The Application of Multichannel Neuro-electrostimulation for Working Memory and Attention Improvement of Young Subjects

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Abstract: The paper discusses the possibilities of using multichannel neuro-electrostimulation method to improve the characteristics of attention and working memory of young subjects. It was shown that the results of the test for assessment of working memory and attention in the experimental group with the use of neuro-electrostimulation was higher than those in the control and placebo groups. In addition, during the processing of the functional studies data, such heart rate variability parameters were obtained, the dynamics of which reflects the positive effect of neuro-electrostimulation. It was found that the effect of neuro-electrostimulation affects the formation of increased activity of the sympathetic nervous system of the body due to the intensification of the action of energy processes.

1 INTRODUCTION

In an intensively developing information society, the need for improving cognitive functions is steadily growing. In recent years, the active attention of many researchers has been drawn to the search for new methods to improve brain function. Improving cognitive skills is a multifaceted concept involving the study of the fundamental mechanisms of the brain functioning at different levels of its organization (Dresler et al., 2019).

Now there is an active study of factors and conditions to provide more effective methods for improving cognitive skills. One of the main conditions for ensuring the ability to learn is the active functioning of neuroplasticity processes (Maslach & Leiter, 2016).

Neuroplasticity is a set of multilevel processes of continuous morphological and functional reorganization of the brain, thus ensuring adaptation to changing external and internal conditions (Schverer et al., 2018). One of the hypotheses is the assumption that neuro-electrostimulation allows to reorganize neural networks by modulating their connections and is able to modulate higher cortical functions - to facilitate learning, recognition of visual images, improve memory and decision-making, and can also be used for neurocognitive rehabilitation (DARPA, 2016). Thus, one of the promising methods for improving cognitive skills can be the use of neuro-electrostimulation methods.

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.

In previous paper (Kublanov & Petrenko, 2018) we described in more detail the research methodology.

2.1 Estimation Method of Attention and Working Memory

N-back test is selected to estimate of working memory and attention functions. Step of memorization is N=2. Subjects work with a sequence of position and audio stimuli presented one in each time interval and must give an answer if the current

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stimulus coincides with the element represented by 2 intervals back (dual 2-back test).

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

2.2 Neuro-electrostimulation Method

The 'SYMPATHOCOR-01' device is selected as the multichannel neuro-electrostimulation method. Device generates spatially distributed field of current pulses (Danilov et al., 2015; Kublanov et al., 2014) and it is approved 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. Applying of the device does not cause side effects (Kublanov et al., 2010).

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.

The advantage of using this method is the application of a non-invasive multielectrode neuroelectrostimulation. The 'SYMPATHOCOR-01' device is a mobile and portable device, has the ability to individually select the parameters of stimulation, as well as its use is possible simultaneously with other functional and psychometric tests.

2.3 Sequence of Research Stages

At the first stage of the study, 65 subjects aged 20 to 25 years took part, randomly divided into the experimental (33 persons), control (10) and placebo (22) groups. Subjects initially performed the dual 2-back test in order to determine the baseline values for attention and working memory parameters.

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	dual 2-back test	5
3	Rest	5
4	dual 2-back test	5
5	Background	5

At the second stage of the study subjects of the experimental group performed simultaneously with the corrective action of the neuro-electrostimulation device during 5 day. Subjects of the placebo group performed dual 2-back test simultaneously with the placebo stimulation during 5 day. In placebo stimulation, a sequence of current pulses is formed by one anode and one cathode, and the target of the implications is the neck areas in which the presence of the sympathetic nervous system fibers is minimal.

Subjects of the control group performed a stress test without corrective action during 5 day.

Table 2: Sequence diagram.

Experimental group	Placebo group	Control group	Duration, min.
Background			5
neuro-electrostimulation + dual 2-back test	placebo stimulation+ dual 2-back test	dual 2-back test	5
Rest			5
neuro-electrostimulation + dual 2-back test	placebo stimulation+ dual 2-back test		5
Background			5

For experimental and placebo groups ECG signal was registered at the 1st and 5th days. The ECG registration was carried out using electroencephalograph-recorder «Encephalan - EEGR-19/26».

«STATISTICA 12.0» software applications were used for statistical analysis of the obtained data during study.

