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The Use of Bioacoustic Stimulation of the Respiratory System in Complex Medical Rehabilitation at a Health Resort Facility for Patients who have had COVID-associated Pneumonia

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Abstract

BACKGROUND: In the context of the COVID-19 pandemic, the relevance of rehabilitation measures for patients with COVID-associated pneumonia has increased.

AIM: The study aimed to review the effect of bioacoustic stimulation of the respiratory system (BSRS) with high-intensity low-frequency sounds on the dynamics of functional indicators of the respiratory system and the cardiovascular system, as well as indicators of psychoemotional and somatic states, the severity of post-traumatic stress disorders (PTSD) and cognitive capabilities in patients who have had COVID-associated pneumonia in the process of their medical rehabilitation at a health resort immediately after treatment of the disease in a hospital.

MATERIALS AND METHODS: The randomized controlled open parallel prospective clinical study involved 28 patients undergoing medical rehabilitation after suffering moderate to severe COVID-19 complicated by community-acquired bilateral polysegmental pneumonia (COVID-associated pneumonia) of moderate to severe severity. Spirometry, pulse oximetry, compression oscillometry, bioelectrography, Mississippi Scale (civil version), and cognitive speed test were used to assess the functional parameters of the respiratory and cardiovascular systems, as well as indicators of psychoemotional and somatic states, the intensity of PTSD and cognitive abilities of patients before and after the course of rehabilitation measures.

RESULTS: According to significant differences in changes in the indexes of external respiration, cardiac activity, psychological status, and the intensity of PTSD in patients of the main and control groups before and after a course of rehabilitation measures, it has been reliably established that the use of BSRS as a part of a complex of rehabilitation measures significantly increases the effectiveness of medical rehabilitation at a health resort for patients after COVID-associated pneumonia.

CONCLUSION: The possibility and feasibility of using medical technology of BSRS with high-intensity low-frequency sound in complex medical rehabilitation of patients after COVID-associated pneumonia at the health resort stage have been scientifically substantiated.

Introduction

Bilateral pneumonia (viral diffuse alveolar injury with microangiopathy) is the most common clinical manifestation of the novel coronavirus infection (COVID-19), a type of viral lung disease characterized by the involvement in the pathological process of interstitial lung tissue, alveolar walls, and vessels, that is, the development of inflammation in all the lung structures involved in gas exchange, which prevents the normal oxygenation of the blood [1], [2], [3], [4], [5], [6].

Events at the stage of medical rehabilitation of patients with coronavirus-related pneumonia (COVID-associated pneumonia), aimed at restoration of function of external respiration, transport and utilization of oxygen by tissues, organs, and systems, the restoration of tolerance to stress, psycho-emotional stability, daily activities, and participation in daily life are crucial to restoring and optimizing the results of intensive and specialized medical care with COVID-19 [1], [3], [4], [5], [6], [7].

As practice has shown, the implementation of the second stage of medical rehabilitation at health resorts immediately after the treatment of patients with COVID-associated pneumonia in the hospital setting is significant for achieving this goal [6], [7], [8], [9].

At present, various programs of the second stage of medical rehabilitation of patients with the post-COVID syndrome at health resorts have been developed and implemented in practical healthcare [3], [5], [7], [8], [9], including methods and means that have proven to be effective [6]. During the implementation of these programs, it was shown that complex rehabilitation measures with the use of various natural and preconditioned therapeutic physical factors contributed to an increase in the overall adaptive potential, improvement of the functional state of the cardiorespiratory system, correction of vegetative imbalance, and increased tolerance to physical activity [9].

At the same time, despite the high effectiveness of these rehabilitation measures noted by several researchers [3], [5], [7], [8], [9], conducting high-quality randomized controlled clinical trials to evaluate new various physical methods of rehabilitation of patients after COVID-associated pneumonia, which can serve as a basis for the development of future valid clinical recommendations, is an important task in the field of restorative medicine, physiotherapy and health resort therapy [6], especially in terms of the ongoing pandemic COVID-19 [6], [8], [9], [10], [11], [12].

