An Impact of Biofeedback Training on the Effectiveness of Cognitive Training in Stroke Patients

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Влияние БОС-тренинга на эффективность когнитивных тренировок у пациентов с инсультом

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Introduction. The clinical significance of cognitive impairments remaining in patients with acute cerebrovascular accidents (stroke) in the second rehabilitation period actualizes the need for their correction. The technique of cognitive training shows a high degree of cognitive function recovery, but negative emotional states that may occur in patients during rehabilitation may reduce its positive effect. In this regard, the use of biofeedback (BFB) training to stabilize the patients' psycho-emotional state before cognitive training can increase its effectiveness.

Purpose. To evaluate the impact of BFB-training on the effectiveness of cognitive training in patients with acute cerebrovascular disorders in the second rehabilitation period.

Design. 41 post-stroke patients (ischemic stroke) in their late recovery period with varying degrees of cognitive impairments, not reaching the level of dementia, completed a course of standard rehabilitation and psychological treatment, including cognitive training sessions. Of these, 20 patients (the experimental group), before cognitive training, addition-

ally underwent a BFB-training based on the skin conductance parameter. Psychodiagnostic evaluation conducted before and after the rehabilitation course included a study of visual and auditory-speech memory, volume, distribution, and attention switching, the level of depression, as well as unconscious and conscious anxiety.

Results. After the course of rehabilitation and psychological treatment, the experimental group showed a statistically significant improvement in all cognitive functions and indicators of psycho-emotional state. Positive dynamics in the control group is observed only in the cognitive sphere. The level of cognitive functions in the experimental group after the rehabilitation course was significantly higher than in the control one.

Conclusions. An additional inclusion of BFB-training in the course of rehabilitation and psychological treatment helps to increase the effectiveness of cognitive training by stabilizing the psycho-emotional state, as well as by providing a positive impact of biofeedback methods on cognitive functions.

Keywords: post-stroke patients; cognitive function impairments; cognitive training; biofeedback.

Введение. Клиническая значимость сохраняющихся когнитивных нарушений у пациентов с острым нарушением мозгового кровообращения во втором реабилитационном периоде актуализирует необходимость их коррекции. Метод когнитивных тренировок показывает высокую степень восстановления когнитивных функций, однако негативные эмоциональные состояния, которые иногда возникают у пациентов в процессе реабилитации, могут снижать его положительное влияние. Использование БОС-тренинга для стабилизации психоэмоционального состояния перед когнитивными тренировками может повысить их эффективность.

Цель. Оценить влияние БОС-тренинга на эффективность когнитивных тренировок у пациентов с острым нарушением мозгового кровообращения во втором реабилитационном периоде.

Дизайн. 41 пациент с ишемическим инсультом в позднем восстановительном периоде с разной степенью когнитивного снижения, не достигающего уровня деменции, прошел курс стандартных реабилитационно-психологических мероприятий, содержащий когнитивные тренировки. Из них 20 пациентов (экспериментальная группа) дополнительно перед тренировками проходили БОС-тренинг по параметру электрической кожной проводимости. Психодиагностическая оценка, проводимая до и после курса реабилитации, включала исследование зрительной и слухоречевой памяти, объема, распределения и переключения внимания, уровня депрессии, а также неосознаваемой и осознаваемой тревоги.

Результаты. После курса реабилитационно-психологических мероприятий в экспериментальной группе отмечено статистически значимое улучшение всех когнитивных функций и показателей психоэмоционального состояния. Положительная динамика в контрольной группе наблюдалась только в когнитивной сфере. Уровень когнитивных функций в экспериментальной группе после курса реабилитации был достоверно выше, чем в контрольной.

Выводы. Дополнительное включение БОС-тренинга в курс реабилитационно-психологических мероприятий способствует повышению эффективности когнитивных тренировок за счет стабилизации психоэмоционального состояния, а также положительного влияния методов биоуправления на когнитивные функции.

Ключевые слова: пациенты с острым нарушением мозгового кровообращения; снижение когнитивных функций; когнитивные тренировки; биологическая обратная связь.

