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Comparative study of adaptive reserves of servicemen and servicemen-athletes with neuromuscular injuries after the post-acute rehabilitation

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Abstract

Purpose. To determine the level of adaptive reserves in servicemen and servicemen-athletes with injuries of the neuromuscular system at the end of the post-acute rehabilitation phase.

Material & Methods. Twenty-two servicemen with identical injuries of the neuromuscular system were examined and divided into two groups. Group A included servicemen who used standard protocols for neuromuscular recovery during the post-acute rehabilitation phase. Group B consisted of servicemen-athletes who used standard protocols and rehabilitation techniques specific to their sports. Special physical exercises and a training regime were used to develop a test task for each study participant. The peculiarities of adaptative and compensatory reactions of servicemen to a physical stimulus were studied based on the results of heart rate variability (HRV), bioimpedansometry, and biochemical blood parameters (creatine phosphokinase, lactate dehydrogenase, testosterone, cortisol).

Results. The bioimpedansometry results indicated that only servicemen of group B had body composition indicators that met morphometric norms. The initial HRV results of group A participants showed a high tension of heart rhythm regulation, and the autonomic balance was shifted towards sympathetic regulation. The basal cortisol level reached the upper limit of the norm, and testosterone was at the lower limit. After-exercise results demonstrated the strengthening of the central sinus rhythm regulation circuit. The cortisol concentration significantly decreased in the blood serum of group A servicemen in response to the stimulus, indicating compensatory reactions. The initial HRV spectral analysis parameters in group B subjects balanced the mechanisms of vago-sympathetic tone. In response to a stressful stimulus, the influence of autonomic regulation increased. The results of the biochemical blood tests for participants in group B specified the readaptation of the neuromuscular system and the recovery of the body's adaptive reserves.

Conclusions. The research results confirmed the necessity of finding new mechanisms to improve the rehabilitation of servicemen with neuromuscular system injuries starting from the post-acute rehabilitation phase. The effectiveness of incorporating sports rehabilitation training with modified kinematic characteristics, alongside anaerobic exercise, in the rehabilitation of servicemen was demonstrated.

Keywords: servicemen, rehabilitation, rehabilitation phases, neuromuscular system, training.

Introduction

Growing demands on servicemen's modern physical rehabilitation system require researchers to develop innovative integrated models using effective diagnostics and management of rehabilitation processes. The absence of a unified approach for implementing an action plan during post-acute and long-term rehabilitation complicates the resolution of this issue. The opposing views between the multidisciplinary team and kinesiology specialists on the effectiveness of standard rehabilitation protocols for each phase contribute to the difficulty of the problem (Butowicz et al., 2022; Ladlow et al., 2022, Olkhovyi et al., 2020). The issues related to the servicemen's neuromuscular system readaptation using models to rehabilitate athletes after injuries are particularly acute (Keenan et al., 2017; Chernozub et al., 2023). Researchers who studied the mechanisms of restoring functional reserves in a state of hypokinesia due to maladaptation pointed to the lack of a load correction system in standard protocols (Spiering et al., 2023; Chernozub et al., 2024; Potop et al., 2024).

The main mechanism for regulating loads in standard physical therapy protocols is to change the sequence of basic exercises and increase quantitative indicators. However, these conditions do not consider the kinematic characteristics of the exercise technique and body position, considering the peculiarities of recruiting agonist, synergist, and stabilizer muscles (Hollman et al., 2021; Lynall et al., 2023). The calculation of load parameters is based only on subjective indicators, without a level of energy reserves and the percentage of active motor units involved.

The lack of medical and biological control during the recovery of servicemen after injuries is one of the main reasons for the complications of rehabilitation in the post-acute and long-term phases. The determining of an effective set of methods for assessing adaptive reserves is especially acute in the servicemen neuromuscular system readaptation of the injured peripheral parts (Keenan et al., 2017; Chernozub et al., 2024; Korobeinikova et al., 2024, Olkhovyi et al., 2016). One of the most relevant scientific areas is determining safe load limits by analyzing the body's adaptive and compensatory reactions to a stressful stimulus during readaptation (Potop et al., 2023; Chernozub et al., 2024). An important aspect of this issue is the definition of informative physiological and biochemical indicators for assessing functional changes for each rehabilitation phase (Corona et al., 2013; Ladlow et al., 2022; Spiering et al., 2023). However, a problem exists due to the lack of established norms and patterns for changes in biochemical blood parameters and heart rate variability during the servicemen's neuromuscular system readaptation. Using anaerobic energy supply loads contributes to the hypertrophy of damaged muscles and increases the number of active motor units.

