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ORIGINAL ARTICLE

The effectiveness of high-tone therapy in the complex rehabilitation of servicemen with post-traumatic stress disorder complicated by traumatic brain injury

Kostyantyn D. Babov[1] · Iryna B. Zabolotna[1] · Alexander L. Plakida[1] · Veronika S. Volyanska[2] · Iryna K. Babova[3] · Sergey G. Gushcha[1] · Iryna A. Kolker[2]

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Abstract

Introduction As a result of local military conflicts that have become more frequent over the past decades, the number of military personnel subjected to combat stress has sharply increased. More than 50% of them suffer from combat posttraumatic stress disorder. The most common comorbidity in this category of patients is a traumatic brain injury. Due to the undesirability of the long-term use of pharmacological agents, for rehabilitation, preference should be given to physiotherapeutic procedures. **Objects and methods** We examined 50 patients with post-traumatic stress disorder in combination with a closed craniocerebral injury. Group 1–25 patients received standard complex treatment at the sanatoriumresort rehabilitation stage (diet therapy, climatotherapy, balneotherapy, exercise therapy, psychotherapy). Group 2–25 patients, in addition to the standard complex treatment, received a course of high-tone therapy.
Results Complex rehabilitation of patients with the use of high-tone therapy contributes to a significant decrease in asthenoneurotic ($p < 0.05$) and asthenic depressive ($p < 0.01$) syndromes and has a psycho-relaxing effect on anxiety syndrome ($p < 0.01$). There was also a decrease in the severity of pyramidal symptoms and regression of the vestibulo-atactic syndrome ($p < 0.05$). The course application of hightone therapy was accompanied by a significant restoration of the elastotonic properties of the vascular wall and an improvement in cerebral perfusion ($p < 0.05$). Positive dynamics of electrophysiological indicators were noted: a decrease in the intensity of slow rhythms against the background of an increase in the frequency and intensity of the alpha rhythm in both hemispheres ($p < 0.05$), which indicates the harmonization of the bioelectrical activity of the brain.

Keywords High-tone therapy · Traumatic brain injury · Electroencephalography

Introduction

The vast majority of military personnel exposed to combat stress during their participation in local wars in recent decades suffer from combat post-traumatic stress disorder (PTSD). According to various researchers, this number ranges from 58.3 to 77.8% of combatants [1–6]. One of the most frequent (and most severe) comorbidities in this category of patients is a traumatic brain injury [7–11]. Most often, the limitation of the vital activity of such patients and, accordingly, a decrease in the quality of life are associated with various types of impairment of body functions: motor (paresis and paralysis, imbalance and coordination), sensory (hearing and visual impairment), and cognitive and emotional (depression, anxiety, aggression, personality changes) [12–15].

It is well-known that the consequences of TBI are characterized, like any disease of exogenous organic origin, primarily asthenia. Clinical manifestations are determined by pathopsychological increased exhaustion, which is a cardinal sign of post-traumatic changes in mental activity [16, 17]. This exhaustion is especially noticeable in the study of intelligence in a pathopsychological experiment [18].

✉ Alexander L. Plakida
aplakida@mail.ru

1 State Institution "Ukrainian Research Institute of Medical Rehabilitation Therapy of Ministry of Health of Ukraine", Odessa 65014, Ukraine

2 Odessa National Medical University, Odessa 65000, Ukraine

3 State Institution "South Ukrainian National Pedagogical University Named After K.D. Ushynsky", Odessa 65020, Ukraine

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Post-traumatic cerebral pathology rarely occurs without intellectual and amnestic disorders. Exhaustion can manifest itself in mental disorders: patients have superficial judgments and difficulty in identifying vital signs of objects and phenomena [19]. This kind of simple judgment can be temporary. Often, even a little mental stress becomes unbearable for the patient and leads to severe exhaustion [20, 21].

In a later period, both destructive and reparative processes in the brain are completed with the possible development of scarring and atrophy processes. Therefore, one of the main criteria for improving the state of the morphological substrate is the complete restoration of cerebral circulation [22–25]. One of the most urgent problems in the long-term period of TBI is the state of adequate cerebral perfusion and maintenance of cerebral autoregulation. The violations of autoregulation and reactivity of cerebral vessels during this period lead to a discrepancy between the volume of cerebral circulation, metabolism, and functional activity of the brain. Significant influence on the autoregulation of cerebral circulation is exerted by intracranial pressure. Therefore, transcranial Doppler sonography (TDS) is a topical study for this contingent of patients since it is it that allows you to quickly and qualitatively assess the state of cerebral blood flow, conduct functional tests to determine the reactivity of blood vessels, and evaluate the resistance of the vascular wall [26–28].

The hospital stage of treatment cannot fully solve the full recovery of patients with PTSD and TBI. The rehabilitation of such patients takes a considerable period [29–32]. In the pharmacological treatment of long-term consequences, preference is given to antidepressants since it is depressive disorders that accompany this ailment in 50% of cases. However, this method, unfortunately, has many negative consequences and side effects [33].

Physiotherapeutic methods of treatment that take into account the specifics of the brain's functioning are more acceptable: transcerebral electric effects, magnetotherapy, laser therapy, and microwave therapy [34–36]. One of the promising physiotherapeutic methods is high-tone therapy (HTT). It uses electric currents with a frequency of 4096 to 32768 Hz. A feature of HTT is the stimulation of intracellular mitochondria, accompanied by an increase in their number and size. As a result, the synthesis of ATP increases, which promotes regenerative processes. Positive data on the use of HTT were obtained in patients with discirculatory encephalopathy [37–39]. It has been demonstrated that hightone therapy leads to a significant regression of complaints and neurological manifestations of the disease, restoration of intellectual amnestic functions, and a significant improvement in cerebral circulation. Unfortunately, the number of published works on the results of the use of HTT is tiny, and therefore, additional research is required [40].