It should be noted that the specific tasks of respiratory rehabilitation in COVID-19, including in patients after COVID-associated pneumonia, include the elimination of inflammatory foci, improvement of bronchial conduction and uniformity of lung ventilation, elimination of dissociation between alveolar ventilation and pulmonary blood flow, improvement of bronchial drainage function, prevention of early expiratory closure of the airways, and economization of the respiratory muscles function through increasing their power and synkinesis, that is, the implementation of adequate gas exchange with minimal stress of compensatory mechanisms [7], [10].

At present, to solve these problems, including at the health resort stage of rehabilitation, a wide range of methods and means are used that implement various types of physical training, a system of breathing exercises, yoga elements, sound and drainage gymnastics, postural drainage, normobaric barotherapy, magnetic therapy, and other therapeutic physical factors [1], [4], [5], [6], [7], [13], [14], [15], [16], [17], [18].

The method that, based on the results of its use in sports medicine, can allow solving some of the aforementioned tasks of medical rehabilitation of patients after COVID-associated pneumonia is bioacoustic stimulation of the respiratory system (BSRS) with high-intensity low-frequency sounds [19], [20], [21], [22], [23].

The BSRS method is based on the biological effects of the interaction of a high-intensity sound wave with the human respiratory tract at individually selected resonant frequencies [19], [20], [23]. In this case, the effects of high-intensity sounds at a low tone frequency result in the opening of extra alveoli, reducing the tone of smooth muscles of the respiratory bronchioles and, consequently, increasing their cross-sectional area, that is, ultimately, increasing lung capacity, improving gas exchange and, therefore, increasing the functional reserves of the respiratory system of the human body [15], [20], [23], [24].

Thus, the use of BSRS in 114 professional cyclists showed that 98.3% of athletes had a marked increase in the functional reserves of the body by increasing lung capacity by 5–15%; 87.9% had an increase in chest excursion and an increase in the time of breath-holding during the exhale; 94.8% had an increase in peak power during the Wingate test, and 84.5% had a minimally 60% decline in maximum oxygen debt after performing aerobic and anaerobic physical activity. At the same time, there was no negative effect on the clinical, hematological, and biochemical parameters of the body [19], [20].

Based on this and the above-mentioned features of respiratory disorders in patients with COVID-associated pneumonia and the rehabilitation tasks carried out in this case, it was suggested that the use of BSRS as one of the methods of medical rehabilitation of patients after COVID-associated pneumonia would allow those patients to increase the vital capacity of the lungs and, as a result, improve gas exchange in the lungs and increase the body's tolerance to physical exertion, as well as improve the psycho-emotional state and reduce the severity of post-traumatic stress disorder (PTSD). It was assumed that the use of BSRS, characterized in contrast to the physical methods currently used in accordance with [1] for the rehabilitation of patients after COVID-associated pneumonia [3], [4], [5], [6], [7], [8], [9], [13], [14], [15], by direct exposure of high-intensity low-frequency sounds on the respiratory system of the patient and the corresponding biological effects of their interaction with this system, will significantly improve the effectiveness of medical rehabilitation at the resort stage of patients who suffered COVID-associated pneumonia. Previously, research on the assessment of the possible effectiveness of BSRS as a physical method of medical rehabilitation of patients who suffered COVID-associated pneumonia has not been conducted.

In this regard, the study aimed to investigate the influence of BSRS - a new medical technology for increasing the functional potential of the human body - on the dynamics of the functional parameters of the respiratory system and the cardiovascular system, as well as indicators of emotional and somatic states, the severity of PTSD, and cognitive abilities in patients undergoing COVID-19, and to study the possibility and feasibility of using this technique in complex medical rehabilitation at the health resort stage for patients with COVID-associated pneumonia.