Purpose of the Study. To determine the level of adaptive reserves in servicemen and servicemen-athletes with injuries of the neuromuscular system at the end of the post-acute rehabilitation phase.

Materials and Methods

Participants

The study involved 22 servicemen aged 23±1.4 years with identical injuries to the neuromuscular system. The participants were examined in medical institutions after two rehabilitation phases (acute and post-acute) lasting for 4-5 months. The participants were divided into two groups (A and B). Group A included 12 servicemen who used standard protocols for neuromuscular recovery during the post-acute rehabilitation phase. Group B consisted of 10 servicemen who had previously competed as qualified athletes in power sports and martial arts. During the post-acute rehabilitation period, in addition to standard punctures, the representatives of this group additionally used methods of neuromuscular system rehabilitation inherent in their sport. The study was conducted in 2024 at the "KINEZUS" Research Centre for Modern Kinesiology and its branches (Uzhhorod, Chernivtsi, Rivne, Ukraine). The Ethics Committee of Lesya Ukrainka Volyn National University, Ukraine, approved the study design. The study participants were explained the risks and benefits of the study and signed an informed consent form prepared following the ethical standards of the Declaration of Helsinki.

Measurements

Heart rate variability (HRV)

A Polar V800 heart rate monitor (Polar Electro Oy, Kempele, Finland) was used to measure RR intervals. A chest strap sensor (H10, Polar Electro Oy, Finland) recorded the heart rate and raw RR intervals. The RR interval data were downloaded to a computer via the Polar Flow web service. The Kubios HRV Standard 3.5.0 software (University of Eastern Finland) assessed HRV parameters in the time and frequency domains. From the time domain, the standard deviation of RR intervals (SDNN, ms) was chosen as the most informative indicator for short-term analysis. For spectral analysis in the frequency domain, the fast Fourier transform was chosen. When analyzing the spectral characteristics of HRV power, the following bands were distinguished: low-frequency (LF, %), very-low-frequency (VLF, %), and high-frequency (HF, %). The LF/HF ratio was determined to indicate the degree of autonomic balance. The RR interval signals were recorded in the subjects sitting at rest before and after acute exercise. To standardize HRV studies with short recordings, the optimal recording duration was 5 min. The ambient temperature was 22-24°C.

Body composition

The participants' body composition was determined with the help of the bioelectrical impedance (BIA) method in combination with computer processing of the results. The body composition parameters were recorded at the beginning of the study. The parameters of body fat mass (BF, %), fat-free mass (FFM, kg), active cell mass (ACM, %), and dry cell mass (DCM, kg) were assessed with a non-invasive method. The composition indicators were determined using the computer software and hardware complex KM-AR-01 Almaz-AST (VUSK. 941118.001).

Biochemical parameters

The level of lactate dehydrogenase (LDH) and creatine phosphokinase (CPK) activity in the blood serum was determined by the kinetic method using equipment from High Technology Inc (USA) with a set of reagents PRESTIGE 24i LQ LDH (Poland). The steroid hormones (testosterone and cortisol) concentration in the blood serum of the study participants was evaluated by enzyme-linked immunosorbent assay using a reagent kit Steroid ELISA-testosterone on the equipment of Alkor Bio. Reference values of the studied biochemical parameters in the participants' blood serum: CK (40-270 units/l), LDH (195-462 units/l), cortisol (150-660 nmol/l), testosterone (8.64-29.01 nmol/l). Blood was taken by medical professionals following internationally accepted requirements for biomedical research. Changes in the studied biochemical blood parameters were monitored at rest (before exercise) and after the test task.

Research Design

The study was conducted in two stages during 2024.

