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Neuromuscular and motor patterns in breaststroke technique

Padrões motores e musculares na técnica de bruços

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Abstract – The aim of this study was to analyze the inter-temporal neuromuscular and motor patterns in breaststroke technique. Five national level male swimmers performed 200 m breaststroke at maximal effort. Electromyography data onbiceps brachii, deltoid anterior, pectoralis major and triceps brachiiwere 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 toanalyse the detected patterns in each swimmer. The neuromuscular pattern revealed that by the average rectified value the biceps brachiiand triceps brachiiwere increased at the end of the test for swimmers 1 and 5, while biceps brachii, deltoid anteriorand pectoralis majorwere 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. These findings suggested that each swimmers adapted their own motor and neuromuscular pattern in a unique and distinct way.

Key words: Biomechanics; EMG; Muscular activity; Swimming; T-patterns.

Resumo – *O objetivo deste estudo consistiu em analisar a relação entre os padrões neuromusculares e motores na técnica do nado de peito. Cinco nadadores masculinos de nível nacional realizaram 200 mnado peito na máxima intensidade.Foram registrados dados de Electromiografia do bicepsbrachii, deltoid anterior, pectoralis major etricepsbrachii. A duração relativa da fase ativa e não ativa e o valor médio retificado dos padrões neuromusculares foram analisados. Os percursos de nado foram gravados no plano sagital e analisados para detectar os padrões motores de cada nadador através do software THÉME software 5.0. Os padrões neuromusculares indicaram, por meio do valor médio retificado que a atividade dos músculos bíceps brachii e tríceps brachii aumentam no final do teste para o nadador 1 e 5, enquanto que o bíceps brachii, deltoid anteriore pectoralis major aumentam para o nadador 2 e 4. Diferentes padrões motores entre ciclos e entre nadadores foram observados, indicando que existem semelhanças entre eles, levando a um ajuste do estilo e modelo técnico de nado. A ausência de um padrão neuromuscular para todos os nadadores poderá estar relacionada com os diferentes modelos técnicos utilizados por cada nadador, como demonstrado nos padrões motores. Esses resultados sugerem que cada nadador adapta o seu padrão motor e muscular de uma forma única e distinta.*

Palavras-chave*: Atividade muscular; Biomecânica; EMG; Natação; Padrão-T.*

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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 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 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, Ruweet al.[9]described and compared the patterns of electrical activity of theshouldermuscles, 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 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 behaviour situation, involve the fulfillment 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 analyze the neuromuscular patterns in breaststroke, through the support of the description of the detection patterns, and introduce a method to examine the data and analyze the inter-temporal relationship between the structures of events.

METHOD

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 of147.60 ± 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. All ethical standards provided according to the Helsinki Declaration in respect to human research were considered.

Protocol

Measures were performed in a 50m indoor swimming pool at a temperature of 27.5 °C 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 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. Additionally, 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[8-10]. 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 inter electrode resistance did not exceed 5 kOhm[17]. The ground electrode was positioned over the cervical vertebrae(C7). Transparent 10.0cm 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 of1kHz; weight of 86 g, and 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 (Math works, Inc., Natick MA, USA). It was determinate the EMG boundary´s, the process of determining the muscle activity boundaries consists of 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 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.

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 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 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 at10cm above. The images from both cameras were recorded simultaneously, and it was possible to follow the swimmers trajectory and visualize five swimming strokes for each lap.

T- pattern 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 behavior 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 characterized 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 characterization 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 3presented 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 behavior 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.

Analyzing the relative duration of the active and non-active phase, we can observed that all swimmers had a different behavior, although we can note some similarities between them. In regard to the duration of the active phase, the main behavior 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 swimmers2, 4 and 5 in the beginning but for swimmers1 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 (swimmers3, 4 and 5). Finally, the TB had predominantly higher duration of the active phase in the beginning of the swimming bout for (swimmers1, 2 and5).

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 swimmers2 and 4. In the BB, PM and TB, we can observed that, predominantly, they presented higher ARVs in the beginning: swimmers 1, 3 and4, for BB, swimmers1, 2, 3 and5 for PM and swimmers 2, 3 and4 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