Materials and Methods

The study involved 28 patients enrolled immediately after discharge from the hospital for medical rehabilitation at a health resort after having from COVID-19 of moderate to heavy severity complicated by community-acquired bilateral polysegmental pneumonia (COVID-associated pneumonia) of moderate to heavy severity. The criteria for participation in the study included informed consent of the patient; the age of patients was between 40 and 65 years; patients were objectively diagnosed with moderate-to-severe COVID-associated pneumonia in the hospital; and patients received the same rehabilitation measures prescribed by their attending physician in accordance with [1].

The patients were divided into two groups. The main group included 20 patients (16 women and 4 men, average age: 54.1 ± 2.4 years) and the control group included eight patients (four men and four women, average age: 55.5 ± 4.1 years).

The patients of the main group, in addition to the recommended rehabilitation measures carried out for 14 days (physiotherapy procedures, physical therapy, etc.) [1], were given 5 sessions of BSRS every other day, starting from the 2^{nd} or 3^{rd} day of their stay at a health resort. Each session included 5 stimulation procedures lasting 1.5 min with an interval of 30 s between them. The stimulation was carried out at the duration of the inhalation/exhalation phase T_f = 3 s in the frequency range of 23–38 Hz with the amplitude of the polyharmonic sound signal, which was 70% of the maximum level of the stimulating sound pressure equal to 130 dB (63.2 Pa). In the control group, rehabilitation measures were carried out under the established procedure (without BSRS).

BSRS was carried out using a specialized acoustic system [12], presented in the form of a hardware and software complex (HSC) shown in Figure 1.

Figure 1: Hardware and software complex for human bioacoustic stimulation of the respiratory system

During BSRS, in patients of the main group, oxygen saturation (SaO_2) was determined directly before and after each session with a medical pulse oximeter Armed YX300 and forced indicators of external respiration the forced expiratory volume in 1 s (FEV1) and forced vital capacity (FVC) were registered using the USPS-01 spirometry test and also measured on a scale from 0 to 10, where 5 points were neutral. A subjective evaluation of the effectiveness of the procedure was also performed by the patients.

Before and after the BSRS course (five sessions with five procedures in each; at the end of the whole course) a spirometric test was performed in the patients of the main group using a MicroLoop electronic medical spirometer, a bio-electrographic study using the Diamed-MBS HSC [22] to assess psycho-emotional and somatic states; a compression oscillometry study on the CAB TsGosm-Globus device to assess cardiovascular system indicators; assessment of rates of simple numbers addition speed (automated speed cognitive test) to assess cognitive abilities. In addition, based on the fact that many people recovering from COVID-19, according to Soloveva *et al*. [25], will face PTSD and some of them will go into a protracted mental disorder in the form of so-called coronavirus syndrome, the main group of patients before and after rehabilitation was assessed for PTSD severity on the Mississippi scale (civilian version).

Similar studies were also conducted in patients of the control group before and after rehabilitation measures (before the discharge from the health resort). Statistical data processing was performed using Statistica 10.0 software (StatSoft Inc., USA). The values of the assessed indicators of patients' condition before and after the course of rehabilitation measures were compared using the nonparametric Wilcoxon signed-rank test for dependent samples. Differences were considered statistically significant at $p < 0.05$.

Results

The results of the assessment of SaO_2, the forced external respiration indicators, and the subjective assessment of the effectiveness of the procedure by patients of the main group during BSRS are presented in Table 1.

As a result of the conducted study, it was found that 70–80% of patients, already starting from the first or second session of BSRS, had subjectively noted that they breathed more easily ("it became easier to breathe," "I breathe more freely") and that the inhalation and exhalation had become deeper ("I inhale and exhale more," "I got more intensive breath"). Starting from the third session of stimulation, on average in the group of patients, there was a significant ($p < 0.05$) increase in the values of subjective assessment of the effectiveness of the procedure by patients compared to the first session.

