptation of the Observing System Performance in Breaststroke Technique (OSPBT) was conducted based on five core criteria: first propulsive action of arms (FPAA), second propulsive action of arms (SPAA), first propulsive action of legs (FPAL), second propulsive action of legs (SPAL) and recovery (R) 26 . These criteria characterised the conduct deemed critical in the cycle of the breaststroke swim.

For this study, the instrument was set with 431 alphanumeric codes, with a total of 44 configurations of 20 long 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 characterisation delimiting the beginning and end of each stage. In each of these stages, a list of key points was defined, being critical to the implementation of the exploratory phase. According to Louro et al. [26] , an alphanumeric code was assigned to each of them.

For the detection of temporal patterns, we used the software Theme 5.0 since the algorithm of T-patterns was developed by Magnusson 14 . The software detect temporal patterns based on a binominal probability theory that allows the identification of sequential and temporal systems of data.

The analyses were performed using Microsoft Office Excel 2007, and the arithmetic means of the indices and standard deviations were calculated.

RESULTS

Swimmer 1 had a higher active phase in the TB muscle (0.33 ± 0.07 s) than the BB, PM and DA in the beginning (Figure 1). The BB (0.17 ± 0.01 s) and the DA (0.23 ± 0.09 s) muscles had a higher relative duration in the active phase in the end of the test compared to the beginning, unlike the PM (0.26 ± 0.05 s) and the TB (0.33 ± 0.07 s), which both had higher relative duration in the beginning that in the end. Comparing the two phases for the BB muscle, swimmer 1 had 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. In contrast, the TB achieved the opposite behaviour, i.e. higher relative duration of the active phase in the beginning and also a higher duration of the non-active phase in the end. The DA and PM presented similarities in their behaviour, where 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 (Figure 1). Only the BB (0.26 ± 0.02 s) had a higher duration in the active phase at the end of the test, unlike the DA (0.27 ± 0.03 s), PM (0.20 ± 0.02 s) and, TB (0.23 ± 0.05 s), which had higher values in beginning. Under synthesis, swimmer 2 obtained a similar behaviour for the DA and TB, in which both had a higher relative duration in both active and non-active phase in the beginning of the swimming bout. In contrast, the BB and PM muscles had opposing behaviours.

Swimmer 3 presented a higher period for the TB (0.26 ± 0.03 s) at the end of the test, than for the BB, DA and PM muscles, and unlike other swimmers, the relative duration of active phase was higher for all the muscles in the end compared to the beginning: BB (0.19 ± 0.03 s), DA (0.25 ± 0.03 s), and PM (0.18 ± 0.02 s) (Figure 1). The swimmer also presented a very similar behaviour for all the muscles in active and non-active phase, excepted for the TB, which presented a higher relative duration of the non-active phase in the end of the swimming bout.

Swimmer 4 demonstrated higher relative duration of the active phase in the TB (0.32 ± 0.04 s) at the end of the test, compared to the BB, PM and DA muscles (Figure 1). The swimmer showed higher values of activation at the end of the test for all muscles, except for the DA (0.27 ± 0.02 s), which showed higher values in the beginning.

Additionally, swimmer 4 demonstrated that in the active phase, all muscles had a higher duration at the end of the swimming bout, except for the DA, which was high in the beginning. As for the non-active phase, duration was higher for all muscles in the beginning except for the BB.

Lastly, in the beginning of the test for swimmer 5, the DA (0.33 ± 0.03 s) muscle had higher duration in the active phase, 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) at the end of the test.

This swimmer presented a distinct behaviour in the muscles studied. In the duration of the active phases, two muscles (DA and TB) had higher duration in the beginning, whereas for the other two muscles (BB and PM), it was higher in the end.

