Correction of Attention in a Learning Ability Task with using Non-invasive Neurostimulation of Peripheral Nervous System

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Abstract: The paper contains the results of pilot research on neuro-electrostimulation influence with a help of special field of the current pulses on characteristics of attention, which are some of the main parameters of the learning process. The method of dynamic correction of the activity of the sympathetic nervous system implemented by means of the «SYMPATHOCOR-01» device for improving educational and cognitive parameters is proposed. It is shown that the attention parameters such as speed and productivity can be improved by using neuro-electrostimulation. Also, it was shown that some of the autonomic nervous system characteristics, in particular LF and VLF spectral components of heart rate variability, can be chosen as indicators of human efficiency changes.

1 INTRODUCTION

At the current stage of science and technology progress, in terms of implementation of new technologies, people have to be able to materialize their potential in order to be fully engaged in social life. During this process, development of learning technologies and evaluation of individual learning capabilities have a special role. Providing of effective training of difficult technical systems specialists is now becoming an urgent task in connection with a rapid development of a technical component of difficult systems amid decrease in general level of training. It is caused by a number of factors (including those of exogenous nature) depending on a situation in each country.

That is why issues related with improving the efficiency and speed of learning are the most important at the present time. Generally, learning capability means the totality of human intellectual properties, which express the cognitive activity of the subject and its ability to assimilate new knowledge, action, complex forms of activity. Expressing general abilities, learning capability acts as a general possibility of mental development, achieving more generalized knowledge systems, common modes of action. As an empirical characteristics of the human capacity to learn, learning ability includes many indicators and parameters of the human personality. These include, above all, the cognitive capabilities of humans (features of sensory and perceptual processes, memory, attention, thought and speech), personality characteristics - motivation, character, emotional displays (Hickok and Small, 2016). Various departments of a brain participate in these processes. Brain integrates the complex and varied input signals from several sensor systems simultaneously for a quick understanding and evaluating information at performing complex operations. The relationship of these systems is carried out by the operation of neural networks (DARPA, 2016).

According to one of key principles of neurobiology, our brain is plastic and is constantly changing as a result of training. The cognitive reserve and human adaptive responses to stress, traumatic events and illnesses are formed in the training process. Thus, the problems associated with learning, reflect inefficient using of brain resources (The Royal Society, 2011). There is the idea of activation of these resources in order to increase the speed and efficiency of training. Synaptic plasticity can be enhanced by activation of certain brain areas via peripheral neuro-electrostimulation. At the same time there is a release of neurotransmitters associated with the components of training, such as acetylcholine, dopamine, serotonin and noradrenaline.

There are assumptions that the conjunction of

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peripheral neuro-electrostimulation with traditional learning methods allows to use endogenous neural circuitry for enhancement of learning quality by accelerating the setting of neural networks responsible for the cognitive functions (DARPA, 2016). Therefore, there is an interest to investigate the possibility of such the approach for education quality improvement.

In this paper the results of a pilot research of neuro-electrostimulation of the peripheral nervous system on characteristics of attention. As noted above, these characteristics are one of the main parameters of the learning process.

2 MATERIALS AND METHODS

2.1 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.

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. 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 most important formations that are involved in the organization of neuro-electrostimulation are as follows: glossopharyngeal nerve and its branches, vagus nerve and its branches, the accessory nerve, the nerve plexus around the carotid artery, the sympathetic trunk structures (upper cervical node, middle cervical node, vertebral ganglion, stellate ganglion), spinal nerves (C2-C4) forming the cervical plexus and having in its composition afferents.

Figure 2 shows the conventional areas of the nerve structures location in the neck.

They are as follows:

Area 1 - location of sympathetic trunk;
Area 2 – location of sleepy plexus;
Area 3 - location preferential cervical spinal plexus;
Area 4 - the vagus nerve;
Area 5 - accessory nerve and branches of the glossopharyngeal nerve (Kublanov et al., 2015).

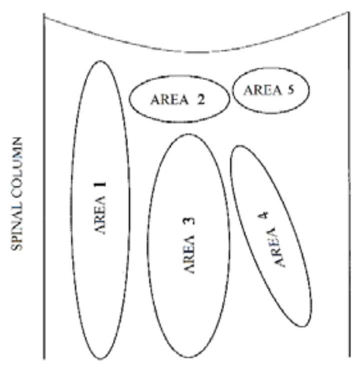

Figure 2: Conventional areas of the nerve structures location in the neck.

