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Neuroscience Letters 426 (2007) 155–159
Neuroscience Letters
www.elsevier.com/locate/neulet

Electrophysiological analysis of a sensorimotor integration task

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Received 23 July 2007; received in revised form 17 August 2007; accepted 24 August 2007

Abstract

The present experiment aimed at investigating electrophysiologic changes observed as beta band asymmetry, by Quantitative Electroencephalography (qEEG), when individuals performed a reaching motor task (catching a ball in free fall). The sample was composed of 23 healthy individuals, of both sexes, with ages varying between 25 and 40 years old. All the subjects were right handed. A two-way ANOVA was applied for the statistical analysis, to verify the interaction between task moment (i.e., 2 s before and 2 s after ball's fall) and electrode (i.e., frontal, central and temporal regions). The first analysis compared electrodes placed over the somatosensory cortex. Central sites (C3–C4) were compared with temporal regions (T3–T4). The results showed a main effect for moment and position. The second analysis was focused over the premotor cortex, which was represented by the electrodes placed on the frontal sites (F3–F4 versus F7–F8), and a main effect was observed for position. Taken together, these results show a pattern of asymmetry in the somatosensory cortex, associated with a preparatory mechanism when individuals have to catch an object during free fall. With respect to task moment, after the ball's fall, the asymmetry was reduced. Moreover, the difference in asymmetry between the observed regions were related to a supposed specialization of areas (i.e., temporal and central). The temporal region was associated with cognitive processes involved in the motor action (i.e., explicit knowledge). On the other hand, the central sites were related to the motor control mechanisms per se (i.e., implicit knowledge). The premotor cortex, represented by two frontal regions (i.e., F3–F4 versus F7–F8), showed a decrease on neural activity in the contralateral hemisphere (i.e., to the right hand). This result is in agreement with other experiments suggesting a participation of the frontal cortex in the planning of the apprehension task. This sensorimotor paradigm may contribute to the repertoire of tasks used to study clinical conditions such as depression, alzheimer and Parkinson diseases.

Keywords: Motor control; Sensorymotor integration; Asymmetry; qEEG

The preparation of future actions in order to achieve a goal is a fundamental aspect of the performance and control of a motor task [26]. The performance of movements needs a motor planning in different levels and involves the choice of various actions [18,30]. Catching an object is a complex movement which involves not only programming but also effective motor coordination. Such behavior is related with the activation and recruitment of cortical regions which take part in the integration process that occurs between the information provided by the environment and the performed motor task [4]. Experiments that use electromyography have shown changes that occur in the muscular activity when individuals have to catch an object as a ball [13,14]. However, few studies have tried to clarify the changes that occur in the cortical electrical activity during the performance of movements related with catching objects [25]. QEEG is able to detect these changes related to the motor preparation, in particular as the predominance of contralateral activity (to the hand that moves) following the movement [1,6,22]. QEEG changes are associated with a neural re-organization that follows the acquisition and the motor ability control [32]. Previous results have demonstrated variations in the beta band, as

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0304-3940/$ – see front matter
doi:10.1016/j.neulet.2007.08.061

synchronization and dessyncronization before and during the movement. Precisely, a decrease in beta activity starts 1 (one) second before the beginning of the action [1], and it is typically found in central areas during voluntary tasks which are performed manually [21,24,33]. Alterations in the beta band are also associated with movement control and sensoriomotor integration processes [12,20], besides having been recently correlated to attention, but in this case having a complex, multifocal topographic distribution [3]. In this study, we analyzed the asymmetry measures in the moments prior to and following the objects' free fall. These measures allow one to verify the possible differences in activation in different brain regions along the right and left hemispheres [17], by an absolute comparison of amplitudes between homologous electrodes [16]. Specifically, we antecipated that somatosensory and the frontal areas would change power values few seconds before the ball's fall. Although some studies have examined this asymmetry measures in different experimental situations [5,16,17], few studies have tried to investigate such measure during reaching anticipation motor tasks.