Analysing the relative duration of the active and non-active phase, we can observed that all swimmers had a different behaviour, although we can note some similarities between them. In regard to the duration of the active phase, the main behaviour was in the BB, where it presented always a higher duration at the end of the swimming bout for all swimmers. In comparison, the DA had very irregular behaviour, where it had a higher active phase in swimmers 2, 4 and 5 in the beginning but for swimmers 1 and 3, it was higher at in the end. Moreover, the PM had a higher duration in the active phase mostly at the end of the swimming bout (swimmers 3, 4 and 5). Finally, the TB had predominantly higher duration of the active phase in the beginning of the swimming bout for (swimmers 1, 2 and 5).

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

The average rectified value (ARV) for all muscles was compared for each swimmer (Figure 2). Our study showed that, TB and DA presented higher ARV in all swimmers. Moreover, the DA obtained higher ARV in the beginning and end of the swimming bout for all swimmers, except for Swimmers 2 and 4. In the BB, PM and TB, we can observed that, predominantly, they presented higher ARVs in the beginning: swimmers 1, 3 and 4, for BB, swimmers1, 2, 3 and5 for PM and swimmers 2, 3 and 4 for TB.

Figure 3 shows the motor pattern equivalent of five different events, corresponding to the five moments of observation made in each stroke, which was repeated in 10 cycles for each swimmer. Swimmers1 and 4 had technical model of swimming that is close to the variant “very wavy, arched” from Silva and Alves[20], and a motor pattern that is characterized by the following settings: FPAA:1p1,1p3,1p6,1p7,1t1,1t5,1t6,1c2,1c4,1b1 according to Louro et al.[26]. These settings characterized a swimmer that has his or her knees extended, ankles above the hip and extended, and legs inclined upward.

The head must be up relative to the trunk, and in elevate position inclining upward and parallel to the waterline. Further, the orientation of the vision must be diagonal/looking down, with the head below the water line (or intermediate) and hands above the shoulder level (horizontal relationship). InSPAA: 2p1,2p4,2p5,2p8,2t3,2t4,2t7,2c2,2c3,2b2,2b3

