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Brain-Computer Interface on the Basis of EEG System "Encephalan"

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ABSTRACT

We have proposed brain-computer interface (BCI) for the estimation of the brain response on the presented visual tasks. Proposed BCI is based on the EEG recorder Encephalan-EEGR-19/26 (Medicom MTD, Russia) supplemented by a special home-made developed acquisition software. BCI is tested during experimental session while subject is perceiving the bistable visual stimuli and classifying them according to the interpretation. We have subjected the participant to the different external conditions and observed the significant decrease in the response, associated with the perceiving the bistable visual stimuli, during the presence of distraction. Based on the obtained results we have proposed possibility to use of BCI for estimation of the human alertness during solving the tasks required substantial visual attention.

Keywords: Electroencephalogram, continuous wavelet analysis, brain-computer interface, concentration of attention

1. INTRODUCTION

The brain-computer interface (BCI) is an exciting topic of neuroscience, physics and engineering. Such modern technology is in demand in various applied fields, including medicine, industry and others.[1–5] The BCI is known to be based on real-time detection of characteristic forms of electrical (or magnetic) activity of the brain and the transformation of the obtained information into computer commands for controlling hardware. At present, the developed neurointerfaces allow one to control the 2-D movement of a cursor,[6] partially synthesize speech,[7] and control simplest movements.[8] The BCIs can be effectively used for rehabilitation,[9] controlling exoskeletons[1] and robots.[10]

Further development of this technology, along with detection of features associated with the simple motor functions, requires detection of more complex cognitive processes associated with fine motor skills, positioning, attention, etc. In this context, the development of BCIs that allow to evaluate and monitor a person's psychophysical state attracts a great research interest.[11] In this case, the most studied characteristic of a person's psychophysical state is the concentration of attention.[12] Estimation of the degree of concentration was actively studied in[13] in the context of the implementation of interfaces for monitoring the psychophysical state of operators with heavy workload. Recently, the analysis of the processes associated with the switching of attention, is used to develop neurointerfaces for completely paralyzed people,[14] and the development of systems for training attention, in particular for children with attention deficit hyperactivity disorder.[11] It should be noted that, while significant progress has been made in the field of estimating human concentration from the multichannel signals of brain electrical activity, the task of developing techniques that allow to estimate and control changes in concentration in real time is still poorly understood.[15]

In the framework of the current research problem our study is focused on the development BCI for the estimation the response of the brain on the consecutive simple visual tasks.

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2. METHODS

Healthy subjects males and females, between the ages of 20 and 43 with normal or corrected-to-normal visual acuity participated in the experiments. All of them provided informed written consent before participating in the experiment. The experimental studies were performed in accordance with the Declaration of Helsinki and approved by the local research ethics committee of the Yuri Gagarin State Technical University of Saratov.

The Necker cube[16] was used as the visual stimuli, Such ambiguous stimulus is a popular object of many psychological experiments[17–19] and theoretical models.[19–21] It represents itself a cube with transparent faces and visible ribs; an observer without any perception abnormalities sees the Necker cube as a 3D-object due to the specific position of the cube's ribs. Bistability in perception consists in the interpretation of this 3D-object as to be either left- or right-oriented depending on the contrast of different inner ribs of the cube. The contrast $I \in [0,1]$ of the three middle lines centered in the left middle corner was used as a control parameter like that which was considered in Ref.[22] The values $I = 1$ and $I = 0$ correspond, respectively, to 0 (black) and 255 (white) pixels' luminance of the middle lines. Therefore, we can define a contrast parameter as $I = y/255$, where y is the brightness level of the middle lines using the 8-bit grayscale palette.

All participants were instructed to press either the left or right key depending on their first impression of the cube orientation at each presentation. The whole experiment lasted around 10–15 min for each participant, including short recordings of the brain background activity before and after the stimuli presentation. During experimental sessions, the cubes with different I were randomly presented (each configuration for about 30 times) and the electrical brain activity was recorded using the electroencephalographic recorder Encephalan-EEGR-19/26 (Medicom MTD, Russia) which provided simultaneous registration of up to 20 EEG channels and a two-button input device. The monopolar registration method and the classical ten-twenty electrode system were used. The ground electrode N was located above the forehead and two reference electrodes $A_{1,2}$ were located on mastoids. The EEG signals were filtered by a band pass filter with cut-off points at 1 Hz (HP) and 100 Hz (LP) and a 50-Hz Notch filter. The electroencephalograph"Encephalan–EEGR–19/26" (Taganrog, Russian Federation) with multiple EEG channels was used for amplification and analog-to-digital conversion of the EEG signals.

The gray-scale images were demonstrated on the 24" BenQ LCD monitor with a resolution of 1920 × 1080 pixels and a refresh rate of 60 Hz. The subject was located at a distance of 70–80 cm from the monitor with a visual angle of approximately 0.25 rad.

