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Patterns of Bioelectrical Brain Activity of Stroke Patients after Using Neurofeedback in the Rehabilitation Process

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Abstract

Background: Stroke patients develop the ability to perform higher levels of functional activity on basis of concentrated rehabilitative training which affects sensory, motor and cognitive functions. *Objective*: The main aim of our work was to show the usefullness of neurofeedback therapy in rehabilitation of stroke patients. *Design*: 27 stroke patients with severe disabilitis were included in the pilot study (men aged 32 to 68 years, mean age 52.4 $\pm$ 3.29 years, median 57 years). They all underwent complex study of brain bioelectrical activity EEG and 15 trainings of neurofeedback. *Results*: By the end of the rehabilitation (after 17 sessions) recollection of psychotrauma led to an increase in the power of the alpha rhythm in both left and right hemispheres. At the endpoint of the study differences in the power of the alpha rhythm in the left hemisphere were 1.47 times greater, and in the right hemisphere, 1.95 times greater than at the first visit. The regress of theta rhythm (1.25 times in the left, 1.11 times in the right hemisphere) decreased considerable, which affected the alpha / theta ratio - decreased 1.04 times in the left, 1.18 times in the right hemisphere, and also the coefficient (alpha + theta) / beta - decreased 1.17 times in the left and 1.21 times in the right. Differences in the saturation of blood vessels index at the last visit were 1.69 times greater than at the first visit. Neurophysiological changes correlated with an improvement in the emotional shpere. By the time of discharge, the indicators on the Beck depression scale decreased by 1.4 times, on the Spielberger-Khanin scale, situational anxiety decreased by 1.63 times, personal anxiety - by 1.4 times; regression of indicators in the hospital scale of anxiety and depression (HADS) was observed in 1.89 times. *Conclusion*: The data presented indicate that the use of the neurofeedback method leads to a reduction of anxiety-depressive disorders, which positively affects the usefulness of combine rehabilitation.

Keywords: stroke, neurofeedback, electroencephalogram, alpha rhythm, rehabilitation.

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1. Introduction

Cognitive disabilities and changes in bioelectrical brain activity are the most often causes for stroke [8, 12, 13, 20, 22]. Neurofeedback can be used as rehabilitation method for people after stroke. Studies of Kober [15] and Kropotov [17] showed that neurofeedback sessions positively change bioelectrical brain activity and reduce cognitive disabilities. With the use of neurofeedback people can voluntarily change their brain processes. Specific characteristics such as frequency bands can be analyzied in real time and delivered over to the patient through visible/ auditory feedback [25].

Consequently, neurofeedback directly modulates the electrical activity of the brain, effects on the brain structures associated with cognitive functions [27]. Direct access to neuronal activity affects the functional reorganization of the brain of stroke patients. Neurofeedback increases the rate of functional recovery with the use of mechanisms that would not have been triggered without using the feedback method [21, 29]. Thus, the purpose of our study is to study the bioelectrical activity of the brain of stroke patients with an assessment of the neurofeedback training effect.

The electroencephalogram (EEG) is a highly sensitive method of detecting cerebral or hemorrhagic strokes. Stroke changes in the EEG are revealed in patients who underwent stroke compared with healthy subjects. The use of quantitative EEG in acute and subacute phases of stroke has high predictive value regarding the consequences of stroke [7, 8, 26, 28]. In this context, slow EEG activity in the delta range (0.5-4 Hz), as well as rapid oscillatory activity in the alpha range (8-12 Hz) play a key role [22]. The power of the delta activity is negatively correlated with the regional cerebral blood flow, in contrast to the alpha-rhythm power, which has a strong positive correlation [8, 30].

In the acute phase of the disease in patients with unilateral ischemic stroke, delta activity is detected in the affected hemisphere [8, 12, 28]. In the acute phase of a stroke, the topogram of the delta activity reaches a maximum both in the affected and in healthy hemisphere consistently for several hours. Such interhemispheric dynamics of delta rhythm is associated with worsening of cerebral pathophysiology and the clinical status of the patient [8, 22, 28, 31]. This indicates that the pathological asymmetry in the delta of EEG activity decreases after thrombotic therapy, which leads to a reduction in clinical symptoms [7]. A decrease in the amplitude of alpha activity often points at cortical damage [7, 8, 14]. The power of alpha rhythm in the acute phase of stroke is negatively correlated with the severity of symptoms in patients with unilateral cerebral artery disease (CMA) [7]. In patients in the acute phase of subarachnoid hemorrhagic stroke, delta activity is increased, in contrast to reduced alpha activity [3, 22]. Some EEG studies show differences in brain electrical activity in subacute and chronic stages [9]. Such studies show that the greatest changes in the EEG occur within the first three months after a stroke [20]. Patients with unilateral stroke in SMA demonstrate a decrease in delta rhythm power and an increase in alpha rhythm in the affected hemisphere during the first three months after the disease manifest. The power of the alpha-rhythm also rises in the healthy hemisphere. The overall increase in alpha rhythm is also partly due to changes in motor function and vital activity [9]. Moreover, the power of delta and alpha activity becomes more symmetrically distributed in both hemispheres, which is accompanied by clinical recovery [18]. This is an indicator of the stabilization of brain electrical activity [9, 28].

