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Functional Brain Network Analysis in Children Performing Working Memory Tasks: EEG Study

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***Abstract*—In the current study, we analyzed EEG data from children 10-12 years old during the performance of Working Memory Task. To calculate connectivity between some areas of brain (Frontal, Left and Right Temporal, Central and Occipital-Parietal) we calculated average Phase-Locking Value between each areas. We find relationships between reaction time and Left Temporal - Central and Right Temporal - Central synchronizations. These results can indicate a relationship between the speed of decoding information during working memory load and the phase synchronizations between mentioned brain areas.**

***Index Terms*—EEG, cognitive task, functional analysis, functional brain, Phase-Locking Value**

I. Introduction

Within the framework of this work, special attention is paid to the functional analysis of the interaction of brain structures, which remains an important problem in the field of human neurophysiology [1], and neurophysiological studies using EEG, MEG, fNIRS and other neuroimaging tools are currently being actively conducted to study it [2]–[9]. The results of such works, in addition to their fundamental importance, are also of applied importance. For example, in the diagnosis of pathological processes related to the functioning of functional networks of the brain [5], [6], [10], [11] – in the context of this issue, there is a particularly urgent need to study the functional networks of the brain of children in order to timely identify and assess the severity of cognitive impairment. Within the framework of functional analysis, it is of interest to study the synchronicity of bioelectric activity of neural structures both between different areas of the brain (general synchronizations) and within a separate area (so-called local synchronizations) [12]. One of the proven methods for estimating the synchronicity of neural activity is the calculation of the phase synchronization value (PLV) [13], which is a statistical value for detecting phase synchronization between signals depending on a specific point in time. Thus, the purpose of this work is to study the features of synchronization between different parts of the brain in solving working memory task.

II. Methods

The experiment was approved by the Immanuel Kant Baltic Federal University Ethics commission, and the parents of the subjects signed a voluntary consent for their children to participate in the experiment. Totally 22 children aged 11-12 years (8 girls, 14 boys) took part in the neurophysiological experiment. To study brain activity, EEG recording was performed using 64 leads according to the standard montage "10-10"(see Fig. 1).

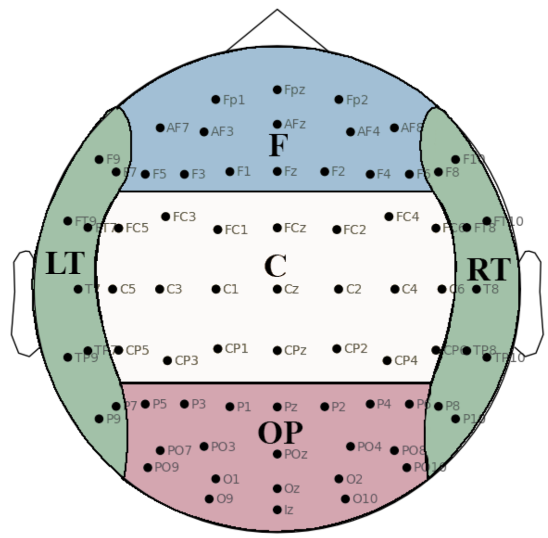

Fig. 1. The EEG montage "10-10" scheme with used averaged areas(F- Frontal, LT - Left Temporal, RT - Right Temporal, C - Central, OP - Occipital-Parietal

The experimental paradigm based on Sternberg's paradigm and the design of the experiment is described in detail in the early article [14]. In this work we have focused on the analysis of electrical activity associated with the type of task called "Working Memory": it is based on the well-known experimental paradigm of S. Sternberg for evaluating working memory. We analyzed the results of completing 60 trials for each subject(see Fig. 2).

During preprocessing, filtration [0.1 - 40 Hz] was used to remove noise and the Independent Component Analysis (ICA) to remove oculomotor artifacts (it is an EEG activity resulting from eye movement).

Segmentation (it is a process of forming epochs - individual fragments of recording associated with a certain activity of the subject) was carried out so that each task has two epochs (see Fig. 2):

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1) "Attention". The period of preparation for implementation. The time of the beginning and end of each epoch was [-0.5; 2] seconds relative to the time of the beginning of showing the white cross to the subject to attract the attention of the subject;
2) "Task". The period for completing tasks. The time of the beginning and end of the epochs was [-0.5; 3] seconds relative to the display of the number. Epochs with excessively long answers, the responses of the subjects outside the 95th percentile in response time for each type of task were determined as statistical outliers and excluded from further analysis with relevant "Attention" epochs.

