Neuroscience Letters 446 (2008) 7–10

Contents lists available at ScienceDirect

Neuroscience Letters

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

Integration of cortical areas during performance of a catching ball task

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ARTICLE INFO

Article history:
Received 7 August 2008
Received in revised form 1 September 2008
Accepted 16 September 2008

Keywords:
Absolute power
Catching
qEEG
Sensorimotor integration

ABSTRACT

The study aimed to elucidate electrophysiological and cortical mechanisms involved in anticipatory actions when healthy subjects had to catch balls in free drop; specifically through quantitative electroencephalography (qEEG) alpha absolute power changes. Our hypothesis is that during the preparation of motor action (i.e., 2 s before ball's drop) occurred integration among left medial frontal, left primary somatomotor and left posterior parietal cortices, showing a differentiated activity involving expectation, planning and preparedness. This hypothesis supports a lateralization of motor function. Although we contend that in right-handers the left hemisphere takes on a dominant role for the regulation of motor behavior. The sample was composed of 23 healthy subjects (13 male and 10 female), right handed, with ages varying between 25 and 40 years old (32.5 ± 7.5), absence of mental and physical illness, right handed, and do not make use of any psychoactive or psychotropic substance at the time of the study. The experiment consisted of a task of catching balls in free drop. The three-way ANOVA analysis demonstrated an interaction between moment and position in left medial frontal cortex (F3 electrode), somatomotor cortex (C3 electrode) and posterior parietal cortex (P3 electrode; $p < 0.001$). Summarizing, through experimental task employed, it was possible to observe integration among frontal, central and parietal regions. This integration appears to be more predominant in expectation, planning and motor preparation. In this way, it established an absolute predominance of this mechanism under the left hemisphere.

Motor behavior is the product of a fine integration between cortical and peripheral components associated to afferent information. It has acknowledged the relevance of identifying, acquiring and processing sensory stimuli during the execution and control of a motor task [15]. Such factors are the elementary components of the preparation and adjustment of a motor gesture, and they take part in the integration among different specialized centers in the final production of the movement [18]. This process occurs through sensorimotor integration, when sensory information is integrated by central nervous system to attend to motor programs. The possibility of adjusting a certain action to the different environmental demands provides a variety of movements and skills essential to the improvement of the desired motor execution [17]. 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 coming from the environment and the performed motor task [6].

The quantitative electroencephalogram (qEEG) might be well suited to the task of monitoring the changes in brain state that occur when an individual performing a task comes to adopt an effective strategy and to develop appropriate skills. Spectral features of the electroencephalography (EEG) in the alpha (8–12 Hz) band are sensitive to variations in perception, cognition or motor action [3]. In this manner, the assessment of EEG would be informative as it could address how the brain organizes and integrates sensory information, performs cognitive operations and achieves motor control

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doi:10.1016/j.neulet.2008.09.036

during the performance of multiple complex tasks. Identification of such cortical dynamics could be useful in the future with the appropriate technologies for assessment of these processes [14]. This study aimed to elucidate electrophysiological/cortical mechanisms involved in anticipatory actions when individuals had to catch balls in free drop; specifically through qEEG alpha absolute power changes. Our hypothesis is that during the preparation of motor action (i.e., moment preceding balls drop) occurred integration among left medial frontal, left primary somatomotor and left parietal posterior cortices, showing a differentiated activity involving expectation, planning and preparedness. This hypothesis supports a lateralization of motor function. Although we contend that in right-handers the left hemisphere takes on a dominant role for the regulation of motor behavior.

Sample was composed of 23 healthy subjects (13 male and 10 female), right handed [20], with ages varying between 25 and 40 years old (32.5 ± 7.5). Inclusion criteria were absence of mental or physical impairments, no history of psychoactive substances and no neuromuscular disorders (screened by a previous clinical examination). All subjects signed a consent form and were aware of the whole experimental protocol. The experiment was approved by the Ethics Committee of Federal University of Rio de Janeiro (IPUB/UFRJ). This experimental paradigm has been already used in other experiment [26].

The task was performed in a sound and light-attenuated room, to minimize sensory interference. Individuals sat on a comfortable chair to minimize muscular artifacts, while electroencephalography 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. All experiment had six blocks that lasted 2 min and 30 s with 1 min intervals between them.

