Influence of muscular fatigue in evoked electromyogram

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Abstract. In this work we present the results of the evaluation of the changes happened in M wave during application of functional electrical stimulation. Electromyogram from the tibialis anterior muscle and ankle angle were measured to determine the occurrence of the fatigue phenomenon. The results report a decrease of the signal amplitude and the median of the power spectrum and are encouraging for the development of strategies of control of FES applications.

1. Introduction

Functional electrical stimulation (FES) is a rehabilitation technique used to restore functional movement in patients with paralysis [1]. It is based on the application of electrical stimulation to the peripheral nerves that innervate the paralyzed muscle in order to generate action potentials in motoneurons, which propagate towards the muscle causing its contraction [2]. The stimulation is applied when it is necessary to make a movement and it is controlled by the subject that is being stimulated, adjusting its parameters according to the neuromuscular changes that take place during the time of use. Among their main applications it can be mentioned the stand and walk of spinal cord injured people, the correction of the foot drop during the phase of balance or the grasp and release of objects [3]. Nevertheless, these systems have like disadvantage the occurrence of muscular fatigue phenomenon that limits its effectiveness and use in long periods of time. The fatigue is shown as a reduction in the ability to maintain a certain level of muscular force in a sustained contraction or as the incapacity to reach a level of initial force in intermittent contractions, and it is accompanied by changes in the muscular electrical activity [4].

The electromyogram (EMG) is the registry of the electrical potential generated by the depolarization of the membrane of the muscular fibers that compose the motor unit. Its detection is made by means of intramuscular or surface electrodes. In this last case the signal is called surface electromyogram (SEMG). The SEMG is then the sum of individual motor unit action potentials (MUAP) that are generated by the continuous and irregular discharges of the active motor units in the muscle; which is demonstrated in his irregular waveform. The SEMG signal registered during the application of FES is the synchronous sum of the action potentials generated by active muscle fibers [5] and receives the name of M-wave. The properties of M-wave depend on the number of motor units activated by the electrical stimulation, the dispersion of their innervation zones, the conduction velocity and the form of their action potentials. M-Wave suffers morphologic and spectral changes in accordance to the changes in the conditions of registry and the recruited motor units. These changes can be seen in peak...
to peak amplitude (PTPa), and in the mean and median of the power spectrum of the SEMG signal [6]. It is expected that similar changes happen in the presence of muscular fatigue being very important to detect them with the purpose of correcting the obtained muscular response during the application of FES.

In this article we present a study carried out to value the temporal and spectral changes of the M-wave in function of the muscular fatigue.

2. Materials and Methods

The experimental design used in this study is showed in figure 1.

Signals of SEMG of the tibialis anterior muscle, whose contraction was evoked by constant current rectangular pulses of electrical stimulation applied to the common peroneal nerve, were registered in healthy subjects. The stimulation intensity was fixed -and kept constant during all the experience- to the maximum tolerated by the subject that produced a good foot dorsiflexion. In table I the parameters of the stimulation are detailed.

| Table 1. Stimulation parameters |
|--------------------------------|
| Parameter       | Value   |
| Frequency       | 30 pps  |
| Pulse width     | 0.3 ms   |
| Intensity       | Constant |

The dorsiflexion angle was measured by means of a goniometer positioned in the ankle joint. For the EMG recording, the electrodes were placed between the innervation zone and the myotendinous junction and the reference electrode in the ankle, in according to the recommendations of the SENIAM. Electrodes of Ag-AgCl were used, whose area of registry had 1 cm of diameter and the
distance between the detection surfaces was 2 cm [6]. The occurrence of the fatigue phenomenon determined by an increase in the angle of dorsiflexion was quantified through the goniometer [7].

The EMG signals were amplified and filtered using GRASS© amplifiers. The cut-off frequencies were in 5Hz for the high-pass and 300Hz for the low-pass filter. The output of the amplifier and of the goniometer was digitalized using a 16 bits acquisition module (Data Translation DT9816) and whose communication with the PC is made through USB port. The sampling frequency was 2 kHz and the data were stored and later processed using Matlab ©. In order to eliminate the stimulation artifact, blanking of the signal via software using a threshold detection method was made.

For the analysis of the changes happened in M-Wave, the signal was divided at epochs, each one of them corresponding to one M-wave, assuming that the signal is stationary at each epoch [2]. The averaged periodogram of signal corresponding to the beginning and the end of the protocol of stimulation were calculated.