The study aimed to study the effectiveness of the high-tone therapy in the complex treatment of military personnel with post-traumatic stress disorder and the consequences of traumatic brain injury of mild severity at the sanatorium-resort stage of rehabilitation.

Object and research methods

We examined 50 military combatants with PTSD and the consequences of a traumatic brain injury of mild severity (mTBI), who were admitted to early sanatorium-resort rehabilitation immediately after being discharged from hospitals. All patients were men; the average age was (29.43 ± 5.86) years.

The inclusion criteria were as follows: (1) the patient must be at least 18 years of age, (2) meet the criteria for diagnosing post-traumatic stress disorder and a reliably diagnosed mild closed craniocerebral injury according to ICD 10; (3) a confirmed fact of direct participation in hostilities; (4) the limitation of participation in hostilities is not less than 1 year; (5) male gender; and (6) voluntary informed consent to participate in the study.

The exclusion criteria were as follows: (1) suicidal risk; (2) an ongoing episode of bipolar illness or psychotic disorder; (3) current alcohol or drug abuse; (4) simultaneous psychiatric or psychological treatment of post-traumatic stress disorder outside of spa treatment; (5) craniocerebral injury of moderate and severe severity; (6) epileptic seizures in history or epileptiform activity, registered according to electroencephalography data; and (7) the presence of implanted metal structures and the presence of a pacemaker.

A comprehensive examination of patients included:

- Neurological examination: patient complaints, conditions of injury, life history, objective neurological status for the presence of focal symptoms, dysfunction of the cranial nerves, signs of damage to the brain stem, pyramidal tract, speech, vestibular and autonomic disorders
- Self-assessment of psychological status according to the WAM method (well-being, activity, mood), assessment of the level of anxiety–depressive state using the Hamilton Anxiety Rating Scale (HARS) and Hamilton Depression Rating Scale (HDSR) scales [41, 42]
- Assessment of the state of cerebral circulation by ultrasound Dopplerography and transcranial duplex scanning
- Assessment of the state of the electrical activity of the brain by the method of electroencephalography

After the examination, all patients were randomly divided into two groups:

Group 1 (control): 25 patients with PTSD and the consequences of mTBI received standard complex treatment at the spa stage of rehabilitation:

- Diet therapy (balanced nutrition with a total caloric content of 2500–2800 kcal)
- Climatotherapy (walks in the fresh sea air, with a mandatory stay in the air during the daytime for at least 2 h)
- Balneotherapy (general oxygen baths) (procedures were carried out every other day, in the amount of 8–10 procedures per course of treatment, temperature 38–40° C)
- Physiotherapy exercises (group, using active dynamic and static exercises)
- Psychotherapy (group and individual)

Group 2 (main): 25 patients with PTSD and the consequences of mTBI received a course of high-tone therapy in addition to the standard complex treatment. A therapy device, HiTOP 184 (gbo Medizintechnik, Rimbach, Germany), was used for the procedures. The electrodes were located in the neck–collar area. We used a sinusoidally modulated current with a frequency of 10 to 100 Hz. The duration of the first two procedures was 40 min, all subsequent ones — 60 min. The whole course consisted of 12 procedures.

Statistical analysis of the data obtained was performed using Microsoft Excel and Statistica v. 5.0. According to the Shapiro–Wilk test, the empirical distribution of indicators was checked for compliance with the normal law. The assessment of differences in values in related samples was carried out using the G-sign test and, in unrelated samples, the Student's *t* test. Differences between the studied data for all types of statistical analysis were considered significant when $p < 0.05$.

Results and discussion

At the initial examination of patients, the most frequent complaints of a violation of the psychological state were the following: sleep disturbance (96.0%), emotional lability (94.0%), irritability (92.0%), inability to relax (88.0%), withdrawal and indifference (82.0%), depressed mood (80.0%), and anxious perception of everyday life events (88.0%). There were also somatic symptoms of anxiety in the form of causeless tremors in the body (84.0%), subjective sensations of disturbed heartbeat (78.0%), lack of air (76.0%), and a "lump in the throat" (70.0%). The patients did not express feelings of acute melancholy and despair.

All patients had a low baseline level of self-esteem according to the indicators of the WAM questionnaire. The indicator of well-being was (15.78 ± 1.46) points, the indicator of activity was (22.35 ± 1.52) points, and the indicator of mood was (16.91 ± 1.28) points, which corresponded to an overall low score.

The level of anxiety, determined on the HARS scale at the beginning of treatment, was (19.18 ± 2.55) points, which corresponds to the average level of anxiety.

The study results on the HRDS scale were (15.28 ± 1.65) points, which made it possible to characterize the level of depression as a depressive disorder of moderate severity.

In the mental status of patients in the overwhelming majority of cases (84.0%), one could note gloomy irritability; readiness for affective outbursts when discussing emotionally important topics; increased fatigue; intolerance to bright light and loud sounds; emotional lability; fixation on their feelings; persistent fears of possible side effects of treatment; and pessimistic assessment of the present and the future. In almost all patients, during targeted questioning, hypothymia was revealed, which manifested itself, first of all, a loss of interest in activities that used to be enjoyable.