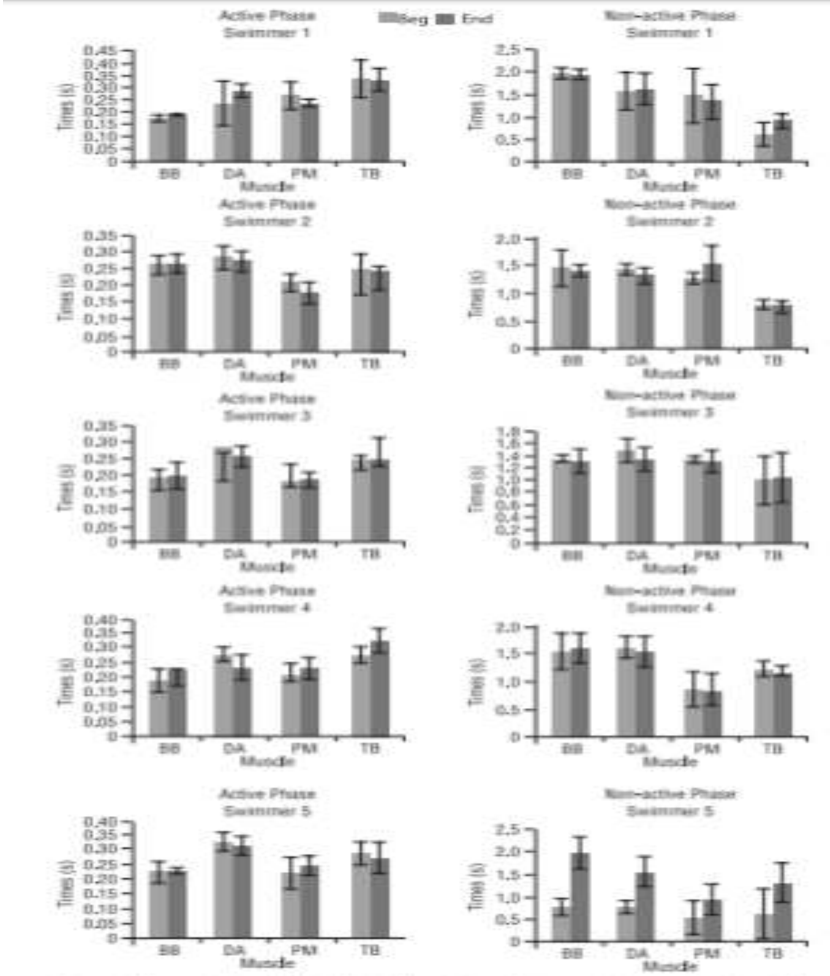

Figure 1. Mean and standard deviation of the duration of active and non-active phase in the beginning (dark grey) and end (grey) of the swimming bout for each swimmer, BB- biceps brachii; DA- deltoid anterior; PM- pectoralis major; TB- triceps brachii.

according to Louro et al. [26] these settings characterize a swimmer that has his or her knees in extension inclining down and oblique to the water, feet parallel and ankles below the hip (in prolonging). Further, the trunk arched inclining up ward and parallel to the waterline, with the gluteus below the water line, vision oriented diagonally down and head above the water line (or intermediate). Fingers are pointed at the bottom, and the hands are in front of the shoulders with no extension (vertical relationship). The moment of observation for FPAL is characterized by: 3p1,3p3,3p6,3t3,3t4,3c1,3b2, 3b4according to Louro et al. [26], which means the knees and feet's are apart and standing straight out (ratio: foot-leg). The head is up the water line (or intermediate), forearms inclined down and, hands below the water line/on the shoulders line and below (horizontal ratio: hand-shoulder). In SPAL, the settings are: 4p1,4p3,4p 6,4t2,4t5,4t6,4c1,4b2,4b4according to Louro et al. [26], which means the knees are apart with the ankles above the hip (ratio: ankle-hip) and a right angle between the foot and the leg. The gluteus is below the waterline (or intermediate), and the trunk arched inclining up ward and parallel to the waterline. Further, the head is up the waterline (or intermediate), forearms inclined down and elbow below the shoulders (in prolonging) (relationship elbow-shoulder). Lastly, R has the settings: 5p2, 5p3, 5p5, 5p8, 5t2, 5t4, 5t6, 5c2, 5b2according to Louro et al. [26], which means the ankles are below the hip in extension, toes directed downwards and backwards, the midpoint trunk-hip-knee-ankle in obtuse angle and legs inclined down. For swimmers 2 and 5, we can surmised that the technical model of swimming is close to the variant "very wavy, slightly arched" from Silva and Alves20, and a motor pattern 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:4p1,4 p4,4p6,4t2,4t5,4t6,4c1,4b2,4b4,R:5p2,5p3,5p5,5p8,5t2,5t4,5t5,5c2,5b2.

Swimmer 3 presented a technical model of swimming close to the variant "very wavy, slightly arched" from Silva and Alves20, and a motor pattern characterized by, FPAA:1p1,1p4,1p6,1p8,1t1,1t5,1t6,1c2,1c4,1b2,SPAA:p2,2p4,2p5,2p8,2t3,2t4,2t7,2c1,2c 3,2b1,2b3,FPAL:3p1,3p3,3p5,3t3,3t4,3c1,3b2,3b4,3b6,SPAL:4p1,4p4,4p6,4t2,4t5,4t6,4c 2,4b2,4b4, and R: 5p2,5p3,5p5,5p8,5t2,5t4,5t5,5c2,5b2. Consequently, in all the motor patterns complete by five swimmers, there are swimmers who have a greater stability in stroke cycle. This greater stability comes from the more number of occurrences of the same 5 cycle events in the 5 observation moments: FPAA, SPAA, FPAL, SPAL and R. Swimmer 1 had the more stable behavior during swimming 10 cycles recurred (in 5 equal events), followed by swimmers, 5, 3, 2 and 4, in that order, who repeat the same cycle in

7, 6, 3 and 3 cycles, respectively. The behavioural variability occurred with higher frequency in the moments of higher propulsive force production (e.g. SPAA).

