Analysis of information perception and processing during long-term and intense cognitive load using combined EEG and NIRS

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***Abstract*—This work is devoted to the analysis of information perception and processing during long-term and intense cognitive load using combined EEG + NIRS. We consider changes in the reaction time during long-term and intense cognitive load and a comparison of brain activity with behavioral characteristics. We found the establishment of a characteristic mode in the brain corresponding to a routine cognitive task.**

***Index Terms*—EEG, NIRS, cognitive task, visual perception**

I. Introduction

The level of attention is one of the most important characteristics of brain cognitive processes. The success and effectiveness of operator activity, in which there is an information load, largely depends on the current level of attention. Therefore, in conditions of increased responsibility for the results of work with a high significance of the error, it is necessary to take into account the level of attention. So, for example, when working with electronic training aids or when air traffic controllers work, a high level of involuntary attention can lead to the fact that extraneous incentives will constantly distract from the task being solved, reducing the productivity of the work as a whole. Therefore, one of the most important tasks is to study the process of information processing in conditions of increased load. Note that a lot of work is devoted to the study of the process of visual perception and information processing, as well as the level of attention associated with them [1]–[6].

This work is devoted to the research of the process of perception and processing of visual information using combined EEG + NIRS. Also, the paper considers changes in the reaction time during long-term and intense cognitive load and a comparison of brain activity with behavioral characteristics.

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II. Methods

The operators are presented with Necker cube images with various face contrasts for a short period, each of which lasted from 1.0 to 1.5 seconds then abstract background images are demonstrated 3-5 seconds. The test subject is instructed to determine the orientation of the Nuker cube by pressing the corresponding remote control key. Using background images allows you to neutralize possible negative secondary effects that may occur after the perception of the previous image of the Necker cube. The total duration of the operator work was 30 minutes.

For EEG recording we used electroencephalograph“actiCHamp” by Brain Products (Germany). EEG was recorded for 31 channels according to “10-10” system with ground electrode placed in the “Fpz” position on the forehead and one reference electrode on the right mastoid. For EEG signal recording we used “ActiCap” — active Ag/AgCl electrodes (one for each EEG channel) placed on the scalp with the help of special cap. To increase the skin conductivity we treated scalp skin with abrasive “NuPrep” gel before the experiment and placed EEG electrodes on conductive “SuperVisc” gel. After the electrodes were placed, we monitored the impedance to get best possible quality of EEG recordings. Common impedance values were < 25 kΩ which is quite sufficient for active EEG electrodes. EEG signals were recorded with sampling rate of 1000 Hz and filtered by band-pass filter (cutoff frequencies at 0.016 Hz and 70 Hz), as well as 50-Hz notch filter.

For hemodynamic recording we used ”NIRScout” with sampling rate of 7.8125 Hz by NIRx Medical Technologies (USA, Germany). The signal of fNIRS was filtering in the range of 0.012 to 0.4 Hz using 5th order Butterworth filter to reduce the physiological noise of low and high frequency such as respiration and cardiac-related fluctuations. The fNIRS signals were then converted to changes in the concentration of oxyHb, deoxy Hb and total Hb using the modified Beer-Lambert law. Furthermore, these changes oxyHb, deoxy Hb, and total Hb concentration were further processed by the moving average. Note that since the responses were more pronounced in oxyHb, we limited our analysis only to oxyHb signals.

The hemodynamic was recorded for 16 channels to cover the occipital, prefrontal and parietal lobes because these areas are closely related to the perceptual decision-making task.

We have analyzed the EEG signals using the continuous wavelet transform which is now widely used in neuroscience and neurophysiology [7]. We calculate separately the average energy in the alpha(8–13 Hz) and beta(13–34 Hz) bands one second before the presentation of the visual stimulus and in the first second of perceiving the stimulus. For each representation of the cube, we calculate the ratio, energy changes in the alpha and beta range before the presentation and during the presentation of the visual stimulus $\frac{E^n_{\alpha 1} E^n_{\beta 2}}{E^n_{\alpha 2} E^n_{\beta 1}}$.

For the analysis of hemodynamics, we calculated the characteristic correction time in the window of t_w= 300 sec for each of the fNIRS channels and different stage of the experiment.

III. RESULTS

We analyzed the dynamics of energy changes in alpha and beta bands for each channel during the experiment. It was found that the dynamics of the ratio, energy changes in the alpha and beta range before the presentation and during the presentation of the visual stimulus have complex nature. At the same time, a pronounced feature is observed in the parietal cortex – the closer to the end of the experiment, the closer the dynamics of $\frac{E^n_{\alpha 1} E^n_{\beta 2}}{E^n_{\alpha 2} E^n_{\beta 1}}$ to periodic.

We performed an analysis of hemodynamic activity. For this, the dependence of the characteristic correlation time for each of the NIRS channels at different stages of the experiment was calculated. It was found that after about half of the experiment ($\sim$ 15 minutes), the characteristic correlation time in the parietal and prefrontal cortex sharply increases. At the same time, it should be noted that the parietal cortex, is more correlated and more active, in terms of the magnitude of the $\Delta O2Hb$ oscillations.

We analyzed behavioral characteristics during the experiment, such as the time and number of errors in interpreting the orientation of the cube. It was found that the average reaction time varies during the experiment. Moreover, the dynamics of the reaction time is such that at first during the experiment its growth is observed, and then after about 15 minutes it decreases. At the same time, the number of errors has a similar dynamics.

Such dynamics indicate the establishment of a characteristic mode in the brain corresponding to a routine cognitive task.

IV. DISCUSSION

It is known that visual attention is associated with interaction in the alpha and beta bands in the occipital and parietal regions [8]. In particular, changes in alpha band activity are associated with visual perception [9] , while changes in beta band activity are associated with stimulus processing and switching the brain to a state of attention.

One of the hypotheses for the existence of characteristic frequency ranges (alpha, beta and etc.) in the electrical activity of the brain is the organization of effective interaction between different parts of the brain. This is due to the presence of a refractory period in neurons. The period of refractoriness is the time after the appearance of an action potential on the excitable membrane, during which the membrane excitability decreases, and then gradually restores to the initial level. In this regard, it becomes necessary to organize a certain rhythm in the generation of spikes of connected neural ensembles.

According to this fact, the results treated in this paper can be interpreted as follows: when continuously performing monotonous cognitive tasks for a long time (in the present experiment for more than 15 minutes), the brain adapts to this type of load, controlling the process of attention and redistributing energy resources in the brain. This is evidenced by the establishment of characteristic dynamics in the electrical and hemodynamic activist of the brain, as well as a decrease in the average reaction time to the stimulus and interpretation errors in the second stage of the experiment.

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