Investigation of brain activity characteristics during working memory activation for multimodal stimuli

Vladimir Antipov
Baltic Center for Artificial Intelligence and Neurotechnology
Immanuel Kant Baltic Federal University
Kaliningrad, Russia
Innopolis, Russia
vantipovm@gmail.com

Artem Badarin
Baltic Center for Artificial Intelligence and Neurotechnology
Immanuel Kant Baltic Federal University
Kaliningrad, Russia
Badarin.a.a@mail.ru

Vadim Grubov
Baltic Center for Artificial Intelligence and Neurotechnology
Immanuel Kant Baltic Federal University
Kaliningrad, Russia
vvgrubov@gmail.com

***Abstract*—This paper is devoted to the development of effective methods for assessing a person's ability to learn new information based on the neurophysiological activity of the brain, as well as the creation of brain-computer neurointerfaces for testing the knowledge obtained and implementing this methodology in the educational process.**

***Index Terms*—working memory, multimodal stimuli, neuropedagogy, neurointerfaces**

I. Introduction

The development of intelligent neurointerfaces to determine the human learning abilities is a trending task in world science that lies at the intersection of modern neurophysiology, computer science and neuropedagogy [1]–[5]. The functioning of such neurointerfaces requires processing large amounts of neurophysiological data, and approaches for assessing the quality of information assimilation during the learning process. This can be done with modern methods for research of brain electrical activity, which includes various methods of neuroimaging [6]–[11]. The main scope of this work is creating effective methods and intelligent devices for practical implementation in the educational process, aimed at a better and faster assimilation of new information, as well as an objective assessment of the level of knowledge of the tested subject based on the characteristics of its neurophysiological processes.

II. System to detect human cognitive states

The work is aimed at the development of an intelligent system that allows to detect human cognitive states. The proposed system is based on cross-platform software developed in compilable, statically typed C/C++ language. The rendering functionality and user interface are implemented on the FireMonkey (FMX) GUI framework. This framework allows to develop high-quality cross-platform applications for such operating systems as Windows, Mac OS, Apple iOS and Android. Embarcadero RAD Studio was chosen as an IDE for development, which allows to get executable files for different platforms from a single source code. The main core of the developed application is the module (class) of cognitive tasks or "Cognitive Test Stack" (see Figure 1). This module is a scalable container of cognitive tests. Each test has a separate settings module with the ability to connect to external measurable devices through control input/output streams. Figure 1 below shows the functional diagram of the hardware-software interaction between different modules of the developed system.

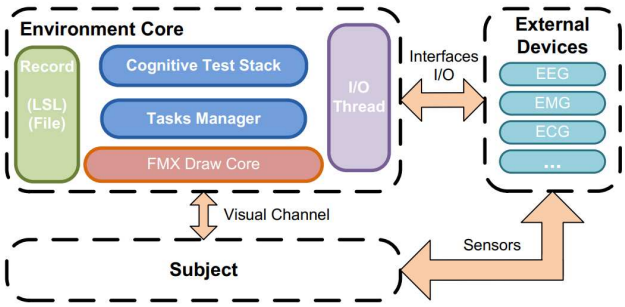

Fig. 1. Functional scheme of hardware-software interaction of the system for detecting human cognitive states.

The basic management, as well as control of compliance with the exact time intervals between events or sequences of stimuli, is performed by the "Task Manager" module and the high-resolution timer built into it. The software also supports several logging and data transfer modes: LSL, MAT. LSL (Lab Streaming Layer) — a system for unified collection of time series of measurements in research experiments [12], synchronization and access in real time, as well as for centralized data collection, viewing and writing to disk. MAT is a standardized format from the Matlab software package for storing, processing and analyzing multivariate data. To detect the exact time of the actual stimulus output, the system used a photo-sensor that accurately registers the moments of pixel color change on the monitor. These image output delays are caused by video memory buffering, peculiarities of graphics drivers, and image refresh delays on the IPS matrix.