Introduction

A high prevalence of cognitive impairment after stroke determines the relevance of research in this area. It is cognitive impairments that mainly result in a deterioration of post-stroke patients' recovery prognosis, exacerbating the risk of recurrent stroke, and a significant decrease in their quality of life (Prokopenko, Mozhejko, & Koryagina, 2014). It is known that active recovery of cognitive functions occurs within the first six months after a stroke and most of the scientific studies regard this period of recovery (Ostankova & Habarova, 2016; Naumenko, Gromova, & Preobrazhenskaya, 2017; Guzeva V. I. et al., 2018). However, in the late recovery period, according to the literature, from 11 to 31 % of the remaining cognitive impairments are observed (Guzeva V. I. et al., 2018; Levin, Usoľceva, & Yunishchenko, 2007), so a decrease in interest in this period must be viewed unjustified.

A high significance of restoring cognitive functions and difficulties emerging during this process give rise to a reasonable question about how to correct them. One of the most actively developing areas today is a cognitive training technique and its positive impact has been confirmed in numerous studies (Prokopenko et al., 2014; Prokopenko et al., 2017; Gamito et al., 2017; Jaeggi, Karbach, & Strobach, 2017; Zlobina, Epaneshnikova, & Zinov'eva, 2018; Prokopenko, Bezdenezhnykh, Mozheyko, & Petrova, 2018). The appearance of a large number of computer programs for implementing this method indicates its availability and effectiveness (Prokopenko et al., 2014; Prokopenko et al., 2017; Gamito et al., 2017). At the same time, in recent years the problem of improving the outcomes of cognitive training has attracted researchers' attention as well. In particular, it has been found that applying transcranial electrical stimulation enhances working memory training (Richmond, Wolk, Chein, & Olson, 2014; Wang et al., 2019).

It is known that the process of post-stroke recovery is a quite complex and lengthy one, therefore, patients may experience various types of adverse emotional states (Ermakova, 2018). A lack of rapid success generates depressive reactions, an inability to perform ordinary actions creates a feeling of frustration, changes in their somatic state lead to an increased feeling of anxiety, etc. It is worth noting that these states may be situational in their essence and do not reach a clinical level of their manifestation, but their presence can have a negative impact on the effectiveness of the rehabilitation process in general and cognitive training in particular. For example, depressive symptoms have been found to reduce the effectiveness of cognitive training (Felix, Du, Taylor, & Rebok, 2019).

In our opinion, a method for correcting such dynamic negative emotional states could be a biofeedback training aimed at reducing post-stroke patients' emotional tension and improving their adaptive state (Dyomin & Poskotinova, 2014; Epaneshnikova & Kabataev, 2017). Therefore, additionally including the biofeedback training into the course of rehabilitation and psychological treatment can increase the effectiveness of cognitive training by stabilizing such patients' psycho-emotional state, as well as by having a positive impact of biofeedback techniques on cognitive functions (Sutarto, Wahab, & Zin, 2013; Trofimova, Kayutina, Isajchev, Chernorizov, & Varako, 2018; Marinina, 2019).

Methods

Participants

The study sample consisted of 41 people (25 men and 16 women) aged from 45 to 63 years (57.0±3.21) who had an acute cerebrovascular accident (onset of an ischemic stroke was six months or longer prior) and were in their second rehabilitation period (the late recovery stage). All the patients had cognitive impairments of varying degrees of severity, not reaching the state of dementia. All participants had the highest level of education. Participants gave their informed consent form for additional research procedures.

Procedure

The experimental base was the Neurological Department of the Tomsk Research Institute of Balneology and Physiotherapy of the Federal Siberian Research Clinical Centre under the FMBA of Russia (Tomsk), where the study participants underwent a course of rehabilitation for 3 weeks (21 days), which, in addition to physiotherapy procedures, included cognitive training sessions. The choice of cognitive training programs was determined by the existing cognitive impairments in the patients and was aimed at restoring the visual memory and attention functions. The sessions were carried out daily (5 times a week) for 30 minutes by means of the CogniPlus software (CPS, SCHUHFRIED GmbH; the NBACK and SELECT (S3) programs).