Table 1: The results of the evaluation of SaO_2, forced external respiration indicators, and subjective assessment of the effectiveness of the procedure by patients of the main group during the BSRS course (n = 20)

Indicator	Bioacoustic stimulation session number									
	1st session		2nd session		3rd session		4th session		5th session	
	Before	After	Before	After	Before	After	Before	After	Before	After
SaO2, %	97.5 ± 0.3	98.6 ± 0.3*	97.0 ± 0.4	98.7 ± 0.3*	97.1 ± 0.3	98.3 ± 0.3*	97.4 ± 0.3	98.6 ± 0.2*	97.3 ± 0.3	98.7 ± 0.3*
FEV1, l	2.17 ± 0.14	2.13 ± 0.13*	2.07 ± 0.11	2.20 ± 0.12*	2.12 ± 0.11	2.16 ± 0.11	2.08 ± 0.11	2.11 ± 0.10	2.17 ± 0.10	2.23 ± 0.12*
FEV1, % of the proper value	71.52 ± 3.07	70.10 ± 3.09*	68.75 ± 3.25	72.38 ± 2.70*	70.05 ± 3.05	71.58 ± 2.75	68.92 ± 2.87	69.99 ± 2.60	71.15 ± 2.78	72.94 ± 3.12
FEV1, change in %	–1.41 ± 0.47		3.63 ± 1.24		1.53 ± 1.43		1.07 ± 1.07		1.79 ± 0.85	
FVC, l	2.36 ± 0.14	2.36 ± 0.15	2.24 ± 0.11	2.42 ± 0.12*	2.31 ± 0.12	2.40 ± 0.11	2.26 ± 0.12	2.32 ± 0.10	2.38 ± 0.11	2.44 ± 0.13
FVC, % of the proper value	61.80 ± 2.62	61.88 ± 2.93	52.55 ± 2.14	56.42 ± 1.80*	53.96 ± 2.04	56.48 ± 1.91	52.83 ± 1.98	54.37 ± 1.69*	55.31 ± 1.80	56.83 ± 2.25
FVC, change in %	0.08 ± 0.88		3.87 ± 1.17		2.52 ± 1.13		1.54 ± 0.75		1.37 ± 0.91	
Subjective assessment of the procedure, score	5.7 ± 0.2		6.1 ± 0.3		6.1 ± 0.3*		6.3 ± 0.3*		6.9 ± 0.3*	

*Significantly different from the Before testing result ($p < 0.05$) according to the Wilcoxon test, FVC: Forced vital capacity, FEV1: Forced expiratory volume in 1 s, BSRS: Bioacoustic stimulation of the respiratory system.

At the same time, after each stimulation session, on average, a significant ($p < 0.05$) increase in SaO2, a 1–6% increase in forced respiratory parameters FEV1 and FVC, and a 1–7% increase of the proper values, respectively, was registered in patients in the group. A significant ($p < 0.05$) increase in FEV1 and FVC on average in the group was determined after the second, fourth, and fifth BSRS sessions. It should be noted that an increase in FEV1 and FVC by 3.4–12.2% and 2.3–13.9% of the proper values, respectively, after the second session of BSRS was observed in 65% of patients.

The generalized results of spirometric, bio-electrographic, and oscillometric tests, as well as the results of evaluating the simple numbers addition speed and the severity of PTSD before and after a course of medical rehabilitation measures in patients of the main and control groups, are presented in Tables 2 and 3.

The spirometric test showed that in patients after the course of BSRS, on average in the group, the external respiration indicators VC, FEV1, PEF, and MEF75 had increased significantly ($p < 0.05$). Positive changes in those indicators were observed in 70–80% of patients. Thus, an increase in VEL by 1–45% from the proper values was noted in 80%, an increase in FEV1 by 4–43% was noted in 70%, an increase in PEF by 1–44% was noted in 80%, and an increase in MEF 75 by 5–48% was noted in 80% of patients. The FVC index had not significantly increased on average in the group, although positive changes by 1–39% in this indicator were observed in 80% of patients.

