Cortical and muscle response to focal vibro-tactile stimuli

Tijana Jevtic, Aleksandar Zivanovic and Rui C. V. Loureiro

***Abstract*—This paper investigates cortical responses to vibro-tactile stimuli. EEG was recorded in two conditions: when vibrations were applied focally on the muscle during relaxation and during muscle contraction. Mu and beta waves analysis of the EEG signals suggest that vibrations applied before the contraction increases the stretch of the muscle, thus improving its output performance. Further analysis of the vibrations applied during the muscle contraction shows cortical activation while modulating vibro-tactile stimuli to stabilise muscle performance.**

I. Introduction

Vibro-tactile stimulation appears to have an impact on both the healthy and impaired populations [1]. There is a growing interest in vibro-tactile modalities in particular with applicability in neurorehabilitation of spasticity [1]. Our initial work suggests that focal vibrations could also be used to improve the vibrated muscle's force output [2].

Evidence is mounting on the potential of vibro-tactile stimulation in rehabilitation, but what its lacking at present is the understanding of why such vibrations are effective, in particular when considered, for preconditioning the muscles to achieve better performance.

This paper discusses the cortical response to focal muscle vibro-tactile stimulation applied in two conditions: before the contraction and during the contraction. The study is based on the analysis of mu (μ) waves as they are associated with muscle and joint perception and motion coordination [3].

II. Materials and Methods

A. Subject

This paper presents a case study of an on-going larger study. The participant was a left-handed healthy male volunteer. The experiments were performed with approval of the local Ethics Committee. The participant gave informed consent to the experimental procedure as required by the Helsinki declaration (1964).

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B. Experimental setup

The experimental setup is adapted from a previous study [2]. The participant was asked to rest the hand on a table, in a midsuppination position. To achieve muscle contraction the participant was instructed to abduct the index finger by pushing against a force transducer. The vibrations were applied in two conditions over the muscle belly of the first interosseous muscle: during the relaxation period (i.e. before the contraction) or during the muscle contraction. Experimental protocol comprised of three repetitions of relaxation period lasting 60 seconds followed by 20 seconds of muscle contraction, allowing the muscle to relax between the contractions. During the contraction phase the participant was asked to maintain the specified force limits, which represented 80%±5% of maximal voluntary contraction force level.

Focal vibrations were applied using a small vibration motor (12mm Pico Vibe™) with the frequency generated by the motor modulated to 30Hz.

EEG was recorded using TMSi water based electrodes (spatial representation on Fig. 1. left) connected to a porti7 amplifier (TMSi, Netherlands).

C. Data Analysis

The signal processing and analysis were conducted in MATLAB® using well-established functions and signal processing toolboxes. The raw signals were band pass filtered between 5 and 35Hz using FIR filtering. Time frequency domain was represented using a spectrogram function, which calculates time-frequency dependency based on Fourier transformation. Power spectral density was calculated using the Welch method on both whole signal and on cut subsignals corresponding movement phases. The Welch power spectrum was calculated for the mu band (8-12Hz). The maximum(s) were represented with a topographic heatmap function corresponding to the electrode placement on a head.

III. Results

Magnitude of the mu waves corresponding electrode placement on head (represented on Fig. 1. left) are represented on Fig. 1, right. Comparative topographic representations corresponding to vibrations applied during relaxation are represented on the top-right plots, and during contraction on the bottom-right plots. The topographs in left column represent consecutive relaxation and contraction periods are presented in the right column.

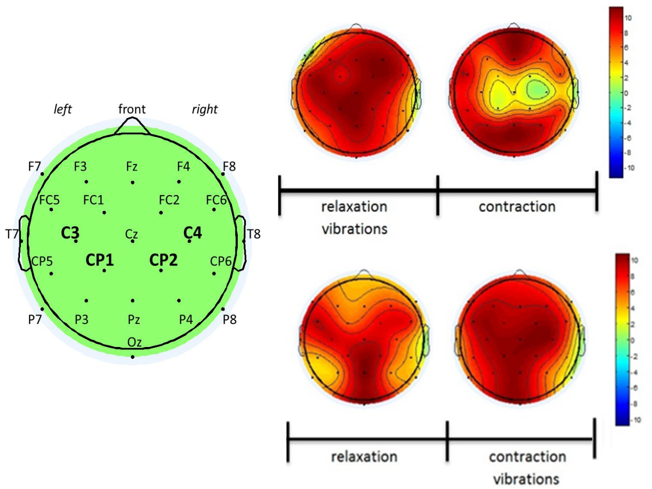

Fig. 1. (Left) Electrode placement (Right) Magnitude of mu waves in head topographic heat maps corresponding two vibration conditions: during relaxation (top) and during contraction (bottom).

