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Electromyographic study in 5 muscles during an isometric fatiguing protocol*

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Abstract— **In this study, 12 healthy men aging 22.8 ± 2.2 years old were submitted to a protocol of isometric resistance to fatigue contemplating elbow flexion on three different angles: 45°, 90° and 135°. The objective was to study electromyographic median frequency (MDF) in the following muscles: i) Biceps Brachialis Long Head (BBL), Brachioradialis (BRD), Flexor Digitorum Superficialis (FDS), Triceps Brachialis Long Head (TBL), and Extensor Digitorum (ED). It was verified that, for all muscles, including the muscles that act in opposition to the contraction, fatigue presence was verified by the decrease of MDF value.**

I. INTRODUCTION

Surface electromyography (S-EMG) has been used in many studies due to its practicality and non-invasive characteristics [1], [2]. Through the spectral variation of the S-EMG, it is possible to follow the progress of muscle fatigue during isometric exercise [3]-[6]. Other studies have been able to verify the relations between S-EMG parameters and muscle fatigue during single joint contractions [4], [6]-[10].

Masuda *et al*. [3] analyzed the fall of S-EMG MDF during isometric and isotonic contractions of the vastus lateralis. Masuda identified isometric contractions as the most fatiguing ones and has found that the reduction of MDF was more evident in fatiguing movement than changes in other estimators. In contrast, little is known about the behavior of electromyographic variables associated with fatigue during contractions of antagonist muscles [11]. Several examples show that the analysis of an isolated muscle limits discussions [1]-[3].

On the other hand, simultaneous investigation of various muscles contributed to a significant number of new discoveries. For example, it is known that the BBL muscle is strongly influenced by the joint angles of the elbow [13], shoulder [14], wrist [15], and forearm [16]. Moreover, it is known that during synergistic elbow flexion, the muscles brachioradialis (BRD) and the brachialis (BR) are more fatigable than the BBL [17]. Also, it is suggested that the BBL muscle fatigues mainly in slow motion, while the BRD fatigues mainly in quick short strokes [18]. Corcos *et al*. [19] found changes in the activation time of elbow flexor phasic muscles in a fatiguing protocol. Thus, several works in the literature suggest that the recording of S-EMG signals in multiple muscles can lead to a better understanding of muscle behavior.

Previous works from our research group have found no significant difference in S-EMG signal records during biceps brachial long head (BBL) fatiguing-contraction in different lengths of fiber [12], and these results led us to further explore the electromyographic variables at different angles in the current work.

The goal of this work is to investigate the interaction of the flexor muscles (BBL, BRD and FDS), elbow extensor (TBL) and extensor digitorum (ED), during an isometric fatiguing protocol at three different angles formed between the arm and forearm: 45°, 90° and 135°.

In order to contemplate that goal the following hypotheses were considered about the action of the BBL muscle, synergist and agonist muscles during isometric elbow flexion in a hand grip: i) BBL muscle is the main agonist muscle, being little aided by its synergistic BRD and the flexor digitorum superficialis (FDS). ii) BRD and FDS fatigue at a lower rate when compared with BBL. iii) the Triceps Brachialis Long Head (TBL) muscle does not participate in elbow flexion.

II. MATERIALS AND METHODS

A. Subjects

The study involved 12 healthy men (22.8, ±2.2 years old, height of 73.4 ±16.7 kg, and weight of 1.74 ±0.6 m); subjects presented 31.0 ±0.4 cm arm circumference and 25.8 ±2.1 cm forearm circumference.

All volunteers were not regular exercise practitioners and did not present any symptoms of neuromuscular disorders or ligament problems, and were not using anti-inflammatory medication or muscle relaxants during the sessions. Written informed consent was obtained from all subjects prior to the sessions. Each subject answered an individual questionnaire, which was followed by an Edinburgh Handedness Inventory. The experimental protocol was conducted in the Laboratory

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B. Experimental protocol

The study was conducted in accordance with the Declaration of Helsinki and the experimental protocol was approved by the research ethics committee of the University of Brasilia (protocol Nº 016/2004).

During signal acquisition, the volunteers stayed in orthostatic position, with the foot of the contralateral leg positioned in front of the equipment. The arm sustained a 90° isometric contraction of elbow flexion, with the forearm in supine position, and flexed fingers in a hand grip (Fig. 1). The force was monitored by a SS25L strain gauge hand dynamometer (Biopac Systems Inc, USA). Three measurements of maximum voluntary contraction (MVC) were performed with intervals between measurements of 3 minutes, and the highest value was used in the experiment. Prior to each MVC, subjects were encouraged to exceed the previous force value. Visual force biofeedback was shown on a computer monitor (with a distance of 1.1 m from the subject). The force signal was acquired with an amplifier circuit with a gain of 1000 and an A/D converter with a 500 Hz sampling frequency.

