On The Possibilities of Neuro-electrostimulation for Increasing Learning Parameters

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Abstract: The paper describes the results of using the neuro-electrostimulation device for improving the attention and working memory characteristics, which are one of the main parameters of cognition in the learning process. It was shown that the quality of the test for assessment of working memory and attention in the experimental group with the use of neuro-electrostimulation was higher than in the control group. Also it was found that the application of neuro-electrostimulation could be used as a corrective technique for subjects with low initial values of test parameters, which allows increasing the test results for assessing working memory and attention.

1 INTRODUCTION

In many ways teaching and learning affect many behavioural and social factors, including human potential improvement, cognitive ability, motivation, social interaction, communication, and self-evaluation. Perfect education helps to develop a person's cogitation and communicate: in a democratic society these social skills are necessary (Whybrow, 2015).

Learning is a complex cognitive activity that is carried out with the interaction of various brain structures. Timeliness of education and the usefulness of functional systems are the psychophysiological basis of higher mental functions, mental forms of activity and the success of learning (Sirotyuk, 2011).

According to one of the key principles of neurobiology, our brains are plastic and are constantly changing as a result of training. In the process of learning, a person's cognitive reserve and adaptive reactions to stress, traumatic events and illnesses are formed. Thus, the problems that arise in training reflect the inefficient use of resources that the brain possesses (Royal Society, 2011).

Learning in a broad sense is understood as a set of individual opportunities for mastering educational information, including memorizing of educational material, performing orientation actions in the task, solving it, and self-monitoring.

Learning, first of all, is connected with the cognitive capabilities of man: the peculiarities of sensory and perceptual processes, memory, attention, thinking and speech (Karpenko, 2008).

At the moment it is not possible to predict or evaluate the learning ability of a particular individual.

In the process of cognition, the brain is directed to the organization of obtained information. This process involves acquiring information (perception), selecting (attention), representing (understanding) and retaining (memory) information, and using it to guide behaviour (reasoning and coordination of motor outputs). Interventions to improve cognitive function may be directed at any one of these core faculties (Bostrom and Sandberg, 2009).

Improvements in the diagnosis of learning through technical progress and various methods of neuroimaging using cognitive tests are expected in the next decade (Royal Society, 2011). One of the steps in solving of this problem is to study the learning process and ways to increase the potential of students in order to increase the effectiveness of the learning process (Tolmie, 2013).

There are various ways in which the person's cognitive abilities can be increased. One of these methods is the use of drugs that improve the neuro-metabolic processes. However, their use is limited

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due to the development of serious side effects and complications.

To solve this problem, one can consider neuro-electrostimulation of the peripheral nervous system.

Neurostimulation methods allow to use an endogenous neural circuit for improving the quality of learning by accelerating the tuning of neural networks responsible for cognitive functions (DARPA, 2016).

The fundamental training mechanism consists in the formation of complex, distributed neural networks that unite functionally different parts of the brain (Karpenko, 2008).

The possibilities of using the device ‘SYMPATHOCOR-01’ for improving the attention and working memory characteristics, which are one of the main parameters of cognition in the learning process, are considered in the present work.

2 MATERIALS AND METHODS

The study was approved by the local ethics committee at the Ural State Medical University in accordance with the protocol number 8 on October 16, 2015. Practically healthy subjects participated in the studies.

2.1 Method for the Estimation of Cognitive Capabilities

Evaluation of cognitive capabilities (memory and attention functions) was carried out using the dual 2-back technique, which was used as a simulation of the learning process and stress testing for subjects.

The dual 2-back method is a modern and highly effective way of training memory and attention. It is also a task of continuous performance (Pelegrina et al, 2015). The task requires on-line monitoring, updating, and manipulation of remembered information and is therefore assumed to place great demands on a number of key processes within working memory.

As the learning process involves visual and auditory channels of information perception, the fundamental structural basis for an effective learning process is to achieve a harmonious combination of auditory and visual perception channels.

Thus, visual and auditory sequences were chosen as loading stimuli. During the performance of this test, subjects must learn to activate their attention and combine the two channels of perception.

The subject works with a sequence of visual and auditory stimuli presented one in each time interval. The subject must give an answer if the current stimulus coincides with the element represented by 2 intervals back.

The quality of the test was assessed according to the following parameters: score of position stimuli, score of audio stimuli, total score, average response time.

The evaluation of the test accuracy for each sequence of stimuli is determined by the percentage of correct responses to the total number of responses of the subject. The total score is calculated by the ratio of the sum of the correct responses for the position and audio stimuli to the total number of responses during the test run.