Neurological examination of servicemen with PTSD and the consequences of mTBI revealed almost all the primary clinical neurological syndromes that limit the life of the victims: sensory disorders, pyramidal insufficiency, vestibular syndrome, liquor dynamic syndrome, and autonomic disorder syndrome (Table 1). In most cases (76.0%), each patient had a combination of several syndromes with varying degrees of manifestation.

In general, when comparing neurological examination data with complaints presented by patients, there is an advantage of subjective neurological symptoms over objective ones.

Sensory impairments were manifested by symptoms of paresthesia, such as tingling or numbness and hypersensitivity to sensory stimuli.

Reflex disorders manifested the defeat of the pyramidal pathways in the form of asymmetry of tendon-periosteal reflexes, the appearance of pathological flexion or extension signs, and positive axial reflexes.

Table 1 Frequency of major neurological syndromes (disorders) in servicemen with PTSD and mTBI, *n* = 50

Syndrome	Absolute amount, *n*	Percent, %
Sensitive disorders	12	24.0
Pyramidal insufficiency	14	28.0
Vestibular syndrome	18	36.0
Autonomic disorder syndrome	37	74.0
Liquor dynamic syndrome	27	54.0

Symptoms of coordination disorders of varying severity (vestibular syndrome) in most patients were represented by instability in the Romberg position (without a tendency to fall), as well as difficulties in performing coordination tests.

The liquor dynamic syndrome manifested itself as headache, dizziness, weakness, and tinnitus.

The most common symptoms were autonomic disorders. Autonomic dysfunction most often manifested itself in the form of color changes (80.0%) and skin temperature (66.0%), distal or generalized hyperhidrosis (58.0%), meteorological dependence (44.0%), and fluctuations in blood pressure (38. 0%).

When examining the state of cerebral blood flow by the transcranial Doppler sonography, the most frequent changes were angiospasm and venous outflow obstruction from the cranial cavity. According to the absolute values of velocity indicators, a slight decrease in the linear blood flow velocity (LFV) in the middle cerebral artery and the vertebrobasilar basin ($p<0.05$) was revealed. A decrease in the rate of blood flow in the cerebral vessels may reflect the depletion of compensatory-adaptive reactions aimed at maintaining adequate brain perfusion. It should also be noted that a decrease in the functional activity of the brain, which is typical for patients with atrophic processes of the brain, also usually more pronounced after TBI, can also lead to a decrease in LVF. These disorders could cause a decrease in cerebral perfusion and, consequently, a violation of its functional activity, which will be discussed below.

During the EEG, all patients showed a tendency towards a decrease in the values of the main background rhythm of the brain — the alpha rhythm ($p < 0.05$). At the same time, significant changes in the spontaneous bioelectrical activity of the brain were found, which were diffuse and were expressed in an increase in intensity in the delta and theta rhythm ranges, as well as in a decrease in intensity in the beta-1 rhythm range in all areas of the brain in both hemispheres [43].

Thus, in patients with PTSD complicated by mTBI, at the stage of early rehabilitation, there is a combination of neurophysiological, psychovegetative, emotional, and personality disorders, accompanied by changes in cerebral hemodynamics and electrical activity of the brain.

As a result of the restorative treatment, positive dynamics of subjective and objective symptoms of the disease were observed in both groups. However, significant changes were registered only in patients who received HTT, in contrast to the control group.

HTT led to the correction of several pyramidal symptoms: the asymmetry of muscle tone and tendon reflexes in the upper and lower extremities decreased ($p < 0.05$). The number of patients with manifestations of the vestibular ataxic syndrome also decreased: instability in the Romberg position ($p < 0.05$) and impaired functional tests — heel–knee and finger–nose tests ($p < 0.05$).

Under the influence of the therapy, patients of both groups 1 and 2 showed positive changes in indicators on the WAM scale (Table 2). However, in patients of group 1, significant improvements were recorded only in terms of well-being and mood, while in group 2, all three indicators significantly improved. The level of WAM indicators after treatment in patients of group 2 was significantly higher than in patients of group 1, which indicates a significant improvement in self-esteem of the functional state. These results are consistent with the data of other authors on the positive effect of HTT on the functional state of patients [44].

After the treatment received, the patients of both groups experienced possible positive changes in the indicators of the anxiety and depression scales HRDS and HARS, namely, a decrease in the manifestations of anxiety–depressive syndrome (Table 3).

Noteworthy is the fact that treatment with HTT affects the symptomatology of anxiety to the greatest extent. If after treatment on the depression scale there are no significant differences between the values in groups 1 and 2, then on the scale of anxiety in patients of group 2, there was a more significant improvement ($p < 0.001$).

Positive changes in patients were observed after the appointment of high-tone therapy in terms of cerebral hemodynamic parameters. They were characterized by an increase in the velocity parameters of blood flow and a decrease in peripheral resistance in individual vessels of the carotid and vertebrobasilar basins (Table 4).

As can be seen from Table 4, the tendency to improve cerebral circulation is observed in patients of both groups.

