Spatio-temporal cortical activity during a visual task accomplishing

Alexander Kuc
Patent and license department,
Saratov State Technical University,
Saratov, Russia,
kuc1995@mail.ru

Vladimir Maksimenko
Neuroscience and Cognitive Technology Laboratory, Center for Technologies in Robotics and Mechatronics Components
Innopolis University,
Innopolis, Republic of Tatarstan, Russia
maximenkovl@gmail.com

***Abstract*— It is known that neuronal populations of cortical brain network are involved in the processes, related to accomplishing of different tasks, e.g. processing of sensory information and making decisions. Each particular type of tasks is characterized by the specific features of neuronal activity both in time-frequency and spatio-temporal domains. These features of neuronal activity reflect the structure of electrical activity signals (EEG) registered from the head surface via noninvasive electrodes. EEG signals are composed of the different rhythms of neuronal activity. While some studies relate these rhythms to the particular basic brain functions, other studies demonstrate that specific scenarios of EEG rhythms dynamics can be associated with accomplishing of cognitive task and affect human behavioral performance. With this in mind we analyze the spatio-temporal dynamics of alpha and beta rhythms of cortical activity during processing visual task and relate the features of rhythms dynamics to human's behavioral performance.**

Keywords—cortical network, visual task, reaction time, wavelet analysis, spatio-temporal activity.

I. Introduction

Modern concepts in neuroscience implies the key role of the whole cortical network in accomplishing of cognitive tasks [1]. For instance, it is known that remote cortical regions can interact during processing high amount of sensory information [2]. Moreover, depending on human's condition, the same task can be accomplished via involving neuronal populations in different cortical areas [3].

Activity of the neuronal population, belonging to the particular cortical region can be captured by recording electrical signal (EEG) from the corresponding area of the head surface. The recorded EEG signals are composed of different rhythms of neuronal activity e.g. delta (1-5 Hz), theta (5-8 Hz), alpha (8-12 Hz), beta (15-30 Hz) and gamma (50-100 Hz).

According to recent experimental works [4], while the spiking activity of individual neurons in a particular area appears in the high-frequency gamma-band, the low-frequency activity modulates activity of single neurons and serves for a communication between distant brain regions. Thus, increase of the EEG spectral energy in particular frequency bands in particular areas can be associated with the involvement of these areas in cognitive process.

In this paper we consider the spatio-temporal neuronal activity during visual task accomplishing by analyzing time-frequency structure of EEG signals. We focus on alpha and beta frequency bands since they are related to visual information processing [5]. For instance, it is known that changes in alpha-band activity are associated with the visual attention [6] and changes of beta-band activity - with the stimuli processing [7] and shift of the brain to an attention state [8].

II. Materials and Methods

A. Participants

Twenty healthy unpaid volunteers, 11 males and 9 females, between the ages of 26 and 35 with normal or corrected-to-normal visual acuity participated in the experiments. All of them provided informed written consent before participating. The experimental studies were performed in accordance with the Declarationof Helsinki and approved by the local research Ethics Committee of the Innopolis University.

B. Visual task

The visual task was the classification of consistently presented ambiguous Necker cubes as left- or right-oriented [9]. The Necker cube is a 2D-image which looks like a cube with transparent faces and visible ribs (Fig. 1).

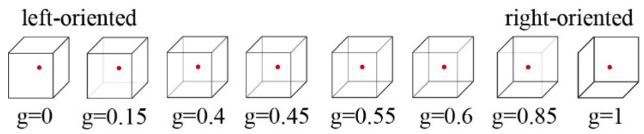

Fig.1. The examples of presented Necker cube images with different values of control parameter *g*

An observer without any perception abnormalities perceives the Necker cube as a bistable 3D-object due to the specific position of the inner ribs. The value g defining a contrast of the three middle ribs is usually used as a control parameter. The values g=1 and g=0 correspond, respectively, to 0 (black) and 255 (white) pixels' luminance of the middle lines. Each Necker cube image drawn by black and gray lines was located at the center of the computer screen on a white background. A red dot drawn at the center of the Necker cube was used to attract the attention of subjectsand prevent possible perception shifts due to eye movements while observing the image. To demonstrate a stimulus, we used a 24" BenQ LCD monitor with a spatial resolution of 1920-1080 pixels and a refresh rate of 60Hz. The subjects were located at a distance of 70–80 cm from the monitor with a visual angle of approximately 0.25 rad. The Necker cube size on the monitor was 14.2 cm. Bistability in the cubeperception consists in its interpretation as to be either left- or right-oriented depending on the inner ribs contrast.

