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Comparative Muscle Study Fatigue with sEMG signals during the Isotonic and Isometric Tasks for Diagnostics Purposes

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Abstract—**The study of fatigue is an important tool for diagnostics of disease, sports, ergonomics and robotics areas. This work deals with the analysis of sEMG most important fatigue muscle indicators with use of signal processing in isometric and isotonic tasks with the propose of standardizing fatigue protocol to select the data acquisition and processing with diagnostic proposes. As a result, the slope of the RMS, ARV and MNF indicators were successful to describe the fatigue behavior expected. Whereas that, MDF and AIF indicators failed in the description of fatigue. Similarly, the use of a constant load for sEMG data acquisition was the best strategy in both tasks.**

I. Introduction

In the last years the reports of motor diseases show an increase of different failures in motor behavior, as Fibromyalgia (FM), that occurs in 0.66-4.4% of population, and is more common to women between 35 to 60 years old [1,2]. Also, diseases like chronic fatigue, artrosis, rheumatic diseases [3], low back pain (LBP) [4], corticomuscular coupling [5], between others, have a similar feature that is the fatigue behavior, and the principal tool to compute is the signal processing analysis.

In a previous work for 5th Latin American Congress of Biomedical Engineering (CLAIB, 2011) in Havana Cuba [6], we present a historical review of the fatigue behavior with sEMG. The result of that research provided different uses of the fatigue indicators in areas as robotics control [7], sports [8], ergonomics [9], diagnostics [10,11] and physiology. Among which, the Root-Mean Square (RMS), Average Rectified Value (ARV), Mean Frequency (MNF), Median Frequency (MDF) and Average Instantaneous Frequency (AIF) [12, 13,14,15,16], were tested in the present work.

This paper reports the results of slopes and intercepts of linear regressions of five different muscle fatigue indicators. The isotonic and isometric tasks measured in the *biceps brachii* [11] used a rigid cable and latex tube versus constant load, for 30%, 60% and 80% of the Maximum Voluntary Contraction (MVC). Then, the selected indicators will be used in future researches of motor diseases, as *cronic fatigue*, *fibromyalgia*, motor pain between others.

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II. Methodology

A. Experimental Conditions

For this experiment, a healthy subject was positioned sitting comfortably with his spine supported in the chair, knees bent 90 degrees and feet resting on a horizontal surface. In his front there is a monitor showing the sEMG signal, the goniometer and the dynamometer signals, to provide feedback. First of all, the MVC was obtained by using the dynamometer coupled to a rigid cable (1m, diameter 7mm) and using the goniometer to maintain the elbow joint position of 90°. In relation to the isometric task, the effort with 30, 60 and 80 % of the MVC was performed with the rigid cable coupled to the dynamometer (Figure 1-a), which gives the visual feedback to maintain the predefined strength until exhaustion. This task was also performed using constant loads with 30, 60 and 80 % of the MVC attached to the rigid cable (Figure 1-b), in which the goniometer was used to measure the decrease of 10° related to the elbow joint initial position of 90° that indicates exhaustion, and then, the end of the task.

The isotonic task was consisted of a motor routine of extension and flexion of the elbow joint until exhaustion. The effort with 30, 60 and 80 % of the MVC was performed with a latex tube coupled to the dynamometer (Figure 1-c). The latex tube No. 204, mark Lengruber, diameter 12 mm, light with a diameter of 6 mm, coefficient elasticity of 20N and was fitted with the elastic band for Knob Mercur®. This task was also performed using constant loads with 30, 60 and 80 % of the MVC attached to the rigid cable (Figure 1-d), in which the goniometer was used to measure the decrease of 10° related to the elbow joint initial position.

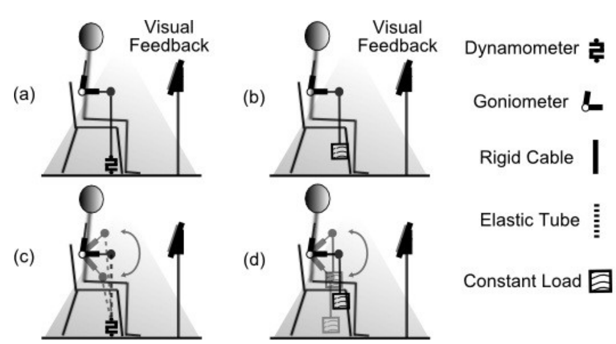

Fig. 1. Isometric tasks: (a) motor task using the rigid cable / (b) motor task using the constant load. Isotonic task: (c) motor task using elastic tube; (b) motor task using the constant load.