The median of the power spectrum was calculated from the periodogram. The median $f_p$ of the power spectrum $S(f)$ is defined like that frequency that divides the spectrum in two zones of equal energy and is given by:

$$
\int_0^{f_p} S(f)df = p\int_0^{f_p/2} S(f)df,
$$

Where $p=0.5$ [5]

### 3. Results

In figures 2 and 3 periods of 10 epochs of the signal at the beginning of the stimulation, corresponding to $96^\circ$ of dorsiflexión and during the fatigue period corresponding to $111^\circ$ of foot dorsiflexión were observed.

![Figure 2. Epochs of the EMG signal at the beginning of the stimulation (96° of dorsiflexion).](image-url)
Figure 3. Epochs of the EMG signal during the fatigue period (110° of dorsiflexion).

The median of the power spectrum changed from 80Hz at the beginning of stimulation the protocol to 64Hz during the fatigue period. In figure 4 it can be seen averaged periodograms of the signals during the beginning and the fatigue period of the stimulation protocol. A shift toward lower frequencies in the power spectrum was observed.

Figure 4. Averaged periodogram of periods of signal corresponding to the beginning (dotted line) and the end (solid line) of stimulation.
4. Discussion
The results showed a reduction in the amplitude and median of the power spectrum. Initially, in voluntary contractions, the amplitude of the SEMG increases because, like mechanism of compensation of fatigue, the muscle tries to keep the same force recruiting additional motor units, but when this is not possible, the force begins to diminish showing a reduction in the signal amplitude. In evoked contractions at constant intensity and frequency stimulation, the muscle cannot increase the number of motor units recruited or its firing frequency, therefore the unique variable that would explain the occurrence of the fatigue phenomenon would be the conduction velocity. During fatiguing contractions, these reduction in the conduction velocity and therefore in the characteristic frequencies of the signal appears; being the lactic acid accumulation one of the causes of this [9]. The results show a reduction in the amplitude of M-wave, and it is observed in figures 2 and 3. This reduction in the conduction velocity, results in a compression and a shift of the power spectrum towards the lower frequencies. This is observed in figure 4 and agrees with the reported by Merletti et all [6] y Tepavac et all [10].

5. Conclusions
The detection of the beginning of muscular fatigue phenomenon would allow the development of control techniques to optimize the performance of FES systems. The fatigue phenomenon can be detected or even better, predicted, by means of the analysis of the evolution of the SEMG signal, in special of the M-wave. Although these preliminary results are satisfactory, is necessary a deeper analysis about the variation of the M-wave parameters during the appearance of this fatigue.

6. References
[1] G Loeb y R Davoodi 2005 The functional reanimation of paralyzed muscles. Biomimetic Strategies IEEE Eng Med Biol Mag 24 45-51
[2] G Hefftner, W Zucchini and G Jaros 1998 The electromyogram as a control signal for functional neuromuscular stimulation – part I: autoregressive modeling as a mean of EMG signature descrimination IEEE Trans. Biomed. Eng 3 230-237
[3] M Popovic, T Keller, I Pappas, V Dietz and y M Morari 2001 Surface-Stimulation technology for grasping and walking neuroprostheses IEEE Eng Med Biol Mag 20 82-93
[4] N Dimitrova and G Dimitrov 2003 Interpretation of EMG changes with fatigue: facts, pitfalls, and fallacies J Electromyogr Kinesiol 13 13–36
[5] R Merletti, A Rainoldi and D Farina 2004 Myoelectric manifestations of muscle fatigue Electromyography: Physiology, Engineering and Noninvasive Applications (USA. IEEE Press. Wiley-Interscience) p 233-258
[6] R Merletti, M Knaflitz and C De Luca 1990 Myoelectric manifestations of fatigue in voluntary and electrically elicited contractions J Appl Physiol 69 1810-1820
[7] Surface Electromyography for the Non-Invasive Assessment of Muscles 2007, Available in: http://www.seniam.org/.
[8] J. Winslow, P Jacobs and D Tepavac 2003 Fatigue compensation during FES using surface EMG J Electromyogr Kinesiol 13 555–568
[9] L Brody, M Pollock, S Roy, C De Luca and y B Celli 1991 pH induced effects on median frequency and conduction velocity of the myoelectric signal J Appl Physiol 71 1878-1885
[10] D Tepavac and L Schwirtlich 1997 Detection and prediction of FES induced fatigue J Electromyogr Kinesiol 7 939–950