On average, assessment of the psycho-emotional and somatic state using the Diamed-MBS HSC showed, compared with the baseline level (immediately before the first BSRS session), a significant decrease in the number of complaints and improved psychological status ($p < 0.05$), as well as physical and emotional condition. These changes were observed in 45–75% of patients.

The compression oscillometry showed a significant decrease in the SO of the heart on average in the group ($p < 0.05$) after a course of BSRS. However, these changes were observed in 65% of patients. When assessing PTSD according to the Mississippi scale (civilian version), on average in the group patients showed a significant decrease in the severity of PTSD from 80.8 ± 3.6 to 76.6 ± 3.8 points ($p < 0.05$) after the course of BSRS and overall medical rehabilitation. It should be noted that these values roughly correspond to the indicators of firefighters (73.79 ± 13.05 points) and refugees without PTSD (79.70 ± 18.19 points) [26].

The number of complaints significantly decreased in patients of the control group when assessing the psychosomatic state at the Diamed-MBS HSC ($p < 0.05$). A decrease in the number of complaints was observed in 100% of patients. When conducting spiro- and oscillometric tests, there were no significant changes in the aforementioned indicators of external respiration and SO of the heart after a course of rehabilitation measures on average for the group. At the same time, positive changes in external respiration indicators were observed in 37.5–62.5% of patients. Thus, an increase in VC by 3–23% from the proper values was noted in 62.5%, an increase of FEV1 by 3–9% in 50%, an increase of FVC by 6–7% in 37.5% of patients, an increase of PEF by 1–42% in 62.5%, and an increase of MEF 75 by 4–44% in 50% of patients.

It should be particularly noted that in the main and control groups, the indicators of the simple numbers addition speed (cognitive speed test) generally improved. Thus, in both groups, after the rehabilitation measures, including BSRS, compared with the initial level, the number of decisions per minute significantly increased ($p < 0.05$), respectively, the average speed of their adoption significantly decreased ($p < 0.05$), and the calculated "Reliability coefficient" indicator reliably increased ($p < 0.05$).

Discussion

The results of the conducted clinical study provide convincing evidence that during medical rehabilitation of patients who had COVID-associated pneumonia, the new medical technology to improve the functional capabilities of the human body based on BSRS was successfully applied [16], [17], [18], [19], [20], [21]. We also obtained data characterizing subsequent positive changes in the functional indices of the respiratory and cardiovascular systems,

Table 2: The results of spirometric, bio-electrographic, and oscillometric tests before and after a course of medical rehabilitation measures in patients of the main and control groups