B. Data Acquisition

The sensors captured signals with six 8-channels amplifiers with a Biomec400 equipment (EMG System do Brasil, BRA). sEMG amplifier, dynamometer and goniometer were also used to record signals sampled at 1000 Hz. sEMG used a bandpass filter (3-dB bandwidth 20–500 Hz) and filter noch for 60 Hz (noise power grid). The goniometer used a lowpass filter (3-dB, 0.2 Hz). Data were stored on a computer Intel®CoreTM^2 Duo and processed in MATLAB 7.6 platform (R2008b).

The skin was cleaned and abraded with alcohol to minimize impedance of the electrical contact of the electrodes. sEMG sensors (Bipolar; Ag-AgCl; 20mm inter-electrode distance) were placed according to SENIAM recommendations in the following muscles of the dominant side of the patient: *biceps brachii* [18], *deltoideus anterior* and *upper trapezius.* The longitudinal axis of the electrodes were positioned parallel to the fibers of these muscles and the reference sensor was placed in the patient's wrist Figure 2 - Left) [19].

The goniometer was placed over the lateral aspect of the elbow joint, with the fulcrum positioned over the *lateral epicondyle* of the *humerus*. The proximal arm of the sensor was aligned with the lateral midline of the *humerus*, with the center of the *acromion process* used as reference point. The distal arm was aligned with the lateral midline of the radius, using the *radial styloid process* for reference (Figure 2 - Right) [20].

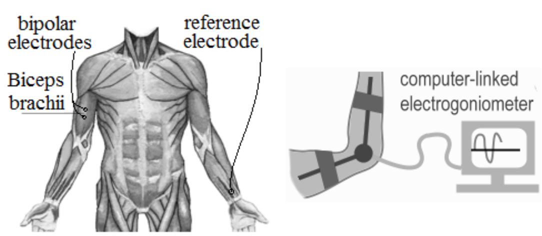

Fig. 2. Electrodes and goniometer positions.

C. Signal Processing

After all isotonic data were collected, the sEMG signals were segmented into epochs, where one epoch represents one contraction, as shown in figure 3(a). The goniometer signal, θ(*t*), varied between approximately 145° when extensioned to 80° when flexioned, as shown in figure 3(b). Then, an algorithm using the goniometer signal was designed to automatically identify the beginning and ending of each isotonic task. The goniometer signal was filtered to remove the high frequency noise of quantization and differentiated, as shown in figure 3(c). The differentiated signal, *d*θ/*dt*, is centered about zero, then, two constant values (horizontal dotted lines) were adjusted to signalize the beginning and ending of the epoch. In this figure the hatched area represents the epochs.

During quantification of the aforementioned coefficients (RMS, ARV, MNF, MDF and AIF), sEMG time windows of 1 s were taken. The time windows are continuously displaced by 10 ms and overlapped by 990 ms, which is the sliding window technique. This method was used to calculate the standard deviation, σ(*t*), of the sEMG over the time. The values of σ(*t*) above a empirical cutoff constant, *k*, given by 60% of the maximum value of σ(*t*), are used to compose a window with the sEMG maximum energy. Figure 4 shows the application of the described method in the second epoch of figure 1, where the hatched area represents the window with the sEMG maximum energy.

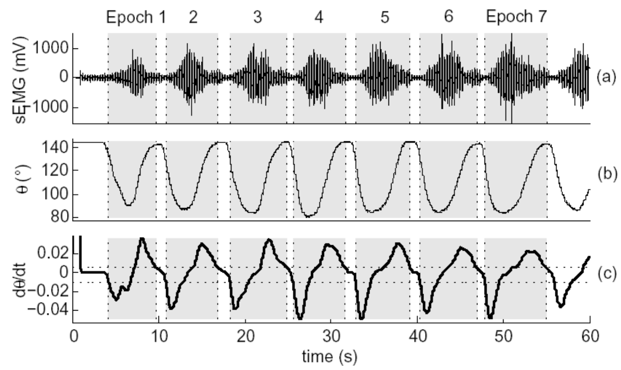

Fig. 3. Isotonic Data: (a) sEMG signal; (b) Goniometer angle signal; (c) derived of the filtered goniometer signal.

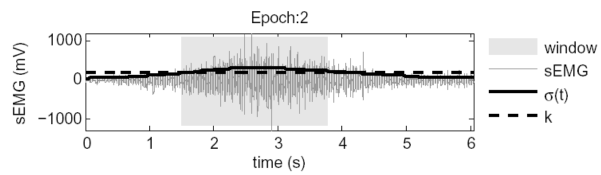

Fig. 4. sEMG signal from second epoch of an isotonic task, sEMG standard deviation and the window with the sEMG maximum energy.