We analyzed the EEG signals recorded by five electrodes (O_1, O_2, P_3, P_4, P_z) placed on the standard positions of the ten-twenty international system,[23] using the continuous wavelet transform.[24] The wavelet energy spectrum $E^n(f,t) = \sqrt{W_n(f,t)^2}$ was calculated for each EEG channel $X_n(t)$ in the frequency range $f \in [1, 30]$ Hz. Here $W_n(f,t)$ is the complex-valued wavelet coefficients calculated as

$$W_n(f,t) = \sqrt{f} \int\limits_{t-4/f}^{t+4/f} X_n(t)\psi^*(f,t)dt, \tag{1}$$

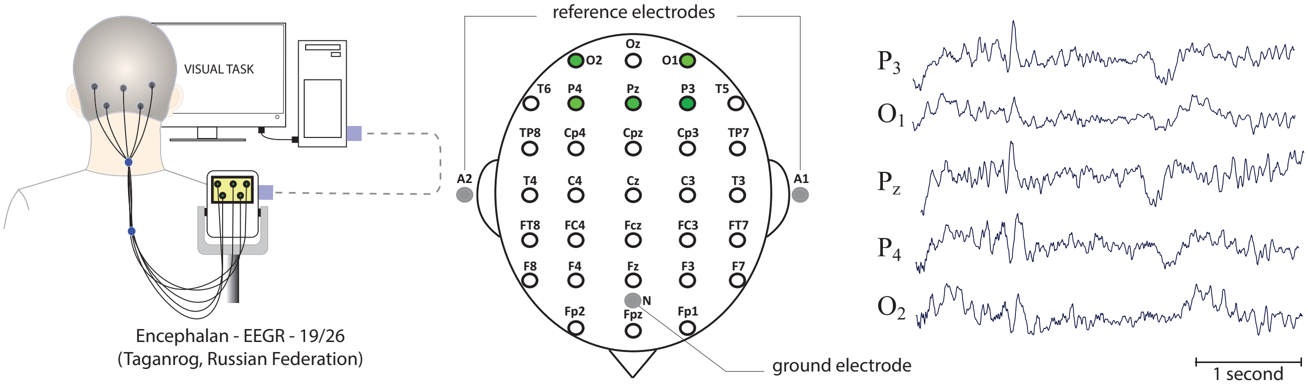
where $n = 1, ..., N$ is the EEG channel number ($N = 5$ being the total number of channels used for the analysis in this paper) and "*" defines the complex conjugation. The mother wavelet function $\psi(f,t)$ is the Morlet wavelet often used for the analysis of neurophysiological data defined as

$$\psi(f,t) = \sqrt{f}\pi^{1/4} \mathrm{e}^{j\omega_0 f(t-t_0)} \mathrm{e}^{f(t-t_0)^2/2}, \tag{2}$$

where $\omega_0 = 2\pi$ is the central frequency of the Morlet mother wavelet.[25]

3. BRAIN-COMPUTER INTERFACE

A brain-computer interface was based on the EEG recorder Encephalan-EEGR-19/26 (Medicom MTD, Russia) supplemented by a special home-made developed acquisition software. A special library from Medicom MTD allowed us to access the data in real time with a sample rate of 250 Hz. The set of $N = 5$ EEG channels (P_3,



(*a*) (*b*) (*c*)

Figure 1. (a) Schematic illustration of the BCI based on the Encephalan-EEGR-19/26 (Medicom MTD, Russia); (b) detailed illustration of the location of EEG electrodes; (c) typical set of EEG traces, used for BCI operation.

O_1, P_z, P_4, O_2) arranged according to "10-20" scheme were used for real-time data processing. The wavelet spectrum of the EEG signals was calculated using a floating window of 2-sec length in the range between 4 Hz and 30 Hz.[26] Each event, associated with the presentation of single visual stimulus was analyzed separately in alpha and beta frequency bands on a 1-sec interval preceding the presentation and followed by the moment of the stimulus appearance. A special digital trigger sent by the software together with the presentation of the stimuli initiated the calculation. As a result, the set of values A_I, A_{II}, B_I, B_{II} were calculated for each presentation as

$$A_{I,II} = \sum_{n=1}^{N} \int_{t\in\Delta t_{I,II}} \xi^n(t')dt', \text{ where } \quad \xi^n(t) = \begin{cases} 1, & \text{if} \quad f^n_{max} \in \Delta f_\alpha, \\ 0, & \text{if} \quad f^n_{max} \notin \Delta f_\alpha. \end{cases} \tag{3}$$

$$B_{I,II} = \sum_{n=1}^{N} \int_{t\in\Delta t_{I,II}} \xi^n(t')dt', \text{ where } \quad \xi^n(t) = \begin{cases} 1, & \text{if} \quad f^n_{max} \in \Delta f_\beta, \\ 0, & \text{if} \quad f^n_{max} \notin \Delta f_\beta. \end{cases} \tag{4}$$

where $N = 5$ is the number of EEG channels and f^n_{max} is the location of the maximal spectral component.