In this study we try to analyze the effect of neurofeedback on depressive and anxious states of stroke patients. In neurofeedback trainings patients were able to voluntary increase or decrease the amplitude of certain EEG frequencies. There is empirical evidence that an arbitrary change in EEG amplitude affects other aspects of brain electrical activity and cognitive functions in healthy people [1, 5, 15, 17, 24]. Several studies devoted to the analysis of single cases of stroke patients demonstrate inconsistent results. Some authors identify the positive effects of neurofeedback training on cognitive functions, also note EEG normalization [19, 23], while others do not reveal any significant changes [4]. Nevertheless, the generalizability of the obtained data is limited due to the insufficient description of specific changes in the EEG signal and because of the lack of control groups. Most studies of neurofeedback consider the effects only at the behavioral level [10]. Typically, successful modulation of EEG frequency range power is occurred due to cognitive and behavioral changes [10, 11, 15, 17, 24]. For example, voluntary regulation of the upper frequency range of the alpha-rhythm (10-12 Hz) usually leads to improve working memory and short-term memory traces [6, 16]. It is believed that the alpha rhythm activates conflicting processes to solve the problem, for example, it helps to increase concentration and memory improvement by suppressing distractions (Klimesch et al. 1997). In addition to a voluntary regulation of the EEG amplitude, neurofeedback can also be used to change the topographic distribution of EEG activity. For example, biofeedback is used to treat symptoms of depression through changes in hemispheric asymmetry in the alpha range (8-12 Hz) in the prefrontal regions of the brain [2, 17]. Summarizing, the purpose of our study is to identify the features of the brain bioelectric activity of patients with acute cerebrovascular disorders, with an assessment of the impact of neurofeedback training on the depressive and anxiety states of such patients.

2. Methods

Twenty-seven patients (men aged 35-66 years, mean age 52.4 ± 3.29 years, median 57 years) with severe disabling due to a stroke were included in the study (mean age 54.6 ± 4.01 years) and hospitalized in the rehabilitation center for disable people "Preodolenie" for a month of comprehensive rehabilitation. All patients were consulted by various specialists of the multidisciplinary team, including a psychiatrist. The criteria for inclusion in this study were: a severe neurological deficit, a functional status on the Rankin score of 3-4 points, a stroke duration of at least a year, the presence of anxiety-depressive disorders (mean score on the Beck depression scale was 21 ± 10.87, on the Spielberger- Khanina: situational anxiety - 49,43 ± 13,27, personal - 43,57 ± 7,26, the HADS scale - 13,28 ± 8,01).

The evaluation of patients' condition was carried out in dynamics based on the complex study of brain bioelectrical activity EEG (alpha, beta, theta, alpha / beta, alpha / theta, alpha + theta). The patient sat on the comfortable chair and listened to the instruction of psychologists. The electrodes were attached to patient's scalp to verify the normal duty of the equipment. Patients were asked to sit in about five minutes with the eyes open, and after that 5 minutes of eyes closed. Stage of psychotrauma recollection were recorded with eyes closed for 5 minutes. Before this stage psychologist had a talk with the patient about the most emotionally hard situation in life. Mostly, it was the period of staying resuscitation department. During recording, the patients were asked not to talk or move.

Bioelectrical activity of the brain were registered on the 19-channel Electroencephalograph-recorder "Encephalan-EEGR-19/26". An electrode cap was used with 19 electrodes located on the surface of the head in accordance with the international system "10-20" in the leads Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2. As a referent, ear lobes were used, on which clip electrodes were attached. The resistance of the electrodes did not exceed 5 kOhm. The frequency of EEG digitization was 500 Hz. The parameters of the high and low frequency filters were 0.5 and 30 Hz. EEG was recorded in the installation with a combined ear-referent.

The functional evaluation of the cardiovascular system (respiration, ECG, photoplethysmogram (FPG), skin-galvanic reaction (GSR) were registered in three stages: eyes open, eyes closed and recollection of psychotrauma, with 4-channel patient multifunction transceiver "Rehacor".

Emotional sphere were evaluated by several psychological scales: Beck depression scale, self-assessment scale of SD Spilberg and YL Khanin and hospital the scale of anxiety and depression (HADS).

The study was conducted for 28 days and included 17 visits. At the first meeting, the complex assessment was carried out twice, the background level of anxiety-depressive disorders was determined at the recollection of psychotrauma (distress). In the next 15 meetings, neurofeedback training was conducted.