Testing

The psychodiagnostic instruments involved the following techniques: Learning 10 Words by A.R. Luria (for evaluating one's direct memorizing as well as short- and long-term memory) (Rubinshtejn, 1999); the Hospital Anxiety and Depression Scale (HADS) (to assess one's level of anxiety and depression) (Zigmond & Snaith, 1983); the NS-PsychoTest computer complex (Neurosoft Company, Russia): Memory for Numbers (to evaluate visual memory) (Balin, Gajda, & Gerbachevskij, 2000), the Schulte-Platonov Red-Black Tables (to assess attention volume, distribution and switching) (Shapar', Timchenko, & Shvydchenko, 2007), M. Lüscher's eight-color test (to evaluate one's unconscious anxiety) (Sobchik, 2001).

Statistical Analyses

Each of the patients was randomly assigned to either the experimental group ($n = 20$) or the control group ($n = 21$) based on simple randomization with random number generator. In experimental group ($n = 20$) in addition to cognitive training, underwent a biofeedback (BFB) training as well. The sessions were conducted using the Biofeedback 2000 x-pert software and hardware system (SCHUHFRIED GmbH; the JigsawPuzzle program) every day (5 times a week) for 15 minutes before cognitive training. The BFB-training was carried out based on the skin conductance parameter (SC) in parallel with registering the study participants' uncontrolled physiological indicators: the level of electrical skin resistance (ESR), hand temperature (HT), heart rate (HR). The choice of skin conductance as a parameter to be controlled is due to its relationship with conscious and unconscious emotional stimuli (Gordievskaya & Gordievskij, 2014; Christopoulos, Uy, & Yap, 2016).

Microsoft Excel (2010) and IBM SPSS Statistics v19 were used for statistical processing of the data collected. Testing the normality of the data distribution was performed applying the Shapiro-Wilks criterion. If there was a normal distribution of the parameter, the data were presented as a mean and a standard deviation ($M \pm SD$). If the distribution was different from normal, the data were presented as a median (Mdn) and an interquartile range in a format of Mdn [$Q1, Q2$], where $Q1$ is the lower quartile and $Q2$ is the upper quartile.

To determine significant differences in the paired samples (before and after psychological treatment) under the normal distribution law, the Student's paired t-test ($t; p$) was used. If the parameter distributions in the dependent samples being analyzed differed from the normal one, the Wilcoxon T-test ($Z; p$) was applied. If the parameter distribution in the two independent samples in question differed from the normal one, the non-parametric Mann–Whitney U-test ($U; Z; p$) was used. To compare the effectiveness of psychological treatment and rehabilitation, the variable Es was introduced, which was calculated as the ratio of the difference in the indicator values before and after psychological treatment to the indicator with a higher value (the comparison of variables was performed as that of independent series). To reveal the relationship between the indicators if differed from the normal distribution, the Spearman r_s-test ($r_s; p; n$) was used.

Results

Before the beginning of the rehabilitation and psychological treatment concerned, no statistically significant differences in psychological indicators were found between the groups ($p > 0.05$). Patients in the control and experimental groups were characterized by a decrease in visual and auditory-speech memory, a low level of attention volume, distribution and switching. Indicators of their emotional sphere did not reach negative values; however, 10 % (2 patients) in each group were diagnosed with a subclinical level of anxiety and depression.

After the rehabilitation and psychological treatment in the control group, there was a statistically significant positive dynamics in the attention indicators within the low level. Visual memory reached the lower norm, and auditory-speech memory improved

within the reduced values (see *Table 1*). There were no statistically significant changes in the indicators of the emotional sphere.

The experimental group after the rehabilitation and psychological treatment was characterized by statistically significant positive dynamics for all the cognitive sphere indicators in question (see *Table 1*). Visual memory indicators reached their average norm, auditory-speech memory approached the standard values, and attention indicators corresponded to the level below the average. Statistically significant positive dynamics of the emotional sphere was observed in the indicators of unconscious and conscious anxiety and depression. After the rehabilitation and psychological treatment in the experimental group there were no patients with a subclinical level of anxiety and depression.