As the isometric task consists of one long epoch, there is no need for the segmentation performed with the goniometer signal, but the sEMG signal is also windowed using the cutoff of 60% of the maximum σ (see Figure 5-a).

The coefficients are calculated for each time window of the windowed sEMG, then, all coefficients are related to time. RMS is the square root of the averaged energy of the signal and the ARV performs the average of the energy of the signal module [12]. Both coefficients were calculated using the sliding window technique with time windows of 1 s displaced by 10 ms.

MNF is can be found in [15] and represents the mean frequency of the sEMG spectrum of each time instant. MDF is the frequency at which the spectrum can be divided into two parts of equal power [15]. These estimators were calculated performing the Fast Fourier Transform in the aforementioned sliding windows of 1 s.

AIF is the average of the instantaneous frequency, which can be found in [15]. The instantaneous frequency is defined as the first derivative of signal's phase. The signal's phase is determined by means of the analytic signal, whose complex part is given by the Hilbert transform.

The curve related to time of each coefficient (RMS, ARV, MNF, MDF and AIF) was obtained, and then the linear regression of this curve presents two parameters, the angle between the horizontal axis, the slope α, and the point at which the line crosses the vertical axis, and intercept β.

The linear regression was obtained performing a polynomial fit for one degree in a least-squares sense. Figure 5 shows an example of the sEMG signal during an isometric task, where it is shown the fatigue coefficients and the linear regressions.

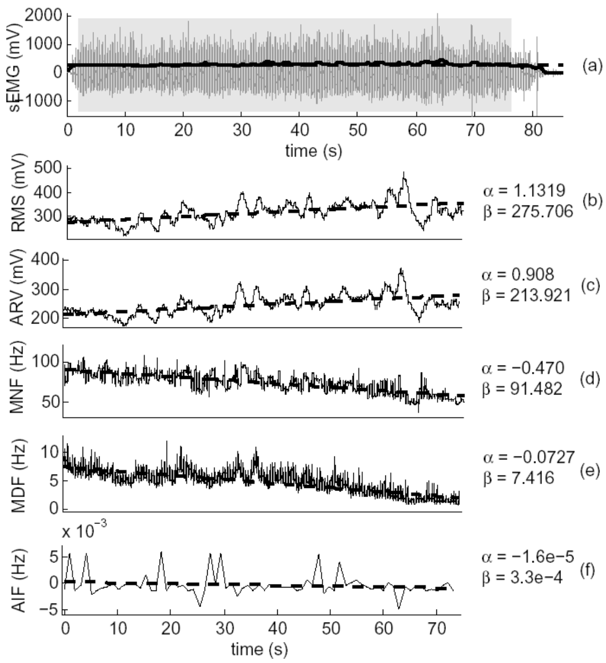

Fig. 5. Isometric Data using 60% of MCV: (a) sEMG signal; (b) RMS; (c) ARV; (d) MNF; (e) MDF and (f) AIF.

III. Results and Discussion

Two experiments were conducted for isometric and isotonic tasks. For the isometric case, the first experiment used a rigid cable and the second experiment used a constant load. For the isotonic case, the first experiment used an elastic tube and the second experiment also used a constant load.

Table I shows the results of the performance in one isometric task for different MVC percentages and table II shows the results of the performance in one isotonic task that was consisted of 20 epochs.

In Table I, the results of slope parameter, α, obtained with rigid cable, using 60% of MCV are positive for RMS and ARV and negative for MNF and AIF, but the behavior of slope was positive for MDF.

The results with slope obtained with constant load, using 60% of MCV are positive for RMS and ARV and negative for MNF, MDF and AIF. These results corroborate the findings of Bonato et al. (2001) and Sarmiento et al. (2011). But, with constant load using 30% of MCV, the slope of RMS and ARV do not agree with the fatigue behavior expected. Something similar occurs with the 80% but with MDF [11]. Using the rigid cable with 30% of MCV, the slope of MDF was positive. While for the 80% the slope of MNF, MDF and AIF were positive.

The results obtaining with the rigid cable were not as expected, especially with MDF. We noticed that this approach produces oscillations in the strength during the task. These oscillations allow the muscle recovery, partly masking the fatigue behavior during the isometric task.