In the first stage, the research team analyzed the study participants' medical records to determine the state of their neuromuscular system before the study. The initial body composition indicators were assessed using the bioelectrical impedance method to determine the ratio of body fat to muscle mass. The spectral characteristics of the HRV power of the examined groups of servicemen at rest (before exercise) were studied to identify the level of functional state.

Using the obtained data, a test task with special physical exercises and a training regime was created for each study participant. Depending on the type of neuromuscular injury, exercises included modified kinematic characteristics and changes in body position.

The magnitude of the load is regulated by the muscle effort of the partner who opposes the performance of the given exercise. However, the amount of such a load should allow the research participant to perform the given exercise, observing the specified technique and intensity, within 20-30 seconds. During this time, it is necessary to achieve maximum fatigue of working muscle groups and exhaustion of functional reserves, observing the characteristics of the established load regime. Loads were performed in a mixed anaerobic energy supply mode (creatine phosphokinase and anaerobic glycolysis). The key feature of the proposed exercises is the requirement to engage the maximum number of synergist and stabilizer muscle groups while performing them. The damaged muscle groups are involved only for 25-30% of the maximum. Control testing consisted of a series of 4 sets with a rest interval of 50-60 seconds between them.

In the second stage, the peculiarities of adaptive and compensatory reactions of the organism of the participants of both groups were investigated during the implementation of the developed test task. The changes in the results of HRV and biochemical blood indicators (LDH, CPK, cortisol, and testosterone) following 25-30 seconds of exercise under the specified conditions were identified. The studied indicators at rest, before and after the specified load, were analyzed, and the results were processed.

Statistical Analysis

The statistical analysis of the research results was performed using the IBM *SPSS*Statistics 26 program package (StatSoftInc., USA). The program G-Power 3.1.96 (Germany) allows you to determine the smallest sample size for the study (calculation of statistical power). Median (Me) and interquartile range (IQR) were determined using non-parametric statistical analysis methods. The Mann-Whitney U test was used to compare baseline parameters between two groups of examined servicemen. The Wilcoxon t-test was used to compare two dependent samples with each other.

Results

Table 1 presents the results of bioelectrical impedance (BIA) indicators in servicemen of the examined groups at the end of the post-acute rehabilitation phase.

Body fat mass (BF, %) in servicemen of group A was lower than the physiological norm, taking into account their age and anthropometric parameters. In group B, the body fat mass was 3.8% higher ($p<0.05$) than in group A, reaching the lower limits of the normal range. A similar difference between the groups was observed in BF (7.2% higher, $p<0.05$), ACM (11.9% higher, $p<0.05$), and CDM (32.5% higher, $p<0.05$). The study results showed that group B participants reached the physiological norm indicators after 4-5 months of rehabilitation. However, group A representatives had signs of hypokinesia and a lack of neuromuscular system readaptation at the end of the post-acute rehabilitation phase.

The HRV results of the examined servicemen

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Table 1. **Results of bioelectrical impedance (BIA) indicators in the examined groups of servicemen at the end of the post-acute rehabilitation phase (median, IQR), n=22**

Body composition indicators	Participants of the examined groups with pronounced hypokinesia and neuromuscular system injuries at the end of the post-acute rehabilitation phase (4-5 months)	
	Group A (servicemen)	Group B (servicemen-athletes)
Body Fat mass (BF, %)	8.87 (0.41); U=14; p=0.04*	12.71 (0.32); U=14; p=0.04*
Fat-free mass (FFM, kg)	51.51 (4.33); U=15; p=0.05*	55.23 (5.01); U=15; p=0.05*
Active Cell mass (ACM, %)	53.41 (4.87); U=16; p=0.05*	59.78 (5.66); U=16; p=0.05*
Dry Cell mass (DCM, kg)	6.43 (0.72); U=14; p=0.04	8.52 (0.56); U=14; p=0.04

Notes: U – Mann-Whitney test; *– p<0.05.