Table 1

The effectiveness of rehabilitation and psychological treatment in the experimental and control groups (*Mdn* [*Q1, Q2*], scores)

	Control group (n = 21) BEFORE, AFTER	Z	p	Experimental group (n = 20) BEFORE, AFTER	Z	p
Visual memory	3 [2, 4.5], 5 [4, 6,5]*	−3.648	.000	4 [3, 5.75], 7 [6.25, 73.5]*	−4.053	.000
Attention volume	83 [57.5, 106], 80 [54.5, 100.5]*	−3.808	.000	81.5 [57, 90], 62 [49, 73.5]*	−3.927	.000
Attention distribution	155 [117, 168.5], 132 [112, 170]*	−2.904	.004	136 [100.25, 160.5], 100 [84.5, 122.5]*	−3.921	.000
Attention switching	82 [63, 109.5], 71 [45.5, 83.5]*	−3.318	.001	79 [54, 94.5], 60,5 [36.7, 73.75]*	−3.921	.000
Immediate recall	3 [2, 4], 4 [3, 5]*	−2.739	.006	4 [3, 5], 6 [4.25, 6]*	−3.100	.002
Number of recalling all the 10 words	0 [0, 0], 0 [0, 1]	−2.236	.025	0 [0, 0], 0 [0, 1]	−2.264	.008
Delayed recall	5 [3, 5.5], 5 [5, 6]	−2.074	.038	4 [2.25, 4], 6.5 [4.25, 8]	−3.203	.001
Unconscious anxiety	2 [2, 3], 3 [2, 3]*	−1.542	.123	3 [2.5, 4], 1.5 [1, 2]*	−3.886	.000
Anxiety	4 [1.5, 6], 2 [1, 5]*	−1.145	.252	4 [2, 6], 1 [1, 2]*	−3.336	.001
Depression	3 [0, 5], 5 [1, 3]*	−0.909	.363	3.5 [3, 5.75], 1 [1, 1.75]*	−3.426	.001

Note. The Wilcoxon T-test; * means statistically significant differences between the groups.

Comparison of the psychodiagnostic test results for the two groups after the rehabilitation and psychological treatment revealed statistically significant differences in vi-

sual memory ($U = 63.50$, $Z = -3.905$, $p = .000$), attention volume ($U = 127$, $Z = -2.167$, $p = .03$), attention distribution ($U = 110$, $Z = -2.610$, $p = .009$), attention switching ($U = 132$, $Z = -2.037$, $p = .042$), immediate recall ($U = 94.50$, $Z = -3.097$, $p = .002$), unconscious anxiety ($U = 68.50$, $Z = -3.845$, $p = .000$), conscious anxiety ($U = 138.50$, $Z = -2.049$, $p = .034$), depression ($U = 136.50$, $Z = -2.134$, $p = .033$). In the experimental group, attention indicators were significantly lower, which indicates a higher level of attention processes, while other psychological indicators also showed higher values compared to the control group results.

Cognitive training results also reveal a more pronounced positive dynamics in the experimental group. Patients of the experimental group achieved a higher level in the training programs; they demonstrated a higher rate and a better quality of responses (see *Table 2*).

Table 2

Comparison of the effectiveness of cognitive training in the experimental and control groups (*Mdn* [*Q1, Q2*], the level of training — scores; the average response rate — ms; the number of timely responses — scores)

		Es, the experimental group (*n* = 20)	*Es,* the control group (*n* = 21)	*U*	*Z*	*p*
NBACK	The level of training	−3 [−3, —1.25]	−2 [−3.5, —1]	121.00	−2.965	.041
«SELECT»	The level of training	−4 [−5.75, —2.25]	0 [−2, 0]	44.00	−4.397	.000
	The average response rate	344 [210.5, 475.25]	259 [169.5, 420.5]	90.00	−2.356	.036
	The number of timely responses	−42.5 [−59, —28]	−14 [−24, —9]	60.50	−3.901	.000

Note. The Mann–Whitney U-test.