2.2 Neuro-electrostimulation Method

The ‘SYMPATHOCOR-01’ device, which generates spatially distributed field of current pulses, is selected as the neuro-electrostimulation method (Kublanov, 2008). The device provides multi-channel percutaneous non-invasive impact on the pathways of nerve formations and neck ganglia of the sympathetic nervous system by the method of dynamic correction of the activity of the sympathetic nervous system (DCASNS) (Danilov et al, 2015). The ‘SYMPATHOCOR-01’ device is permitted for use in medical institutions of the Russian Federation and has a state certificate of the Federal Service on Surveillance in Healthcare and Social Development № FSR 2007/00757 от 27.09.2007. Application of the device does not cause side effects (Kublanov et al, 2010).

The general view of the ‘SYMPATHOCOR-01’ device is shown in Figure 1.

Figure 1: The general view of the ‘SYMPATHOCOR-01’ device.

As it is shown on Figure 1, two multi-element electrodes in the device have a 13 partial electrodes by which field of current pulses is formed. The partial electrodes may act as anodes or cathodes depending on the field direction of the current pulses. Parameters field of the current pulses can change in the following range: the amplitude of the partial current pulses from 0 to 100 mA, the pulse duration of the partial current from 10 to 100 microseconds, the frequency of the partial current pulses from 1 to 200 Hz.

For the current study parameters field of the current pulses were as follows: the amplitude of the partial current pulses is 4mA, the pulse duration of the partial current is 50 microseconds, the frequency of the partial current pulses is 80 Hz.

It is well known, that the processes in the central nervous system are the basis of all human mental activity. It is worth to note here the role of the cerebral circulation: mental performance (attention, memory and perception, logical thinking) is reduced at the deterioration of blood supply to the brain (Kadykov, 2015). This feature determines the search for solutions to manage the blood supply of the brain. Therefore, those physiological mechanisms of the sympathetic nervous system are fundamental which allows to control the tone of the blood vessels of different caliber.

The stimulation of neck nodes of the sympathetic trunk affects both the vascular tone of arteries of the brain, and autonomic spinal nucleus (Klossovskiy, 1951). Thus, our hypothesis consists in the following the statement that neuro-electrostimulation system is able to fully modulate the autonomic processes and affect motor control and cognitive function (Kublanov et al, 2015).

2.3 Sequence of Research Stages

In the first stage of the study, 54 subjects aged 20 to 25 years took part, randomly divided into the experimental (32 persons) and control (22) groups.

Prior to the study, subjects underwent a preliminary examination of the test to evaluate the baseline values for the test parameters.

Subjects of the experimental group performed the stress test simultaneously with the corrective action of the neuro-electrostimulation device.

Subjects of the control group performed a stress test without corrective action.

The sequence diagram of the first stage of the study is shown in Table 1.

Table 1: Sequence diagram.

№ step	Name of step	Duration, min.
1	Background	5
2	Stress testing (dual 2-back task)	5
3	Rest	5
4	Repeated stress testing (dual 2-back task)	5
5	Background	5

At the second stage of the study, new 33 subjects aged 20 to 25 were selected at low baseline values for the test parameters.

Then neuro-electrostimulation procedures during 5 days were carried out to the chosen subjects. During procedures subjects have performed the stress testing.

During the first and fifth procedures, an additional EEG registration was performed. The registration and analysis of the EEG were carried out according to the generally accepted standard scheme 10-20 monopolarly relative to the reference electrode on the earlobes. The registration was carried out using the 8-channel electroencephalograph-recorder «Encephalan - EEGR-19/26» (Russia) for six frequency ranges: delta$_1$ (0.5-2 Hz), delta$_2$ (2-4 Hz) theta (4, 0-8.0 Hz), alpha (8-13 Hz), beta$_1$ (13.0-24.0 Hz), and beta$_2$ (24.0-35.0 Hz).

An example of registration of EEG signals is shown in Figure 2.

Figure 2: Realization of recorded EEG signals during experimental studies of the second stage.

“STATISTICA 10.0” software applications were used for statistical analysis of the obtained data in the course of study.

3 RESULTS

3.1 Results of the First Stage

To analyze the obtained data, the relative changes in the attention and working memory parameters were calculated.

The variance analysis (ANOVA) of relative changes of test parameters was carried out to assess difference between experimental and control groups.

The main purpose of the ANOVA is to study the importance of differences between the mean values by comparing variance.

The results of the variance analysis of relative changes in variables for position and audio stimuli with the marked ranges of standard deviation in the main and control groups are presented in the Table 2 and Figures 3-5.