3 RESULTS

3.1 Results of the Test Parameters

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

During the ANOVA significant changes were obtained for the mean response time position and total score variables. The values obtained are reliable at the level of $p \leq 0,05$.

The results of the ANOVA for mean response time position and total score with the marked ranges

of standard deviation in the experimental, placebo and control groups are presented in Figures 1-2.

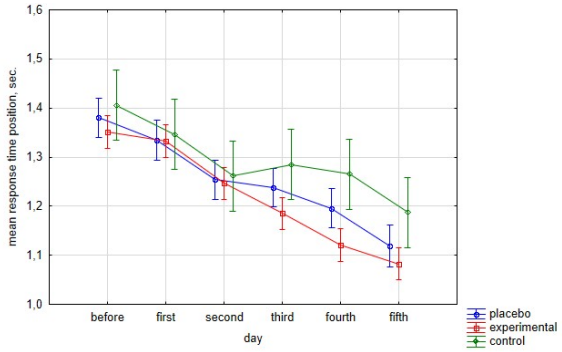

Figure 1: Changes of mean response time position for each groups.

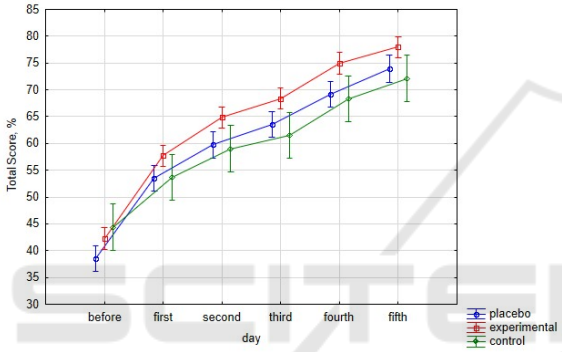

Figure 2: Changes of total score for each groups.

For the experimental group, the test was re-evaluated after 2 months without the use of neuro-electrostimulation. The results are presented in Figures 3-4.

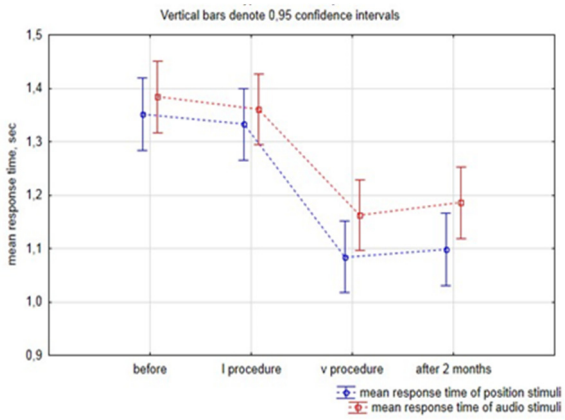

Figure 3: Repeated ANOVA results of mean response time in the experimental group.

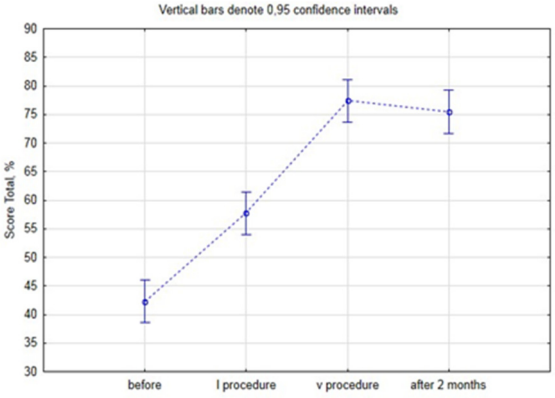

Figure 4: Repeated ANOVA results of Total score in the experimental group.

According to the primary assessment of the parameters of the dual 2-back test, the average values of total score in the three groups was (41 ± 1.9)%.

After the first procedure of neuro - electrostimulation, the average values of total score in the experimental group was (58.5 ± 1.9)%, in the control group - (53.3 ± 3.1)%, in the placebo group - (52.7 ± 2.1)%. At the same time, there is the greatest increase in total score values - in all three groups.

A significant difference between the three groups is observed as early as 3rd day of the neuro-electrostimulation procedure. The average values of total score in the experimental group after the 3rd neuro-electrostimulation was (69.6 ± 1.8)%, in the control group - (63 ± 5.6)%, in the placebo group - (63 ± 2.3)% .

