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Restoration of the functional state of military personnel after gunshot wounds to the upper limb using physical therapy measures based on the principles of neuroplasticity

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Abstract

Purpose. To evaluate the impact of physical therapy (PT) measures on the fastest possible recovery of military personnel after gunshot wounds to the upper limb (GWUL), taking into account the principles of neuroplasticity.

Material & Methods: The study involved 72 patients aged 28 to 52 years diagnosed with gunshot wound of the upper limb (GWUL), who were divided into two groups - the main group (MG, n=36) and the control group (CG, n=36). Patients in the MG underwent rehabilitation according to the developed PT program, which included: motor activity of targeted actions to simulate situations significant for each patient and his professional activity, bimanual therapy, therapeutic massage, therapeutic exercises, special training devices of the Thera-Band progressive exercise system, Artromot training devices. And the CG - according to the standard program carried out in a medical institution: therapeutic exercises, physiotherapy, kinesiotherapy, Artromot training devices, therapeutic massage. For a comprehensive examination of patients in both groups, medical, biological and sociological methods were used: the DASH scale (Disability of the Arm, Shoulder and Hand Outcome Measure), questionnaires (military questionnaire), goniometry, dynamometry and methods of mathematical statistics.

Results: After PT, the DASH severity scores ($p<0.05$), goniometry scores in the elbow joint of the upper limb ($p<0.05$), and dynamometry scores ($p<0.05$) were significantly better in MG patients than in CG. MG patients experienced significantly fewer limitations associated with upper limb dysfunctions compared to CG, which had a positive effect on the ability to perform exercises related to professional activity according to the results of the military questionnaire.

Conclusions: The application of neuroplasticity principles in the PT program in the MG contributed to the improvement of the functional state of military personnel, as well as their professional and social capabilities, and can be applied to wider practical implementation in specialized medical and rehabilitation institutions.

Keywords: upper limb, gunshot wounds, physical therapy, principles of neuroplasticity.

Introduction

The complex nature of gunshot wounds and the high frequency of their complications as a result of the ongoing military operations in Ukraine require improved approaches to physical therapy aimed at restoring not only the impaired functions of the upper limb, but also achieving independence and returning the professional skills of military personnel, received gunshot wounds to the upper limb according to modern demands.

Restoration of upper limb function and return of the wounded to professional activity largely depends on the nature of the upper limb injury, adequate treatment and effective use of physical therapy measures during the rehabilitation period, which determines the relevance of research in this area. The introduction of rehabilitation services should begin with an assessment of the needs of individuals after injury and should be carried out within the framework of health care systems.

Many scientists (Lototsky et al., 2016; Oderov et al., 2020; Yagodzinsky et al., 2021; Yuriev et al., 2021) note the substantive content and improvement of the physical training system in the Armed Forces of Ukraine, but the influence of rehabilitation programs for the use of PT tools has not yet been sufficiently studied, taking into account the principles of neuroplasticity, which are similar in their influence on the professional actions and physical activity of military personnel of various military specialties and can serve as an important means of restoring lost skills after injury.

Neuroplasticity research has shown relevance, which is critical for learning, memory and may improve the effectiveness of therapeutic interventions in upper limb rehabilitation (Price et al., 2002; Romero et al., 2002; Muñoz-Cespedes et al., 2005).

Most neuroplasticity and brain imaging research focuses on motor function recovery after stroke or traumatic brain injury (TBI) (Raymont et al., 2011; Chandra et al., 2015; Prigatano et al., 2015; Bressi et al., 2020), At that time, there were few scientific studies on the problem of developing measures to restore patients after GWUL using PT using the principles of neuroplasticity and they were isolated in nature. (Kopp et al., 2008; Kerr et al., 2011; Inoue et al., 2024).

Based on the above, the development and implementation of a new set of physical therapy measures using the principles of neuroplasticity, in which attention is focused not only on the injury to the upper limb itself, but also on the restoration of lost skills of military personnel with GWUL, is extremely relevant.