Table 2. **Results of changes in heart rate variability indicators in servicemen of the examined groups at the end of the post-acute rehabilitation phase under control testing conditions (median, IQR), n=22**

Groups	HRV indicators				
	SDNN, мс	VLF, %	LF, %	HF, %	LF/HF
	Before exercise, at rest				
A	40.80 (3.09)	1.06 (0.14)	89.97 (2.22)	8.41 (0.63)	10.69 (0.31)
B	53.10 (2.44)	4.42 (0.72)	55.34 (3.02)	40.21 (2.89)	1.37 (0.13)
	After exercise, under control testing conditions				
A	143.41 (9.43)*	92.39 (1.54)*	6.22 (0.51)*	1.37 (0.11)*	4.52 (0.22)*
B	106.70 (8.13)*	4.90 (0.25)	32.55 (3.61)*	62.28 (2.27)*	0.52 (0.09)*

Notes: * p<.05 – comparing with the results before the load at rest

at rest and in response to stress after completing the developed test tasks are shown in Table 2.

The before-exercise HRV results had significantly different parameters in study participants. The SDNN index in group A servicemen was 30.1% (p<0.05) lower than group B results. This fact advocates a more intense heart rhythm regulation in group A servicemen at the end of the post-acute rehabilitation phase. The spectral analysis results of group A participants showed that their vegetative balance shifted toward sympathetic regulation (LF/HF=10.69). This indicates an increased tension in the regulation of cardiac activity. Group B servicemen, who were qualified athletes in the past, had almost 8 times lower LF/HF values. The spectral analysis showed a balance of the vago-sympathetic tone mechanisms in this group. Strengthening the high-frequency and low-frequency spectrum of the heart rhythm power indicates simultaneous activation of the sympathetic and parasympathetic divisions of the autonomic nervous system (Korobeinikova et al., 2024).

After-exercise results revealed completely different changes in HRV indicators between the groups. SDNN indicator increased 3.5 times in group A and 2 times in group B participants after exercise. A simultaneous decrease in the values of LF (-83.7%), HF (-7.0%), and the vegetative balance index (LF/HF) by 2.4 times was found in group A servicemen. However, the VLF indicator increased 87.1 times compared to the results before exercise. This stimulates the strengthening of the central contour of sinus rhythm regulation in this case. In response to the stimulus, the influence of autonomic regulation increased (HF) by 22.1%, and sympathetic tone (LF) decreased by 22.8% in group B servicemen. The VLF values after exercise did not change compared to rest, and the vegetative balance decreased by 2.6 times in group B.

The activity of the studied enzymes CPK and LDH in the blood did not significantly differ among the participants of the examined groups before exercise. The biochemical results changed in the study participants after the control test. Creatine phosphokinase activity did not change in the blood of group A servicemen in response to a stressful