EEG The International 10/20 System for electrodes [12] 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 between 5 and 10 KΩ. 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 Data Acquisition (Delphi 5.0), developed at the Brain Mapping and Sensory Motor Integration Lab, was employed with the following digital filters: notch (60 Hz), high-pass of 0.3 Hz and low-pass of 25 Hz.

EMG Electromyographic 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 ball's fall that could affect the electroencephalographic signal.

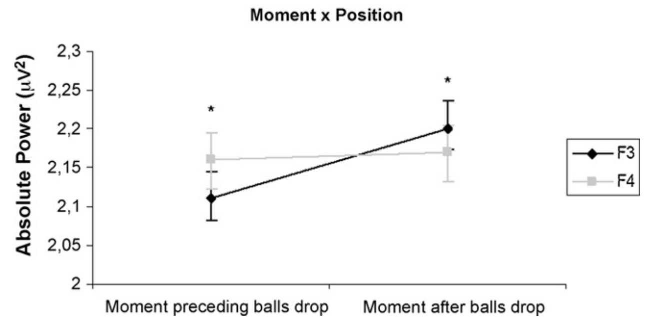

Fig. 1. Interaction between moment and position factors on F3–F4 electrode combination observed through mean and standard deviation values. (*) Significant difference, $p < 0.001$.

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 Fourier transform (FT), which was performed by MATLAB 5.3 (Matworks, Inc.). Quantitative EEG parameters were reduced to 4-s periods (the selected epoch started 2 s before and ended 2 s after the trigger, i.e., moment preceding balls drop and moment after balls drop), for consecutive (non-overlapping) artifact-free, 4 s EEG epochs (spectral resolution: 0.25 Hz), with rectangular windowing. In this manner, based on artifact-free EEG epochs, the threshold was defined by mean plus three standard deviations and epochs with total power higher than this threshold were not integrating the analysis.

The F3 and F4 electrodes represent medial frontal cortex, functionally related to motivation, planning and motor programming [19]. The C3 and C4 represent the primary somatomotor cortex, functionally related to motor execution [25]. Lastly, P3 and P4 electrodes represent the posterior parietal cortex, functionally related to sensorimotor orientation [24]. The alpha band (8–12 Hz) was chosen due to its association with perception, cognition or motor action [21].

In statistical analysis, the EEG absolute power values were $\log_{10}$-transformed by *SPSS* software (version 15.0) to approximate a normal distribution. A three-way ANOVA and a post hoc test (Scheffé) were performed to analyze the factors moment (moment preceding balls drop and moment after balls drop) and blocks (1–6) for each electrode combination: (a) F3/F4; (b) C3/C4 and (c) P3/P4 ($p < 0.05$).

The statistical analysis demonstrated an interaction between the moment and position factors for each electrode combination ($p < 0.001$). It was found a significant decreasing in absolute power values in moment preceding balls drop in F3 electrode (mean = 2.11; s.d. = 0.036) when compared with F4 electrode (mean = 2.16; s.d. = 0.034). On the other hand, it was noted an increasing in absolute power values in moment after balls drop in F4 electrode (mean = 2.17; s.d. = 0.038) when compared with F3 electrode (mean = 2.2; s.d. = 0.027), as observed in Fig. 1. In relation to C3 electrode, it was found a significant decreasing in absolute power values in moment preceding balls drop (mean = 3.21; s.d. = 0.43) when compared with C4 electrode (mean = 3.47; s.d. = 0.56). In moment after balls drop, it was noted an increasing in absolute power values in C4 electrode (mean = 3.57; s.d. = 0.47) when compared with C3 electrode (mean = 3.87; s.d. = 0.52), according to Fig. 2. Lastly, it was found a significant decreasing in absolute power values in moment preceding balls drop in P3 electrode (mean = 3.34; s.d. = 0.07) when compared with P4 electrode (mean = 3.51; s.d. = 0.068). In moment after balls drop, it was noted an increasing in absolute power values in P4 electrode (mean = 3.58; s.d. = 0.048) when compared with P3 electrode (mean = 3.68; s.d. = 0.037), as observed in Fig. 3.