Neuroscience Letters 469 (2010) 150–154

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Changes of somatomotor and parietal regions produced by different amounts of electrical stimulation

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ARTICLE INFO

Article history:
Received 5 October 2009
Received in revised form
12 November 2009
Accepted 21 November 2009

Keywords:
Absolute theta power
Electrical stimulation
qEEG
Sensorimotor integration
Motor control

ABSTRACT

Our study aims to investigate changes in electrocortical activity by observing the variations in absolute theta power in the primary somatomotor and parietal regions of the brain under three different electrical stimulation conditions: control group (without stimulation), group 24 (24 trials of stimulation) and group 36 (36 trials of stimulation). Thus, our hypothesis is that the application of different patterns of electrical stimulation will promote different states of habituation in these regions. The sample was composed of 24 healthy (absence of mental and physical impairments) students (14 male and 10 female), with ages varying from 25 to 40 years old (32.5 ± 7.5), who are right-handed (Edinburgh Inventory). The subjects were randomly distributed into three groups: control ($n = 8$), G24 ($n = 8$) and G36 ($n = 8$). We use the Functional electrical stimulation (FES) equipment (*NeuroCompact*-2462) to stimulate the right index finger extensor muscle, while the electroencephalographic signal was simultaneously recorded. We found an interaction between condition and block factors for the C3 and P3 electrode, a condition and block main effects for the C4 electrode, and a condition main effect for the P4 electrode. Our results support the hypothesis that electrical stimulation promotes neurophysiological changes. It appears that stimulus adaptation (accommodation) of specific circuits can strengthen the brain's ability to distinguish between and respond to such stimuli over time.

Functional electrical stimulation (FES) is a method that involves neuromuscular electrical stimulation that produces changes in functional activity [1,33]. The activity triggered in brain function dynamics due to electrical stimulation is not well covered in the current literature. Thus, understanding the learning process and the changes caused in the brain after electrical stimulation is essential for developing strategies to comprehend sensorimotor integration [6,29]. Through quantitative electroencephalography (qEEG), it is possible to detect changes in the brain caused by sensory, cognitive or motor stimuli [33,10,17]. Previous studies have investigated the relationship between electrical stimulation and electroencephalographic activation [33,25]. These authors observed that FES induces transient changes, which can be detected by qEEG. The relationship between FES and qEEG has been observed in beta and alpha bands, after the application of electrical stimulation to the primary motor cortex [25,20,24].

In the current literature on studies attempting to understand the relationship between qEEG and electrical stimulation, theta band has not been observed and investigated. Theta band (4–7 Hz) is related to functions such as encoding and the retrieval of information [5] and information processing [6,16]. Although theta has been associated with information processing, no study has observed the function of theta band in purely sensorial task. In this context, our study aims to investigate changes in electrocortical activity by observing the variations in absolute theta power in the primary somatomotor and parietal regions of the brain under three different electrical stimulation conditions. Our hypothesis is that the application of different amounts of electrical stimulation quantity will provoke different absolute theta power values in the primary somatomotor and parietal regions.

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doi:10.1016/j.neulet.2009.11.063

The sample was composed of 24 students (14 male and 10 female), with ages varying from 25 to 40 years old (32.5 ± 7.5), who are right-handed [22]. Subjects were screened for mental or physical impairments using previous anamnesis and clinical examinations. Only subjects who did not demonstrate these traits were chosen. They were also screened for psychoactive or psychotropic substances. All subjects signed a consent form and were aware of the experimental protocol. The individuals were not paid for participating in the study. The experiment was approved by the Ethics Committee of the Federal University of Rio de Janeiro (IPUB/UFRJ).

The subjects were randomly distributed into three groups: control ($n = 8$), G24 ($n = 8$) and G36 ($n = 8$). Subjects were seated in a comfortably sound and light-attenuated room during the task. They sat in a chair, and a table was used for arm support in order to reduce muscle artifacts. The participants were blindfolded to reduce potential visual stimuli and blinking. We used an eight channel microcomputer-controlled stimulator (Ibramed, Neuro Compact-2642), with a biphasic (fixed pulse width of 320 μs for each phase), which provided constant-current pulses to the muscle of the participants' hands. 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 provided a constant current and was used to stimulate the extension of the right index finger. The hand was secured to the table and a velcro strip was used to immobilize all other fingers, leaving only the index finger free for stimulation. The resistance of the skin was measured by a multimeter (ohmmeter) and ranged from 800 Ω (ohms) to 1500 Ω. The skin was shaved and cleaned with alcohol. The electrodes were set up at 5 cm from the lateral epicondylus on the lateral forearm side, and the other electrode was placed 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 composed of a stimulation moment (i.e., time on) of 4.86 s of current, plus a resting moment (time off) consisting of 8.39 s without a current. Each block was composed of six trials. The control group simulated four blocks (i.e., 24 trials) with 1-min periods between each block without electrostimulation been applied. The current intensity for this group was zero. The G24 group was exposed to four blocks (i.e., 24 trials) of electrostimulation with 1-min intervals between each block, under the conditions described previously. Only the G36 group was exposed to six blocks (i.e., 36 trials) of electrostimulation with 1-min intervals between each block under the same conditions of G24. 5.693 pulses lasting 116.64 s were applied to G24. 8.539 pulses lasting 174.96 s were delivered to G36. The control group only simulated the electrostimulation procedures as described above. Simultaneously with the electrostimulation of the finger extensor muscle, electroencephalographic signals were recorded.