978-1-6654-6174-0/22/$31.00 ©2022 IEEE

III. Approbation of an intelligent system

A series of experimental works on approbation of the intelligent system for diagnostics of human cognitive states in the process of training and control of study load was carried out, and the effectiveness of the developed system was evaluated. In particular, using the developed system, we assessed the quality of remembering new information immediately after its presentation (evaluation of the examinee's short-term memory) and the quality of information assimilation (evaluation of the examinee's long-term memory). The effect of perceptual modality on quality of remembering and learning new information and on quality of fixing already known information was studied. The correlation between the modality of presenting information, prior knowledge of the facts, and the success of the test was revealed (see Figure 2).

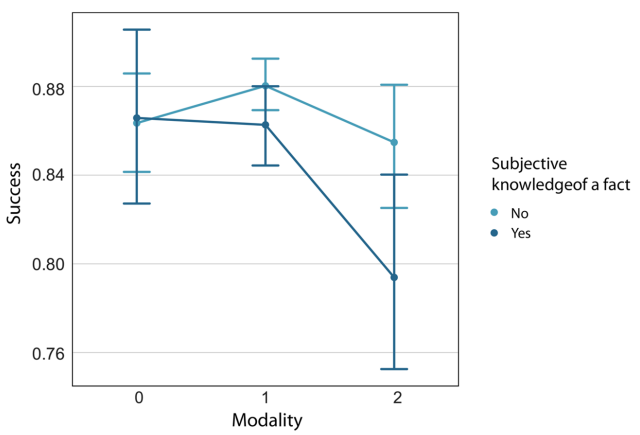

Fig. 2. Dependence of the task success on the first day of testing for two groups of questions (known/not known to the examinee before the training) on the modality of the presented fact.

Note that according to the experimental paradigm, the cognitive task used in the experiment included facts from various fields of knowledge so that the subjects had prior knowledge of some facts due to the natural science or humanities bias of their educational program. To determine prior knowledge of the facts presented for memorization, after taking the second test, each subject was asked to retrospectively assess their knowledge of the facts before the first day of the experiment, that is, whether each presented fact was new or already known to them.

The results of testing for the leading perceptual modality using the questionnaire were compared with the actual results of the quality of remembering and assimilation of new information. In particular, it was found that the auditory perception channel prevails in the studied group of volunteers, which agrees with the actual results of the quality of remembering in a short time interval, i.e. on the first day of testing. However, the identified leading perceptual modality has no influence on the quality of information assimilation, i.e. long-term memorization of the fact. It should also be noted that the type of modality of presentation of a fact that was known to the examinee prior to the training has an effect on the success of testing on the first day of the experiment; moreover, a mixed modality of presentation for known facts leads to an increase in errors on them. This point may be related to differences in the speed of the subject's reading and the speed of sound reproduction by the hardware, which leads to a resynchronization of the person's perception in the arrival of sensory information, causing a conflict.

Statistical testing was performed using analysis of variance of repeated measurements. A statistically significant effect of subjective prior knowledge of the fact and day of the experiment was found. Figure 3 shows the dependence of task success for two groups of questions (to the examinee before the training) on the day of testing.

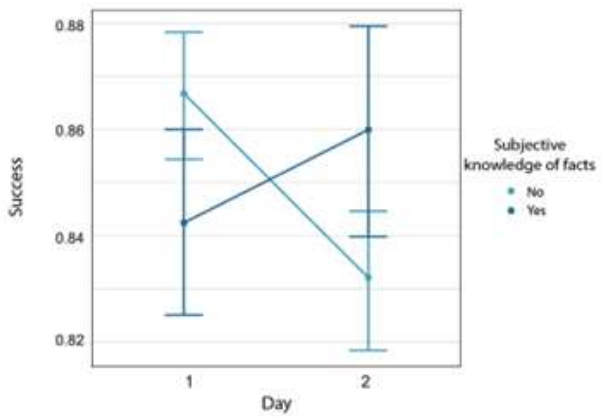

Fig. 3. Dependence of the task success on the first day of testing for two groups of questions (known/not known to the examinee before the training) on the day of testing.

