Muscle Fatigue Analyzed by Zero Crossing Time Intervals (ZCI)

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Introduction
Muscle fatigue has been defined as the failure to maintain the required and expected force output and its properties have been extensively studied (Enoka & Stuart, 1992). Among the methods for analysis, the root-mean-square value (RMS) of the myoelectric (EMG) signals and the mean frequency (MF) from the power spectrum are usually applied to investigate the fatigue mechanisms (Johnston et al., 2001; Gerdle et al., 2000). However, the MF and the RMS values depend on the amplifier gain and saturation level. These methods for analysis of the myoelectric signal can offer different possibilities of results and some of them are sensible to the amplifier's gain and saturation level (Garcia et al., 2000). Garcia and Souza (1998) developed a system for analysis of the EMG signal based on the statistical properties of the intervals of time between adjacent zero crossings (ZCI). The ZCI has shown some correlated advantages for studying muscle force gradation (Garcia, 1998) and no sensibility to the amplifier alterations of gain and saturation. The aim of this study was to test the time intervals between adjacent zero crossings (ZCI) and verify its sensibility to muscle fatigue.

Methods
Five healthy subjects (21 to 34 years old), male and right-handed were tested. They were seated and the left elbow joint adjusted to 90°. A cable fixed to the left wrist and the first one connected to a dynamometer. The EMG acquisition system was composed by an electromyographer constructed in LabView (NATIONAL INSTRUMENTS), a homemade amplifier, and an A/D conversor (DAQPad-1200, NATIONAL INSTRUMENTS). The muscle fatigue was induced on the left biceps brachii muscle (90° of elbow joint flexion) and the EMG surface activity was recorded during isometric contraction at 50% of maximum voluntary contraction (MVC). Surface electrodes (Ag-AgCl) were placed 3 cm apart, over the muscle belly. The sampling frequency and the gain were 2000 Hz and 275, respectively. The subjects were asked to maintain the contraction level by visual feedback (target line on the video screen). A dynamometer was used to collect the MVC and the force during the fatigue test. The MF, RMS value and the mean of ZCI were estimated for each second of the EMG signal until the subjects failure to keep the contraction level.

Results
The Pearson's Correlation Test was applied to verify the relation between MF and RMS with the ZCI. The correlation coefficients are presented on figure 1. The results suggest a better correlation of mean ZCI with the MF (p<0,01) than the RMS. Figures 2 and 3 are examples. For all subjects, the MF decreased with fatigue. The RMS value did not show a defined pattern.

Discussion
With these initial results, the mean ZCI appears to be a promising frequency parameter for muscle contraction analysis, based on its good correlation with MF. It can be the best choice when the EMG signal reaches the saturation level of the amplifier due to a high gain, leading to an alteration of its shape and frequency spectrum. The same relation was not observed with the RMS value that is an amplitude parameter. In order to establish the mean ZCI properties this methodology is being applied to a grater group of subjects.
Figure 1 - The correlation coefficients between MF and RMS with ZCI.

Figure 2 - An example of the diagram of dispersion between ZCI and MF.

Figure 3 - An example of the diagram of dispersion between ZCI and RMS value.
References