As the isotonic task consists of several epochs, in each one, the slope and the intercept were obtained. These parameters were averaged for each new epoch during the task. Figure 6 shows the obtained behavior. In Figure 6(a) can be verified that the RMS and ARV slopes begin negative and turns positive during the progress of the epochs, indicating an increase of the sEMG energy that is related to fatigue. We noticed that after 15 epochs the fatigue estimators tend to converge to a constant value.

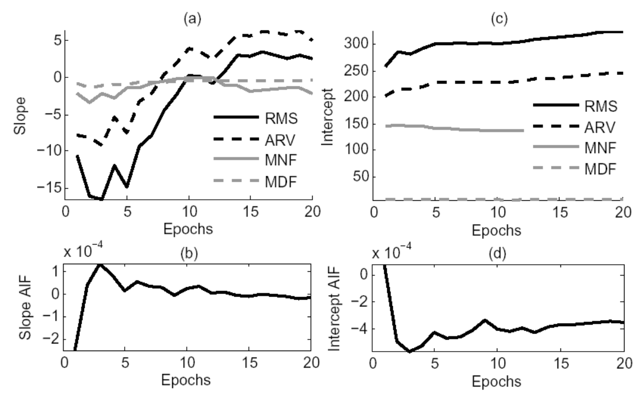

Fig. 6. Isotonic Data using 60% of MCV: (a) slope of RMS, ARV, MNF and MDF; (b) slope of AIF; (c) intercept of RMS, ARV, MNF and MDF; (d) intercept of AIF.

In Table II, the slope and intercept values are the average over all 20 epochs.The results of slope obtained with rigid cable, using 60% of MCV are positive for RMS and ARV and negative for MNF.

TABLE I

	Isometric Task – Rigid Cable										Isometric Task – Constant Load									
	RMS		ARV		MNF		MDF		AIF		RMS		ARV		MNF		MDF		AIF	
MVC	α	β	α	β	α	β	α	β	α	β	α	β	A	β	α	β	α	β	α	β
30%	0.04	61.7	0.03	48.3	-4e-2	114	5e-4	0.98	-3e-6	-3e-4	-1e-2	81.1	-1e-2	81.1	-1e-2	63.2	-1e-3	1.2	-2e-7	-6e-4
60%	0.41	72.6	0.31	57.2	-8e-2	101	3e-3	1.6	-2e-5	5e-4	1.14	275	0.91	214	-0.47	91.5	-7e-2	7.4	-2e-5	-5e-4
80%	0.80	90.3	0.62	71.3	0.75	111	5e-3	2.27	2e-5	-1e-3	4.53	214	3.63	166	-10.4	92.1	7e-2	6.2	-2e-5	-6e-4

TABLE II

	Isotonic Task – Elastic Tube										Isotonic Task – Constant Load									
	RMS		ARV		MNF		MDF		AIF		RMS		ARV		MNF		MDF		AIF	
MVC	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β
0%	1.52	46.6	1.03	46.6	-0.7	135	0.01	0.2	2e-5	3e-4	0.70	86.7	0.63	70.9	-0.4	131	5e-3	0.18	3e-5	3e-5
60%	3.89	386	5.09	245	-1.3	128	5e-3	8.27	5e-6	3e-4	2.64	325	5.09	245	-2.1	136	-0.3	5.46	-3e-5	3e-4

The results with slope obtained with constant load, using 60% of MCV are positive for RMS and ARV and negative for MNF, MDF and AIF, that agree with [6,8,12,18,14,15,16,21,22,23,24]. But, with constant load using 60% of MCV, the slope of AIF was the same with 0%. Using the rigid cable with 60% of MCV, the slope of MDF and AIF were positive.

The results obtaining with the elastic tube were not as expected for both MDF and AIF. This approach also produces oscillations in the sEMG during the task, which affects the recognition of the beginning and the end of the contraction. Then, the sEMG signal in the selected window of $60\%\cdot\max(\sigma(t))$ of the epoch do not have significant fatigue estimators. In addition to vary the amount of load, the window cutoff parameter, k, was varied between 60%, 80% and 90% of the maximum value of $\sigma(t)$.

IV. CONCLUSIONS

We find that using 60% of MCV with the cutoff parameter k of 60% in both cases, isometric and isotonic tasks, with the constant load obtained the expected values supported by literature.

According with our results any of the aforementioned slope parameters could be used to indicate fatigue with isometric tasks. But, only the slope of RMS, ARV and MNF could be used to indicate fatigue with isotonic tasks.

In our experimental conditions we suggest the use of the slope of RMS, ARV and MNF indicators of fatigue with 60% of MCV and constant load in isometric tasks and at least 15 contractions for the isotonic task.

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