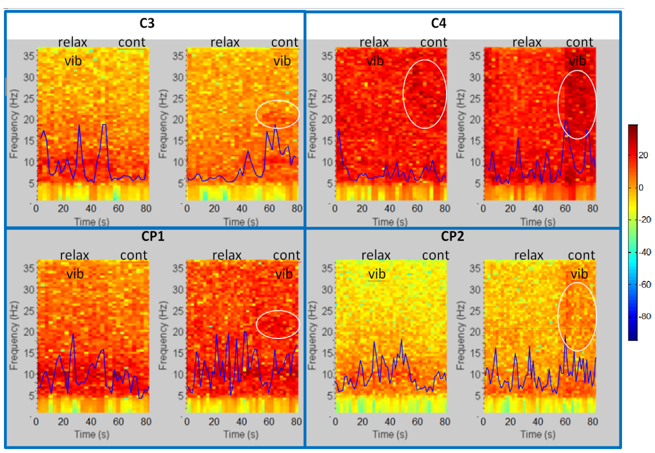

Fig. 2. Spectral analysis of one relaxation-contraction repetition for electrodes C3, C4, CP1 and CP2. The corresponding Welch power spectral density of mu waves is represented by the trace line in blue. White circles mark activation in beta band corresponding to movement (contraction).

Spectral analysis of the relaxation-contraction repetition on electrodes C3, C4, CP1 and CP2 is represented on Fig. 2. Visual inspection of the whole signal showed negligible differences hence only the last repetition is shown. On the same subfigures the corresponding Welch power spectral densities of the mu waves are presented. White circles mark activation in beta band corresponding to movement (contraction).

IV. Discussion

The dependency of the mu waves in relation to the movement can be observed in the first row of the Fig. 1 (right) topographic maps. The increased activity of the mu waves during the relaxation phase with vibrations being applied over the entire sensorimotor cortex (Fig. 1, top-left plot) seem to indicate that the muscle is not responding to vibro-tactile stimuli from cortical level [3]. If the muscle is not activated when vibrations are applied we postulate that the muscle (perhaps spindles and Golgi organ are equally involved) increased afferent thresholds and therefore responded to vibro-tactile stimuli with increased stretch. With increased stretch the muscle can produce more power and force which is in line with our previous findings that the vibrations might be suited to precondition enhanced muscle performance [2].

We also note an increase of the mu waves when vibrations are applied during the contraction (Fig. 1 bottom-right plot). The brain in this case seems to be involved in facilitating vibro-tactile stimuli in order to stabilise the muscle response, i.e. by recruiting less muscle fibres during contraction [4], which could explain the reduced muscle activation observed in our previous study [3].

Further analysis of the time-frequency spectrograms (shown on Fig. 2.) reveals an increase in the beta activity over the entire beta range (15-35 Hz) on the contralateral side in respect to the vibrated side (marked with white circles on the electrode C4). It can be noticed after every 60 Sec the desynchronisation of the mu waves, i.e. movement onset.

Nonetheless, the unexpected co-activation of the mu waves when vibrations are applied during contraction is observed over the contralateral side (right sub-plots of electrode C4 and CP2 plots). Perhaps this relates to co-activation of the movement execution in conjunction with the vibro-tactile stimulation (muscle stabilisation). This claim is further supported with the appearance of lower beta waves in the ipsilateral side around 20Hz (white circles on the right sub-plots of electrode C3 and CP1). Based on the previous assumption that the entire sensory cortex is active due to the vibro-tactile stimuli, the ipsilateral side of the motor cortex seems to be gearing up to respond to the contralateral activation [4]. Further analysis of the pre-motor areas of the cortex with a larger cohort is needed to ascertain this claim.

V. Conclusion

The results here presented exemplify a case study of an on-going larger study. This paper discusses the brain's response to vibro-tactile stimuli. The results of the mu waves analysis appear to indicate cortical involvement in vibro-tactile facilitation. We postulate possible beneficial properties associated with focal vibro-tactile muscle preconditioning reflected in increased muscle stretch producing enhanced muscle performance.

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