In the course of the variance analysis significant changes were obtained by the mean response time, score for each sequence and total score. The values obtained are reliable at the level of $p \leq 0,05$. Table 2 shows the average values of relative changes in variables with standard deviation in each group.

Table 2: Relative variations of the test parameters in experimental and control groups.

Variable	Experimental group	Control group
Total score, %	37,4±3,6	31,3±4,4
Score of audio stimuli, %	40,0±4,9	21,8±5,9
mean response time of audio stimuli, %	5,0±1,9	4,4±2,3
Score of position stimuli, %	41,4±5,5	45,0±6,7
mean response time of position stimuli, %	2,7±2,5	-4,1±3,0

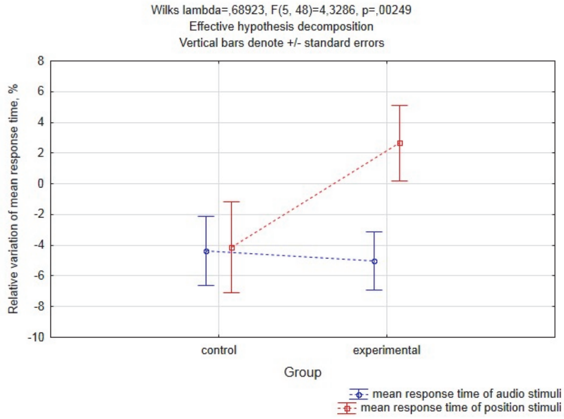

Figure 3: Relative variations of mean response time in experimental and control groups.

Plot on the Fig.3 shows that mean response time of audio and position stimuli in control group decreases by (4,4±2,3)% and (4,1±3,0)% respectively, but in experimental group mean response time of audio stimuli decreases by (5,0±1,9)%, mean response time of position stimuli increases by (2,7±2,5)%.

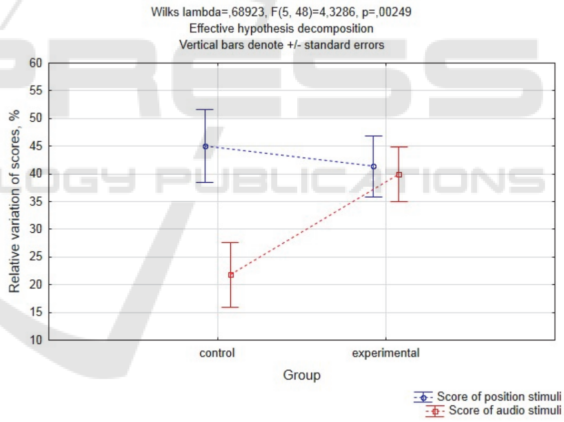

Figure 4: Relative variations of scores in experimental and control groups.

Plot on the Fig.4 shows that score of audio and position stimuli in control group increases by (21,8±5,9) % and (45,1±6,7) % respectively, but in experimental group score of audio and position stimuli increases by (40±4,9) % and (41,4±5,5) % respectively.

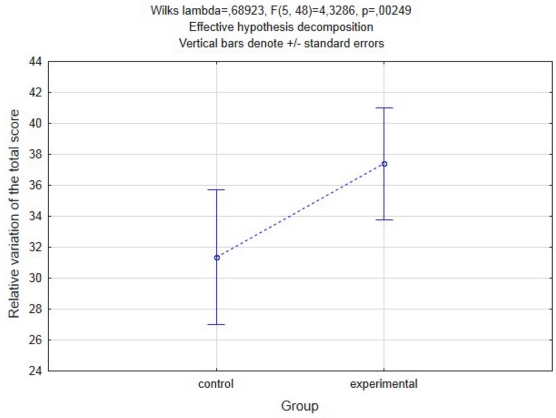

Figure 5: Relative variations of total score in experimental and control groups.

Plot on the Fig.5 shows that total score in control and experimental groups increases by (31,3 ±4,4) % and (37,4 ±3,6) % respectively.

3.2 Results of the Second Stage

Test parameters were assessed before the start of the study, at the first procedure, at the fifth procedure and 2 months later. The results are presented in the Table 3 and Figures 6-8.

Table 3: Test parameters.