The International 10/20 System for electrodes [15] was used with the 20-channel EEG system Braintech-3000 (EMSAMedical Instruments, Brazil). The 20 electrodes were arranged in a nylon cap (ElectroCap Inc., Fairfax, VA, USA) yielding monopolar derivations using the earlobes reference. In addition, two 9 mm diameter electrodes were attached above and on the external corner of the right eye, in a bipolar electrode montage, to monitor eye-movement (EOG) artifacts. Impedance of EEG and EOG electrodes was kept between 5 and 10 kΩ. The data recorded had a 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 *Data Acquisition* (Delphi 5.0) at the Brain Mapping and Sensory Motor Integration Lab, was employed with the following digital filters: notch (60 Hz).

To quantify reference-free data, a visual inspection and independent component analysis (ICA) were applied to remove possible sources of artifacts produced by the task. A classic estimator was applied for the power spectral density (PSD), or directly from the square modulus of the FT (Fourier Transform), which was performed by MATLAB 5.3 (Matworks, Inc.). The number of samples was 800 ($4\,s \times 200\,Hz$) with rectangular windowing. Quantitative EEG parameters were extracted from 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 Fourier Transform resolution was 1/4 s to 0.25 Hz (FFT). To examine a stationary process, the "Run-test" and "Reverse-Arrangement test" were applied. Specially, the stationary process was accepted for each 4 s (epoch's duration in this period). In this manner, based on artifact-free EEG epochs, the threshold was defined by mean plus three standard deviations and epochs with a total power higher than this threshold were not integrated into the analysis.

To evaluate changes in theta power values we analyzed different electrodes: C3, C4, P3 and P4. An ANOVA two-way (repeated measures) and a Bonferroni's post hoc test were used to analyze the factors group (i.e., CG, G24 and G36) and block (i.e., first and last block) for each electrode. We use a *t*-test and an ANOVA one-way (repeated measures) to verify differences within factors, when we observed interaction.

In the first analysis we analyzed the C3 electrode. An interaction between condition and block factors ($p = 0.014$, $F = 4.302$) was demonstrated. To investigate the interaction we performed an ANOVA one-way among conditions (i.e., CG, G24 and G36) for each block (i.e., first and last block). There was verified a condition main effect for the first block ($p < 0.001$, $F = 88.243$) and a condition main effect for the last block ($p < 0.001$, $F = 58.474$). We found a significant difference between GC and G24, and between GC and G36 for the first ($p < 0.001$) and last ($p < 0.001$) blocks, as observed by Bon-

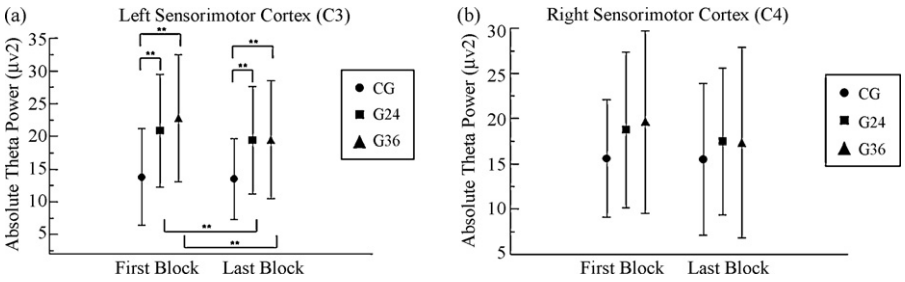

Fig. 1. Mean and standard absolute theta power between the first and last block of electrical stimulation in three experimental conditions (i.e., GC, G24 and G36) in the primary sensorimotor cortex. (a) The findings showed an interaction between condition and block factors for C3 ($p = 0.014$). (b) In the C4 electrode demonstrated a condition ($p < 0.001$) and block ($p = 0.007$) main effect.