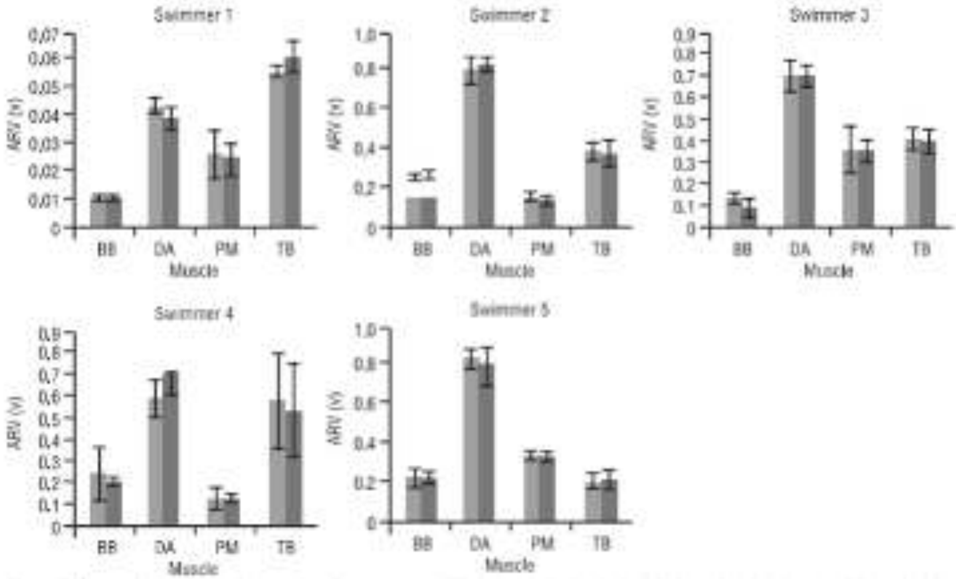

Figure 2. Comparison between the muscles of an average rectified value in the beginning (dark grey) and end (grey) of the swimming bout for each swimmer, BB- biceps brachii; DA- deltoid anterior; PM- pectoralis major; TB- triceps brachii.

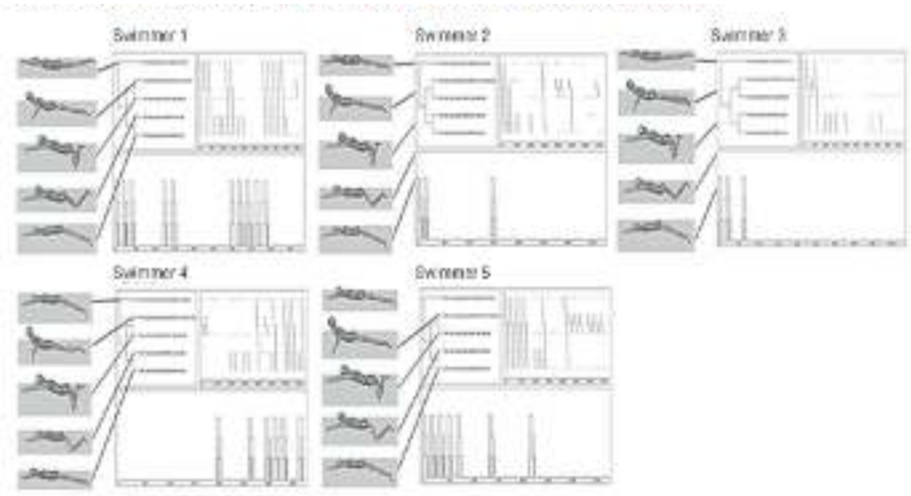

Figure 3. Schematic representation (for each swimmer, left image) and complete behavior pattern with five observation moments (for each swimmer, both images above) and with the spatio-temporal reference of occurrence of the strokes (for each swimmer, diagram in below part of the image), for all the swimmers.