Multidirectional dynamics in the correctness of the test answers were found. Namely, for the group of new facts for the examinee, there is a drop in the percentage of correct answers, while for the group of known facts before training, the number of facts to which the examinee correctly answered, increases.

IV. Acknowledgments

The research was supported from the Ministry of Science and Higher Education of the Russian Federation (Baltic Federal University Program of Development within the Priority-2030 Program) in the part of experimental studies and the Program of Scientific School Support (grant NSH-589.2022.1.2) in the part data analysis.

References

[1] T. V. Bukina, M. V. Khramova, and S. A. Kurkin, "Modern research on primary school children brain functioning in the learning process," *Izvestiya VUZ. Applied Nonlinear Dynamics*, vol. 29, no. 3, pp. 449–456, 2021.

[2] 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.

[3] A. E. Khramov, N. S. Frolov, V. A. Maksimenko, S. A. Kurkin, V. B. Kazantsev, and A. N. Pisarchik, "Functional networks of the brain: from connectivity restoration to dynamic integration," *Physics-Uspekhi*, vol. 64, no. 6, p. 584, 2021.

[4] S. Kurkin, A. Badarin, V. Grubov, V. Maksimenko, and A. Hramov, "The oxygen saturation in the primary motor cortex during a single hand movement: functional near-infrared spectroscopy (fnirs) study," *The European Physical Journal Plus*, vol. 136, no. 5, p. 548, 2021.

[5] N. S. Frolov, E. N. Pitsik, V. A. Maksimenko, V. V. Grubov, A. R. Kiselev, Z. Wang, and A. E. Hramov, "Age-related slowing down in the motor initiation in elderly adults," *Plos one*, vol. 15, no. 9, p. e0233942, 2020.

[6] V. Maksimenko, V. Khorev, V. Grubov, A. Badarin, and A. E. Hramov, "Neural activity during maintaining a body balance," in *Saratov Fall Meeting 2019: Computations and Data Analysis: from Nanoscale Tools to Brain Functions*, vol. 11459. SPIE, 2020, pp. 6–11.

[7] V. V. Grubov, A. A. Badarin, N. S. Frolov, and E. N. Pitsik, "Analysis of real and imaginary motor activity with combined eeg and fnirs," in *Saratov Fall Meeting 2019: Computations and Data Analysis: from Nanoscale Tools to Brain Functions*, vol. 11459. SPIE, 2020, pp. 56–63.

[8] V. Grubov, A. Badarin, N. Schukovsky, and A. Kiselev, "Brain-computer interface for post-stroke rehabilitation," *Cybernetics and physics*, vol. 8, no. 4, pp. 251–256, 2019.

[9] A. A. Badarin, V. V. Grubov, A. V. Andreev, V. M. Antipov, and S. A. Kurkin, "Hemodynamic response in the motor cortex to execution of different types of movements," *Izvestiya VUZ. Applied Nonlinear Dynamics*, vol. 30, no. 1, pp. 96–108, 2022.

[10] G. Guyo, A. Pavlov, E. Pitsik, N. Frolov, A. Badarin, V. Grubov, O. Pavlova, and A. Hramov, "Cumulant analysis in wavelet space for studying effects of aging on electrical activity of the brain," *Chaos, Solitons & Fractals*, vol. 158, p. 112038, 2022.

[11] V. A. Maksimenko, A. E. Hramov, V. V. Grubov, V. O. Nedaivozov, V. V. Makarov, and A. N. Pisarchik, "Nonlinear effect of biological feedback on brain attentional state," *Nonlinear Dynamics*, vol. 95, no. 3, pp. 1923–1939, 2019.

[12] S. C. Stock, A. Armengol-Urpi, B. Kovács, H. Maier, M. Gerdes, W. Stork, and S. E. Sarma, "A system approach for closed-loop assessment of neuro-visual function based on convolutional neural network analysis of eeg signals," in *Neurophotonics*, vol. 11360. SPIE, 2020, pp. 25–42.