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Brain activity during complex cognitive task completion: comparative study of children and adults

Marina V. Khramova
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Alexander K. Kuc
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Vladimir A. Maksimenko
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Nikita S. Frolov
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Vadim V. Grubov
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Semen A. Kurkin
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Natalia N. Shusharina
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Alexander A. Fedorov
Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Alexander E. Hramov
Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University
Kaliningrad, Russia

***Abstract*—In this paper, we analyze the brain activity during the execution by the subject of complex cognitive tasks associated with Schulte Table test completion. We consider two groups of subjects under study — adults and children. We show that adults found numbers faster than children at the beginning of the Schulte Table test. At the same time, we observe a decrease of this effect at the end of test completion. Brain activity analysis provided by the 32-channel electroencephalography demonstrates the well-pronounced parietal alpha-band activity at the end of the task for children. Simultaneously, we measure the well-pronounced frontal beta-band activity at the end of the task for adults. It can indicate the different strategies of test solving in children and adults. The results obtained can be used to develop neural interfaces to increase the efficiency of pupils' mathematical education.**

***Index Terms*—EEG, brain activity, cognitive task**

I. Introduction

A person's performance in solving various complex cognitive tasks mainly depends on the interactions between different cognitive functions and not on their specific aspects. For example, purposeful behavior requires sensory processing and decision-making in order to provide a reasonable behavioral response [1]–[3]. On the one hand, our decisions depend on the quality of sensory information. On the other hand, they are influenced by top-down mechanisms, including context-sensitive expectations and prior knowledge [4]. Thus, the top-down component's substantial evidence or high capacity lowers cognitive demands in the decision-making and facilitates decision-making. The process of accumulating evidence in-

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volves a variety of cognitive functions. For example, selective attention allows you to focus on functions that are important to decision-making and eliminate unimportant details [5]. Cognitive control also aims to prioritize relevant information over irrelevant information. The working memory supports these priorities, so processing resources are allocated with a higher priority for the relevant information [6]. Thus, the active recruitment of certain cognitive functions in the early stages reduces the cognitive load on other components in the latter stages. The mechanisms of interaction of cognitive processes during the performance of mental tasks change with age. Uncovering how they change will greatly complement and expand our knowledge of brain development.

To consider this problem, we subjected children and adults to a Schulte table (ST) test with registration of EEG and behaverial characteristics. ST is a 5×5 matrix of randomly located numbers from one to twenty five, and the cognitive task was to find all these numbers in descending order as quickly as possible. We hypothesized that this task depended on several cognitive processes, including visual search, mental arithmetic, and working memory.

II. Methods

The experiment involved 10 adult subjects (7 males, 3 females, age 18–20) and 10 children (8 males, 2 females, age 7–8). The participants (and their parents in the case of children) were informed in advance about the idea, goals and possible inconveniences of the experiment. They were able to ask any related questions and were given appropriate answers and clarifications. Each participant provided informed written consent before participating in the experiment - adults signed the informed consent form themselves, and the informed consent form of the children was signed by the parents. The experimental procedure was carried out in accordance with the Declaration of Helsinki and was approved by the ethics committee of Innopolis University.

During the experiment, the subject was sitting in a comfortable chair while the tablet computer with pencil was placed on the table before the subject. Experimental design suggested that the subject performed specific cognitive task and EEG signals were recorded during this process. Cognitive task was to accomplish Schulte test — simplified version of Zahlen-Verbindungs-Test (ZVT), widely used in Russia. Schulte test consisted of matrices (tables) of 5×5 randomly arranged numbers from 1 to 25. The subject was asked to find numbers in a descending order from 25 to 1 by pointing each found number with the pencil. We registered time moments corresponding to pointing each number in the table (reaction time RT_i^j, where i is the number of ST, j is the the ordinal number in the table). All participants completed five tables under the direct supervision of a professional psychologist. Between tables the subjects had a short break for 10 s. All experiments were carried out at the Neuroscience and Cognitive Technology Lab of the Innopolis University (Russia).

The RT_i^j were distributed non-normally in the both age groups (children and adults) according to the Shapiro-Wilk test. To analyze the RT_i^j between the different tables and within the table we used the repeated measures ANOVA with the Greenhouse-Geisser correction. The post hoc analysis was performed via the nonparametric Wilcoxon signed-rank test. To compare the RT_i^j between the age groups and between (or within) the tables, we used the mixed ANOVA. The post hoc analysis was performed the nonparametric Mann–Whitney U test. To address the multiple comparison problem when comparing RT_i^j across $i = 24 \dots 1$ conditions we used the cluster based correction with the randomization technique. The statistical analysis was carried out in SPSS.

The wavelet power topograms were compared for the different experimental conditions in the time, spatial and frequency domain via the cluster-based permutation test. The critical α-level for the pairwise comparison was set to 0.05, and the critical $\alpha-$level for the cluster-level statistics was set to 0.025 corresponding to a false alarm rate of 0.05 in a two-sided test. Finally, the minimal number of the elements in the cluster was set to 2, and the number of permutations was equal to 2000. The topograms were compared using the Fieldtrip toolbox in Matlab.

III. Results

We divided the time of the ST test completion into three conditions. Each condition involved searching for 8 numbers. We assumed that the size of the arithmetic problem did not change between the first and second conditions, but decreased in the third condition due to a decrease in the numeric size of the operands and responses. We assumed that the working memory load increased in the second condition compared to the first condition due to the growing number of elements in the memory set array. Then, we hypothesized that the amount of distraction stays the same under different conditions, since each target is among twenty-four distractions.

At the behavioral level, we shown that adults performed ST test faster than children. For both children and adults, the average RT in the second condition was equal to one in the first condition, while the average RT in the third condition was significantly lower than in the other two conditions. Both children and adults decreased their RT under the third condition, but this effect was more spronounced in children.

A within-subject analysis of the swavelet power of the EEG of children and adults did not reveal changes between the first and second conditions. In the third condition, children had a higher power of the parietal α (8–14 Hz) range while adults had a higher power of the frontal range β (20–30 Hz). The high power of the parietal α range in children may indicate a shift from procedural strategy to less demanding fact-retrieval. The high power of the frontal β range in adults may reflect an increase in dependence on top-down mechanisms, cognitive control, or modulation of attention, rather than a change in arithmetic strategy.

A between-subject analysis showed that adults have a higher left-lateralized α-range power, the midline fronto-parietal power of the β-range in the first and second conditions. In the third condition, adults showed a higher left-lateralized α-band power. High left-lateralized α-band power might be an additional evidence for the fact-retrieval strategy in adults. We assumed that the children initially had difficulty working with two-digit numbers. For single-digit numbers, their performance has increased and has reached that of adults.

IV. Conclusion

The results obtained can be used to develop neural interfaces [7], [8] to increase the efficiency of pupils' mathematical education. We believe that these results can help to develop new strategy of mathematical skiils training for children of primary school age [9].

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