Table 2 Dynamics of WAM indicators, M ± m

Indicator	1st group $n=25$		2nd group $n=25$		P
	Before treatment	After treatment	Before treatment	After treatment	
Well-being, points	15.16 ± 1.52	35.23 ± 2.16***	15.78 ± 1.46	46.30 ± 3.21***	< 0.01
Activity, points	22.57 ± 1.72	26.88 ± 2.75	22.35 ± 1.52	46.96 ± 3.42***	< 0.001
Mood, points	16.71 ± 1.38	39.17 ± 2.66***	16.97 ± 1.73	53.25 ± 3.36***	< 0.001

*, reliability of difference ($p < 0.001$) values before and after treatment

P, reliability of difference value reliability of differences in values between groups after treatment

Table 3 Dynamics of HRDS and HARS scales under the influence of treatment, M ± m

Indicator	1st group $n=25$		2nd group $n=25$		*P*
	Before treatment	After treatment	Before treatment	After treatment	
HRDS, points	15.65 ± 1.18	9.86 ± 1.44*	15.12 ± 1.22	6.94 ± 1.09**	> 0.05
HARS, points	19.87 ± 2.38	11.87 ± 1.26*	18.94 ± 1.38	6.83 ± 1.25**	< 0.001

, reliability of difference (, $p < 0.05$; **, $p < 0.01$) values before and after treatment

P, reliability of difference value reliability of differences in values between groups after treatment

Table 4 Indicators of blood flow in intracranial vessels under the influence of treatment, (M ± m)

Indicators	1st group *n* = 25		2nd group *n* = 25	
	Before treatment	After treatment	Before treatment	After treatment
Middle cerebral arteries				
Systolic velocity, cm/s				
Left side		90.26 ± 1.25	86.72 ± 2.11	94.43 ± 1.23*
Right side	87.73 ± 2.14 85.50 ± 2.16	88.23 ± 1.27	83.53 ± 2.20	96.20 ± 1.26*
Pulsation index, c.u				
Left side	0.94 ± 0.02	0.90 ± 0.01	0.92 ± 0.02	0.90 ± 0.01
Right side	0.92 ± 0.01	0.88 ± 0.01	0.88 ± 0.03	0.80 ± 0.01*
Anterior cerebral arteries				
Systolic velocity, cm/s				
Left side	75.46 ± 1.20	75.76 ± 1.29	73.50 ± 1.21	74.82 ± 1.31
Right side	76.50 ± 1.21	75.29 ± 1.42	75.32 ± 1.33	76.36 ± 1.44
Pulsation index, c.u				
Left side	0.88 ± 0.03	0.86 ± 0.01	0.87 ± 0.01	0.85 ± 0.02
Right side	0.86 ± 0.02	0.84 ± 0.01	0.86 ± 0.01	0.84 ± 0.03
Posterior cerebral arteries Systolic velocity, cm/s				
Left side	69.38 ± 1.32	71.36 ± 1.43	64.82 ± 1.34	66.42 ± 1.45
Right side	71.46 ± 1.33	72.28 ± 1.22	69.32 ± 1.31	72.55 ± 1.26*
Pulsation index, c.u				
Left side	0.85 ± 0.01	0.84 ± 0.01	0.89 ± 0.03	0.84 ± 0.01
Right side	0.80 ± 0.02	0.77 ± 0.02	0.79 ± 0.04	0.69 ± 0.01*
Vertebral arteries (V4 segment)				
Systolic velocity, cm/s				
Left side 44.26 ± 1.23 Right side 45.30 ± 1.20		48.22 ± 1.26* 47.34 ± 1.35	45.30 ± 1.20 45.82 ± 1.47*	47.34 ± 1.35 53.69 ± 1.57*
Pulsation index, c.u				
Left side		0.92 ± 0.01 0.90 ± 0.01	0.93 ± 0.01	0.90 ± 0.01* 0.85 ± 0.01*
Right side	0.95 ± 0.02 0.93 ± 0.03		0.89 ± 0.01*	
Basilar artery				
Systolic velocity, cm/s	Systolic velocity, cm/s	Systolic velocity, cm/s	Systolic velocity, cm/s	Systolic velocity, cm/s
Pulsation index, c.u	Pulsation index, c.u	Pulsation index, c.u	Pulsation index, c.u	Pulsation index, c.u
Sinus rectus				
Systolic velocity, cm/s	Systolic velocity, cm/s	Systolic velocity, cm/s	Systolic velocity, cm/s	Systolic velocity, cm/s
Sinus rectus	Sinus rectus	Sinus rectus	Sinus rectus	Sinus rectus

*, reliability of difference ($p < 0.05$) values before and after treatment

However, in patients of group 1, statistically significant index ($p < 0.05$). At the same time, in patients of group 2, changes occurred only in two indicators: blood flow veloc- significant changes were observed in almost all the studity in the vertebral artery and the basilar artery pulsation ied areas of hemodynamics, except for the anterior cerebral arteries. Thus, arterial blood flow velocity in the middle cerebral arteries and vertebral arteries (intracranial section) increased. In the carotid and vertebrobasilar basin vessels, peripheral resistance was decreased according to the pulsation index and the leveling of signs of venous discirculation due to an improvement in venous outflow along the rectus sinus ($p < 0.05$). Attention is drawn to the fact that the most significant changes occurred in the hemodynamics of the right side of the brain. It can be assumed that this is due to the anatomical features of the placement of electrodes during the procedure.

When analyzing the dynamics of EEG indicators, the following results were obtained. The combined brain damage — organic and functional — led to a significant change in the background electrical activity. Against the background of a decrease in the alpha rhythm in all studied areas of the brain and theta and delta rhythms, the rhythms of decreased activity were recorded. These rhythms are an indicator of the slowness of the work of the cerebral cortex and the dominance of the activity of the subcortical and brainstem structures. The primary indicator of rehabilitation success is the displacement of these rhythms and their replacement with the alpha rhythm [45].