Indicator	Main group (n = 20)		Control group (n = 8)	
	Before	After	Before	After
Spirometric test (with a MicroLoop medical spirometer)				
VC, l	3.11 ± 0.22	3.35 ± 0.17*	3.18 ± 0.40	3.42 ± 0.44
VC, % of the proper value	91.5 ± 4.3	98.9 ± 3.5*	90.5 ± 6.7	95.5 ± 3.8
FEV1, l	2.27 ± 0.17	2.48 ± 0.16*	2.40 ± 0.33	2.39 ± 0.34
FEV1, % of the proper value	79.8 ± 3.4	87.9 ± 3.9*	82.4 ± 6.4	81.1 ± 4.8
FVC, l	2.59 ± 0.18	2.77 ± 0.19	2.58 ± 0.36	2.61 ± 0.37
FVC, % of the proper value	76.6 ± 3.2	81.8 ± 3.3	73.6 ± 6.9	73.5 ± 5.6
PEF, ml/min	329.9 ± 27.8	389.9 ± 26.1*	372.5 ± 42.1	389.4 ± 61.3
PEF, % of the proper value	77.6 ± 4.6	92.1 ± 3.9*	85.4 ± 4.8	87.3 ± 6.8
FEV1/FVC,%	88.3 ± 2.6	89.9 ± 1.6	93.8 ± 2.7	92.3 ± 2.8
FEV1/FVC, % of the proper value	112.5 ± 3.2	114.8 ± 2.0	119.6 ± 3.4	117.9 ± 3.4
MEF 75, l/s	4.83 ± 0.36	5.59 ± 0.35*	5.94 ± 0.71	6.14 ± 1.08
MEF 75, % of the proper value	78.5 ± 4.7	90.8 ± 4.5*	92.9 ± 6.5	93.9 ± 10.2
MEF 50, l/s	3.42 ± 0.28	3.77 ± 0.30	4.31 ± 0.53	4.13 ± 0.55
MEF 50, % of the proper value	83.8 ± 6.4	92.0 ± 6.5	101.5 ± 4.5	97.9 ± 8.2
MEF 25, l/s	1.70 ± 0.23	1.66 ± 0.15	1.94 ± 0.32	2.03 ± 0.27
MEF 25, % of the proper value	106.6 ± 13.9	108.0 ± 10.4	121.8 ± 16.1	131.9 ± 19.5
Bioelectrographic test (Diamed-MSB HSC)				
Physical condition, score	3.3 ± 0.19	3.7 ± 0.21	3.1 ± 0.23	3.5 ± 0.19
Emotional state, score	3.4 ± 0.21	3.8 ± 0.20	3.4 ± 0.26	3.4 ± 0.18
Complaints, number	19.4 ± 2.27	12.9 ± 1.95*	22.1 ± 3.46	14.3 ± 3.64*
HR, beats per min	80.7 ± 2.57	83.9 ± 2.59	78.1 ± 2.92	77.0 ± 3.81
Stress index, standard units	859.11 ± 152.18	1,203.58 ± 270.79	1,979.3 ± 961.8	1,080.8 ± 315.4
PARS, score	5.0 ± 0.39	5.7 ± 0.41	6.3 ± 0.6	4.9 ± 0.48
Area without filter, standard units	22,290.1 ± 760.9	23,286.95 ± 600.76	23,987.5 ± 649.7	23,174.6 ± 828.3
Symmetry without filter, standard units	92.4 ± 1.4	94.3 ± 0.7	95.6 ± 0.6	94.1 ± 1.2
Area with filter, standard units	28,249.6 ± 574.3	28,714.1 ± 700.2	29,055.3 ± 711.4	29,245.9 ± 498.4
Symmetry with filter, standard units	97.1 ± 0.4	96.9 ± 0.6	97.8 ± 0.3	97.1 ± 0.7
Psychological status, standard units	−16.8 ± 9.3	3.7 ± 11.7*	0.1 ± 19.2	13.1 ± 16.9
Main risks, units	0.9 ± 0.1	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Related risks, units	2.7 ± 0.4	2.7 ± 0.3	2.9 ± 0.5	2.8 ± 0.5
The number of outputs, units	5.8 ± 2.5	9.0 ± 2.8	10.4 ± 5.0	4.8 ± 1.6
Cardiovascular system test (compression oscillometry)				
SBP, mmHg	122.1 ± 3.0	121.1 ± 3.2	125.9 ± 5.6	122.0 ± 6.0
DBP, mmHg	81.3 ± 3.2	80.5 ± 3.0	86.3 ± 3.9	81.8 ± 4.6
PBP, mmHg	110.3 ± 2.9	109.6 ± 3.1	115.3 ± 4.4	111.4 ± 5.8
Pulse, beats per min	80.0 ± 2.7	84.6 ± 2.7	78.3 ± 2.9	78.9 ± 3.7
CO, l/min	5.54 ± 0.13	5.53 ± 0.13	5.63 ± 0.31	5.64 ± 0.30
SO, ml	70.9 ± 2.8	66.8 ± 2.5*	72.9 ± 5.6	72.5 ± 4.7
PVR, dynes*cm-5/s	1,341.8 ± 37.0	1,317.0 ± 31.7	1,409.1 ± 81.7	1,307.0 ± 60.5
Functional state (FS), standard units	0.484 ± 0.05	0.434 ± 0.04	0.510 ± 0.04	0.509 ± 0.06

*Significantly different from the Before testing result (p<0.05) according to the Wilcoxon test, PEF: Peak expiratory flow, FVC: Forced vital capacity, FEV1: Forced expiratory volume in 1 s, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, PBP: Pulse blood pressure, CO: Cardiac output, SO: Stroke output, PVR: Peripheral vascular resistance, FS: Functional state, HR: Heart rate, PARS: Pediatric Asthma Risk Score.

psycho-emotional and somatic states, PTSD, and cognitive abilities in these patients as a result of its use.

