Network Structure of Children's Brain During Schulte Table Task

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***Abstract*—We have analyzed the neuronal interactions in the children's brain cortex associated with the cognitive activity during simple cognitive task (Schulte table) evaluation in two distinct frequency bands – alpha (8–13 Hz) and beta (15–30 Hz) ranges using linear Pearsons correlation-based connectivity analysis. We observed the task-related suppression of the alpha-band connectivity in the frontal, temporal and central brain areas, while in the parietal and occipital brain regions connectivity exhibits increase. We also demonstrated significant task-related increase of functional connectivity in the beta frequency band all over the distributed cortical network.**

***Index Terms*—functional connectivity, brain, cognitive load, children**

I. Introduction

The problem of the development and implementation of high technologies in the educational process, allowing to optimize educational activities and increase the efficiency of perception of new information, is an important modern task requiring interdisciplinary approaches [15]. In this context, the most intriguing problems are devoted to the analysis of the psychophysiological state of a person during educational activities and solving cognitive tasks. For example, special attention is paid to studying the brain's structure and its cognitive functions to improve the quality of learning [6]. At the moment, the symbiosis of these scientific fields presents great opportunities for optimizing the educational process based on the achievements of cognitive neuroscience [**?**], [14]. Notable success has been achieved in the preschool education [3]. In Ref. [7] the authors showed that, based on the knowledge of the physiological mechanisms of the development of dyslexia and the syndrome of distracted attention in children, it became possible to correct educational activities to suppress these pathologies. There is also possibility to implement the robotics systems controlling by neuronal activity in educational process [1]. In our recent work [12] we have shown that a number of cognitive and psychological characteristics of a person can be evaluated using EEG data during simple tests for the development of attention and memory (Schulte table). Thus, we can conclude that, understanding the features of cognitive activity of students during the educational process, it is possible to significantly increase the effectiveness of training and the quality of assimilation of new information. The key to understanding students' cognitive activity is registering brain activity during the assimilation of new material and developing advanced mathematical methods for analyzing the recorded data obtained during training and/or passing tests.

However, in accordance with modern concepts, the normal functioning of the brain, especially various aspects of its cognitive activity, are associated with complex neural interactions that occur in the spatially distributed cortical network of the brain [4], [5], [8], [9], [13]. The integration process seeks to use the cerebral cortex areas that are functionally distant and distant from each other in space in order to solve a complex task that requires concentration of visual attention, involvement of short-term memory, and spatial thinking. Such

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tasks include the assimilation of new information, the implementation of logical, arithmetic and lexical operations. At the same time, the efficiency of the brain during the long-term solution of such cognitive tasks, as we have shown, cannot be maintained at the same level [10], [11]. The weakening of neural interactions and the reconfiguration of the network of functional connections between brain regions are objective factors that can reflect cognitive fatigue and a decrease in the perception of new information [2].

This paper aims at the revealing features of functional connectivity in children's brain network while performing Schulte table test. Particularly, we consider workload network patterns in alpha (8-13 Hz) and beta (15-30 Hz) frequency bands and analyze inter-areal brain communication under the mental task accomplishment.

II. Results

Participants were recruited among the children of the Innopolis University employees (5 healthy subjects, aged 7–10, right-handed, never participated in this or similar experiments before and having no history of medical brain conditions). All the participants as well as their parents were pre-informed about the goals and design of the experiment. Experimental studies were performed in accordance with the Declaration of Helsinki and approved by the local research Ethics Committee of Innopolis University. The participants were instructed to solve two Schulte table representing in a classical form a 5x5 grid with random distribution of numbers over the cells, is used to measure cognitive performance indexes based on the efficiency of its evaluation [11].

We introduced a mean value of Pearson's correlation coefficient $\overline{\rho_{XY}^{bt}}$ as a functional connectivity metric to explore inter-aerial functional interactions in children's brain during mental task evaluation. First of all, we demonstrate that coupling matrices in background and task-related activity are completely different, while task-related matrices share the same pattern. Statistical cluster-based t-test for independent samples reveals task-related changes of the brain functional connectivity consisting in reduction of correlation between the sensors of frontal, temporal and central regions, whereas the correlation between the occipito-parietal area with the other regions increases. At the same time, brain functional connectivity matrices obtained during two consequent evaluations of the Schulte tables are almost identical with rare significant differences.

The similar effects of task-related changes in brain functional connectivity structure occur in the beta range. Neuronal interactions in the beta band happen in the same way during task-related activity, which is different from the resting state. Having analyzed the statistical differences, we observed that neuronal interactions between EEG sensors exhibit increase of the linear correlation coefficient in almost every pair of sensors. Interaction between the right temporal (RT) area and the other brain regions demonstrates the most pronounced increase of the correlation.