The BFB-training in the experimental group resulted in a decrease in the study participants' heart rate (HR) and skin conductance (SC) and an increase in their hand temperature (HT) and electrical skin resistance (ESR) (see *Table 3*). These changes indicate that the relaxation effect was obtained and the psycho-emotional state was improved.

Table 3

Dynamics of average values of psychophysiological indicators within the BFB relaxation training in the experimental group (*n* = 20) (*M ± SD*; SC, ESR — ms; HT — °C; HR — bpm)

Indicators	At the beginning of the training	At the end of the training	*t*	*p*
SC	2.33±2.08	1.55±1.02	−3.323	.000
ESR	.003±.006	.067±.28	5.275	.003

Table 3 (continued)

Indicators	At the beginning of the training	At the end of the training	t	p
HT	32.42±2.57	33.41±1.82	−2.018	.048
HR	76.03±9.99	71.12±10.94	2.542	.020

Note. Student's t-test.

In order to evaluate the effectiveness of rehabilitation and psychological treatment, we performed a correlation analysis between physiological indicators, data from the techniques used and cognitive training. A positive relationship was obtained between attention distribution ($r_s = .686$, $p = .001$, $n = 20$) and attention switching ($r_s = .467$, $p = .038$, $n = 20$) and skin conductance. Attention distribution was also positively related to heart rate ($r_s = .573$, $p = .003$, $n = 20$). Lower values of attention, characterizing a higher level of development of this process, were observed when the physiological values were decreasing, indicating a decrease in the activity of the sympathetic nervous system and a reduction in negative psycho-emotional states.

Correlations were revealed between hand temperature and immediate recall ($r_s = .490$, $p = .028$, $n = 20$) and unconscious anxiety ($r_s = −.478$, $p = .033$, $n = 20$); therefore, the relaxation effect observed when the hand temperature increases, improves immediate memory and reduces anxiety.

The study participants' response rate was positively related to skin conductance ($r_s = .472$, $p = .036$, $n = 20$) and negatively with electrical skin resistance ($r_s = −.532$, $p = .016$, $n = 20$). The results obtained correspond to the knowledge about the effect of electrical skin activity on the response rate (Christopoulos et al., 2016).

Discussion

A statistically significant improvement in cognitive functions observed in the control and experimental groups is due to the direct impact of cognitive training aimed at correcting the attention and visual memory functions. An improvement in auditory and speech memorization that was not specifically affected is probably due to the "transfer" effect, which involves transferring the improvement in cognitive functioning to adjacent non-trainable cognitive functions (Velichkovsky, 2009). The effectiveness of using cognitive training to restore reduced cognitive functions in patients with acute cerebrovascular disorders is mainly due to neurodynamic disorders of cognitive processes.

The BFB-training based on the skin conductance parameter leads to stabilization of patients' psycho-emotional state before cognitive training, thereby increasing the effectiveness of the latter on. Additionally, the relaxation effect observed in the process of BFB-training contributes to the improvement of cognitive functions (Sutarto et al., 2013; Trofimova et al., 2018; Marinina, 2019). The relationship between cognitive functions,

emotional state and physiological processes explains positive results of the rehabilitation and psychological treatment.

However, some limitations should be noted. First, our study has a relatively small sample size of participants. Increasing the sample will help to increase the statistical significance of the results in future studies. Second, we not used the location and type of stroke in patients. Probably, taking into account these features can influence the dynamics of changes in psychological parameters.

Conclusions

A purposeful impact on memory and attention processes by means of cognitive training using specialized programs causes positive dynamics not only in the cognitive functions that are actually trained, but also in those that are not in question, thereby expanding the area of positive influence on post-stroke patients' cognitive functioning. An additional inclusion of BFB-training in the course of rehabilitation and psychological treatment helps to increase the effectiveness of cognitive training by stabilizing the psycho-emotional state, as well as by providing a positive impact of biofeedback methods on cognitive functions. Working with the current psychological state of patients with acute cerebrovascular disorders before conducting rehabilitation and psychological treatment improves their quality and effectiveness.

Acknowledgements

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