Thus, during and after the complex of rehabilitation measures, including the BSRS course (five sessions with five procedures every other day), patients who had COVID-associated pneumonia showed subjective improvement of breathing and deepening of inhalation and exhalation, as well as improvement of general well-being. Objective data also showed a significant ($p < 0.05$) increase in SaO_2 and external respiration (vital capacity of lungs, volume of the first second forced exhalation, peak exhalation rate, and instantaneous volume rate after exhalation of 75% of the FVC of lungs), improvement of cardiac activity, psychological status, and physical and emotional states, as well as reliable ($p < 0.05$) decrease of PTSD severity and increase of cognitive abilities. This corresponds to the purpose of pulmonary rehabilitation of patients after COVID-associated pneumonia – the restoration of functions of external respiration, transport and utilization of oxygen by tissues, organs, and systems, tolerance to physical activity, and psycho-emotional stability [1], [3], [6], [7].

Table 3: The results of the evaluation of the simple numbers addition speed and the severity of PTSD before and after a course of medical rehabilitation in patients of the main and control groups

Indicator	Main group (n = 20)		Control group (n = 8)	
	Before	After	Before	After
Evaluation of the simple numbers addition speed (cognitive speed test)				
Number of solutions, units	38.3 ± 3.3	41.5 ± 2.9*	36.6 ± 1.7	43.0 ± 2.2*
Erroneous actions, units	2.4 ± 0.5	2.9 ± 0.9	3.6 ± 1.1	3.0 ± 1.1
Average speed, ms	1791.4 ± 147.8	1581.6 ± 112.7*	1660.1 ± 76.2	1422.5 ± 71.4*
SiPPY, standard units	0.512 ± 0.04	0.530 ± 0.04	0.469 ± 0.03	0.524 ± 0.04
Reliability coefficient, standard units	0.472 ± 0.03	0.499 ± 0.03*	0.442 ± 0.03	0.504 ± 0.03*
PTSD severity assessment (Mississippi scale, civil version)				
PTSD severity, score	80.8 ± 3.6	76.6 ± 3.8*	75.0 ± 3.6	76.1 ± 4.7

*Significantly different from the before testing result (p<0.05) according to the Wilcoxon test. PTSD: Post-traumatic stress disorder.

The presented data support the assumption made at the time of the study, based on the effectiveness of BSRS in sports medicine [17], [18], [19] and the features of respiratory dysfunction in COVID-associated pneumonia [1], [2], [3], [4], [5], [6], that the use of BSRS as a method of medical rehabilitation in patients after COVID-associated pneumonia will increase lung capacity and, as a result, improve lung gas exchange and increase exercise tolerance in these patients, as well as to improve the psycho-emotional condition and reduce the severity of PTSD.

The data obtained correlate with the results of studies in which the positive effect of low-frequency sound vibration (LFSV), particularly infrasound, on the respiratory system of humans and experimental animals was shown when exposed to these oscillations in certain conditions [27], [28], [29] and it was suggested that LFSV can be used as a physical medical treatment factor [27].

For example, in the study [27], it has been experimentally shown that LFSV causes significant changes in external respiration, which occur already at the next respiratory cycle after exposure and are characterized by a decrease in respiration (bradypnea), an increase in the duration of the inhalation phase, a change in the shape of the respiratory pattern with an equal probability at all frequencies of acoustic stimulation. Based on these results, as well as the data obtained in this study on the sensory perception of low-intensity LFSV by auditory receptors, skin mechanic receptors, muscle spindles, and visceroreceptors of the heart, we justifiably claim that these results, together with the developed complex of methods for adequate modeling and evaluation of the effects of LFSV, can be used to create new methods of therapeutic acoustic effects on the body to correct its functional state.