Regulating centers of vital functions are placed in the nuclei of the brain stem, midbrain, pons and the cerebellum, as well as - in the autonomic nuclei of the brain and spinal cord. Many of the mentioned pathways are located in the neck.

The nervous formations of neck area are closely associated with brainstem, which have two-side connections with midbrain, cerebellum, thalamus, hypothalamus and the large brain cortex. Presence of these connections provides participation of the neck nervous formations in analysis of sensory stimulation, regulation of the muscle tonus, autonomic and the highest integrative functions (Moore et al., 2013, Netter, 2014).

As a stimulation targets can be used not only the superior cervical ganglia of the sympathetic nervous system and (or) the stellate ganglion, but also other components of the sympathetic trunk, the afferent branches of the cervical plexus, cranial nerves and their branches (IX, X and XI pair) that are conductive paths nerve structures of the brainstem. And it significantly extends the capabilities of the neurostimulation method (Kublanov et al., 2015).

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

Features of the neuro-electrostimulation realized using the «SYMPATHOCOR-01» device:

- the target of neuro-electrostimulation can be changed in accordance with current task by selecting of partial electrodes as anodes of the multi-element electrode which involved in formation of the current pulse field;
- biotropic parameters of field of current pulse (amplitude, frequency and duration) are selected in accordance with the state of autonomic balance: activity of the sympathetic nervous system is blocked at sympathicotonia, and is activated at vagotonia;
- the frequency of switching the partial electrodes of the multi-electrode performing the role of anodes is at least by N times smaller than the switching frequency of the partial electrodes performing the role of cathodes;
- commutation (switching) of these electrodes is performed either clockwise, or counter-clockwise, or in the arbitrary order by a random law (Kublanov, Petrenko and Babich, 2015).

Parameters of the current pulsed field 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.

2.2 Method for the Estimation of Attention Parameters

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.

The study involved 15 participants aged 18 to 35 years who gave their informed consent to voluntary participate in the study.

The study consisted of 4 stages. The sequence diagram of the experiment is shown in Table 1.

Table 1: Sequence diagram.

№ stage	Name of stage	Duration, min.
1	Base line	5
2	Stress testing (Bourdon- test)	10
3	Neuro-electrostimulation procedure	20
4	Repeated stress testing (Bourdon test)	10

Methodology «Bourdon test» was used for the estimation of attention parameters (Brunner, 2006). Table filled with symbols formed randomly was presented to participants at Bourdon test performance. Looking through the table row by row, the participants must locate and highlight certain characters. Bourdon test is designed to assess the stability of the volume and switching of attention. The quality of the test was assessed by the speed of browsing, the general number of errors, the number of omission errors, the number of commission errors, the number of scanned characters and productivity index. Prior to the study subjects were conducted a training session to familiarize themselves with the Bourdon test. Training session and research carried out on different days.

The adapted subjective questionnaire of acute mental fatigue by A.B. Leonova was used to assess the mental fatigue (Leonova and Velichkovskaia, 2002). The questionnaire contains 18 statements describing different degrees of mental fatigue. Index of mental fatigue (IMF) was calculated based on these data. Mental fatigue is the most important factor that limits human performance in the workplace, especially in learning activities (Karpenko, 2008). IMF estimation was carried out after each stage of the study.

Electrocardiogram (ECG) was recorded during 1,2 and 4 stages. The characteristics of heart rate variability (HRV) were analyzed as a physiological indicator of changes of the human functional state during the study. Encephalan - EEGR-19/26 (Medicom MTD, RF, Taganrog) was used to register the HRV signal.

It is known that the spectral components of HRV reflect the physiological changes in the body and allow to find patterns in the regulation of physiological and mental (psycho-emotional) condition of the person: HF component reflects the activity of the parasympathetic part of the autonomic nervous system, in particular vagus activity and the power of respiratory waves; LF component characterizes the state of the sympathetic division of the autonomic nervous system, in particular, the system of regulation of vascular tone; VLF spectral component is closely related to psycho-emotional stress and the functional state of the cerebral cortex (Baevsky, 2001).

Analysis of the spectral components of HRV data was performed using the in-house software developed in MATLAB.