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.

Our results showed that each swimmer had their own behavioral pattern, since each adjusted their own technical characteristics of swimming. The methodology used in this study increased the capacity to assess the neuromuscular and motor behavior of the swimmers and coaches. On the one hand, the wireless EMG device for the neuromuscular patterns assessment is a fairly useful new approach since it allows to reduce the constraints on the swimmer during the swimming bout. This technology has been suggested by some previous studies[21,22,24]. On the other hand, the construction of ad hoc instruments presented in this study to assess the motor patterns had advantages in their flexibility of use, the ability to adapt to very different behaviors and situations, and the precision on the application of the various procedural operations in non-restrictive and unobtrusive nature of their appraisal of real situations[23].

By analyzing the rectified EMG signal, it is possible to observe very clearly the differences between the activation and resting periods of the muscles. Following this, the relative duration of the active phase demonstrated a increasing trend in the TB muscle for all swimmers, except for swimmers 2 and 5, in whom the DA had a higher duration. This tendency of the TB was similar in the 100m front crawl test at maximal intensity, developed by Stirn et al.,[7] .In regard to the non- active phase, we can not state that there is a relative tendency in the beginning and end of the swimming bout, because each swimmers presented a different behavior for each muscles studied.

The neuromuscular pattern provided by the ARV demonstrated an increased at the end for BB and TB in swimmers1 and 5, and for BB, DA and PM in swimmers 2 and 4. These were in agreement with Conceição et al.10butin disagreement with the results achieved by Nuber et al.[8] where biceps firing was inconsistent. These outcomes in neuromuscular pattern were also in accordance with the study developed by Ikai et al.[25], where they showed qualitatively that the BB, TB and 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 from the beginning to the end of the swimming bout.

The motor pattern results were in line with other studies in which similar methodologies were used in simultaneous techniques[11,13,26]. Campaniço et al.[13] compared male and female swimmers in butterfly technique, in which they found no equal complex pattern among all swimmers, but in study each swimmers individually, they found a complex pattern, indicating that all swimmers are totally different and that each individuals has their own motor patterns. Additionally, Louro et al.[11] studied four male butterfly swimmers and, verified that each of the swimmers had their own behavioral pattern, and that each pattern was adjusted for individual characteristics. Moreover, the behavioral patterns were different at both intra and inter-individual levels because they are tailored to each specific needs of the different swimmers.

In fact, according to Silva and Alves[20], breaststroke techniques, by their very nature, feature parameters that are not readily addressed by traditional research. This statement gave rise to a new trend: the quantification of the work done during breaststroke rounds by means of video graphic analysis of temporal structure detected. Although, different patterns among cycles and swimmers were observed in our study, it seems there are some similarities between them, by adjusting the style to the technical model. In our results, relative to the technical model presented, swimmers 1 and 4 adopted the “very wavy, arched” variant, whereas swimmers 3 and 5 used the variant “very wavy, slightly arched”. Lastly, swimmer 2 chose the “wavy, slightly arched” variant, according to Colman et al.[27]. Regarding the standard model[11,26] as a reference, each swimmer adapted their swimming pattern in a unique and distinct way, leading to, behavioral changes with different complexities. This study is a novelty in the field of EMG and motor patterns in swimming. Because the amount of information to be removed through qualitative observations are massive and varied, we can verify the existence of different line of research using the same software and algorithm[14,19].By characterizing of the neuromuscular and motor patterns in individual point, we found a relationship between them, where each swimmer adopted a distinct motor and neuromuscular pattern. However, there were similarities that remained between some swimmers, i.e. swimmers 1 and 4 showed similar neuromuscular pattern in the DA and TB muscles and adopted the “very wavy, arched” variant, while swimmers 3 and 5 showed similar pattern in the DA muscle and adopted the variant “very wavy, slightly arched”.

