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Changes in slow and fast alpha bands in subjects submitted to different amounts of functional electrostimulation

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ABSTRACT

Objective: To examine the changes in slow (8–10 Hz) and fast (10–12 Hz) alpha bands of EEG in three groups of subjects submitted to different amounts of functional electrostimulation (FES). Our hypothesis is that different amounts of electrostimulation may cause different patterns of activation in the sensorimotor cortex. In particular, we expect to see an increase in alpha power due to habituation effects. We examine the two bands comprised by alpha rhythm (i.e., slow and fast alpha), since these two sub-rhythms are related to distinct aspects: general energy demands and specific motor aspects, respectively. *Methods*: The sample was composed of 27 students, both sexes, aging between 25 and 40 years old. The subjects were randomly distributed in three groups: control ($n = 9$), G24 ($n = 9$) and G36 ($n = 9$). A FES equipment (*Neuro Compact*-2462) was used to stimulate the right index finger extension. Simultaneously, the electroencephalographic signal was acquired. We investigated the absolute power in slow and fast alpha bands in the sensorimotor cortex. *Results*: The G36 indicated a significant increasing in absolute power values in lower and higher alpha components, respectively, when compared with the control group. Particularly, in the following regions: pre-motor cortex and primary motor cortex. *Discussion*: FES seems to promote cortical adaptations that are similar to those observed when someone learns a procedural task. FES application in the G36 was more effective in promoting such neural changes. The lower and higher components of alpha rhythms behave differently in their topographical distribution during FES application. These results suggest a somatotopic organization in primary motor cortex which can be represented by the fast alpha component.

The functional electrostimulation (FES) is considered one useful tool to improve the process of functional rehabilitation. However, the effects of its application in relation to the brain dynamics have not been consistently explored. Few studies have investigated the effects of FES on the electroencephalographic activity (EEG). Ecard et al. [2] observed a reduction of the electroencephalographic variable (i.e., asymmetry inter-hemispheric) related to beta's rhythm (13–35 Hz) after electrostimulation in the right upper limb. The decrease in asymmetry was interpreted by researchers as an indicator of the electrocortical activity normalization. In another experiment with FES on ischemic stroke victims, the authors argued that the normalization of the neural activity (i.e., a balance between the hemispheres) has been associated with a better clinical recovery [18]. Event-related synchronization (ERS) paradigm suggested that both limb movement and electrical stimulation of the dominant hand induced bursts of beta oscillations. Such oscillation patterns occurred within 1 s after movement/stimulation with a clear focus close to the corresponding sensorimotor representation area [8]. These oscillations might be indicative for a resonance-like behavior of connected sub-networks in sensorimotor areas. Event-related beta electroencephalographic changes during wrist movements induced by functional electrostimulation of the appropriate forearm muscles were studied. A prominent ERD was found immediately after the beginning of the FES movement. Moreover, beta ERS was seen after active wrist movements. Both changes were

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maximal over the contralateral primary hand area. The main difference between active and induced stimulation movements was that in the latter case, ERD was detected prior to movement onset [7]. These findings suggest that sensorimotor processing during FES is similar when individuals have to use voluntary hand movements. Therefore, the aim of the study was to examine changes in slow (8–10 Hz) and fast (10–12 Hz) alpha bands of EEG in three groups of healthy individuals submitted to different amounts of electrostimulation. Our hypothesis is that different amounts of electrostimulation may produce different patterns of activation in the sensorimotor cortex. We expect to see an increase in alpha power due to habituation effects. In particular, we expect to detect different response patterns of the two bands comprised by alpha rhythm (i.e., slow and fast alpha), since these two sub-rhythms are related to distinct aspects, general energy demands and specific motor aspects, respectively [1,4,5].

The sample was composed of 27 students (16 male and 11 female), aging between 25 and 40 years old (32.5 ± 7.5), right-handed [9]. The subjects were randomly distributed in three groups: control ($n = 9$), G24 ($n = 9$) and G36 ($n = 9$). Inclusion criteria were absence of mental or physical impairments (screened by a previous anamnesis) and absence of the use of psychoactive or psychotropic substances. Moreover, all individuals did not have any known neuromuscular disorders. All subjects signed a consent form and were aware of all the experimental protocol. The experiment was approved by the Ethics Committee of Federal University of Rio de Janeiro (IPUB/UFRJ).

