
Time-Frequency EMG Analysis during Elbow Extension: The Role of Lateral and Long Heads of Triceps Brachialis

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Resumo: O objetivo deste trabalho foi quantificar o sinergismo entre a porção longa (TLo) e a porção lateral (TLa) do tríceps braquial durante uma série de extensões do cotovelo (EE) por eletromiografia de superfície (SEMG). Vinte sujeitos saudáveis do gênero masculino realizaram as contrações musculares concêntricas e excêntricas durante as EE no aparelho de roldana alta, até a fadiga. A transformada de Fourier de curto prazo do SEMG permitiu observar um maior desvio padrão da potência de TLa ($1,15 \pm 0,74 \text{ (mV)}^2$) do que de TLo ($0,69 \pm 0,50 \text{ (mV)}^2$) ($p < 0,01$). A frequência mediana diminuiu e TLo mostrou um maior coeficiente angular absoluto do que TLa ($-1,33 \pm 0,51$ e $-0,90 \pm 0,32 \text{ Hz/s}$; $p < 0,01$). Estes resultados sugerem que TLo é responsável por frear e acelerar o antebraço durante a transição da contração excêntrica para a concêntrica.

Palavras-chave: Eletromiografia, Exercício, Fadiga, Sinergismo Muscular, Análise Espectral.

Abstract: This work aims at quantifying the synergism between long (TLo) and lateral (TLa) heads of triceps during a series of elbow extension (EE) by surface electromyography (SEMG). Twenty healthy male accomplished concentric and eccentric muscular contraction in EE at pulley machine, until fatigue. The short time Fourier transform of SEMG allowed observing a greater standard deviation of TLa total power ($1.15 \pm 0.74 \text{ (mV)}^2$) than in TLo ($0.69 \pm 0.50 \text{ (mV)}^2$) ($p < 0.01$). The median frequency decreased with TLo showing higher slope than TLa (-1.33 ± 0.51 and $-0.90 \pm 0.32 \text{ Hz/s}$; $p < 0.01$). These results suggest TLo as the responsible for breaking and accelerating the forearm in the eccentric to concentric transition.

Keywords: Electromyography, Exercise, Fatigue, Muscular Synergism, Spectral Analysis.

TIME-FREQUENCY EMG ANALYSIS DURING ELBOW EXTENSION: THE ROLE OF LATERAL AND LONG HEADS OF TRICEPS BRACHIALIS

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Abstract: This work aims at quantifying the synergism between long (TLo) and lateral (TLa) heads of triceps during a series of elbow extension (EE) by surface electromyography (SEMG). Twenty healthy male accomplished concentric and eccentric muscular contraction in EE at pulley machine, until fatigue. The short time Fourier transform of SEMG allowed observing a greater standard deviation of TLa total power ($1.15 \pm 0.74 \text{ (mV)}^2$) than in TLo ($0.69 \pm 0.50 \text{ (mV)}^2$) ($p < 0.01$). The median frequency decreased with TLo showing higher slope than TLa (-1.33 ± 0.51 and $-0.90 \pm 0.32 \text{ Hz/s}$; $p < 0.01$). These results suggest TLo as the responsible for breaking and accelerating the forearm in the eccentric to concentric transition.

Keywords: electromyography, exercise, fatigue, muscular synergism, spectral analysis.

Introduction

The muscular synergism can be defined as an integrated action at which various muscles act for performing a specific motor task [1]. In this context are the one-joint, two-joint, and multi-joint muscles, in addition to muscles with one or more heads [1-2]. According to the need, a muscle can act as agonist of the movement, stabilize a joint so that agonist carries out the specific movement, or neutralize some undesirable agonistic action [1-2]. The detailed knowledge of the muscular synergism in a certain motor task is a fundamental factor to exercise prescription and evaluation.

Correlated discharge of motor units is often used as an index of the common synaptic input received by the motor neuron pool [3]. This is carried out because common synaptic inputs onto motor neuron pools can cause coincidental discharges of action potentials by motor neurons [3-4]. The level of correlation can indicate synchronization and the cross-correlation function is the tool used in signal processing to study this phenomenon. Surface electromyograms (SEMG) have been used to quantify synchronization among population levels of motor units [5]. Although the peak of cross-correlation function represents the level of the synchronization, this maximum can occur with non-zero time lag. Thus, the time lag of the peak correlation also can be an index of the synchronization.