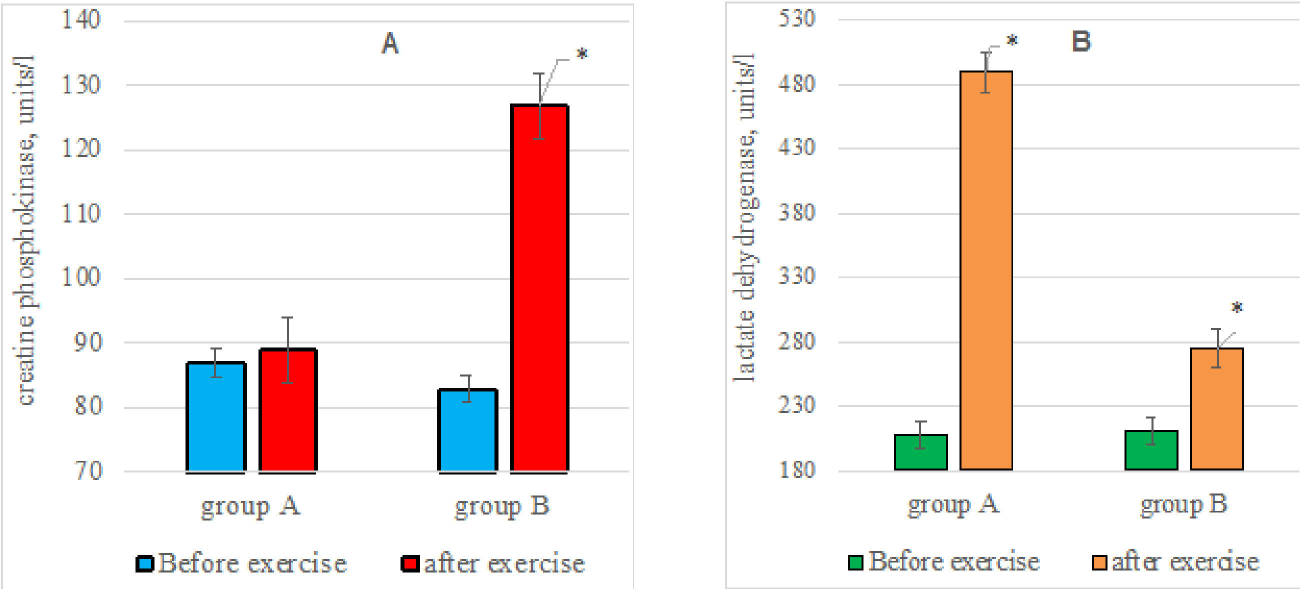

Figure 1. **Shows the results of changes in the enzymes creatine phosphokinase (Fig. 1A) and lactate dehydrogenase (Fig. 1B) in the blood serum of servicemen of both groups during control testing.**

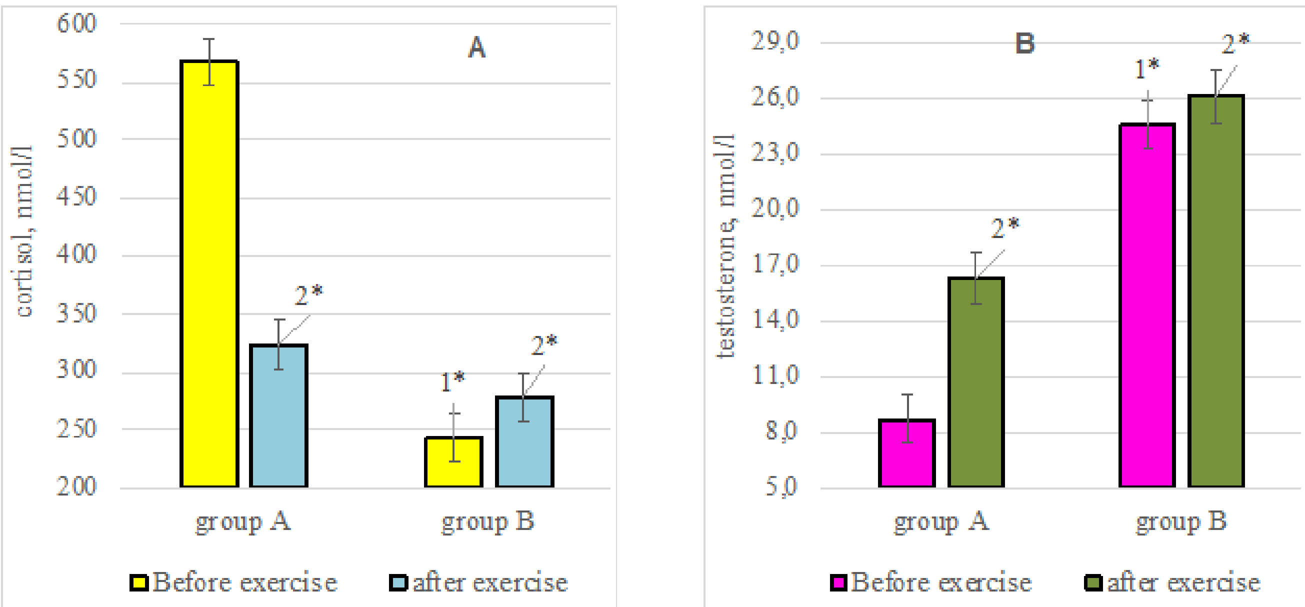

Figure 2. **Results of changes in the concentration of cortisol (A) and testosterone (B) in the blood serum of servicemen of the examined groups during control physical testing, n=22**

Note: 1* – p<0.05, compared to the indicators of the other group (subgroups) before exercise;
2* – p<0.05, compared to the indicators before exercise.

stimulus. However, this enzyme increased in the blood serum of group B participants after exercise by 53.0% (p<0.05) compared to the state of rest. A 2.44-fold increase in lactate dehydrogenase enzyme was noted in group A representatives, and only by 30.0% in group B participants. The peculiarities of these changes in the studied biochemical indicators of blood are related to the readaptation processes happening during the post-acute rehabilitation phase. These results proved that creatine phosphate reserves did not recover after rehabilitation in the representatives of group A, and their muscle activity energy supply was anaerobic glycolytic.