Purpose of the study

To evaluate the effectiveness of the influence of the developed PT program, taking into account the principles of neuroplasticity, on the fastest possible restoration of the manipulative function of the upper end and mobile skills of military personnel after GWUL.

Material and methods of research

Participants

The study involved 72 people after GWUL, who were undergoing rehabilitation at the rehabilitation, professional pathology and alternative treatment clinic of the Military Medical Hospital in Irpen. The age of the subjects varied from 28 to 52 years, and the average age was

38±2,4 years. Exclusion criteria: other types of injury (by localization), conservative treatment. The study was approved by the University Ethics Committee (No. 2/2017) and was conducted in compliance with the international principles of the World Medical Association Declaration of Helsinki (2013) on ethical standards and rules for conducting medical research involving human subjects. All participants were familiar with the measurement procedure and signed informed consent.

Methods

All patients with GWUL were randomly divided into two groups – the main (MG) (n=36) and the control (CG) (n=36). In the MG, we used the developed PT program (motor activity of targeted actions to simulate situations that are significant for each patient and his professional activity, bimanual therapy, therapeutic massage, therapeutic exercises, special simulators of the Thera-band progressive exercise system, Artromot simulators). CG – according to the standard program conducted in a medical institution: therapeutic exercises, physiotherapy, kinesiotherapy, Artromot exercise machines, therapeutic massage. All patients were given a PT program, the total duration of which was 5 months. All patients visited the clinic every day except weekends. The studies were conducted before and after the PT course.

First, the daily activities and needs of each patient were analyzed, then the functional capabilities for performing these types of activities were determined, and the professional skills of military personnel were taken into account for the ability to put on military equipment, hold weapons, perform protective actions, and shoot.

Participation in daily life was determined using the DASH scale, which determined the degree of physical and affective health status that limits participation in self-care, social participation in communication, daily role work, performing daily duties with a decrease in the volume of work and a decrease in its quality. The DASH scale consists of 30 items related to the state of the upper limb. In this case, 21 of them reveal the degree of difficulty in performing various physical actions due to limitation of the upper limb function (self-service); 6 points concern the severity of social activity and 3 everyday role functions. 5 answer options were offered, assessed in points from 1 to 5: 1 - not difficult, 2 - moderately difficult, 3 - difficult, 4 - very difficult, 5 - impossible. Interpretation of the results: 1 - 30 - excellent; 31 - 60 - good; 61 - 90 - satisfactory; > 91 - unsatisfactory (Veehof et al., 2002).

The questionnaire was used to collect additional information about the performance of motor activity to simulate situations with the help of a military man. This allowed us to collect data not specified in the personal file about the previous motor status, features of professional activity, risk factors. The questionnaire consists of 12 items. Five answer options were offered: 1 - not difficult, 2 - moderately difficult, 3 - difficult, 4 - very difficult, 5 - impossible.

Goniometry was used to measure the angles of motion (in degrees) in the wrist and elbow joints of the upper limb using a goniometer. First, the range of active movements in the joints was determined, and then passive movements. The movements in the joints of the limbs were measured using the international SFTR method (neutral – 0°, S – movements in the sagittal plane, F – in the frontal plane, T – movements in the transverse plane, R – rotational movements) (Laputin et al., 2000). The patient was in a sitting position, and the upper limb lay on the table.

Dynamometry was performed using a handheld hand dynamometer to study the grip of the hand on the healthy and injured limb. Combining these indicators, a strength index was calculated, demonstrating the level of strength of the flexors of the hand depending on body weight (Loskutov et al., 2021).

Statistical analysis

All statistical analyses were conducted using Statistica 10.0 (StatSoft, USA). Mean ± standard deviation (M±SD), median (Me), upper and lower quartiles (25%; 75%) were measured. To measure the significance of the difference, Student's t-test (for dependent groups) was used provided there was a normal distribution of study results. Wilcoxon test (for dependent groups) and Mann-Whitney U test (for independent groups) were used provided the indicators had a distribution other than normal. Statistical significance defined at $p<0.05$.