The function of each elbow flexor muscle was firstly described by Basmajian and Latif [6]. Myoelectrical activity of two heads of the biceps brachialis, brachialis and brachioradialis were compared by bipolar concentric-needle electromyography during flexion, extension, maintenance of elbow flexion at 90 and 135 degrees, pronation and supination of the forearm, and flexion and abduction of the shoulder. The authors consistently observed reciprocal contractions between biceps brachialis and other flexors, as confirmed by subsequent works [7]. In spite of a great interest at elbow flexors synergism, some studies emphasized the myoelectrical activity of elbow extensor muscles, which presented strong correlation with the acceleration of elbow extension [8].

Most studies about muscular synergism employed the measurement of myoelectrical activity of different muscles [6-7]. Even though describing the behavior of different heads of the same muscle, the main concern has been the study of the intermuscular synergism [6]. In the elbow joint complex, the intramuscular synergism of the biceps brachialis was related and, between the two heads of this muscle the long head seems to be the relatively more active during several movements and positions of the elbow and shoulder joints [6]. In the case of the biceps brachialis, the two heads are two-joint muscles, with fusiform arrangement and muscular orientation with similar anatomy [1-2]. Therefore, the actions of the long head of the biceps were similar to those of the short head of the biceps [6]. However, the triceps brachialis muscle presents only one two-joint head, which is agonist at elbow and shoulder extension [1-2]. On the other hand, lateral and medial heads of the triceps brachialis are agonists only of the elbow extension [1-2]. Thus, only long head can be involved in increasing mechanical efficiency [9] and stabilization of the shoulder while elbow extension is made.

This work describes the synergism between lateral head (TLa) and long head (TLo) of the triceps brachialis muscle. The analysis was based on the differences between the time behaviors of the myoelectric activity amplitude and between the rates of fatigue.

Materials and Methods

Subjects – The sample comprised 20 healthy men, undergraduate students of physiotherapy and physical

education of the Estácio de Sá University, with age 23.3 ± 4.1 years (mean \pm standard deviation), body mass 79.3 ± 13.3 kg and height 176.6 ± 8.4 cm, with no history of neurological disorders or orthopedic diseases. This work was part of a project approved by the Ethical Human Research Committee of the Federal University of Rio de Janeiro [CAAE – 0013.0.197.000-05], and all subjects were voluntary and signed a free informed consent before inclusion in the study.

SEMG Recording – Raw electromyographic signals were recorded using an electromyograph EMG1000 (Lynx, Brazil). Each electromyographic channel has a signal conditioning, which includes a differential amplifier (gain 50) with input impedance $10\text{ G}\Omega$, common mode rejection factor 100 dB, a low-pass 2nd order analogical Butterworth filter with cutoff frequency 1 kHz, and a 1st order high-pass Butterworth analogical filter with cutoff frequency 1 Hz. Each SEMG signal was collected by a pair of active surface silver electrodes AE1010 (Lynx, Brazil), with differential amplification (gain 20, rectangular, 10 and 1 mm, length and width respectively), fixed on both TLa and TLo of the right arm. The pre-amplifier of the active electrodes has a low-pass filter with cutoff frequency of 7 kHz, and CMRR > 100 dB. Electrodes were positioned at 50% of the distance between the acromion and the olecranon and were placed following the fibers direction [10]. The inter-electrodes distance was 10 mm and the reference electrode was placed on the right wrist. The skin was prepared by shaving the hair, abrasion with sponge and alcohol cleansing.

Software – SEMG signals were sampled in 16 bits at 2 kHz with the data acquisition software Bioinspector 1.8 (Lynx, Brazil) and all data analysis was performed using Matlab, version 6.5 (The Mathworks, USA).

Experimental Protocol – Subjects performed the elbow extension at pulley machine. Initially, the subjects were evaluated by measurements of height and body mass and were instructed to perform the elbow extension exercise with some restrictions: the amplitude was limited between 90 and 180 degrees of the elbow position and the concentric and eccentric contractions were repeated until exhaustion with the static arms resting close to the trunk (Figure 1). The cadence was controlled by a metronome at one cycle at each 3 s. The forearm movements were performed at pulley machine with straight bar and pronated handgrips. Subjects were oriented to maintain the normal lordosis of the lumbar column, and the distance between hands and feet were delimited by the shoulder and hip widths. Following one set of submaximal contractions for warm-up and familiarization, the one-repetition maximum (1 RM) from each subject was determined by trial and error, by asking the subject to lift the maximum amount of weight they could twice. The 1 RM was accepted when subjects successfully perform the first repetition, but failed to achieve full elbow extension on the second. Repeated attempts were performed with three to five minutes of rest in between each bout. The 1 RM determination for the 20 subjects occurred in the range

1-3 attempts. After a resting period of three to five minutes, a single set of continuous elbow extensions with a load equivalent to 80% of the 1 RM was performed until failure. The task was discontinued when the subjects were unable to achieve full elbow extension or to maintain the cadence applied by metronome, or if they chose to spontaneously stop. The exercise was controlled and encouraged by the same instructor, by continuous verbal instruction at each repetition, for promoting the maximal subject's effort [11].