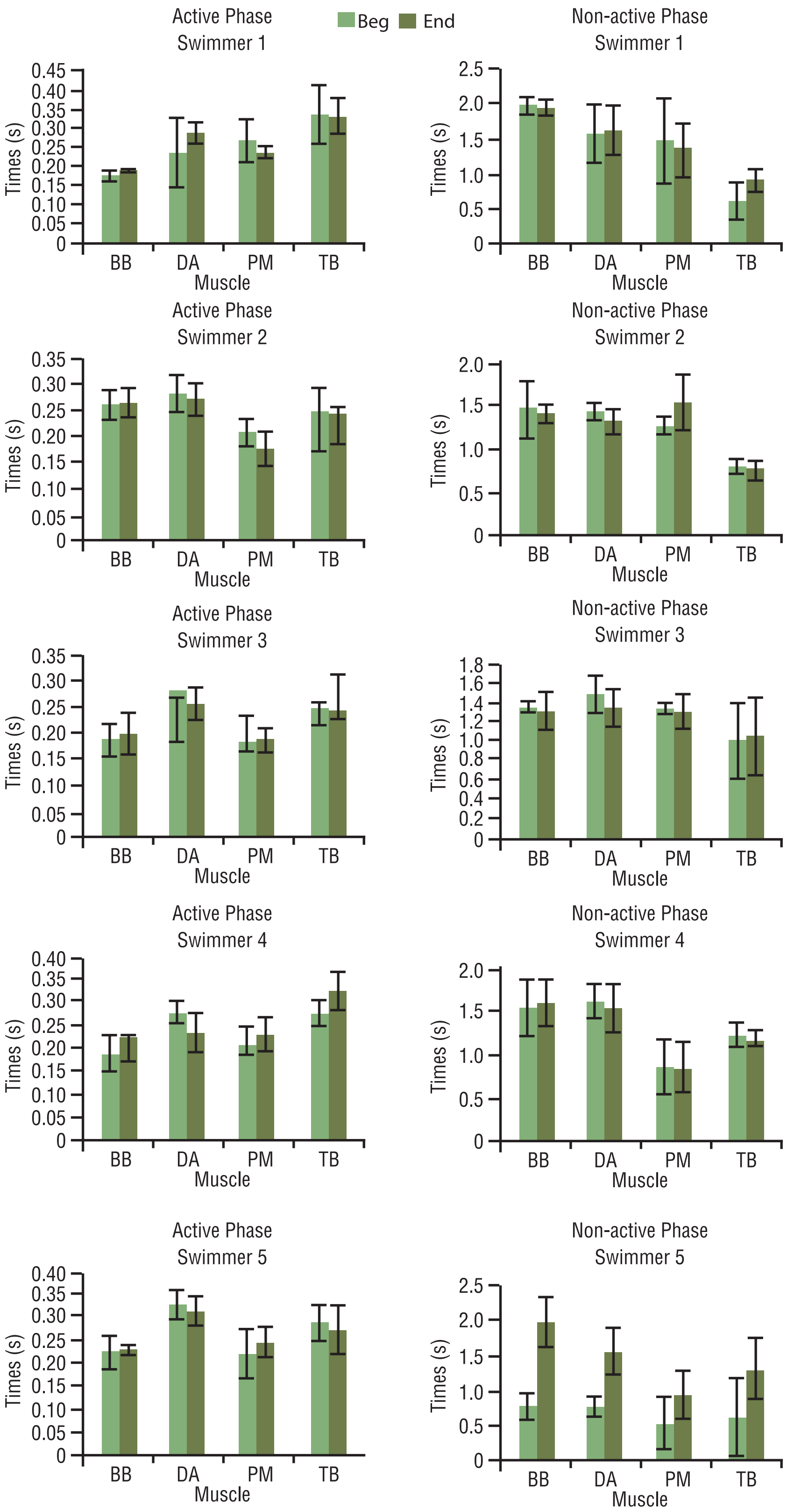

Figure 1. Mean and standard deviation of the duration of active and non-active phase in the beginning (dark grey) and end (grey) of the swimming bout for each swimmer, BB- biceps brachii; DA- deltoid anterior; PM- pectoralis major; TB- triceps brachii

relationship). InSPAA: 2p1,2p4,2p5,2p8,2t3,2t4,2t7,2c2,2c3,2b2,2b3 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 swimmers2 and 5, we can surmised that the technical model of swimming is close to the variant "very wavy, slightly arched" from Silva and Alves[20], and a motor pattern characterized by,FPAA:1p1,1p4,1p6,1p 8,1t1,1t5,1t6,1c2,1c4,1b2;SPAA:2p1,2p4,2p5,2p8,2t3,2t4,2t7,2c1,2c3,2b 2,2b3,FPAL:3p1,3p3,3p5,3t3,3t4,3c1,3b2,3b4,3b6,SPAL:4p1,4p4,4p6,4 t2,4t5,4t6,4c1,4b2,4b4,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 Alves[20], 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:3p1,3p3,3p 5,3t3,3t4,3c1,3b2,3b4,3b6,SPAL:4p1,4p4,4p6,4t2,4t5,4t6,4c2,4b2,4b4, 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).