Sample was composed of 23 students, of both sexes, right handed [19], with ages ranging from 25 to 40 years old. Inclusion criteria were: absence of mental or physical impairments (screened by a previous anamnesis) and the lack of use of psychoactive substances. Moreover, all individuals had no known neuromuscular disorders. All subjects signed a consent form and were aware of all experimental protocol. The experiment was approved by the Ethics Committee of Federal University of Rio de Janeiro (IPUB/UFRJ).

The task was performed on dim illumination and silence, to minimize sensory interference. Individuals sat on a comfortable chair to minimize muscular artifacts, while electroencephalography (EEG) and electromyography (EMG) data were collected. An electromagnetic system, composed of two solenoids, was placed right in front of the subject and released 8 cm-balls, one at each 11 s, at 40 cm above the floor, straight onto the subject's hand. The right hand was placed in a way that the four medial metacarpi were in the fall line. After its catch, the ball was immediately discharged. Each released ball composed a trial and blocks were made of 15 trials. The total experiment had six blocks that lasted 2 min and 30 s, with 1-min intervals between them.

The International 10/20 System for electrodes 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 monopolar 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 was kept under 5 kΩ and 20 kΩ, respectively. 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 35 Hz (low-pass), and sampled at 240 Hz. The software *Data Acquisition* (Delphi 5.0), developed at the Brain Mapping and Sensorimotor Integration Lab, was employed with the following digital filters: *notch* (60 Hz), high-pass of 0.3 Hz and low-pass of 25 Hz.

Electromyographic (EMG) activity of the flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), extensor carpi radialis (ECR) and extensor carpi ulnaris (ECU) was recorded by an EMG device (Lynx-EMG1000), to monitor and assess any voluntary movement during the task. Bipolar electrodes (2 mm recording diameter) were attached to the skin. The reference electrode was fixed on the skin overlying the lateral epicondyle near the wrist joint. The skin was cleaned with alcohol prior to electrode attachment. The EMG was amplified (×1000), filtered (10–3000 Hz), digitized (10,000 samples/s), and recorded synchronously to the EEG onto the computer's hard drive. In each trial, the EMG signal was rectified and averaged over the 500 ms starting from the trigger onset. EMG was used in order to detect and remove possible artifacts related to the object's fall that could affect the electroencephalographic signal.

A classic power spectral density (PSD) estimator was used (i.e., based on the squared absolute value of the Fourier Transform), for consecutive (non-overlapping) artifact-free, 4-s EEG epochs (spectral resolution: 0.25 Hz), with rectangular windowing. One relative power value (percentage of the total power) was estimated for each epoch based on numerical integration of PSD in each considered EEG band, resulting in a set of values for each moment. Asymmetry measure is defined as the functional difference between the left and right hemispheres; it measures the difference in absolute amplitude which exists between the homologous electrodes located on these hemispheres [16,17]. It was calculated from the equation: $Pa - Pb/Pa + Pb$, where Pa corresponds to the absolute power of the electrode located on the left hemisphere, and Pb corresponds to the absolute power located on the right hemisphere.

Beta band is associated with the state that most of the brain is in when humans have their eyes open and are listening and thinking during analytical problem solving, judgment, decision making, movement preparation and processing information about the world around them [6,24]. Therefore, three scalp areas were assessed: frontal, central and temporal. The central and temporal areas are influenced by the somatossensory cortex, which plays an important role in providing information for the production and performance of the voluntary movement. The following pairs of electrodes were observed: C3–C4 versus T3–T4. On the other hand, the frontal cortex is related to cognitive processes (planning) of voluntary movements and event anticipation [29], and it plays a primary role in voluntary motor tasks [8]. Two homologous pairs were also observed: F3–F4 versus F7–F8. Due to the laterality of the participants (right handedness), the right hemisphere was considered ipsilateral.