Experiments were performed in three stages with different angles. Each subject performed a 30% MVC isometric contraction using the elbow flexor muscles of the arm in elbow flexion angles of 45°, 90° and 135° until exhaustion. Each angle was performed in a different session with an interval of 48 hours, to allow recovery of neuromuscular fatigue.

The S-EMG signals were recorded during a 30% MVC isometric contraction exercise until exhaustion. S-EMG was recorded in 5 different muscles divided into three groups: i) elbow flexors (BBL and BRD), ii) flexors of the digits (FDS), and iii) antagonists (TBL and ED). All measurements were performed during isometric contraction of the non-dominant arm, and were conducted by the same investigator.

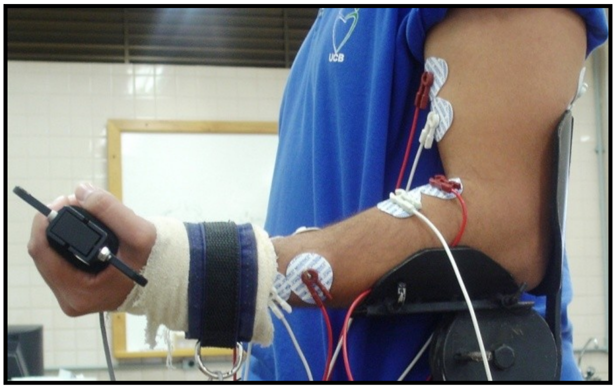


Fig. 1 – Subject position in the experimental protocol (Adapted by Di Oliveira [20]-[21]).

C. Electromyographic signal acquisition

EMG signals were acquired using passive bipolar Ag/AgCl circular electrodes with gel and hydrogel adhesives (Kendall, MedTrace, New York, USA), with 36 mm of total diameter and a 10 mm electrode diameter of signal acquisition area. The interelectrode distance was 36 mm. Surface electrodes were applied following appropriate skin preparation to reduce skin impedance to less than 30 kΩ. Impedance was monitored using a digital multimeter. Electrodes were placed on the muscles following the SENIAM recommendations [22]. The electrode location was marked with a dermatographic pen. Cables were taped down in order to avoid motion artifacts.

EMG signals were acquired using an MP30 data acquisition system (Biopac Systems Inc, Santa Barbara, CA, USA) and BSL Pro software version 3.6.5 (Biopac Systems Inc, Santa Barbara, CA, USA). The sampling frequency was 2000 Hz, the band-pass filter was set to 30–500 Hz, and the amplification gain was 2500. The trigger signal had a gain of 1000. The signal-to-noise ratio was measured without load to verify the quality of the measured signal. The recorded signals were saved on a computer and transferred to dedicated software packages for off-line processing and analysis.

D. EMG signal processing

Segmentation of the raw signal was performed in the BSL Pro software. The segmented signals were processed in Matlab 2008 (Mathworks Inc., South Natick, MA, USA), in which the median frequency (MDF) of the signal's power spectrum was calculated [23]. The power spectrum was calculated using 1-second Hamming sliding windows with 0.5-second overlap, according to Welch's sub-windowing method [24]. For each signal, the mean MDF values, calculated for the first 20 seconds of the signal, were used for analysis.

For each 20 second data epoch, a regression line was found, and this line was normalized so that the MDF value at the initial time is 1.

E. Statistical analysis

The angular coefficient of each regression line, for all angles and muscles of the12 subjects where used in the statistical analysis. The main goal was to check if the slope is negative for most of the cases, and to check if the mean values of the slopes are negative in a statistically significant way (5%).

The Matlab software was used for the statistical analysis. Data normality was analyzed using the Lilliefors test. When p was significantly greater than 0.05, Student's t-test was used. When p was smaller than 0.05, Wilcoxon test was used.

Paired t-tests were performed as post-hoc comparisons to determine if there is significant difference between the initial and final MDF values for each muscle.

III. RESULTS

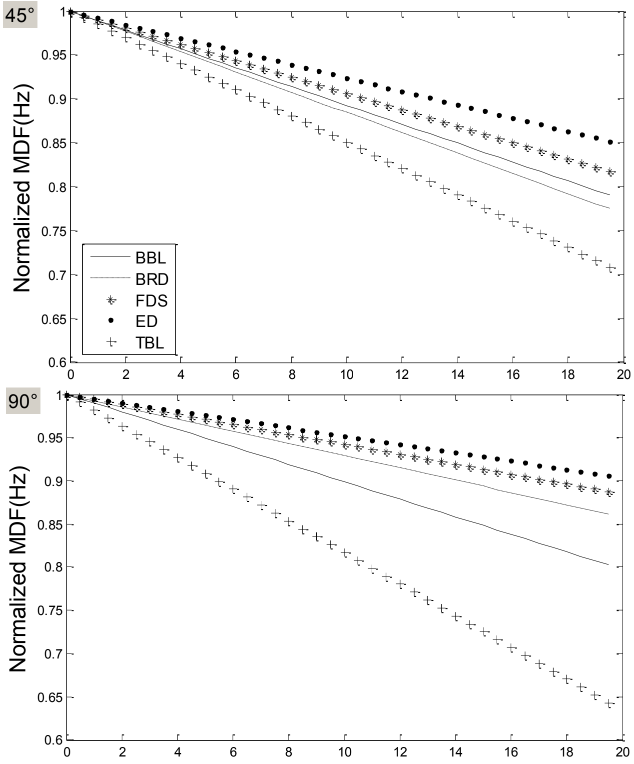
T-test shows that the MDF of the flexor muscles decreased with time (except for the FDS at 45° for which $p > 0.05$). See Table I.