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

3 RESULTS

Analysis of variance with repeated measures of variables (ANOVA) was carried out to assess changes of the attention parameters obtained in the course of study "before" and "after" correction procedure with using neuro-electrostimulation. The main purpose of the ANOVA is to study the importance of differences between the of mean values by comparing variance. As a result of ANOVA significant variance were received in changing the speed performance, the productivity index, and the number of scanned characters. No significant changes were observed for parameters of the general number of errors, the number of omission errors, the number of commission errors. These values are significant at $p \leq 0.05$ level. Figures 3-5 shows the average values of the variables obtained in the course of study "before" and "after" correction procedure with the noted standard deviation.

Also, the processing of IMF at different stages of research were evaluated by using ANOVA. Figures 6 shows the average values of IMF at various stages of study with the noted standard deviation.

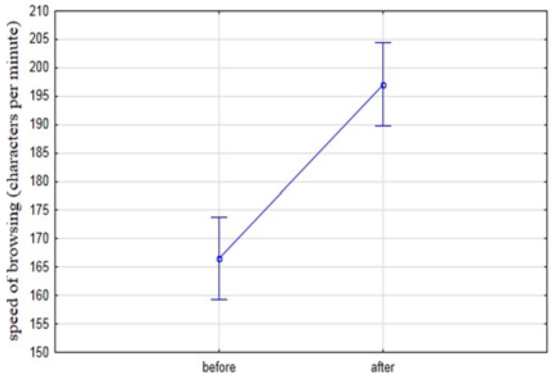

Figure 3: Variance analysis of the speed of browsing "before" and "after" correction procedure.

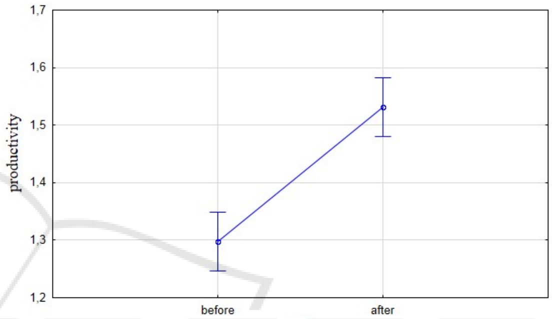

Figure 4: Variance analysis of the productivity "before" and "after" correction procedure.

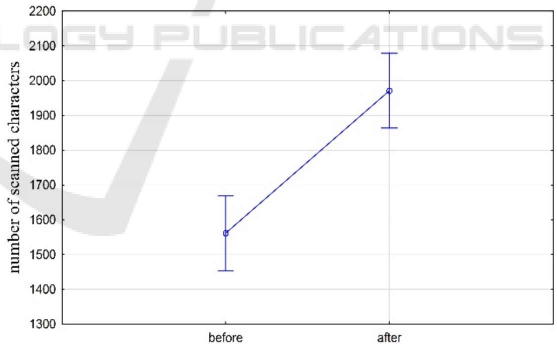

Figure 5: Variance analysis of the number of scanned characters "before" and "after" correction procedure.

Thus the average IMF value in course of the stress test on the second stage of the study increases, that indicates the appearance of mild mental fatigue. But after neuro-electrostimulation correction procedure IMF reduces and returns to the original background values in the third stage of the study.

Relative values of the spectral components HFn, LFn and VLFn were calculated in processing of the HRV data. At the assessment of the relative values of the HRV spectral components at different stages of

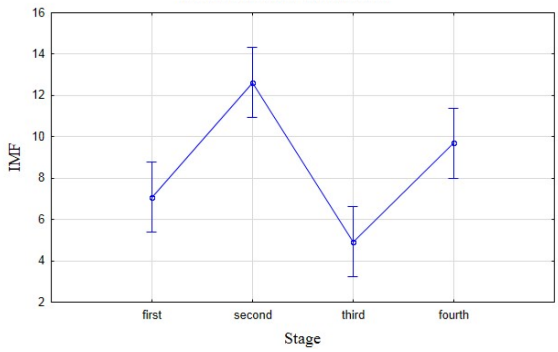

Figure 6: Variance analysis of the IMF at each stage of research.

the study significant differences were obtained in LFn and VLFn components. No significant differences were observed in the HFn component. VLFn component is increased in the course of stress test, and LFn is reduced in the course of stress test. After the neuro-electrostimulation correction procedure VLFn and LFn components are approaching to initial background values. Figure 7 shows the average values of the HRV spectral components at different stages of the study with the noted standard deviation.