The subject was instructed to press left or right button on the joystick depending on the interpretation of the current image (left- or right-oriented). The reaction time was estimated for each stimulus as the time interval between image presentation and button pressing moment.

C. Continuous wavelet transform

To analyze time-frequency structure of EEG signals we used continuous wavelet analysis. Wavelet coefficients were calculated via equation

$$W(f,t_0) = \sqrt{f}\int_{-\infty}^{+\infty} x(t)\varphi^*\big(f(t-t_0)\big)dt, \qquad (1)$$

where the mother wavelet function φ was used to be Morlet wavelet.

To analyze network activity in alpha and beta frequency bands, we calculated wavelet coefficients averaged over the corresponding frequency ranges (8-12 Hz and 15-30 Hz)

$$W_{\alpha,\beta}(t) = \int_{f\epsilon f_{\alpha,\beta}} W(f,t)df. \qquad (2)$$

For these bands we considered the values of wavelet spectral energy:

$$E_{\alpha,\beta}(t) = \sqrt{W_{\alpha,\beta}}(t), \qquad (3)$$

calculated for 1-s. EEG-trials, associated with processing of visual stimulus.

III. Results

We have recorded 31 EEG signals via noninvasive electrodes, arranged according to 10-10 layout (Fig. 2, a). At the first stage, EEG-trials associated with visual stimulus processing were divided into two groups according to subject's reaction times. Group S1 included trials with long reaction time and S2 – with short reaction time (Fig. 2, b). Each group contained 20 trials.

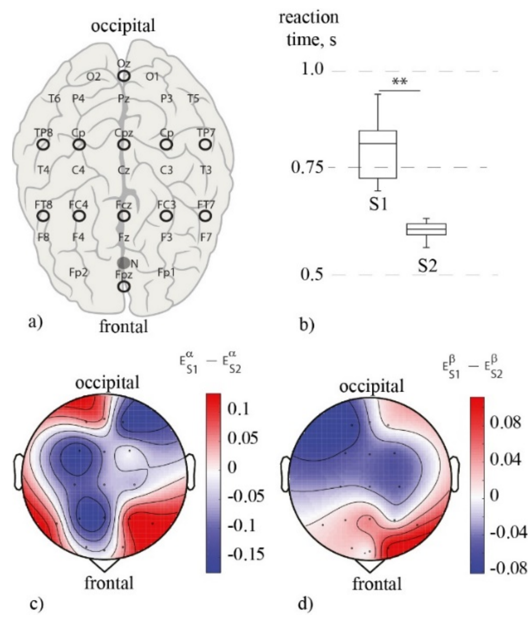

Fig.2. (a) 10-10 electrode layout; (b) Reaction times for two groups of trials; Differences between EEG spectral energy related to processing S1 and S2 stimuli in alpha (c) and beta (d) frequency bands

For groups S1 and S2 EEG spectral energy was averaged over 20 trials. Then, for each channel the difference between values, obtained for S1 and S2 was calculated and visualized by a color map over the head surface. Results are presented in Fig. 2 for alpha (c) and beta (d) frequency bands. One can see that in both bands the obtained difference exhibits negative value. It evidences higher value of spectral energy for S2 trials, where the reaction time is small. It can be seen that S2 is characterized by increase of beta-band energy in parietal area (Fig. 2, d). According to works [10, 11], this area is associated with the center of visual attention exciting in beta-band frequencies. Along with the beta-band, the spectral energy in alpha-band exhibits increase in fronto-parietal area (Fig. 2, c). It can be associated with establishing neuronal functional interaction between these remote cortical regions for speeding up stimuli processing [12].

IV. Conclusion

We have analyzed the time-frequency and spatio-temporal neural activity during processing of visual sensory stimuli. Analysis of the behavioral data has revealed, that processing of each stimulus takes either long or short time. The short time of stimulus processing is achieved when EEG spectral energy increases in beta-band in parietal region and in alpha-band in parieto-frontal region.

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