Two statistical analyses were performed: (a) the first was a two-way ANOVA, which compared task moment and scalp position factors, being that the former represents the pre and post ball release times (2 s before and 2 s after), and the later the scalp's electrode position: central (C3–C4) versus temporal (T3–T4); (b) a second two-way ANOVA was carried out analyzing the moment and position factors in the frontal cortex region. This

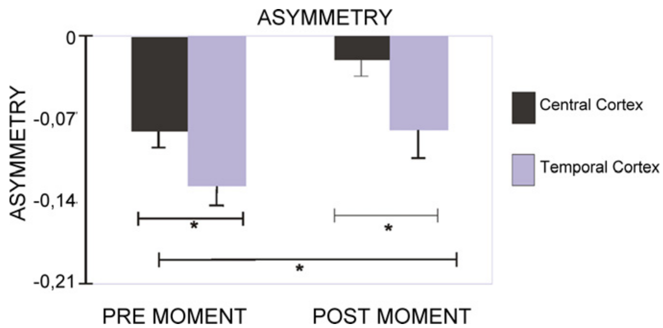

Fig. 1. Beta band asymmetry between pre and post moment (balls' drop) in two differents scalp's sites, central and temporal cortex. The results showed a main effect for moment ($p = 0.006$) and position ($p = 0.005$) ($p < 0.05$) (*0.01).

region was subdivided into orbitofrontal cortex (MOC) (F3–F4) and lateral orbitofrontal cortex (LOC) (F7–F8), which were then compared.

The first statistical analysis performed compared central and parietal regions (somatossensory) in the moments before and after the fall of the ball, and the results showed a main effect for the moment ($p = 0.006$; $F = 7.717$) and position ($p = 0.005$; $F = 8.051$) factors. However, no interaction occurred between these two factors ($p = 0.451$; $F = 0.569$) (Fig. 1). In the second analysis, a main effect for the position factor was observed ($p = 0.000$; $F = 34.585$). There was neither an interaction between the factors ($p = 0.451$; $F = 0.571$) nor a main effect for the moment factor ($p = 0.650$; $F = 0.206$) (Fig. 2).

The main goal of the current experiment was to examine the possible electrophysiological changes that might occur prior and following the act of catching a free falling object. The behavior of the asymmetry variable was analyzed in the beta frequency band, in different cortical regions, specifically frontal, central and temporal [9,31].

The motor task is represented in various cortical areas. The somatosensory region plays a key role in the movement's mnemonic representation. In spite the fact that this experiment was not associated with the learning process of how to catch and object, but rather to the movement control, the somatosensory cortex could provide information in parallel to the processes of preparing and performing the task [9]. Changes in the somatosensory cortex were observed when individuals

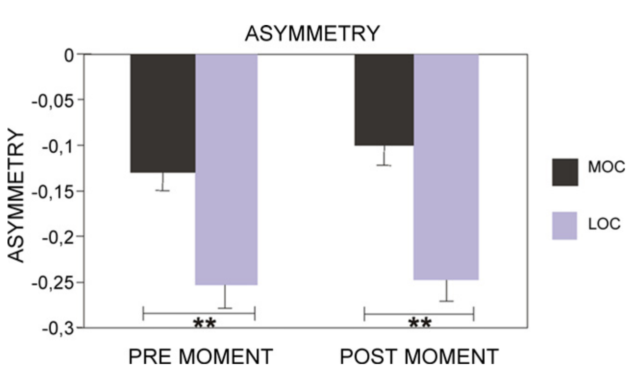

Fig. 2. Beta band asymmetry between pre and post moment (balls' drop) in two differents scalp's sites in the frontal lobe. The results showed a main effect for position ($p = 0.000$) ($p < 0.05$) (**0.001).