	Before	I procedure	v procedure	After 2 months
mean response time of position stimuli, sec	1,35±0,03	1,33±0,03	1,08±0,03	1,1±0,03
mean response time of audio stimuli, sec	1,38±0,03	1,36±0,03	1,16±0,03	1,19±0,03
Score of position stimuli, %	41,45±2,23	57,1±2,2	78,43±2,2	77,11±2,23
Score of audio stimuli, %	42,59±2,09	58,19±2,06	76,5±2,06	74,01±2,09
Score Total, %	42,31±1,89	57,72±1,87	77,40±1,87	75,43±1,89

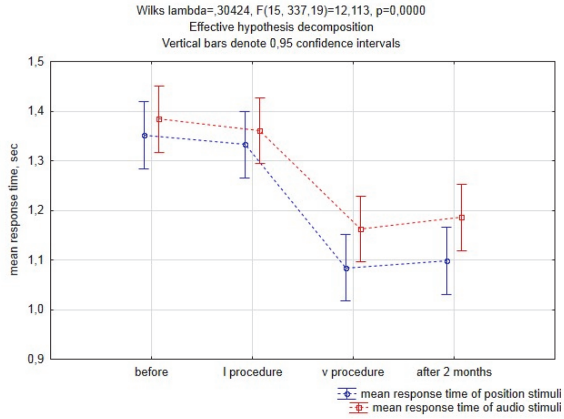

Figure 6: Results of repeated measures ANOVA of mean response time.

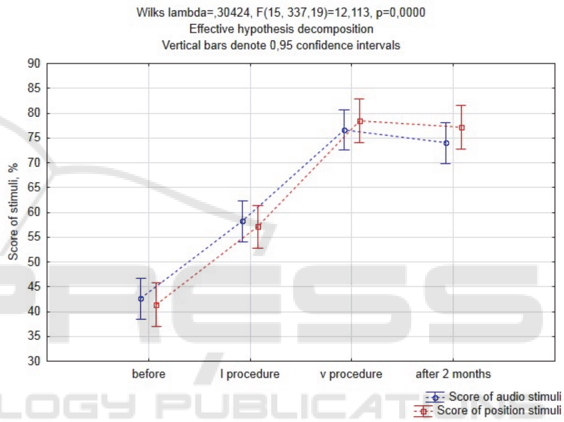

Figure 7: Results of repeated measures ANOVA of scores.

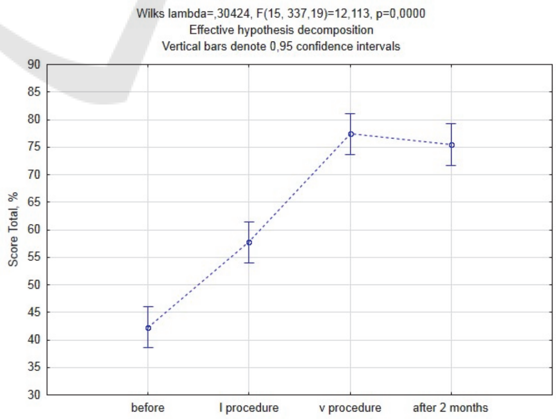

Figure 8: Results of repeated measures ANOVA of total score.

Plot on the Fig. 6-8 shows how test parameters change during the research stages.

3.3 Results of the Coherent Analysis of the EEG

At the second stage of the study, a coherent analysis of the EEG data obtained during the first and fifth procedures was carried out. Coherent EEG analysis is used to assess the regularity of plastic restructuring of cortical structures (Melnikova et al, 2011). Coherence greater than 0.7 points out a high degree of relationship between processes. In the course of the analysis, coherence values were obtained at each step, according to the sequence diagram. Then, the number of intrahemispheric and interhemispheric connections with coherence values above 0.8 was calculated and the statistical analysis was performed using ANOVA.

An example of the distribution of the coherence values at the second step of the study (dual 2-back task) during the first and fifth procedures is shown in Figures 9, 10.

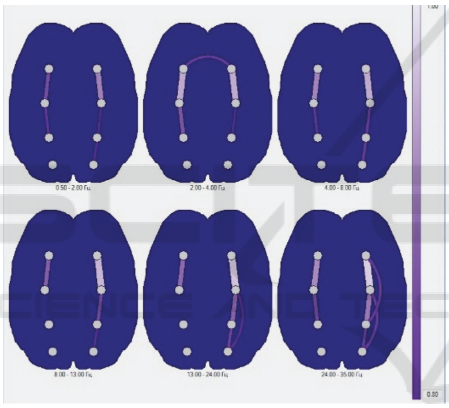

Figure 9: An example of the distribution of coherence values (0.8-1.0) during the first procedure in the second step of the study (dual 2-back task performing).