As follows from Tables 5 and 6, as a result of treatment in patients of both groups, there is a decrease in the delta rhythm and theta rhythm activity. However, the reliability of these changes is observed only in patients of group 2.

Delta rhythm activity significantly decreases in the frontal and occipital areas, and this decrease is recorded in both cerebral hemispheres ($p < 0.05$).

Table 5 Dynamics of indicators of brain bioelectrical activity (μV) in the delta rhythm range under the influence of treatment (M ± m)

Brain area	1st group $n = 25$		2nd group $n = 25$	
	Before treatment	After treatment	Before treatment	After treatment
Frontal area				
Left hemisphere	0.72 ± 0.10	0.65 ± 0.08	0.73 ± 0.06	0.60 ± 0.05*
Right hemisphere	0.73 ± 0.09	0.70 ± 0.07	0.70 ± 0.09	0.61 ± 0.05*
Central area				
Left hemisphere	0.72 ± 0.11	0.70 ± 0.09	0.73 ± 0.10	0.70 ± 0.09
Right hemisphere	0.74 ± 0.11	0.69 ± 0.09	0.71 ± 0.10	0.68 ± 0.08
Temporal area				
Left hemisphere	0.67 ± 0.08	0.62 ± 0.06	0.63 ± 0.08	0.59 ± 0.05
Right hemisphere	0.66 ± 0.08	0.63 ± 0.08	0.62 ± 0.07	0.57 ± 0.05
Occipital area				
Left hemisphere	0.77 ± 0.07	0.76 ± 0.05	0.79 ± 0.05	0.70 ± 0.04*
Right hemisphere	0.86 ± 0.07	0.82 ± 0.05	0.86 ± 0.06	0.72 ± 0.05*

*, reliability of difference ($p < 0.05$) values before and after treatment

Table 6 Dynamics of indicators of brain bioelectrical activity (μV) in the theta rhythm range under the influence of treatment (M ± m)

Brain area	1st group $n = 25$		2nd group $n = 25$	
	Before treatment	After treatment	Before treatment	After treatment
Frontal area				
Left hemisphere	0.75 ± 0.04	0.72 ± 0.03	0.74 ± 0.03	0.63 ± 0.03**
Right hemisphere	0.73 ± 0.06	0.72 ± 0.05	0.72 ± 0.06	0.58 ± 0.05*
Central area				
Left hemisphere	1.09 ± 0.09	0.98 ± 0.09	1.05 ± 0.09	0.96 ± 0.09
Right hemisphere	0.92 ± 0.08	0.90 ± 0.08	0.95 ± 0.11	0.93 ± 0.08
Temporal area				
Left hemisphere	0.75 ± 0.07	0.71 ± 0.06	0.74 ± 0.06	0.61 ± 0.05*
Right hemisphere	0.70 ± 0.09	0.68 ± 0.07	0.70 ± 0.06	0.59 ± 0.05*
Occipital area				
Left hemisphere	0.70 ± 0.09	0.68 ± 0.07	0.70 ± 0.06	0.59 ± 0.05*
Right hemisphere	0.85 ± 0.02	0.80 ± 0.03	0.85 ± 0.02	0.78 ± 0.03*

, reliability of difference (, $p < 0.05$; **, $p < 0.01$) values before and after treatment

A similar situation is observed with the theta rhythm. A significant decrease in its activity also occurs in both cerebral hemispheres. However, unlike the delta rhythm, the decrease in the activity of the theta rhythm occurs not only in the frontal and occipital zones but also in the temporal zone, which confirms the positive dynamics of the rehabilitation process [46, 47].

From Table 7, it follows that before treatment, the beta-1 rhythm was noted not only in the frontal regions but also in the temporal, parietal, and occipital regions, which indicates a state of persistent psycho-emotional tension and diffuse cerebral disorders against the background of suppression of the main cortical rhythm of rest.

Under the influence of the treatment, a statistically significant decrease in the index and power of the beta-1 rhythm (as an indicator of stress) was observed. In patients of group 1, changes in the power of the beta-1 rhythm were statistically insignificant. In patients of group 2, the reduction in the power of the beta-1 rhythm was statistically significant in all studied areas of the brain (the only exception was the frontal area of the right hemisphere).

When considering the effect of high-tone therapy on the structure of the bioelectrical activity of the brain, special attention was paid to the dynamics of the alpha rhythm, the main background EEG rhythm [48] (Table 8).

We see that in patients of group 1, changes in the alpha rhythm activity were not only statistically insignificant but also multidirectional. At the same time, in patients of group 2, a significant increase in the activity of the alpha rhythm is observed in almost all zones of both hemispheres of the

Table 7 Dynamics of indicators of brain bioelectrical activity (μV) in the beta-1 rhythm range under the influence of treatment (M ± m)

Brain area	1st group $n = 25$		2nd group $n = 25$	
	Before treatment	After treatment	Before treatment	After treatment
Frontal area				
Left hemisphere	1.30 ± 0.04	1.26 ± 0.03	1.37 ± 0.04	1.19 ± 0.05***
Right hemisphere	1.23 ± 0.04	1.21 ± 0.02	1.28 ± 0.04	1.26 ± 0.02
Central area				
Left hemisphere	1.85 ± 0.05	1.80 ± 0.04	1.95 ± 0.05	1.84 ± 0.04*
Right hemisphere	1.78 ± 0.04	1.73 ± 0.02	1.80 ± 0.04	1.70 ± 0.03*
Temporal area				
Left hemisphere	1.45 ± 0.04	1.41 ± 0.03	1.47 ± 0.04	1.12 ± 0.02***
Right hemisphere	1.50 ± 0.04	1.46 ± 0.02	1.46 ± 0.05	1.19 ± 0.05***
Occipital area				
Left hemisphere	2.38 ± 0.04	2.32 ± 0.02	2.39 ± 0.05	2.24 ± 0.06*
Right hemisphere	2.37 ± 0.06	2.28 ± 0.05	2.40 ± 0.06	2.25 ± 0.005*