Taken together, the results of the functional connectivity of children's brain during mental task accomplishment show the suppression of the interaction in the alpha band, except for the link between occipito-parietal region and frontal and central regions. On the contrary, beta-band connectivity increases with dominating role of right temporal zone. These results are in line with the knowledge about the pathways of the visual sensory information within the cortical brain network through the synchrony of alpha-oscillations in the occipitoparietal zone and frontal area. At the same time, activation of the beta-band neuronal interactions in the right temporal area indicates the brain region involved in visual sensory information processing.

References

[1] N. A. Aleksandrova, A. E. Hramov, and M. V. Khramova, "Designing, implementation and use of robotic devices in the social sectors in foreign studies," in *2018 IEEE International Conference" Quality Management, Transport and Information Security, Information Technologies"(IT&QM&IS)*. IEEE, 2018, pp. 536–541.

[2] R. F. Betzel, T. D. Satterthwaite, J. I. Gold, and D. S. Bassett, "Positive affect, surprise, and fatigue are correlates of network flexibility," *Scientific Reports*, vol. 7, no. 1, pp. 1–10, 2017.

[3] J. M. Dubinsky, "Neuroscience education for prekindergarten–12 teachers," *Journal of Neuroscience*, vol. 30, no. 24, pp. 8057–8060, 2010.

[4] N. Frolov, V. Maksimenko, A. Lüttjohann, A. Koronovskii, and A. Hramov, "Feed-forward artificial neural network provides data-driven inference of functional connectivity," *Chaos: An Interdisciplinary Journal of Nonlinear Science*, vol. 29, no. 9, p. 091101, 2019.

[5] N. S. Frolov, V. A. Maksimenko, M. V. Khramova, A. N. Pisarchik, and A. E. Hramov, "Dynamics of functional connectivity in multilayer cortical brain network during sensory information processing," *The European Physical Journal Special Topics*, vol. 228, no. 11, pp. 2381–2389, 2019.

[6] U. Goswami, "Neuroscience and education: from research to practice?" *Nature reviews neuroscience*, vol. 7, no. 5, pp. 406–413, 2006.

[7] U. Goswami, "Mind, brain, and literacy: Biomarkers as usable knowledge for education," *Mind, Brain, and Education*, vol. 3, no. 3, pp. 176–184, 2009.

[8] V. V. Makarov, M. O. Zhuravlev, A. E. Runnova, P. Protasov, V. A. Maksimenko, N. S. Frolov, A. N. Pisarchik, and A. E. Hramov, "Betweenness centrality in multiplex brain network during mental task evaluation," *Physical Review E*, vol. 98, no. 6, p. 062413, 2018.

[9] V. A. Maksimenko, N. S. Frolov, A. E. Hramov, A. E. RUNNOVA, V. V. Grubov, J. Kurths, and A. N. Pisarchik, "Neural interactions in a spatially-distributed cortical network during perceptual decision-making," *Frontiers in behavioral neuroscience*, vol. 13, p. 220, 2019.

[10] V. A. Maksimenko, A. E. Hramov, N. S. Frolov, A. Lüttjohann, V. O. Nedaivozov, V. V. Grubov, A. E. Runnova, V. V. Makarov, J. Kurths, and A. N. Pisarchik, "Increasing human performance by sharing cognitive load using brain-to-brain interface," *Frontiers in neuroscience*, vol. 12, p. 949, 2018.

[11] V. A. Maksimenko, A. E. Runnova, M. O. Zhuravlev, V. V. Makarov, V. Nedayvozov, V. V. Grubov, S. V. Pchelintceva, A. E. Hramov, and A. N. Pisarchik, "Visual perception affected by motivation and alertness controlled by a noninvasive brain-computer interface," *PloS one*, vol. 12, no. 12, p. e0188700, 2017.

[12] V. A. Maksimenko, A. E. Runnova, M. O. Zhuravlev, P. Protasov, R. Kulanin, M. V. Khramova, A. N. Pisarchik, and A. E. Hramov, "Human personality reflects spatio-temporal and time-frequency eeg structure," *PloS one*, vol. 13, no. 9, p. e0197642, 2018.

[13] J. D. Medaglia, M.-E. Lynall, and D. S. Bassett, "Cognitive network neuroscience," *Journal of cognitive neuroscience*, vol. 27, no. 8, pp. 1471–1491, 2015.

[14] L. Meltzer, *Executive function in education: From theory to practice*. Guilford Publications, 2018.

[15] H. M. Truong, "Integrating learning styles and adaptive e-learning system: Current developments, problems and opportunities," *Computers in human behavior*, vol. 55, pp. 1185–1193, 2016.

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