In the group of servicemen (B), who were qualified athletes in the past, the main source of energy supply during control testing was creatine phosphate reserves. This exemplifies the readaptation of the body's energy reserves during rehabilitation. However, the absence of similar readaptation manifestations in group A participants remains unclear.

The changes in the cortisol (Fig. 2A) and testosterone (Fig. 2B) concentrations in the blood of servicemen of both groups during control test are presented in Figure 2.

The laboratory control results indicated that the basal cortisol level in the blood of group A participants was 2.3 times higher than group B indicators. The high cortisol level in the blood of group A may be related to their stress or body resistance level. This assumption is confirmed by the HRV results (Table 2), which highlight intense heart rhythm regulation in group A servicemen. The cortisol concentration in the blood serum of group A participants in response to physical load decreased by 42.9% ($p<0.05$). This is due to the possible gluconeogenesis activation because of a pronounced deficit of energy supply reserves during anaerobic glycolysis loads (Chernozub et al., 2024). These changes reflect compensatory responses and low body resistance to such loads. However, the cortisol concentration in the blood of group B representatives increased by 14.3% ($p<0.05$), which is an adequate reaction to a stressful stimulus.

Biochemical blood analysis showed that the basal testosterone level in the blood of group A servicemen was at the lower limit of the norm. The concentration of this hormone in the blood of group B representatives was 2.8 times lower than group A results. This fact indicates that the neurohumoral system may have been optimized because of hypokinesia, which led to a decrease in the basal level of testosterone. These assumptions are confirmed by the results of bioimpedance measurement (Table 1), which demonstrate low parameters of FFM and ACM indicators of participants in group A compared to the other group. It happened due to the absence of pronounced readaptation processes associated with hypertrophy of damaged muscles and restoration of adaptation reserves during the previous rehabilitation phase. However, the testosterone concentration increased by 87.5% ($p<0.05$) in group A servicemen, and by 6.1% ($p<0.05$) in group B representatives. The results also indicate that representatives of group A had a lower level of resistance to physical loads during muscle activity in the anaerobic energy supply mode.

Discussion

This research compares the adaptation reserves of servicemen and servicemen-athletes with neuromuscular injuries at the end of the post-acute rehabilitation phase. The investigation focused on the adaptive and compensatory responses of servicemen without sports experience who followed standard protocols for neuromuscular system recovery during the initial rehabilitation. Similar adaptation processes were examined in the servicemen who were previously qualified athletes. This was particularly relevant during the post-acute rehabilitation phase, when, alongside standard procedures, these servicemen used readaptation methods specific to their respective sports. The results showed that the adaptation reserves in servicemen-athletes did not exhibit compensatory responses to intense anaerobic loads at the end of the post-acute rehabilitation phase. This study will contribute to solving the problem of improving the rehabilitation system of servicemen with peripheral injuries of the neuromuscular system, using innovative recovery methods in post-acute rehabilitation.