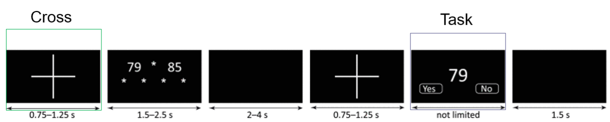

Fig. 2. The timeline of each trial with specified "Cross" and "Task" periods (for forming epochs).

To calculate synchronization between each brain areas, we use PLV (Phase-Locking Value – phase synchronization coefficient). This metric were calculated and averaged for each category of epochs for each frequency ranges. Unlike the common method of coherent analysis based on the calculation of the spectral power of signals, PLV does not take into account the amplitude of the studied signals, but relies only on their phase difference. [13] For subsequent statistical processing, differences in PLV values were calculated for each subject in the epochs of attention fixation (preparation for the next task), as well as the subsequent period of task completion (separately for each type). The obtained values of ΔPLV were averaged between the zones in which each pair of electrodes is located and were calculated as:

$$\Delta PLV = PLV_{Task,i} - PLV_{Cross,i} \quad (1)$$

Here:

$PLV_{Task,i}$ – averaged PLV in brain area i, $PLV_{Cross,i}$ – averaged PLV in brain area i.

III. Results

During the correlation analysis (using Pearson correlation coefficient) between calculated EEG-based δPLV and results of performing the Working Memory Task (reaction time and proportion of correct answers), we found some significant relationships:

1) ΔPLV in β-range for Left Temporal-Central synchronizations and reaction time ($r = 0.49, p = 0.02$, (see Fig. 3a);
2) ΔPLV in β-range for Right Temporal-Central synchronizations and reaction time ($r = 0.5, p = 0.017$, see Fig. 3b).
3) ΔPLV in β-range for Left Temporal - Central and Right Temporal - Central synchronizations ($r = 0.57, p = 0.006$).

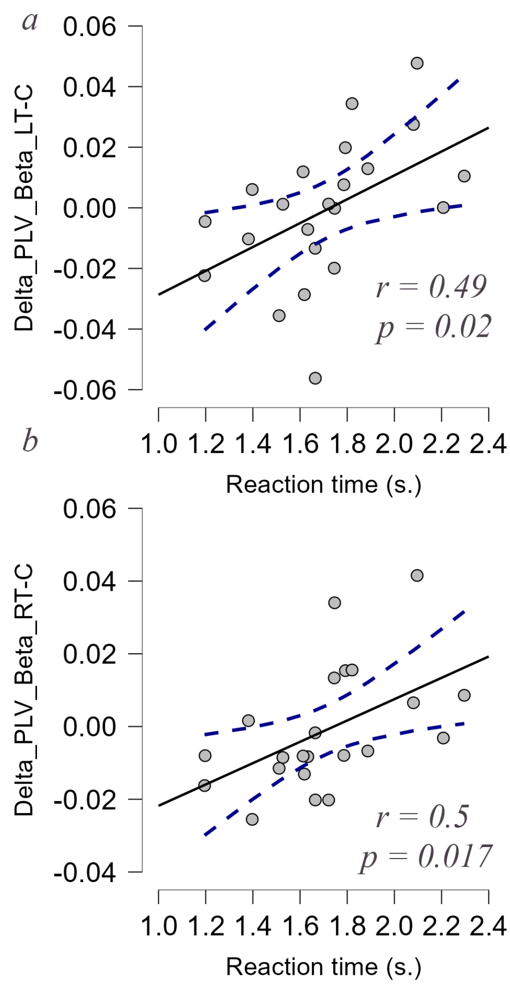

Fig. 3. Graphs of the relationships between ΔPLV in β-range between Left Temporal-Central areas and reaction time (a),ΔPLV in β-range between Right Temporal-Central areas and reaction time (b) and ΔPLV between β-range in Left Temporal - Central and Right Temporal - Central areas(c)(r – Pearson correlation coefficient, p – p-value).

Such observations may mean that an increase in phase synchronization between the specified sites in the process of decoding information for working memory tasks decreases the reaction time without compromising the correctness of the answers. Thus, the high synchronization of these zones, associated with the cognitive load on short-term memory, may indicate the existence of more optimized mechanisms for the coherent work of the left and right temporal, as well as the central regions.

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