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EFFECTS OF FIVE NMES BURST FREQUENCIES ON MECHANICAL TIME-FREQUENCY RESPONSE OF RECTUS FEMORIS MUSCLE IN AN ABLE-BODIED SUBJECT

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SUMMARY
The objective of this study is to investigate the influence of five burst frequencies on mechanical time-frequency response in *retus femoris* muscle of an able-bodied subject. Neuromuscular electrical stimulation (NMES) was applied in quadriceps muscle via femoral nerve of one able-bodied volunteer during 15s with burst frequencies set to 20Hz, 35Hz, 50Hz, 75Hz and 100Hz at 40V of intensity. A mechanomyographic (MMG) sensor was used to acquire the muscular activity. From the signal 10s were extracted and processed in time-frequency domain through Cauchy wavelet transform. The relation between burst frequency and MMG response tends to be influenced for frequencies of up to 50Hz.

INTRODUCTION
Electrical stimulation has been used in different situations such as tissue regeneration, pain treatment and neuromuscular activation. It is used in order to increase muscle strength and performance, besides minimizing repetitive stress injuries both in able-bodied volunteers (ABV) and in spinal cord injured volunteers.
Mechanomyography (MMG) measures muscle mechanical changes both during voluntary contractions and when elicited by neuromuscular electrical stimulation (NMES), and may provide important feedback to assess muscular response during the stimulating current application to avoid muscle fatigue [1] and/or to improve muscle performance [2].
NMES and the MMG can be used simultaneously because the MMG transducer is selective, not dependent of the electrical signals and immune to electromagnetic interference (EMI) [3], differently from electromyography, that suffers interference from electrical stimuli [1]. Regarding the use of different NMES frequencies (5, 10, 15 and 20Hz), Yoshitake *et al.* [4] applied FES in medial *gastrocnemius* muscle of ABV and they concluded that the amplitude of MMG signal (peak to peak amplitude) decreases with FES increasing frequency.
Therefere, the effect of NMES frequency on MMG time-frequency signal is not clear. In this sense, the objective of this study is to investigate the influence of five burst frequencies on mechanical time-frequency response in *retus femoris* muscle of an able-bodied subject.

METHODS
The study was approved by PUCPR human research ethics committee (No. 2416/08). The test was performed with one ABV (22 yrs, 82kg, 1.87m).
Self-adhesive stimulation electrodes were placed in supra-patellar (anode, 5x9cm) and the femoral triangle (cathode, 5x5cm) regions. NMES was applied in the femoral nerve (monophasic square wave, pulse active period of 100µs [5, 6] and frequency of 1kHz, and burst active interval of 3ms [1] and 40V (intensity) with frequencies set to 20Hz, 35Hz, 50Hz, 75Hz and 100Hz. The total NMES delivered was 15s for each frequency. It was excluded the first and the final 2,5s of the MMG signal and the middle 10s was analyzed.
MMG sensor used was Freescale MMA7260Q MEMS triaxial accelerometer sensor (13x18mm, 0.94g) with 800 mV/V sensitivity at 1.5 G (G, gravitational acceleration). The electronic circuits allowed 3.3x amplification. A custom monoaxial electrogoniometer acquired the angular response. After the skin preparation (trichotomy and cleaning), the MMG sensor was positioned over the belly of *rectus femoris* muscle using double-sided adhesive tape. Despite being triaxial accelerometer we chose only the Y-axis which is oriented to the longitudinal muscle direction. The Y axis is sensitive to the tendon insertions approach.
The volunteer was positioned on an adapted bench (110° hip and 90° knee angles; 180º was the maximum extension angle). During the tests the knee joint angle was 105.3±0.40°. The period of stimulation was 15s and the frequencies order (20Hz, 35Hz, 50Hz, 75Hz and 100Hz) were set randomly, respecting an interval time of 2 min among the contractions.
A LabVIEW™ program was coded to acquire MMG signals with an acquisition board Data Translation™ DT300 series with 1 kHz sample rate. A third-order Butterworth filter was selected with bandpass range on 5-100 Hz. The points were selected through the software BioProc2© version 3 and processed by the software MatLab® version R2008a. The 10s of signal was processed in eleven bands of Cauchy wavelet transform [7] (2.07, 5.79, 11.31, 18.63, 27.71, 38.54, 51.12, 65.42, 81.45, 99.19 and 118.63Hz).

RESULTS AND DISCUSSION
The results of this study are shown in figure 1 and represent the MMG time-frequency response in burst frequencies of 20, 35, 50, 75 and 100Hz. For 20Hz, it was observed higher

concentration of the signal into the frequency band of 18.63Hz, suggesting that the muscle vibration is in according to the stimulated frequency. This relationship was also observed (figure 1) in the frequency of 35Hz (38.54Hz), and slightly less in 50Hz (51.12Hz). Although, to burst frequencies above 50Hz (75Hz and 100Hz) the distribution of frequency energy (red color in figure 1) were similarity to the frequency bands of 18.63Hz and 27.71Hz. We believe that MMG time-frequency response is not determined by the electrical stimuli, but there is a specific physiological response of motor units recruited at such frequencies. The higher frequencies of NMES can induce tetanic contractions, a fusion of the active fibers that, according to Esposito et al. [8] result on later reduction in the firing frequency, what might explain the reduction of signal intensity at frequencies above 50Hz.