, reliability of difference (, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$) values before and after treatment

Table 8 Dynamics of indicators of brain bioelectrical activity (Hz) in the alpha rhythm range under the influence of treatment (M ± m)

Brain area	1st group $n = 25$		2nd group $n = 25$	
	Before treatment	After treatment	Before treatment	After treatment
Frontal area				
Left hemisphere	9.83 ± 0.06	9.85 ± 0.07	9.85 ± 0.06	9.89 ± 0.07
Right hemisphere	9.93 ± 0.07	9.97 ± 0.08	9.91 ± 0.06	9.99 ± 0.08
Central area				
Left hemisphere	9.85 ± 0.07	9.86 ± 0.05	9.86 ± 0.05	9.95 ± 0.04*
Right hemisphere	9.93 ± 0.06	9.94 ± 0.05	9.91 ± 0.04	9.99 ± 0.04*
Temporal area				
Left hemisphere	9.95 ± 0.04	9.96 ± 0.05	9.95 ± 0.05	10.07 ± 0.06*
Right hemisphere	10.12 ± 0.06	10.16 ± 0.04	10.11 ± 0.03	10.19 ± 0.04*
Occipital area				
Left hemisphere	9.60 ± 0.05	9.63 ± 0.04	9.68 ± 0.06	9.99 ± 0.07***
Right hemisphere	9.90 ± 0.05	9.94 ± 0.04	9.89 ± 0.05	10.18 ± 0.06***

, reliability of difference (, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$) values before and after treatment

brain. The most significant increase in the activity of the alpha rhythm was recorded in the parieto-occipital regions. The only zone where there was no significant increase in the activity of the alpha rhythm is the frontal zone, in which the competitive influence of the beta-1 rhythm continues.

Thus, in patients of group 2, under the influence of the treatment, there was a statistically significant decrease in the index and power of the beta-1 rhythm (as an indicator of stress), a decrease in the index and power of intensity of slow delta and theta rhythms; and an increase in the index and power of the alpha rhythm, as an indicator of the normalization of the function of thalamic structures and cortex, as well as thalamocortical relationships [49, 50].

The present study has some limitations. The first is the small sample size; larger studies will allow to clarify the reliability of the results. The second limitation is the age of the examined patients (29.43 ± 5.86). Further research on the use of HTT in other age groups may reveal relevant features. And, finally, the HTT exposure protocol used by us is a limiting factor; it is possible that a change in the methodology will lead to different results, which will allow us to recommend its individualization depending on the initial state and the dynamics of rehabilitation.

Conclusions

Medical rehabilitation of patients with PTSD and the consequences of traumatic brain injury at the sanatorium-resort stage using high-tone therapy contributes to a significant decrease in asthenic neurotic ($p < 0.05$) and asthenic depressive ($p < 0.01$) syndromes and has a psycho-relaxing effect in anxiety syndrome ($p < 0.01$). The use of high-tone therapy in the complex of treatment helps to reduce the severity of pyramidal symptoms and regression of the vestibular ataxic syndrome ($p < 0.05$). The course application of high-tone therapy was accompanied by the restoration of the elastic–tonic properties of the vascular wall and the improvement of cerebral perfusion ($p < 0.05$). Under the influence of high-tone therapy, there is a positive dynamics of electrophysiological parameters in patients with PTSD and the consequences of mTBI, namely, harmonization of the bioelectrical activity of the brain in the form of a decrease in the level of intensity of slow rhythms against the background of an increase in the frequency and intensity of the alpha rhythm in both hemispheres ($p <0.05$). Thus, the technique of high-tone therapy can be recommended in the complex rehabilitation of these patients at the sanatorium stage.

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Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent The study was approved by the Bioethics Committee of the State Institution “Ukrainian Research Institute of Medical Rehabilitation Therapy of Ministry of Health of Ukraine”, protocol No. 5 of 23.02.2021. All patients have given their informed consent for participation in the research study.

Conflict of interest The authors declare no competing interests.

References

1. Babov KD, Pinchuk I.Ya, Stenlyuk VV (2015) Rehabilitation of victims in emergencies and hostilities. Post-traumatic stress disorder. Polygraph, Odessa [in Ukranian]
2. Brenner LA, Ivins BJ, Schwab K, Warden D, Nelson LA, Jaffee M et al (2010) Traumatic brain injury, posttraumatic stress disorder, and postconcussive symptom reporting among troops returning from Iraq. J Head Trauma Rehabil 25(5):307–312
3. Fear NT, Jones E, Groom M, Greenberg N, Hull L, Hodgetts TJ et al (2009) Symptoms of post-concussional syndrome are nonspecifically related to mild traumatic brain injury in UK Armed Forces personnel on return from deployment in Iraq: an analysis of self-reported data. Psychol Med 39(8):1379–1387
4. Hruby A, Lieberman HR, Smith TJ (2021) Symptoms of depression, anxiety, and post-traumatic stress disorder and their relationship to health-related behaviors in over 12,000 US military personnel: bi-directional associations. J Affect Disord 283:84–93
5. Kerr NC, Ashby S, Gerardi SM, Lane SJ (2020) Occupational therapy for military personnel and military veterans experiencing post-traumatic stress disorder: a scoping review. Aust Occup Ther J 67(5):479–497
6. LeardMann CA, Smith TC, Smith B, Wells TS, Ryan MAK, Millennium Cohort Study Team (2009) Baseline self reported functional health and vulnerability to post-traumatic stress disorder after combat deployment: prospective US military cohort study. Br Med J 338:b1273
7. Gaydabrus A (2020) Complex post-traumatic stress disorder in participants of the military actions in the operation military groups. Eur Neuropsychopharmacol 40:347–348
8. Otto JL, Smolenski DJ, Stewart L, Workman DE, Kincaid M, Belsher BE et al (2021) Explosive ordnance disposal personnel in the US military have higher risk of insomnia and post-traumatic