All subjects seated comfortably in a sound and light-attenuated room during the test execution. The subjects sat in a chair, with arms supported on a table right in front of them, aiming to reduce muscle's artifacts. The participants were blindfolded to reduce potential visual stimuli and eyes blink. A FES equipment was used, Ibramed's brand model *Neuro Compact* (2462). We used an eight channel microcomputer-controlled stimulator (Ibramed, Neuro Compact-2642), with biphasic (fixed pulse width of 320 μs for each phase), rectangular with constant-current pulses to stimulate the hands' muscle of participants. The frequency of the stimulation pulses was set in 48.8 Hz to achieve a sufficiently smooth and strong contraction of the muscles without extensive fatigue. The current amplitude was set at 2×10^{-3} A. The device consists on a current source and was used to stimulate the right index finger extension. The hand was fixed on a table and a velcro's strip was used to immobilize all other fingers, leaving only the index finger free of stimulation. Skin's resistance was measured by a multimeter (ohmmeter) and ranged from 800 Ω (ohms) to 1500 Ω. The skin was scraped and cleaned with alcohol, it was also used a gel between the electrodes and the skin. The electrodes were set up at 5 cm from the lateral epicondylus on the lateral forearm side, and the other 12 cm from the first one, occupying the posterior forearm side, following the index finger extensor tendon's trajectory. The experiment consisted of trials and blocks. Each trial was determined by stimulation moment (i.e., time *on*) with 4.86 s of current passage, added to a resting moment (time *off*) with 8.39 s without current passage. Each block was composed of six trials. The control group simulated four blocks (i.e., 24 trials) with 1-min period between each block without electrostimulation been applied. The current intensity for this group was naught. The G24 group was exposed to four blocks (i.e., 24 trials) of FES with 1-min interval between each block, obeying the device conditions described before. Only the G36 group was exposed to six blocks (i.e., 36 trials) of FES with 1-min interval between each block under the same conditions of G24. For G24 (i.e., four blocks) were applied 5.693 pulses with a total time of 116.64 s. For G36 (i.e., six blocks) were delivered 8.539 pulses with a total time of 174.96 s. The control group only simulated the electrostimulation procedures as described above. Simultaneously with the electrostimulation of the extensor muscle's finger, electroencephalographic signals were acquired. The synchronization between the electrostimulator and the electroencephalographic device was established by a pulse sent to the EEG's amplifier through the auxiliary channel input, which was obtained directly from the internal stimulator frequency generator's circuit (timer 555).

The International 10/20 System for electrodes [3] was used with the 20-channel EEG system Braintech-3000 (EMSA-Medical Instruments, Brazil). The 20 electrodes were arranged in a nylon cap (ElectroCap Inc., Fairfax, VA, USA) yielding monopole derivations referred to linked earlobes. In addition, two 9-mm diameter electrodes were attached above and on the external corner of the right eye, in a bipolar electrode montage, for eye-movement (EOG) artifacts monitoring. Impedance of EEG and EOG electrodes were kept under 5–10 kΩ. Visual inspection and independent component analysis (ICA) were applied to remove possible sources of artifacts produced by the task. The data acquired had total amplitude of less than 100 μV. The EEG signal was amplified with a gain of 22,000, analogically filtered between 0.01 Hz (high-pass) and 100 Hz (low-pass), and sampled at 240 Hz. The software *DataAcquisition* (Delphi 5.0), developed at the Brain Mapping and Sensorimotor Integration Laboratory was employed to filter the raw data: *notch* (60 Hz), high-pass of 0.3 Hz and low-pass of 25 Hz.

To obtain reference-free data, a classic estimator was applied for the power spectral density (PSD), or directly from the square modulus of the Fourier Transform (FT), which was performed by MATLAB 5.3 (Mathworks, Inc.). The number of samples was 800 ($4\,\text{s} \times 200\,\text{Hz}$) with rectangular windowing. Quantitative EEG parameters were reduced to 8-s periods time-locked with movement-offset or stimulation (the selected epoch started 4 s before and ended 4 s after the trigger, i.e., moment 1 and moment 2, respectively). Thereafter, all raw EEG trials were visually controlled and trials contaminated with ocular or muscle artifacts were discarded. The Fast Fourier Transform resolution was 1/4 s–0.25 Hz (see FFT formula below). To examine stationary, the "Run-test" and "Reverse-Arrangement test" were applied. Specially, the stationary was accepted for each 4 s (epoch's duration in this period). In this manner, based in EEG free epochs (i.e., no artifacts), a threshold given by mean added up three standard deviation was established, and epochs with total power higher than this threshold were not integrated in the analysis. Fast Fourier Transform formula is described below:

$$F_n = \sum_{k=0}^{N-1} f_k \; e^{-i2\pi n(k/N)} = \sum_{k=0}^{N-1} f_k W^{kn}, \quad n = 0, \ldots, N-1$$

In order to evaluate changes in power values in each investigated electrode (i.e., F3, Fz, F4, C3, Cz, C4, P3, Pz, P4), an *ANOVA three-way* (repeated measures), a pair-wise analysis and a post hoc test (Bonferroni's test) were used. The factors group (i.e., control, G24 and G36), moment (i.e., m1: pre-stimuli moment and m2: after-stimuli moment) and block (i.e., first to last block) were compared ($p < 0.05$). The EEG absolute power values were $\log_{10}$ transformed by *SPSS* software (Version 15.0) to approximate a normal distribution.

ANOVA results demonstrated an interaction between group and moment factors for slow alpha band in F3 electrode ($p < 0.05$). A pair-wise analysis indicated a significant increase in absolute power values in G36 (mean = 3.64; S.D. = 0.99) compared with control group (mean = 3.16; S.D. = 0.95) only in m1 (pre-stimulation period) as observed in Fig. 1. In relation to fast alpha band, a group main effect was observed in C3 electrode ($p < 0.05$). A post hoc analysis demonstrated a significant increase in absolute power values in G36 (mean = 4.12; S.D. = 0.85) compared with control group