The main practical applications of this study are for coaches to improve the training plan according to the technical model used by their swimmers, such as developing specific training exercises in water (e.g. scullings, water sensitivity) and dry land (e.g. strength training and neuromuscular coordination) to get more efficient muscle recruitment for each technical model. Thus, we can state that there is a need for developing more advanced measurement systems for the breaststroke technique which would allow us to have clearer insight into the structure of the technical performance.

In conclusion, each swimmer adapted both their motor and neuromuscular pattern in a unique and distinct way. The presented data highlight the potential of utilizing motor patterns and skills in the performance analysis of swimmers. Therefore, it would be useful to apply this methodology to other gender, and different age groups, and analyze the relationship between the muscular behavior of the lower and upper limbs in order to improve the technical quality of the swimmers.

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Capitulo III

Observation and Technical Characterization in Swimming: 200 m Breaststroke

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Observation and Technical Characterization in Swimming: 200 m Breaststroke

ABSTRACT

Introduction: Characterization of the breaststroke technique, regarding the relationship between kinematic and neuromuscular parameters. Method: Surface electromyographic signals (EMG) were

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

Keywords: swimming, kinematics, EMG, amplitude, frequen

Observation and Technical Characterization in Swimming: 200 m Breaststroke

INTRODUCTION

The breaststroke technique is considered one of the leas economical among the four swimming strokes1. 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 CD and low GF; 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].

Observation and Technical Characterization in Swimming: 200 m Breaststroke

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 brachii31, 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 Atkinson34 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 800m 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), gesture frequency (GF = cycle/min), cycle distance (CD, m) and mean of swimming velocity of the entire cycle (SV = m s-1).

Surface EMG signals were analyzed from four muscles: pecto- ralis 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 KOhm42.

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 swimsuit (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).
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

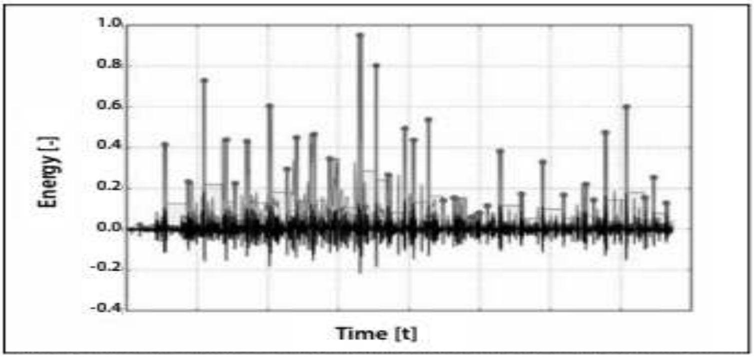

Figure 1. Maximum energy peaks of the EMG signals obtained in the biceps brachii muscle (BB).

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 method44. The periodogram for a continuous signal x(t) of T length was defined as:

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

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

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

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 GF nor SF. Concomitant to the decrease previously indicated of swimming velocity, the lactate concentrations increased from rest to the blood lactate peak after the 200 m breaststroke from 1.12 (0.22) to 12.00 (3.23) mmol.L-1.