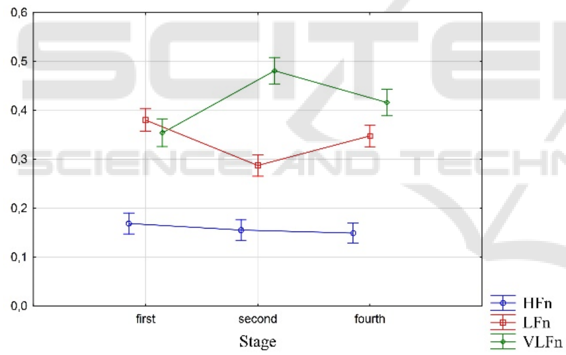

Figure 7: Variance analysis of the HRV spectral components at each stage of research.

The results are shown in Tables 2-3.

Then linear discriminant analysis was applied to determine which variables distinguish (discriminate) states of participants "before" and "after" neuro-electrostimulation correction procedure. A step-by-step analysis algorithm was used to make the analysis. At each step all variables are reviewed and the only one selected that contributes the most to the difference between states. This variable is included in the model at this stage, and the next step follows (Duda et al., 2000).

In the course of discriminant analysis, the variables that make the most significant contribution to the discrimination states of participants "before"

Table 2: Average values of the Bourdon test parameters and IMF in the groups "before" and "after" correction.

Variable	Before	After	Standard deviation
IMF	13	5	2
Number of scanned characters	1561	1971	108
General number of errors	26	24	6
Number of omission errors	24	19	6
Number of commission errors	9	5	5
Speed of browsing	167	197	7
Productivity	1,30	1,53	0,05

Table 3: Average relative values of the HRV spectral components in the groups "before" and "after" correction.

Variable	Before	After	Standard deviation
HFn	0,16	0,15	0,02
LFn	0,29	0,35	0,02
VLFn	0,48	0,42	0,03

and "after" neuro-electrostimulation correction procedure were chosen. They are as follows: number of scanned characters, speed of browsing, productivity, IMF, LF_n and VLF_n spectral components. Productivity is linearly dependent on the number of scanned characters, speed of browsing, so these variables can be excluded. Thus, the four variables were chosen for discrimination.

With the help of these defined variables, a discriminant function can be created, which is a linear equation of the following type:

$$a + b_1 * x_1 + b_2 * x_2 + ... + b_m * x_m = 0 \quad (1)$$

$x_1 ... x_m$ are selected variables, a is a constant, and $b_1 ... b_m$ are the regression coefficients.

Discriminant functions were built in the two-dimensional plane, in which axes are selected variables.

The results are shown in Figures 8-10.

LF_n spectral component was excluded from the number of variables, because it does not affect the accuracy of discrimination. Thus, the discriminant function consists of 3 variables: productivity, IMF and VLF_n.

The corresponding discriminant function and its equation are shown in Figure 11.

The accuracy of the classification of states of participants "before" and "after" neuro-electrostimulation correction procedure is 88,5%.

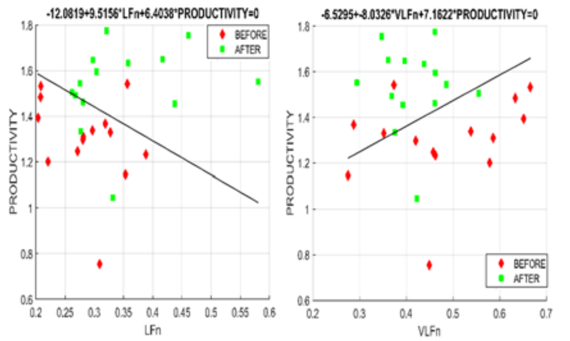

Figure 8: Discriminant functions for states of participants "before" and "after" neuro-electrostimulation in the productivity, LF_n and VLF_n spectral components axes.