stress disorder: a large retrospective cohort study. Ann Epidemiol 57:40–45
9. Proessl F, Dretsch MN, Connaboy C, Lovalekar M, Dunn-Lewis C, Canino MC et al (2020) Structural connectome disruptions in military personnel with mild traumatic brain injury and posttraumatic stress disorder. J Neurotrauma 37(19):2102–2112
10. Babov K, Korshnyak V, Gushcha S, Nasibullin B, Plakida A (2022) Post-traumatic stress disorder complicated by mild combat contusion trauma: clinical features. J Neurosurg Sci 66(4):380–382
11. Simmons AN, Matthews SC (2012) Neural circuitry of PTSD with or without mild traumatic brain injury: a meta-analysis. Neuropharmacology 62(2):598–606
12. Karr JE, Areshenkoff CN, Garcia-Barrera MA (2014) The neuropsychological outcomes of concussion: a systematic review of meta-analyses on the cognitive sequelae of mild traumatic brain injury. Neuropsychology 28(3):321–336
13. Merritt VC, Jurick SM, Sakamoto MS, Crocker LD, Sullan MJ, Hoffman SN et al (2020) Post-concussive symptom endorsement and symptom attribution following remote mild traumatic brain injury in combat-exposed veterans: an exploratory study. J Psychiatr Res 130:224–230
14. Phipps H, Mondello S, Wilson A, Dittmer T, Rohde NN, Schroeder PJ et al (2020) Characteristics and impact of US military blast-related mild traumatic brain injury: a systematic review. Front Neurol 11:e559318
15. Vasterling JJ, Brailey K, Proctor SP, Kane R, Heeren T, Franz M (2012) Neuropsychological outcomes of mild traumatic brain injury, post-traumatic stress disorder and depression in Iraqdeployed US Army soldiers. Br J Psychiatry 201(3):186–192
16. Georgina G, Perez GM, De Gasperi R, Sosa MAG, Otero-Pagan A, Pryor D et al (2021) Progressive cognitive and post-traumatic stress disorder-related behavioral traits in rats exposed to repetitive low-level blast. J Neurotrauma 38(14):2030–2045
17. Koliatsos VE, Rao V (2020) The behavioral neuroscience of traumatic brain injury. Psychiatr Clin North Am 43(2):305
18. Rosenfeld JV, Ford NL (2010) Bomb blast, mild traumatic brain injury and psychiatric morbidity: a review. Injury Int J Care Inj 41(5):437–443
19. Smith TC, Ryan MAK, Wingard DL, Slymen DJ, Sallis JF, KritzSilverstein D et al (2008) New onset and persistent symptoms of post-traumatic stress disorder self reported after deployment and combat exposures: prospective population based US military cohort study. BMJ Br Med J 336(7640):366–371
20. Likhterman LB (2014) Traumatic brain injury. Diagnostics and treatment. Geotar-Media, Moscou, p 504 [in Russian]
21. Cafin OD, Balabushka YO (2016) Individual psychological features and severity of post-traumatic stress disorder as a basis for the success of psychological rehabilitation of combatants. Probl Extreme Crisis Psychol 19:171–183 [inUkranian]
22. Kaplan GB, Vasterling JJ, Vedak PC (2010) Brain-derived neurotrophic factor in traumatic brain injury, post-traumatic stress disorder, and their comorbid conditions: role in pathogenesis and treatment. Behav Pharmacol 21(5–6):427–437
23. Lippa SM, Gill J, Brickell TA, French LM, Lange RT (2021) Blood biomarkers relate to cognitive performance years after traumatic brain injury in service members and veterans. J Int Neuropsychol Soc 27(5):508–514
24. van Vliet EA, Ndode-Ekane XE, Lehto LJ, Gorter JA, Andrade P, Aronica E et al (2020) Long-lasting blood-brain barrier dysfunction and neuroinflammation after traumatic brain injury. Neurobiol Dis 145:e105080
25. Calviello LA, Donnelly J, Zeiler FA, Thelin EP, Smielewski P, Czosnyka M (2017) Cerebral autoregulation monitoring in acute traumatic brain injury: what's the evidence? Minerva Anestesiol 83(8):844–857
26. Rasulo FA, Transcranial BR (2019) Doppler and optic nerve sonography. J Cardiothorac Vasc Anesth 33:38–52
27. Blanco P, Abdo-Cuza A (2018) Transcranial Doppler ultrasound in neurocritical care. J Ultrasound 21(1):1–16
28. Robba C, Goffi A, Geeraerts T, Cardim D, Via G, Czosnyka M, Park S et al (2019) Brain ultrasonography: methodology, basic and advanced principles and clinical applications. A narrative review. Intensive Care Med 45(7):913–927
29. Cooper DB, Bunner AE, Kennedy JE, Balldin V, Tate DF, Eapen BC et al (2015) Treatment of persistent post-concussive symptoms after mild traumatic brain injury: a systematic review of cognitive rehabilitation and behavioral health interventions in military service members and veterans. Brain Imaging Behav 9(3):403–420
30. Heslot C, Cogne M, Guillouet E, Perdrieau V, Lefevre-Dognin C, Glize B et al (2021) Management of unfavorable outcome after mild traumatic brain injury: review of physical and cognitive rehabilitation and of psychological care in post-concussive syndrome. Neurochirurgie 67(3):283–289
31. MacGregor AJ, Shannon KB, Dougherty AL (2021) Time since injury as a factor in post-concussion symptom reporting among military service members with blast-related concussion. J Neurotrauma 38(17):2447–2453
32. Mahoney EJ, Silva MA, Reljic T, Dams-O'Connor K, Hammond FM, Monden KR et al (2021) Rehabilitation needs at 5 years posttraumatic brain injury: a VA TBI model systems study. J Head Trauma Rehabil 36(3):175–185
33. Moore BA, Pujol L, Waltman S, Shearer DS (2021) Management of post-traumatic stress disorder in veterans and military service members: a review of pharmacologic and psychotherapeutic interventions since 2016. Curr Psychiatry Rep 23(2):e9
34. Opie GM, Foo N, Killington M, Ridding MC, Semmler JG (2019) Transcranial magnetic stimulation-electroencephalography measures of cortical neuroplasticity are altered after mild traumatic brain injury. J Neurotrauma 36(19):2774–2784
35. Mu WY, Catenaccio E, Lipton ML (2017) Neuroimaging in blast-related mild traumatic brain injury. J Head Trauma Rehabil 32(1):55–69
36. Fickling SD, Greene T, Greene D, Frehlick Z, Campbell N, Etheridge T et al (2020) Brain vital signs detect cognitive improvements during combined physical therapy and neuromodulation in rehabilitation from severe traumatic brain injury: a case report. Front Hum Neurosci 14:e347
37. Shmakova IP, Afanasyeva Ya S (2004) Application of high-tone therapy in rehabilitation of patients with dyscirculatory encephalopathies of the I – II stage. Int J Immunorehabil 6(1):178–179 [in Russian]
38. Shmakova IP, Panina SO (2020) The effect of high-tone therapy on clinical and neurofunctional parameters in patients with hypertension with encephalopathy and concomitant diabetes. Bull Mar Med 1:95–99 [inUkranian]
39. Schaffler-Schaden D, Sassmann R, Johansson T, Gampenrieder SP, Rinnerthaler G, Lampl K et al (2020) Comparison of high tone therapy and transcutaneous electrical nerve stimulation therapy in chemotherapy-induced polyneuropathy. Medicine (Baltimore) 99(19):e20149
40. Ogrodzka-Ciechanowicz K, Glab G, Slusarski J, Gadek A (2021) Quadriceps muscle strength recovery with the use of high tone power therapy after anterior cruciate ligament reconstruction: a randomized controlled trial. BMC Musculoskelet Disord 22(1):975