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

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

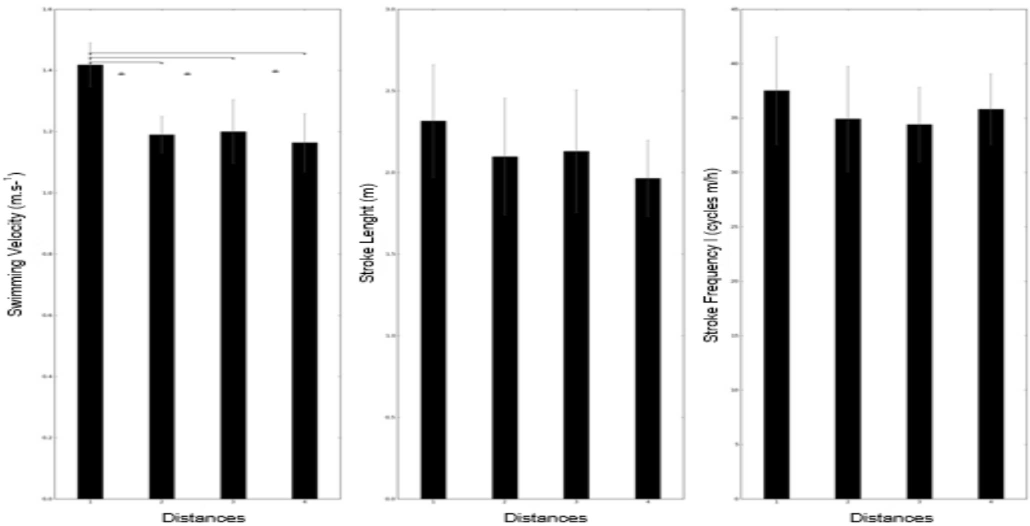

Figure 2. Mean (SD) of the swimming velocity (SV), cycle distance (SL), and gesture frequency (SF) for the four swimming distances of 50m of the 200m breaststroke *P<0,05.

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

	*Δ*VN	*Δ*DC	*Δ* FG	*Δ* La
***Δ* VN**	-			
***Δ*DC**	-0.19	-		
***Δ* FG**	0.71*	-0.78	-	
***Δ* La**	-0,61*	0.09*	-0.44	-

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). Concerning amplitude, light correlation was obtained for the BB and TB muscles: as the SV, GF and SL variables increase, the amplitude decreases, while for the AD and PA muscles, the contrary was observed: as the SV, GF 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

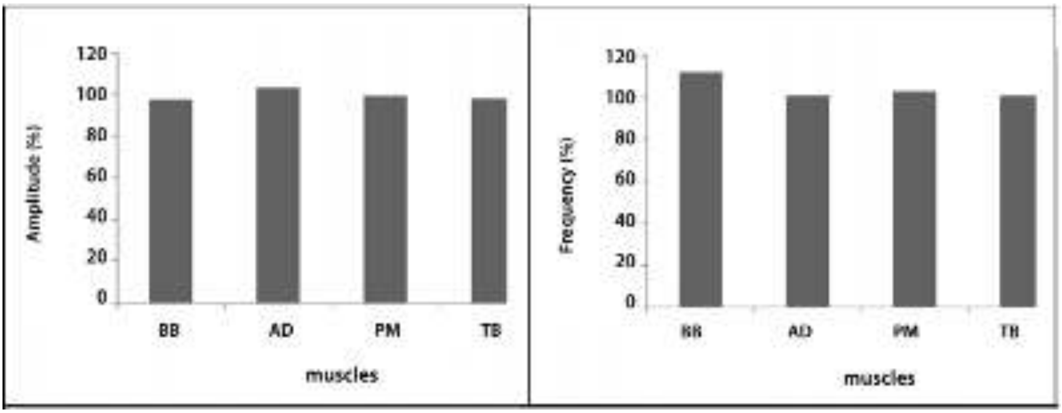

Figure 3. Mean (SD) of the amplitude and frequency between the first and fourth swimming distances for all the studied muscles during the 200m breaststroke (pectoralis major (PM), biceps brachii (BB), triceps brachii (TB) and anterior deltoids (AD).

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

	Frequency			Amplitude		
Muscles	**SV**	**CD**	**GP**	**SV**	**CD**	**GF**
BB	-0.77*	-0.71*	-0.88*	-0.32*	-0.22*	-0.49*
DA	-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.

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 styles9 , corroborating alteration in the technique during the 200 m3 .

The correlation between ΔSL and ΔSF reflect the capacity of the swimmers to keep the SV during the 200 m6, 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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Capitulo III

Observation and Technical Characterization in Swimming: 200 m Breaststroke

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