The obtained values were averaged over six presentations and the control characteristic $G(t)$ was calculated as

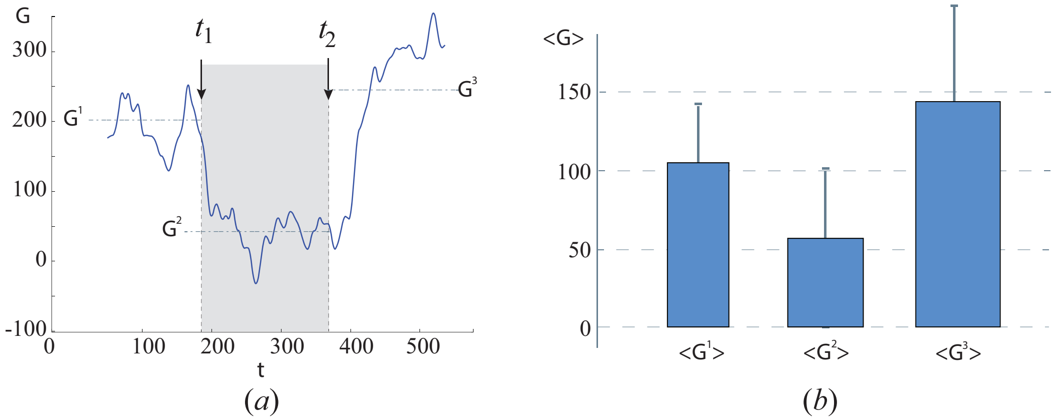
$$G(t) = \frac{(< A_I > - < A_{II} >) + (< B_{II} > - < B_I >)}{2}, \tag{5}$$

where $< ... >$ means the average over six presentations.

The value of $G(t)$ was calculated using Eqs. (3-5) in real time. This value reflected the intensity of the brain response on the appearing visual stimuli. Large values of $G(t)$ were associated the high response which was expected to be connected with the careful procession of the images by the subject. Small values of $G(t)$ were vise-versa associated with the low response, taken place when subject did not pay so much attention to visual stimuli.

4. RESULTS

The developed BCI was experimentally tested on three volunteers. In this experiment, each subject participated in three 4-min subsequent sessions. The experimental results are illustrated in Fig. 2 (a, b). The left and right arrows indicate, respectively, the moments of time, t_1 and t_2, when the external influence was switched on and switched off, respectively. These moments divided the experiment into three sections. During the first section ($t < t_1$), the subject performed the task in the absence of external influence. One could see that $G(t)$ fluctuated near a certain mean value of G^1, individual for each subject. The second section ($t_1 < t < t_2$) included the



(*a*) (*b*)

Figure 2. (a) Typical dependency of the control characteristic $G(t)$ on the time, calculated for one subject, shaded region corresponds to time interval for which the subject is affected by external influence; (b) The values of $G(t)$, averaged over time intervals $t < t_1$, $t_1 < t < t_2$, $t > t_2$, respectively, and over group of participants. Error bars indicate standard deviations.

external influence on the subject in the form of an additional cognitive task. It was easy to see that when the external influence took place, the value of $G(t)$ sharply decreased and oscillated near the mean value G^2, significantly lower than the mean in the first section. Finally, the third section started at $(t = t_2)$ demonstrated the effect of restoring attention on the visual stimuli. One could see that $G(t)$ significantly increased for all subjects and oscillated near the mean values $G^3_{1,2,3}$.

It is important to note that a significant change in $G(t)$ is observed within a relatively short time interval (less than 30 seconds) during which the visual stimulus is presented about 5 times. This means that the significant loss of attention can be promptly detected and controlled in real time.

5. CONCLUSION

Proposed brain-computer interface is able to estimate response of the human brain on the presented visual task in real time. Application of the BCI for the control of this response in the condition of external stimuli demonstrates that the decrease of the brain response caused by the distraction can be detected.

It should be noted that the revealed phenomena can be associated not only with visual perception of bistable object, but also with other types of cognitive tasks which require a high level of alertness. The demonstrated possibility of the assessment of the brain response to the visual task by a real-time processing of the EEG signals, have possible important applications in monitoring and controlling human attention and alertness during tasks which require substantial attention, e.g., air traffic control, monitoring nuclear power plants, development of training programs and tests of human psychological conditions. This also opens the possibility to estimate the variation of the degree of human attention in time, which is necessary for the development of systems for control and training.

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