A study of hygienic aspects of human exposure to LFSV [28], [29] involving volunteer testers recorded an increase (1.2–1.5 times) in exhaled air volume immediately after exposure to LFSV with a sound pressure level up to 140 dB for 1–4 min. The range of frequencies causing this effect varied according to the individual parameters of height and constitution of the tester. Spirometric measurements at 5 and 15 min after LFSV exposure showed a tendency for the values to return to baseline. A detailed study of this fact revealed that the increase in lung vital capacity was based on the opening of the reserve alveoli of the lung tissue by exposing them to high-intensity sound waves at resonant frequencies of the bronchopulmonary tract.

Based on the aforesaid, it also seems possible to conclude that the use of BSRS can successfully solve a significant part of tasks of respiratory rehabilitation (the improvement of bronchial conduction and uniformity of ventilation, elimination of dissociation between alveolar ventilation, and pulmonary blood flow, etc.) in patients after COVID-associated pneumonia, providing realization of adequate gas exchange with minimal tension of compensatory mechanisms [7], [10]. Similar problems are solved in the treatment of medical (pulmonological and pulmonary) rehabilitation of patients with other acute and chronic lung diseases, as respiratory function defects in respiratory diseases, including chronic obstructive pulmonary disease (COPD), are most often associated with a change in the mechanism of the respiratory act (defects of the correct ratio of the inhalation phase, exhalation phase and pause, the appearance of shallow and rapid breathing, and discoordination of respiratory movements), which leads to pulmonary ventilation defects, gas exchange defects in the lungs and, as a result, to a decrease in the body's tolerance to physical exertion [10], [30].

Based on the indicated impaired respiratory function in patients with acute and chronic lung diseases, in particular, COPD, the identified effects of BSRS on the functional state of the human respiratory system when used in athletes, in particular, a significant increase in the vital capacity of the lungs, an increase in the excursion of the chest (due to the exhalation phase), an increase in peak power, and a decrease in maximum oxygen debt when performing aerobic and anaerobic physical exertion, as well as when used in a complex of methods of medical rehabilitation of patients who underwent COVID-associated pneumonia, in particular, an easing of breathing and deepening of inhalation and exhalation, an improvement in general well-being, a significant increase in SaO_2 and external respiration rate, improvements in cardiac activity, psychological status, and physical and emotional states, a significant decrease in the severity of PTSD, it seems possible to recommend this method as a method of treatment and medical (pulmonological and pulmonary) rehabilitation of patients with acute and chronic lung diseases, in particular, diagnosed with "Other chronic obstructive lung disease."

The data obtained in this clinical study along with the results of other studies on this problem can serve as the basis for the development of valid clinical recommendations on the use of BSRS in the complex of medical and rehabilitation measures for acute and chronic lung diseases.

Conclusion

Based on the results of the study, it seems possible to conclude that the use of BSRS in the complex of rehabilitation measures significantly increases the effectiveness of medical rehabilitation of patients after COVID-associated pneumonia at a health resort. As a result of using the BSRS course (five sessions with five sessions every other day) in the complex of rehabilitation measures in patients who had COVID-associated pneumonia, breathing became easier and deepened, general well-being improved, SaO_2 increased significantly, indexes of external respiration increased, cardiac activity, psychological status, and physical and emotional condition improved, the severity of PTSD significantly decreased, and cognitive abilities increased.

Thus, the developed new physiotherapeutic technology of BSRS with high-intensity low-frequency sounds can be recommended as an effective physical method for inclusion in complex medical rehabilitation at the health resort stage of patients with COVID-associated pneumonia and, based on the similarity of respiratory function disorders, in the therapy and medical (pulmonological and pulmonary) rehabilitation of patients with other respiratory diseases, in particular with COPD.

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