Results of the study

According to various sources, the use of PT programs taking into account the principles of neuroplasticity is crucial for the restoration of physical and social activity of military personnel after gunshot wounds of the upper limb (Muñoz-Cespedes et al., 2005; Lototsky et al., 2016).

The main principles of neuroplasticity (Kleim et al., 2008):

1. Use it or Lose it: If a particular motor skill is not used, the connections in the brain can become weaker or deteriorate.

2. Use and Improve: Actively learning a specific motor skill helps strengthen neural connections.

3. Specificity: the formation of a motor skill in a lesson with a physical therapist should be as close as possible to the desired end result of the connections. This determines concreteness.

4. Repetition: Repeating an activity helps strengthen the neural connections associated with that activity.

5. Intensity: Doing a motor skill more intensely helps improve connections and neuroplasticity, and the motor skill is learned faster.

6. Timing: The effectiveness of learning a motor skill or its recovery depends on when after the injury or during life the learning occurs. The earlier the better.

7. Significance: Motor learning that has personal meaning or importance has a greater chance of being learned.

8. Age: Although neuroplasticity occurs at any stage of life, the brain is usually more plastic at a younger age than as it ages.

9. Transfer: Skills acquired in one setting can be transferred to other performance settings. This is called transfer or transfer of a motor skill to other activities.

10. Interference: learning two similar motor skills at the same time can hinder or interfere with the development of that skill.

Application of these principles of neuroplasticity, as the ability of the nervous system to adapt and change in response to experience, has contributed not only to the restoration of upper limb motor function, but also to the lost specialization skills of military personnel.

The differences between the PT program in the MG compared to the CG were that an integrated approach was applied to the rehabilitation of persons with gunshot wounds of the upper limb using PT means, taking into account the principles of neuroplasticity and the performance of motor activity to simulate situations that are significant for each military personnel.

The DASH scale was used to assess the upper limb performance of military personnel. Apparently, functional improvement was observed in both study groups (the difference between the indicator is statistically significant compared to the previous result at the level of $p < 0.01$). However, the positive dynamics in the MG was more pronounced (the difference between the indicator is statistically significant compared to the CG result at the level of $p < 0,05$).

After the course of PT, the average indicators in the MG decreased by 2–3 points, and in the CG by 1–2 points, and the total score (Me (25%; 75%)) changed in the MG from 116 (95; 123) points to 40 (38; 48) points compared to the CG, where changes occurred from 118 (98; 125) points to 67 (60; 77) points. The dynamics of the indicators of the general assessment of the ability of the upper limb of patients before and after PT is shown in Figure 1.

