# The activity of the brain cortical network during solving tasks

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***Abstract*—In this paper, we analyze the functional connectivity between changes in the concentration of oxyhemoglobin, deoxyhemoglobin, and total hemoglobin, recorded by various leads of fNIRS from the frontal and parietal cortex. The obtained coefficients characterizing the functional connectivity between a pair of leads were presented in the form of a matrix. We analyzed the changes in functional connectivity during the performance of the subject of simple cognitive tasks associated with spatial perception.**

***Index Terms*—cognitive tasks, functional connectivity, fNIRS, brain activity**

## I. Introduction

The study of the mechanisms of the work of the brain is one of the most important tasks of modern science. Interest in works related to the study of the brain and neural activity has been growing since the publication of the first works on brain mapping in the early 20th century [1]–[9]. Brain research is now being done in neuroscience, which is a fundamentally interdisciplinary field of knowledge [8]–[10]. It incorporates a variety of methods and concepts from physics, mathematics, computer science, and other disciplines to advance understanding of how the brain works [11]–[20].

At the same time, one of the most important tasks of neuroscience is the study of the process of perception and processing of information [3], [7], [21]–[24]. It is known that the brain's response to visual stimulation is complex and involves the activation of coherent neural structures in various areas of the brain responsible for processing external sensory information. At the same time, characteristic time-frequency patterns are formed, which can be detected using modern neuroimaging methods (EEG, fNIRS, fMRI and ect.).

This work is devoted to the analysis of the dynamics of the functional connectivity of the cerebral cortex during processing and perception of simple cognitive stimuli associated with spatial perception. fNIRS is used to obtain information about brain activity.

## II. Materials and Methods

The experimental studies involved nonsmokers, not involved in professional sports, without neurophysiological diseases, volunteers who did not take medications at the age of 19-21 - 10 people (approximately equal ratio of men and women). All volunteers were asked to adhere to a healthy lifestyle (at least 8 hours of sleep, eliminate alcohol consumption, eliminate or limit consumption of caffeine-containing foods) for 48 hours before each experiment. The volunteers were familiarized in advance with the procedure for conducting the experiment and the possible inconveniences caused by it, had the opportunity to ask questions of interest and get satisfactory answers to them. Each subject completed and signed an informed consent form to participate in the experiment. All experimental work was carried out in accordance with the requirements of the Declaration of Helsinki and approved by the Ethics Commission of Innopolis University.

The experiment was carried out as follows. The subject was sitting in a comfortable chair, and a tablet was placed on the table in front of him (distance from the screen to the eyes $\approx 30-40$ cm). The tablet was used both for the demonstration of simple tasks for spatial perception and for registering answers with a stylus. The duration of each individual experiment was $\approx$ 30 minutes, depending on the speed and performance of tasks by the subjects.

During the experiment, brain activity was recorded using functional near-infrared spectroscopy (fNIRS). For this, equipment was used at the disposal of the Neuroscience and Cognitive Technologies Laboratory. The arrangement of optodes was the same as in [23]. The obtained neurophysiological data were used to restore functional connectivity between the neuronal activity of different parts of the cortical network of the brain based on the joint processing of signals of electrical activity and hemodynamic response.

The signals obtained during the perception and processing of sequentially presented visual stimuli were used. The functional connectivity between the recorded hemodynamic response signals in different areas was restored. The areas under consideration were the parietal and frontal cortex, which are known to demonstrate functional interaction in processing sensory information in the event of an increase in cognitive load [25].The hemodynamic response signals had been pre-

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processed and were filtered in three narrow-frequency ranges (0.005-0.03, 0.03-0.06, 0.06-0.09 Hz) using the Butterworth filter of the fifth-order [26].

## III. Results

For each pair of obtained time series, cross-correlation coefficients were calculated. The correlation coefficients of Pearson [27] and Spearman [28] were calculated. A comparison was made of the results obtained using these approaches. As a result, it was shown that the deviation averaged + -0.07, which is insignificant. Thus, further analysis of changes in functional interaction with varying experimental parameters was carried out on the basis of Pearson's correlation.

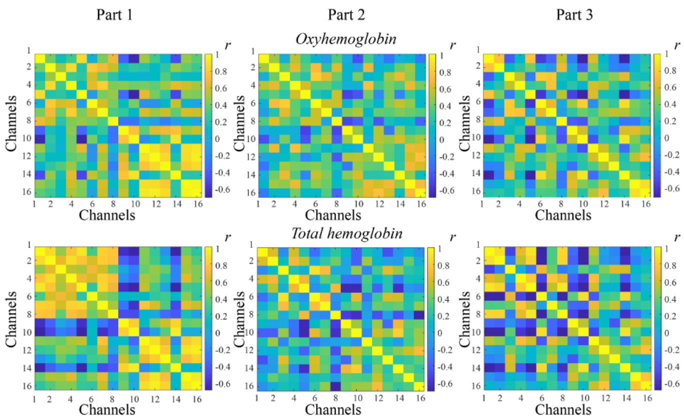


Fig. 1. Coefficients of functional connectivity of the cortical network of the brain in the frequency range 0.005-0.03 Hz between all branches of the fNIRS for signals of total hemoglobin and oxyhemoglobin in various parts of experiment.