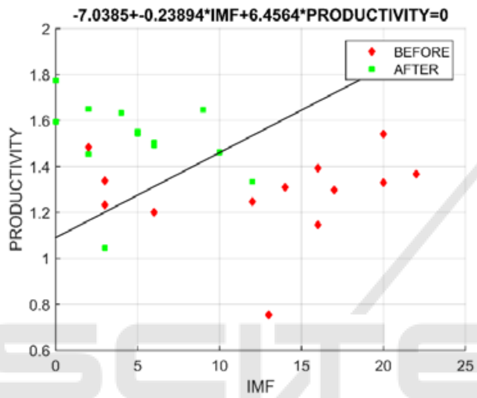

Figure 9: Discriminant function for states of participants "before" and "after" neuro-electrostimulation in the productivity and IMF axes.

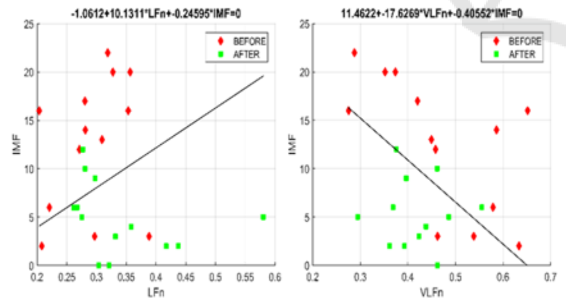

Figure 10: Discriminant functions for states of participants "before" and "after" neuro-electrostimulation in the IMF, LF_n and VLF_n spectral components axes.

4 DISCUSSIONS

Analysis of the obtained results showed the following:

1. Significant changes were obtained for the speed of browsing, productivity index and the number of scanned characters. An average of the speed browsing and productivity increased up 18%, and the number of characters scanned up 26%.

2. IMF increased at Bourdon test performance but after the correction procedure using "SIMPATHOCOR-01" it dropped and returned to the original background values.

3. Significant differences were obtained in LF_n and VLF_n components. No significant differences were observed in the HF_n component. VLF_n spectral component increases at performing the Bourdon test that indicating the psycho-emotional stress, and LF_n spectral component reduces that indicating the decrease in vascular tone, but after the neuro-electrostimulation correction procedure the indices of spectral components normalize.

4. As the result of discriminant analysis three variables were selected, by which the discriminant function was built for states of participants "before" and "after" neuro-electrostimulation correction procedure. They are as follows: productivity, IMF, and VLF_n spectral components. This indicates the need for an integrative assessment of physiological and psychometric data.

Thus, during the course of this pilot study it was showed that the method neuro-electrostimulation of the peripheral nervous system allows to enhance and to activate the attention parameters, namely speed of browsing and productivity, and reduce index of mental fatigue. At the same time indicators of human efficiency changes are changes of some characteristics of the autonomic nervous system, in particular LF_n and VLF_n spectral components.

5 CONCLUSIONS

The received data in the course of the pilot study

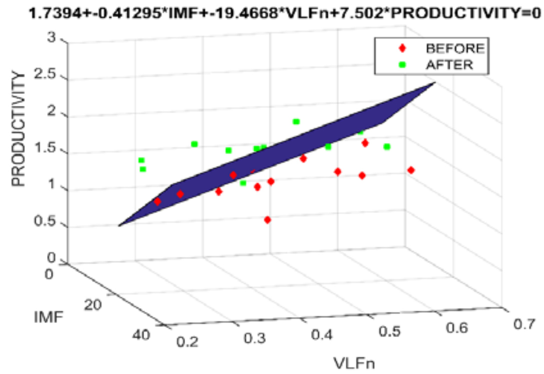

Figure 11: Discriminant function for states of participants "before" and "after" neuro-electrostimulation.

shown that the application the «SYMPATHOCOR-01» device for neuro-electrostimulation of the peripheral nervous system can improve attention parameters, namely speed of browsing and productivity. It can demonstrate activation of the mechanisms underlying human cognitive activity. Thus, realization of the neuroplasticity principle can allow to control development of a nervous system and to intensify process of training and restoration of a cognitive reserve.

Knowledge of the pathophysiological mechanisms underlying neuroplasticity, will optimize therapeutic approaches for development of science-based correction techniques to restore and to improve cognitive abilities (Zhivolupov et al., 2013). The results of the research can be applied in the design programs aimed to improve the learning efficiency and the development of techniques for the cognitive abilities correction. Also the follow-up work will involve clinical trials on patients with various diseases associated with impaired attention parameters.

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