Also, after data processing the, significant changes were obtained in the mean response time of position stimuli.

According to the initial assessment, the mean response time of position stimuli in the three groups was (1.39 ± 0.06) sec.

On the 3rd day, the mean response time of position stimuli in the experimental group was (1.19 ± 0.03) sec., in the placebo and control groups - (1.24 ± 0.05) sec. and (1.26 ± 0.06) sec. respectively.

By re-evaluating the test parameters in the experimental group after 2 months, the results are preserved both in the mean response time total score.

3.2 Results of HRV Analysis

Heart rate variability (HRV) data were obtained from the recorded ECG signal. For data analysis, the 64 parameters of HRV were obtained using in-house software in Python (V. Kublanov & Dolganov, 2019). Further, artifacts and outliers were excluded and

calculated the mean values and the corresponding standard deviations for each group.

The ANOVA for the HRV parameters was carried out during the 1st and 5th procedures of neuro-electrostimulation and placebo stimulation in the experimental and placebo groups to assess functional changes.

Significant changes were obtained at the level of $p \leq 0.05$ in the following variables: Stress index or index of regulatory systems tension (SI), index of autonomic balance (IAB), autonomic rhythm index (ARI), indicator of the adequacy of regulation processes (IARP). The obtained data are presented in Table 3.

Table 3: Values of HRV parameters for the experimental and control groups on 1st and 5th days.

		Experimental group		Placebo group	
day		1	5	1	5
SI	mean	150,63	156,96	129,92	114,06
	std	7,4	7,45	13,7	13,28
IAB	mean	215,43	224,22	192,41	173,32
	std	9,37	9,43	17,34	16,8
ARI	mean	7,35	7,53	6,62	6,29
	std	0,23	0,23	0,42	0,41
IARP	mean	51,58	52,76	48,58	44,69
	std	1,39	1,4	2,57	2,49

The results of analysis of variance are shown in Figures 5-7.

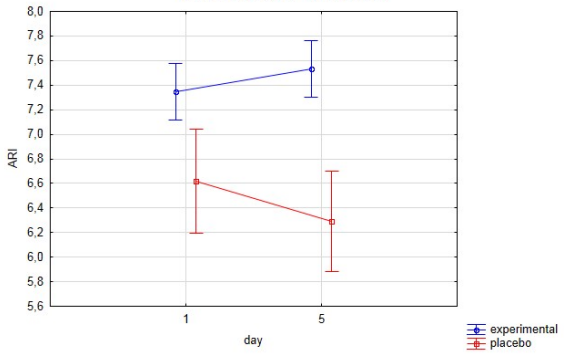

Figure 5: ANOVA results of ARI at the first and fifth days in the experimental and placebo groups.

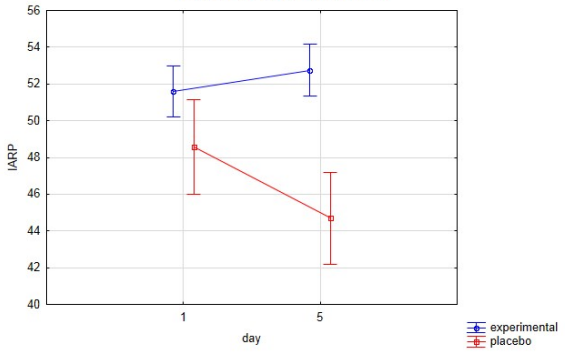

Figure 6: ANOVA results of IARP at the first and fifth days in the experimental and placebo groups.

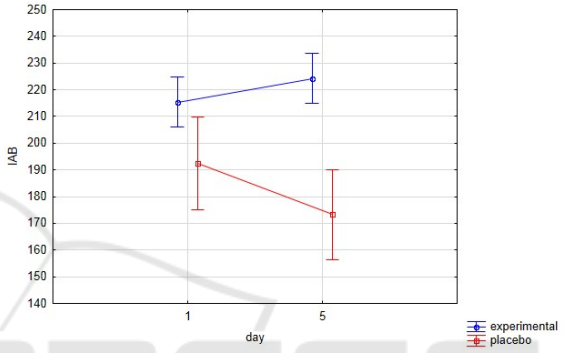

Figure 7: ANOVA results of IAB at the first and fifth days in the experimental and placebo groups.