Figure 1: Subject at the beginning of elbow extension exercise at pulley machine.

Data Processing – SEMG signals were pre-processed by a digital filter whose coefficients were obtained by the convolution of eight Butterworth filters, as proposed by Mello et al. [12]: a 2nd order high-pass, cutoff frequency 10 Hz; a 8th order low-pass, cutoff frequency 400 Hz; and six 2nd order stop-band to attenuate 60 Hz mains noise and its harmonics until 360 Hz. SEMG was filtered in direct and reverse directions to avoid phase shifts, and thus decimated to 1 ksamples/s. Signals were analyzed by spectrograms using short time Fourier transform ($STFT_x$), given by [13]:

$$STFT_x(t, \omega) = \int x(\tau) \cdot h(\tau - t) \cdot e^{-j\omega\tau} d\tau \quad (1)$$

where $h(t)$ is the window function which is moved along the signal $x(t)$ for the time-frequency analysis. The $h(t)$ function was a Hanning window with 1.5 s time length and the $STFT_x$ was calculated with 50% of overlapping. For each data segment it was calculated the median frequency (f_{median}) and the total power (TP). The f_{median} was defined as the frequency at which the power spectrum is divided into two regions with equal power [14]. This condition may be stated mathematically by the following equation:

$$\int_0^{f_{med}} |STFT_x(f)| df = \int_{f_{med}}^{\infty} |STFT_x(f)| df = \frac{1}{2} \cdot \int_0^{\infty} |STFT_x(f)| df \quad (2)$$

The TP was calculated by the integral of magnitude of discrete Fourier transform via trapezoidal method and detrended for subtracting the linear tendency [15].

Normalized cross-correlation function (NCCF) was estimated between the root mean square (RMS) values of the TLa and TLo calculated with 100 ms time

windows. The time lag of the maximum NCCF indicated the latency between TLa and TLo signals.

Statistical Analysis – The standard deviation of the TP (SD-TP) was calculated and a linear regression was performed for calculating the f_{median} slope along the time for each subject. Wilcoxon test was applied to test the differences of f_{median} and SD-TP values between TLa and TLo, as well as to test the null hypothesis that median time lag between TLa and TLo is zero. Significance levels were set with $\alpha = 0.05$.

Results

The spectrograms allowed observing an oscillating pattern of activity, mainly in TLa, which presented periods of relative resting at the end of the eccentric phase (Figure 2). This pattern was confirmed by SD-TP along the exercise series (Figures 3A and 3C), which was significantly higher in TLa than in TLo: 1.15 ± 0.74 and 0.69 ± 0.50 (mV)², respectively ($P < 0.01$). The median frequency decreased in both TLo and TLa during the fatigue development (Figures 3B and 3D), with TLo showing higher slope than TLa (-1.33 ± 0.51 and -0.90 ± 0.32 Hz/s, respectively; $P < 0.01$), giving a clear indication that this muscle portion is the first to reach fatigue.

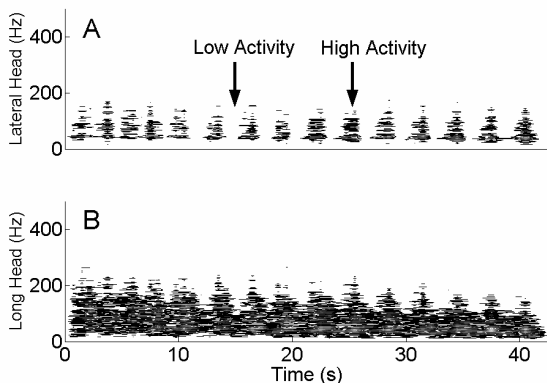


Figure 2: $STFT_x$ of the lateral head (A) and long head (B) of the triceps brachialis. Unlike long head, the lateral head shows alternate low and high activity during exercise.