performed the task of catching the ball, and analysis showed a main effect for moment and position factors. Regarding the former, studies have proved that 2 (two) seconds prior the fall (of the ball), the somatosensory cortex behaved in a more asymmetric way than when compared with the post-fall moment. Such results can be explained by experiments demonstrating that the voluntary movement is preceded by a reduction in beta frequency power, which starts in the contralateral region and around 1.5 s before the beginning of the movement [7,21]. However, many experiments pointed to a reduction in beta power that happens 2 s before the beginning of the movement [11,15]. In the present case, the data were analyzed 2 s before the movement began, which would support such conclusions. This beta reduction (i.e., desynchronization) has been associated with an increase in neural activity, possibly related to a preparatory mechanism in the somatosensory area that generates the motor execution [7,23,24]. Previously published data point to a similar behavior between the beta and alpha bands, i.e., the amplitude would be inversely proportional to the neural activity [7,17]. Alpha band power increases can be considered as an index of transient cortical idling (mainly of posterior cortical areas) [3], with their amplitude being inversely associated with the amount of cortical neuronal populations activated during perceptual, cognitive and motor actions [32]. Summing up, the increase in beta power indicates a decrease in neural activity, while a reduction in beta power is associated with an increase in neural activity. Such reduction in beta, seconds before the beginning of the movement, may thus indicate increased neural activity of the somatosensory cortex. Regarding the post-fall moment, a decrease in beta asymmetry was observed, which suggests a greater balance between the power measurements between the hemispheres. The increase in balance may be related with the increase in beta seconds after the end of the movement, in the contralateral hemisphere. These data match a beta return (i.e., synchronization) which typically occurs 1/2 a second after the end of the movement and continues for a few milliseconds [2,23]. The beta power returns consistently, and, sometimes exceeds the pre-movement levels [24]. This beta increases which follows the end of the movement is known as a beta rebound, and it occurs at a postmovement (i.e., postmovement beta rebound—PMBR). It has been suggested that this event represents an inhibition either of the motor cortex, or the somatosensory cortex, or still a sensory reference [11]. A main effect was observed regarding the position factor. The C3–C4 pair of central electrodes was compared with the temporal electrodes (T3–T4), and the results indicate a greater asymmetry in the temporal region. The difference between these two regions may be related to the functional specialization of the corresponding cortical areas. In other experiments, it was observed that an activation in the temporal region occurs during the performance of motor tasks. This participation has been interpreted as an involvement of this region in the processing of cognitive information related to the movement [10,28]. Regarding the central scalp area, experiments have shown that this region is adjacent to the somatosensory and primary motor cortices [28], thus appearing to relate them with the performance and control of the voluntary movement. Therefore, the more symmetric values seen in our results, i.e., the central region showing a greater balance in the activation of left and right hemispheres when compared to the temporal cortex, support a participation of the midcentral cortex in voluntary movement performance opposed to what one would expect from somatotopic organization.

The results point to a main effect of position, and no differences were found between the pre and post-fall moments. The premotor cortex is greatly represented by the frontal region. The functions related to the premotor cortex are complex and many experiments have proved throughout the years that at least three may be associated with this region: movement planning and preparation [27]; directing a task to its accomplishment and event anticipation [29]; and, finally, the frontal region play a primary role in voluntary motor activities [8]. It was observed that the orbitofrontal region (F7–F8) is more asymmetric than the medial orbitofrontal (F3–F4). Such results suggest a greater activity unbalance between the hemispheres in the lateral orbitofrontal region, when compared with the medial orbitofrontal region. However, in both frontal regions (F3–F4 versus F7–F8), results show increased beta power in the right hemisphere, ipsilateral to the side of catching the object. Differences would be expected to be found between the preparation period, the one that precedes the fall, and the period right after the fall, involving the performance of the motor task. In spite of that, no main effect was observed. This may be related to the participation of both areas in both stages of the act of catching the object, i.e., preparing and performing. It is important to observe that the lateral orbitofrontal and medial orbitofrontal activity, as reflected in EEG, appear related not only to the preparation, but also to the execution of the movement [34,35]. Our findings indicate a reduction in neural activity in the contralateral hemisphere, a possible correlate of mechanisms of preparation for the act of catching the object. Prior experiments have shown that cortical rhythmic reactivity is includes the premotor cortex [33]. Furthermore, these studies also observed that the orbitofrontal region has an inconsistent involvement in the preparation of the movement [33]. It has been suggested that the occurence of movement-related beta activity on the scalp is relatively restricted to a pre-central region, especifically overlapping the frontal premotor cortex [21,33].

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