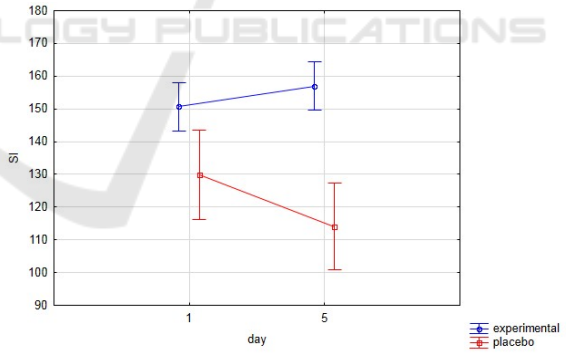

Figure 8: ANOVA results of SI at the first and fifth days in the experimental and placebo groups.

Stress index (SI), index of autonomic balance (IAB), autonomic rhythm index (ARI), indicator of the adequacy of regulation processes (IARP) reflect the degree of adaptation of the cardiovascular system to various factors (Baevsky & Ivanov, 2001).

Autonomic rhythm index (ARI) reflects the balance of regulation of the cardiovascular system by the sympathetic and parasympathetic parts of the autonomic nervous system. During the 5th procedure of neuro-electrostimulation parameter ARI in the

experimental group was higher on 20% than in the placebo group. An increase of the ARI value indicates an increased activity of the sympathetic nervous system in the subjects of the experimental group.

The index of autonomic balance (IAB) shows the ratio of the effect on the cardiovascular system of the sympathetic and parasympathetic systems. For subjects of the experimental group, there is an increase in this indicator at the 5th procedure of neuro-electrostimulation compared with the placebo group. This indicates an increase in the role of the sympathetic nervous system. For subjects in the placebo group, the IAB score is lower; therefore, the parasympathetic nervous system has a predominant effect.

The indicator of the adequacy of regulation processes (IARP) allows one to determine the effect on the sinus node of the sympathetic section and is the most stable indicator. For subjects, this indicator during the 5th procedure of neuro-electrostimulation was 52.76 ± 1.4, which is higher than those in the placebo group - 44.69 ± 2.49. The obtained data indicate an increase in the sympathetic part of the nervous system through the action of neuro-electrostimulation; the influence of the sinus node on heart rate becomes more pronounced.

The stress index (SI) indicates the degree of influence of the nervous system on the work of the heart. For the subjects of the experimental group, there is an increase of this indicator relative to the placebo group, which indicates the formation in the body of an increased activity of the sympathetic division and an increase in the degree of centralization of heart rate control. This may indicate the effect of the influence of neuro-electrostimulation on the regulation of sympathetic nervous structures, which reflects the activation of ergotropic mechanisms of regulation and an increase in the intensity of energy processes.

4 DISCUSSION

The results of the study showed that the use of neuro-electrostimulation of the peripheral nervous system in conjunction with a dual 2-back test improves working memory, reaction time and attention parameters. It was shown that performance of three neuro-electrostimulation procedures is enough to see significant intergroup differences in the parameters of the performed N-back test.

The advantage of the proposed technique for increasing the level of concentration and attention is the use of a non-invasive multielectrode neuro-electrostimulation system implemented in the 'SYMPATHOCOR-01' device. A possible mechanism of action is the activation of peripheral nerves, which in turn facilitate and strengthen neural connections in the brain. The activation of peripheral nerves occurs using neuro-electrical stimulation of the cervical ganglia of the sympathetic nervous system and the corresponding pathways of the nerve formations.

Furthermore, while processing the data of functional studies, HRV parameters were obtained, the dynamics of which reflects the positive effect of neuro-electrostimulation. It was found that the effect of neuro-electrostimulation affects the formation of increased activity of the sympathetic nervous system of the body due to the intensification of the action of energy processes.

To increase the reliability of intergroup differences in other functional parameters of HRV, it is necessary to increase the number of samples in each group.

5 CONCLUSION

During the study, a technique was developed for increasing the level of attention and working memory using neuro-electrostimulation. The advantage of this method is the use of a mobile and portable unit of non-invasive neuro-electrostimulation with the possibility of individual selection of neuro-electrostimulation parameters. The technique allows you to combine neuro-electrostimulation with other loads (for example, with psychometric tests), as well as monitor the functional state of a person using ECG registration.

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