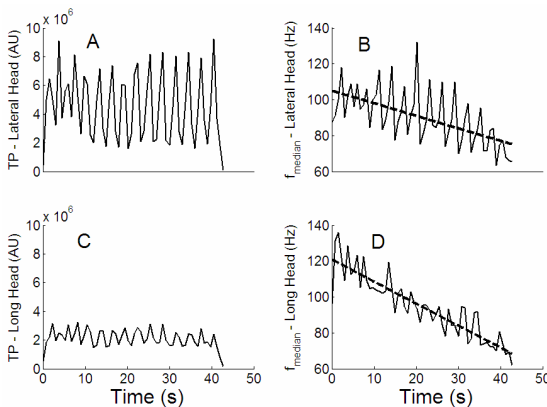


Figure 3: Typical case of the time-series of total power (A and C) and f_{median} (B and D). Note that TP time series of TLa (A) has higher dispersion than TLo (C), while the slope of f_{median} of TLa (B) is smaller than TLo (D).

The maximal correlation and time lag were 0.74 ± 0.11 and -0.07 ± 0.20 s (Figure 4). Therefore the time lag was not significantly different of zero ($P = 0.19$).

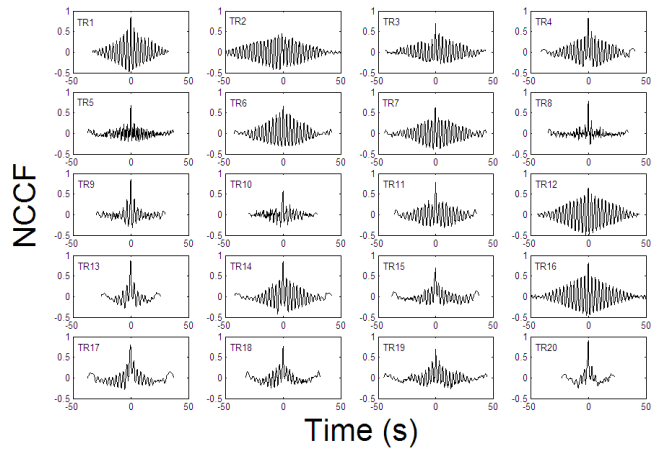


Figure 4: Normalized cross-correlation function of each subject showing maximal correlations at approximately or exactly zero latency.

Discussion

The main found of the present work was the constant activity of the TLo, with consequent greater fatigue rate than TLa. Thus, TLo could be an important stabilizer of the shoulder joint during elbow extension. Therefore, while the brachialis muscle is the flexor *par excellence* of the elbow joint [6], this role is carrying out at elbow extension by the long head of triceps brachialis. This statement is based in fact that the brachialis muscle is called upon to flex the forearm in all positions because the line of its pull does not change with pronation or supination. However, long head of the triceps is activated because shoulder joint needs a fixation, being this muscle responsible by the resistance to inertia during the transition between concentric and eccentric phases.

An underlying mechanism responsible for the shift of power spectrum to lower frequencies was proposed by Gabriel et al. [16]. The initial activity of the fast twitch fibers could generate high median frequency due to the high conduction velocity. These fibers would be the first to be activated due to the high force generated, but its fatigue is reached faster. Further, the slow fatigue resistant twitch fibers will govern the force production. These fibers have lower conduction velocity and this can explain the shift of the median frequency. A complementary explanation is the fall of conduction velocity of the action potential through sarcolemma caused by extracellular K^+ accumulation [16]. However, in these two mechanisms the amplitude of the $STFT_x$ would also owe to decrease [16]. As this did not occur, these explanations must be refuted and the muscular wisdom [17] can be the underlying mechanism of this median frequency shift. The muscular wisdom hypothesis proposes that motoneuron firing rates decline to match the muscle's contractile speed [17].

Cross-correlation function revealed that both triceps heads are synchronously activated with zero time delay. The mean value of the maximal correlation could indicate cross talk between both heads. Additionally, the cross-correlation analysis of SEMG from two adjacent muscles provides a limited estimate of the level of motor unit synchronization between the muscles [3]. However, the location of the maximum correlation can be used, disrespect its value. The peak location can be used when the interest is to find time lags between signals, but it is not important to investigate the strength of the synchronization between signals.

The analysis of muscular synergism by EMG techniques was pioneered by visual inspection, following a subjective scale [6]. In the present study, the $STFT_x$ is presented as a valuable tool for time-frequency analysis of the SEMG signals from one and two joint muscles. The $STFT_x$ was similar to wavelet transform for obtaining spectral indices of muscle fatigue during dynamic contractions [18].

The presented findings suggest TLo as the responsible for stabilizing shoulder joint and breaking and accelerating the forearm in the eccentric to concentric transition. The results also indicate that TLa and TLo are activated in perfect synchronization.

As a conclusion, the dynamic SEMG analysis of the triceps brachialis during elbow extension allowed to determine the differences between loads in muscle heads, being a useful tool for the prescription of located exercises.

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