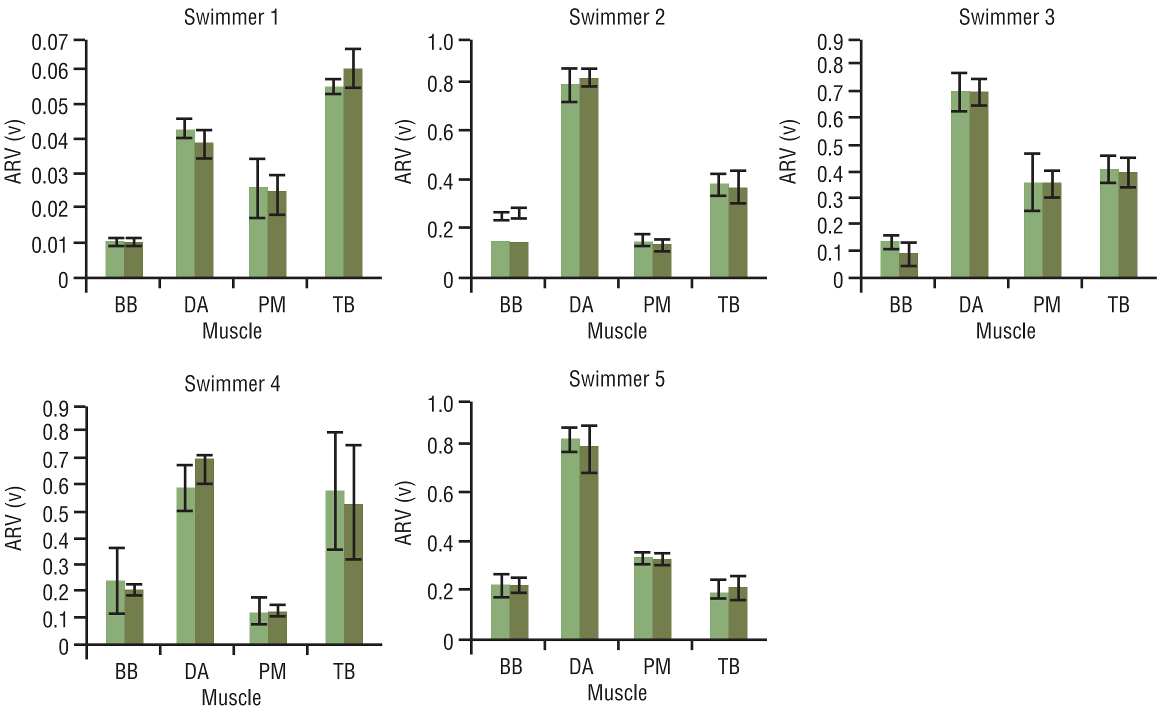

Figure 2. Comparison between the muscles of an average rectified value in the beginning(dark grey) and end (grey) of the swimming bout for each swimmer, BB- biceps brachii; DA- deltoid anterior; PM- pectoralis major; TB- triceps brachii

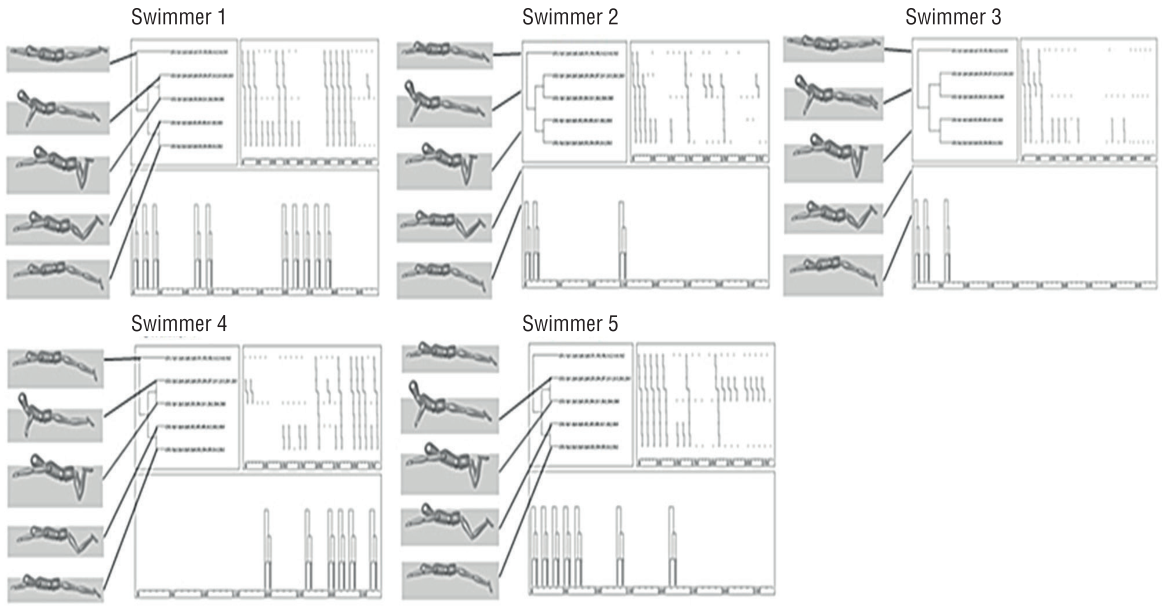

Figure 3. Schematic representation (for each swimmer, left image) and complete behavior pattern with five observation moments (for each swimmer, both images above) and with the spatio-temporal reference of occurrence of the strokes (for each swimmer, diagram in below part of the image), for all the swimmers.

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 swimmers2 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 swimmers2 and 4. These were in agreement with Conceição et al.[10]butin 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 swimmers 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.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

All subjects were informed in advance about the procedures of the study and asked to sign a term of consent that had been approved by the University of Trás-os-Montes e Alto Douro doctoral committee; the study was carried out according to the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Conceived and designed the experiments: ATC; AS; TB. Performed the experiments: ATC; HL Analyzed the data: ATC; TB; HL. Contributed reagents/materials/analysis tools: ATC; JC; TB. Wrote the paper: ATC; AC.

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