CONCLUSIONS

The relation between burst frequency and MMG response in an able-bodied subject tends to be influenced for frequencies of up to 50Hz. On higher frequencies such as 75Hz and 100Hz, the *rectus femoris* muscle have a mechanical response similar to lower frequencies as 18.63Hz and 27.71Hz, respectively. Higher burst frequencies of NMES may induce fusion of active fibers resulting on a later reduction in the firing frequency.

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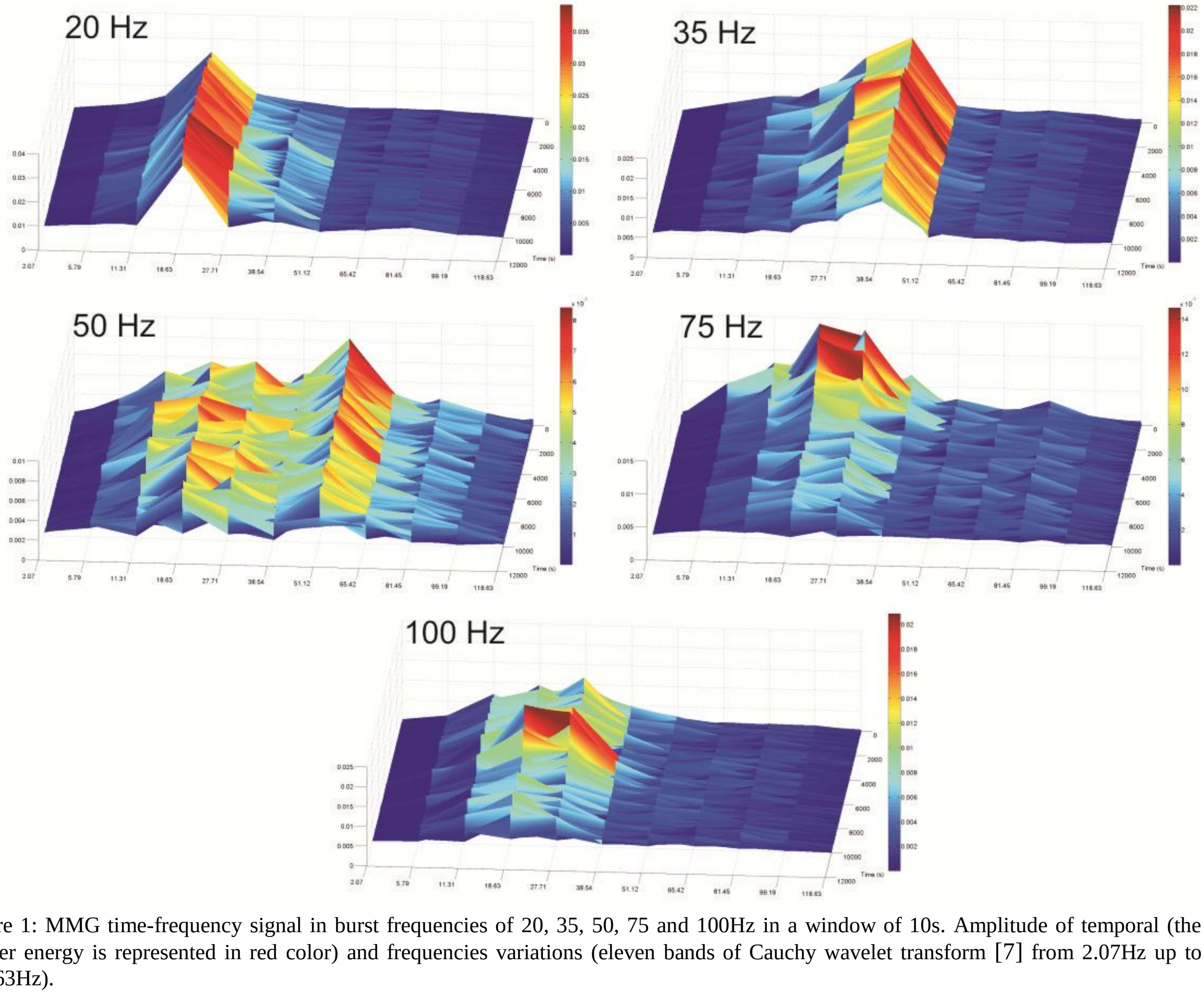

Figure 1: MMG time-frequency signal in burst frequencies of 20, 35, 50, 75 and 100Hz in a window of 10s. Amplitude of temporal (the greater energy is represented in red color) and frequencies variations (eleven bands of Cauchy wavelet transform [7] from 2.07Hz up to 118.63Hz).