The analysis of the dynamics of the functional connectivity of the cortical network of the brain between the signals of oxyhemoglobin and total hemoglobin when performing a monotonous cognitive task for a long time is carried out. For this purpose, the experiment was divided into three equal parts (Part 1, Part 2 and Part 3), for which the above correlation analysis was applied. Found characteristic changes in the dynamics of functional connectivity in the course of the experiment. In particular, in the first stage of the experiment (Part 1), oxyhemoglobin signals in the frequency range 0.005-0.03 Hz, in the parietal cortex (channels 9-16, Figure 1), are characterized by a high correlation coefficient. At the same time, functional connectivity between the frontal and parietal regions are practically absent in the considered frequency range. Then there is a sequential destruction of connections in the parietal cortex and the formation of new connections between the parietal and frontal cortex of the brain, and the formed connections are characterized by a negative correlation coefficient, which indicates an antiphase hemodynamic response between these areas (see figure 1 (Part 2 and Part 3) ).

In turn, the restoration of functional connectivity according to the signals of total hemoglobin shows that in the first stage

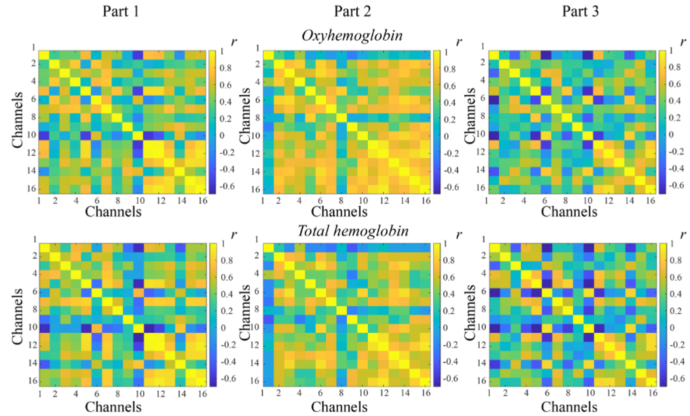


Fig. 2. Coefficients of functional connectivity of the cortical network of the brain in the frequency range 0.03-0.06 Hz between all branches of the fNIRS for signals of total hemoglobin and oxyhemoglobin in various parts of experiment.

of the experiment in the frequency range 0.005-0.03 Hz the prefrontal and parietal cortex are characterized by a high correlation index. At the same time, functional connectivity between these areas of the brain are much weaker. Nevertheless, it is possible to restore the functional connectivity between leads 1, 2 of the prefrontal cortex and 9, 10 of the parietal cortex, and antiphase dynamics is observed between them. Over time, the functional connectivity in the prefrontal and parietal areas is destroyed, as well as the strengthening of the connections between them, and the connections between the areas are characterized by a negative correlation coefficient (see Figure 1 (Part 2 and Part 3)).

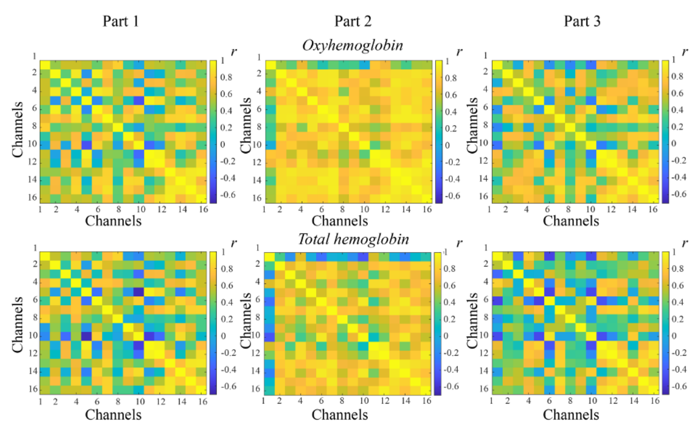


Fig. 3. Coefficients of functional connectivity of the cortical network of the brain in the frequency range 0.06-0.09 Hz between all branches of the fNIRS for signals of total hemoglobin and oxyhemoglobin in various parts of experiment.

Note that the analysis of the dynamics of functional connectivity in the frequency ranges 0.03-0.06 and 0.06-0.09 Hz is characterized by a high correlation between all branches, while the general tendency aimed at the destruction of connections within the frontal and parietal regions during the experiment remains (see Figure 2 and 3). At the same time, the highest correlation between all hemodynamic channels was found in the frequency range 0.06-0.09 Hz.

## IV. Conclusion

In this work, we analyzed the functional connectivity between changes in the concentration of oxyhemoglobin, deoxyhemoglobin, and total hemoglobin, recorded by various leads of fNIRS from the frontal and parietal cortex. The obtained coefficients characterizing the functional connectivity between a pair of leads were presented in the form of a matrix. To analyze changes in functional connectivity over time, the entire experiment was divided into three equal parts, for which the relationship matrices were calculated. The results were analyzed and interpreted. In particular, groups of channels were found and characterized, showing inverse and direct correlation. At the same time, correlations were also compared between the signals recorded by adjacent leads (frontal or parietal) and leads that are distant from each other (for example, located in the parietal and frontal regions).

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