Classes were held daily, for 30 minutes. One session included two trainings: on the regulation of the respiration parameters (the length of the respiratory cycle) and on the control of alpha activity. Training on the regulation of breathing included the following stages: the initial background, the control phase of the contribution of abdominal breathing in comparison with the thoracic breathing, breathing according to the master schedule, control of the systolic wave amplitude. Training on the regulation of alpha activity consisted of the background and the stage of direct control of alpha activity (auditory feedback in the form of increasing the volume of music and reducing noise when the target reached the thresholds). The last visit was made before discharge, it's scheme was identical to the first visit.

The statistical processing of the results was carried out using Microsoft Excel and statistical data analysis package Statistica 8.0 for Windows (StatSoft Inc., USA) and SPSS 20.0 using standard parametric and nonparametric criteria for assessing the statistical significance of differences. Differences were considered significant at $p < 0.05$.

3. Results

Assessment of emotional sphere showed that depression of varying severity was found in 42.9% of patients. Mild depression was diagnosed in 20.4%, moderate - in 9.2%, intense - 11.2% and severe - in 2.0% of patients. The average mark on the Beck scale was 10.0 ± 7.9 (Me = 9). The analysis of the Spielberg-Khanin self-esteem scales showed that personal anxiety significantly prevails over the reactive anxiety (mean score 42.1 ± 8.7 and 36.7 ± 8.8, respectively, $p < 0.05$). The level of reactive and personal anxiety was more often moderate (57.1% and 53.1%).

At the first visit, the assessment of severity of anxiety-depressive disorders were made. This was achieved by giving a sound stimulation of negative coloration (child cry). Evaluation of the same severity of psychotrauma was performed at the time of remembering the patient's most difficult life situation. This was preceded by the patient's initial conversation with the psychologist about the most negative event in his life (more often this was due to the period of being in the intensive care unit).

At that time, the bioelectrical activity of the brain and the cardiovascular system of the brain were evaluated. It was established that at the first visit the recollection of the psychotrauma led to a decrease in the power of the indices of the bioelectrical activity of the brain. So, in the right hemisphere, the alpha-rhythm power decreased 1.45 times, theta - 1.63 times, the alpha / beta index - 1.67 times, the index (alpha + theta) / beta- 1.97 times. In the left hemisphere, the activity of the alpha rhythm decreased 2.33 times, beta - 1.24 times, theta - 2.60 times, which increased the alpha / theta index by 1.26 times. The changes obtained indicate an objective digital criterion for assessing the severity of a psychotrauma, assessed by EEG. Recollection of psychotrauma during the study of the first meeting also led to a change in the cardiovascular system. So, the amplitude of the systolic wave (ASB), estimated with the help of photoplethysmogram, decreased by 1.22 times, skin-galvanic reaction - by 1.2 times against the background of an unchanged increase in heart rate by 16%. The received changes testify an objective presence of a stressful component in recollection of a psychotrauma.

Our study has shown the effectiveness of neurofeedback therapy in the rehabilitation of neurological patients. After 15 trainings by the end of the rehabilitation period, remembering a psychotrauma, unlike the first visit, did not lead to a decrease, but leads to an increase in the power of the alpha rhythm in both the left and right hemispheres. Differences in the power of the alpha rhythm against the background of recalling stress at the endpoint of the study in the left hemisphere were 1.47 times greater, and in the right hemisphere, 1.95 times greater than at the first visit. The regress of the theta rhythm decreased significantly (by 1.25 times in the left one, 1.11 in the right hemisphere), which affected the alpha / theta coefficient - decreased 1.04 times in the left, 1.18 times in the right hemisphere, as well as the coefficient, (alpha + theta) / beta - decreased 1.17 times in the left and 1.21 times in the right. Differences in the amplitude of the systolic wave index against the backdrop of recalling a psychotrauma at the last visit were 1.69 times greater than at the first visit.

Neurophysiological changes correlated with an improvement in the psycho-emotional status. By the time of discharge, the indicators on the Beck depression scale decreased 1.4 times, on the Spielberger-Khanin scale, the situational anxiety decreased 1.63 times, the personal anxiety decreased 1.4 times; the regression of indicators on the hospital scale of anxiety and depression (HADS) was observed in 1.89 times. The data presented indicate that the use of the neurofeedback method leads to reduction in anxiety-depressive disorders, which positively affects the effectiveness of integrated rehabilitation.

4. Conclusion

Thus, neurophysiological patterns of anxiety-depressive disorders have been established. The appointment of neurofeedback therapy contributed to the regression of the severity of anxiety-depressive disorders, which correlated with the dynamics of bioelectrical activity of the brain and the cardiovascular system. The obtained data justify the expediency of the neurofeedback in the framework of complex rehabilitation programs for patients with various pathologies, including stroke.

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