The imperfection of the load correction system and the mechanism for assessing the adaptative body reserves in the second half of the post-acute rehabilitation phase significantly reduces the effectiveness of the neuromuscular system readaptation. This process is especially complicated in conditions of pronounced hypokinesia (Chernozub et al., 2023; Potop et al., 2024). The necessity to change the existing protocols of the second and third periods of servicemen rehabilitation, using non-standard models of classes, constantly causes controversial discussions (Kristensen et al., 2013; Butowicz et al., 2022; Ladlow et al., 2022). Thus, there is a need to develop exercises with a change in the kinematic characteristics of the performance technique in combination with the optimal parameters of the anaerobic load regime. The load on injured muscle groups must be reduced to 20% of the maximum due to the selective involvement of synergist and stabilizer muscle groups (Ladlow et al., 2022; Potop et al., 2023). Determining an effective set of methods for evaluating the readaptation of servicemen with neuromuscular system injuries, based on physiological and biochemical indicators, is a modern priority in scientific research (Lynall et al., 2023; Spiering et al., 2023). One way to implement this direction is to use HRV indicators and biochemical blood control as informative markers for assessing adaptive body reserves (Chernozub et al., 2024; Korobeinikova et al., 2024). Most researchers examining the challenges of developing rehabilitation programs for military personnel with neuromuscular system injuries address these issues partially. This may be attributed to a limited experience in adapting the rehabilitation systems for servicemen with neuromuscular injuries by leveraging the recovery practices used for athletes.

The bioimpedance measurement results showed that only group B representatives had the indicators of body composition corresponding to morphometric norms. This occurs because athletes with similar injuries engage both modes of anaerobic energy supply during rehabilitation (Spiering et al., 2023; Chernozub et al., 2024). When combined with exercises that modify kinematic characteristics and selectively redistribute the load across specific muscle groups, servicemen can achieve significant hypertrophy and muscle mass growth (Keenan et al., 2017).

Baseline HRV results in servicemen who used standard rehabilitation protocols for post-acute rehabilitation showed high stress on heart rhythm regulation. The vegetative balance was shifted towards sympathetic regulation. At rest, the basal cortisol level in the blood reached almost the upper limit of normal, but testosterone was at the lower limit of normal. These results indicate a possible decrease in the body's resistance to an external stressful stimulus even in a state of rest and an imbalance of the neurohumoral system against the background of hypokinesia (Potop et al., 2023; Chernozub et al., 2024; Korobeinikova et al., 2024). The after-exercise results showed that the central contour of the heart sinus rhythm regulation was strengthened. Creatine phosphate reserves did not recover after rehabilitation, and the energy supply for muscle activity was due to anaerobic glycolysis. The cortisol concentration in the blood serum of the examined servicemen significantly decreased in response to the given load. These changes indicate compensatory reactions and gluconeogenesis activation due to the pronounced deficit of energy supply reserves during anaerobic glycolysis loads (Chernozub et al., 2024).

The nature of adaptive and compensatory reactions to the stimulus in group B servicemen proved the restoration of their functional capabilities during rehabilitation. The initial HRV spectral analysis revealed the balance of the vago-sympathetic tone mechanisms. In response to a stressful stimulus (physical exercise), there was an increase in the influence of autonomic regulation. The changes testify to the effectiveness of the neuromuscular system readaptation and restoration of the body's adaptive reserves (Kristensen et al., 2013; Korobeinikova et al., 2024). In response to exercise in a mixed anaerobic energy supply mode (creatine phosphokinase and anaerobic glycolysis), the creatine phosphate activity in the blood increased. The study results support previous research by scientists (Butowicz et al., 2022; Chernozub et al., 2024), showing that anaerobic exercise enhances the reserves of phospholipids and muscle glycogen, alongside significant muscle hypertrophy. An increase in the cortisol and testosterone concentration in the blood serum of the participants in response to a stressful stimulus indicated a pronounced short-term adaptation. The obtained data indicate the absence of compensatory reactions, energy deficit in response to acute physical exertion, and stabilization of the functional state.

Conclusions

The research findings highlight the necessity of identifying new mechanisms to enhance the rehabilitation system for servicemen with neuromuscular injuries, beginning from the post-acute rehabilitation phase. The justification for incorporating specialized exercises with altered kinematic characteristics, combined with anaerobic load regimes, in the rehabilitation of servicemen, is provided. Lowering the load on the injured muscle group by 80% through engaging a maximum number of synergists and stabilizers positively impacts the readaptation process. Biochemical blood analysis indicators and HRV are considered informative markers for evaluating adaptation reserves during the post-acute rehabilitation phase of servicemen's neuromuscular system. Utilizing special tests allows for assessing the nature of the body's adaptive and compensatory responses to a stressful stimulus, and the effectiveness of readaptation processes following rehabilitation.

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Supplementary Information

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Conflict of interest
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