Table I

Muscle	***MDF angles***		
	45°	**90°**	**135°**
BBL	<0.01	<0.01	<0.01
BRD	<0.01	<0.01	<0.01
FDS	0.09	<0.01	<0.01
ED	<0.01	<0.01	0.048
TBL	<0.01	<0.01	<0.01

Estimation of the p values from MDF values fatiguing exercise. n=12.

In Fig. 2, the average value of the normalized regression lines was plotted for the three angles. These figures allow the comparison of the average rate of decay in the MDF for each muscle. This averaged MDF value (A-MDF) is a number that is associated with the rate of decay of the MDF for each muscle in each angle.



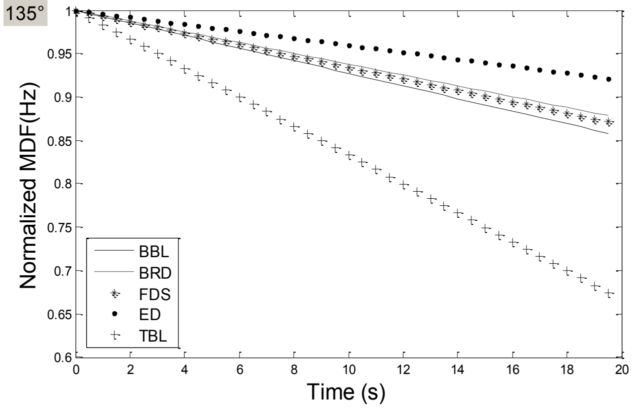


Fig.2 Comparison between normalized averaged MDF values for the muscles BBL, BRD, FDS, ED and TBL at the elbow angles 45°, 90° and 135° in fatiguing exercise.

IV. DISCUSSION AND CONCLUSION

For the three angles, BBL muscle activity was higher than that of other synergist muscles and this fact may probably have led to the fact that the BBL had the highest negative slope among the agonist muscles ($p < 0.01$). An exception to this trend was observed in the slope of the BRD, which was higher than the slope for the BBL in the 45^{o} contraction. This behavior may be due to the fact that during an isometric contraction with the elbow angle at 45^{o} these muscles were less required.

Regarding the results in Figure 2, the fact that, for the three angles, BBL muscle activity was higher than that of other synergist muscles was expected, since the BBL seems to be the main muscle during the contraction. The higher slope of the BRD in the 45^{o} contraction may indicate that this muscle was more required in this particular position, perhaps due to the action of this muscle in the elbow.

Regarding the A-MDF, the values of flexor angles of elbow were low for the 45° angle. This suggested that there is a trend for muscle fatigue in agonists for the 45° angle. The 135° angle was more homogeneous among flexor muscles and had high values of A-MDF.

The lines of A-MDF in 135° were close together (Fig. 2). It is possible that at 135^{o} the synergist muscles show similar characteristics to the BBL. According to Arendt-Nilsen [25], with fiber shortening there is an increase in diameter and this result in an increase in conduction velocity (CV). The opposite happens in a stretched muscle. Other factors (e.g. blood flow, lactic acid and extracellular potassium concentration) also may affect the CV [3]. Another important consideration is that the MDF slope, though generally recognized as an indicator of muscle fatigue, may also be affected by other factors such as muscle size, fiber constitution and blood flow. These simultaneous effects could explain the different trends in muscle behavior for 45°, 90° and 135° angles.

For the three angles, the hypothesis of a high decaying slope for the BBL has been observed.

Very high slopes were observed in the TBL muscle. Its A-MDF indicated a sharp change of spectrum in the direction of the lower frequencies. This result did not confirm our initial hypothesis that the EMG signal of the opposing muscles should not undergo spectral shifts. On the contrary – the TBL showed a spectral shift that was much more intense than the spectral shift of the BBL itself.

For the synergist muscles, it was expected that the spectral shift would be lower than for the BBL. This was observed only up to a certain degree – some of the synergist indeed had lower slopes, but not in all cases.

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