41. Guelfi JD (ed) (1993) L'évaluation clinique standardisée en psychiatrie. Boulogne: Editions Médicales Pierre Fabre
42. Zigmond AS, Snaith AS (1983) The hospital anxiety and depression scale. Acta Psychiatr Scand 67:361–370
43. Kaltiainen H, Helle L, Liljestrom M, Renvall H, Forss N (2018) Theta-band oscillations as an indicator of mild traumatic brain injury. Brain Topogr 31(6):1037–1046
44. Kubsik A, Klimkiewicz P, Klimkiewicz R, Jankowska K, Jankowska A, Woldanska-Okonska M (2014) Wplyw terapii energotonowej na stan funkcjonalny chorych na stwardnienie rozsiane. [The influence of high-tone power therapy on the functional status of patients with multiple sclerosis]. Polski merkuriusz lekarski 37(217):24–29
45. Sheerin CM, Franke LM, Aggen SH, Amstadter AB, Walker WC (2018) Evaluating the contribution of EEG power profiles to characterize and discriminate posttraumatic stress symptom factors in a combat-exposed population. Clin EEG Neurosci 49(6):379–387
46. Wei H, Chang L, Huang Q, Zhou RL (2020) Relation between spontaneous electroencephalographic theta/beta power ratio and test anxiety. Neurosci Lett 73:135323
47. Wen TY, Bani NA, Muhammad-Sukki F, Aris SAM (2020) Electroencephalogram (EEG) human stress level classification based on theta/beta ratio. Int J Integr Eng 12(6):174–180
48. Lewine JD, Plis S, Ulloa A, Williams C, Spitz M et al (2018) Quantitative EEG biomarkers for mild traumatic brain injury. J Clin Neurophysiol 36(4):298–305
49. Pauli R, O'Donnell A, Cruse D (2020) Resting-state electroencephalography for prognosis in disorders of consciousness following traumatic brain injury. Front Neurol 11:e586945
50. Tolonen A, Sarkela MOK, Takala RSK, Katila A, Frantzen J, Posti JP et al (2018) Quantitative EEG parameters for prediction of outcome in severe traumatic brain injury: development study. Clin EEG Neurosci 49(4):248–257