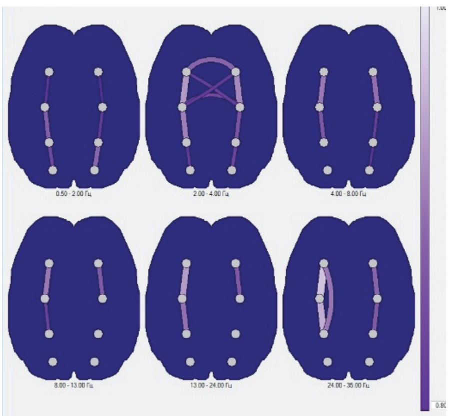

Figure 10: An example of the distribution of coherence values (0.8-1.0) during the fifth procedure in the second step of the study (dual 2-back task performing).

As a result of the variance analysis, significant differences between the first and fifth procedures ($p < 0.05$) were obtained in the number of intrahemispheric connections in delta2 wave during dual 2-back task performing according to 2 and 4 steps of the the sequence diagram, as well as in the number of interhemispheric connections in alpha wave during rest, corresponding to 1,3 and 5 steps of the the sequence diagram. The results are shown in Figures 11, 12.

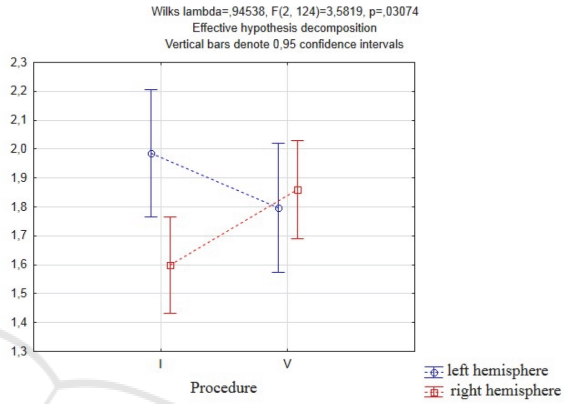

Figure 11: The number of intrahemispheric connections in delta 2 wave during dual 2-back task performing for the first and fifth procedure.

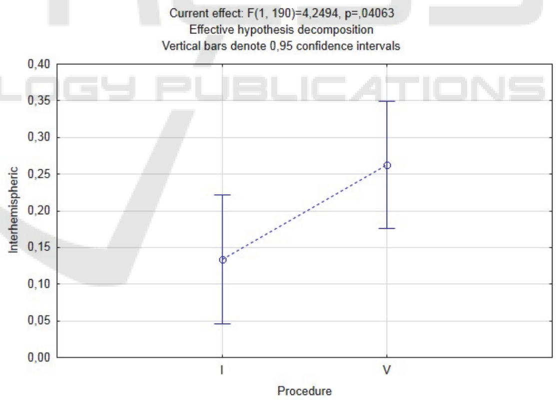

Figure 12: The number of interhemispheric connections for alpha during rest for the first and fifth procedure.

4 DISCUSSION

During the first stage of the study, the significant differences in the test parameters in the experimental and control groups were shown. The quality of the test in the experimental group with the use of neuro-electrostimulation was higher than in the control group. Thus, the use of neuro-electrostimulation allows to increase the test results for assessing working memory and attention.

During the second stage, a corrective procedure was performed on subjects with low test scores (42.3 ± 1.9)%. After the first procedure, the test results averaged (57.7 ± 1.9%), and after the fifth (77.4 ± 1.9)%. After 2 months, the results were preserved and amounted to (75.4 ± 1.9)%. These results indicate an increase in the level of working memory, which allows one to constantly remember, update and analyze the information received.

As a result of the analysis of the frequency-spatial distribution of functional connections during the first and fifth neuro-electrostimulation procedure, it was found that for the low-frequency delta band number of the right hemisphere connections increased, the number of left hemisphere connections decreased at the N-back task performing during the fifth procedure in comparison with first.

Probably, the functional state of the cerebral cortex in cognitive loading is associated with neurophysiological mechanisms that cause the intensification of interrelated slow wave activity.

The stages of functional rest are distinguished by an increase in the number of interhemispheric coherent connections for the alpha range during the fifth procedure in comparison with the first.

To justify the results obtained with the help of coherent EEG analysis in the subsequent stages of the study, an advanced study of the mechanisms of the brain functioning is proposed.

5 CONCLUSIONS

In the course of the study results showed that the use of the 'SYMPATHOCOR-01' device for neuro-electrostimulation of the peripheral nervous system allows improving of working memory and attention parameters, estimated by the correctness of the dual 2-back test and response time.

The results of the research can be applied in the development of programs to improve the effectiveness of teaching and the development of techniques for the correction of cognitive abilities in humans. The use of neuro-electrostimulation of the peripheral nervous system could reduce the amount of time and resources expended on the training process for mastering or improving the acquired skills.

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