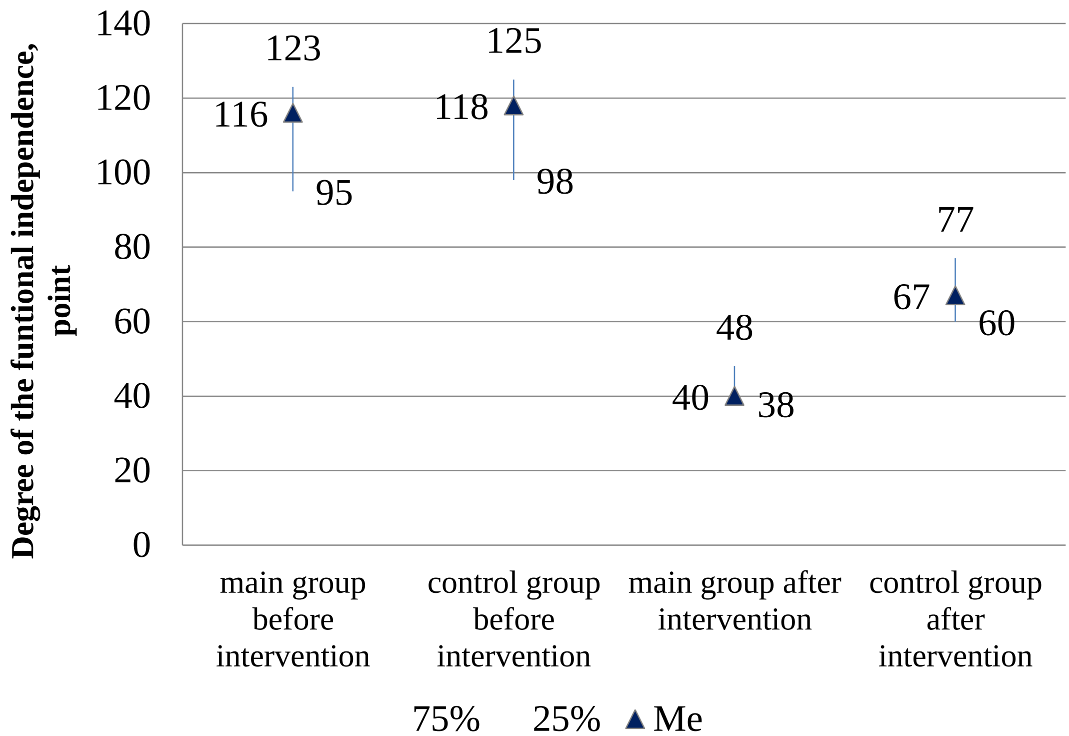

Figure 1. Dynamics of upper limb performance indicators under the influence of PT in persons with GWUL according to the DASH scale, %

To assess the degree of ability of military personnel to return to their professional duties, we used the military questionnaire developed by us. Motor actions with the simulation of the situation in the MG consisted of performing physical exercises similar in their impact to the professional actions and physical loads of military personnel of various military specialties, and served as an important means of restoring lost skills after injury compared to the CG, in which standard PT tools were used, aimed mainly at restoring the structure and function of the injured upper limb, which was reflected in the indicators of the military questionnaire.

After the PT course, performing physical activity to simulate the situation on:

- the ability to put on military equipment (put on a hat, sweater, trousers, belt; fasten and unbutton a jacket, etc.) - 87% of respondents answered “not difficult”, 13% answered “moderately difficult”;

- the ability to hold weapons of different calibers with one hand (shift a weight of 1 - 2 kg (dumbbells) from one place to another - 69% of respondents answered “not difficult”, 24% answered “moderately difficult”, 7% of respondents answered “difficult”;

- the ability to hold weapons of different calibers with two hands (holding an object with two hands, a dumbbell from 3 kg to 4.5 kg (weight of an automatic weapon) - 78% of respondents answered "not difficult", 22% answered "moderately difficult";

- the ability to put on a bulletproof vest (open and close a backpack carabiner, lift a backpack weighing 5 kg to chest level with two hands, put on a backpack weighing 5-10 kg) - 72% of respondents answered "not difficult", 28% answered "moderately difficult";

- the ability to shoot (bend the index finger, simulating pressing the trigger; pull a thin rubber band with the index finger, attached to the straight fingers of the other hand; open a can by the ring, etc.) - 91% of respondents answered "not difficult", 9% answered "moderately difficult";

- the ability to perform defensive actions (push-ups from a bench, throw a 300 g ball (weight of a grenade) from a distance of 10 m into a basket or for accuracy) - 75% of respondents answered "not difficult", 19% answered "moderately difficult", 6% of respondents answered "difficult";

- the ability to perform a forced march (walking on a treadmill with a backpack weighing 5 kg (the initial weight of the bulletproof vest) for 20 minutes) - 89% of respondents answered "not difficult", 11% answered "moderately difficult".

To analyze and evaluate the effectiveness of PT for patients with GWUL, the change in mobility in the elbow joint of the upper limb was measured using the goniometry method. The average values of the angle of active bending of the injured limb during repeated measurements were 56,2 ± 7,8 ° ($p < 0,01$) in the MG and 65,1 ± 7,9 ° ($p < 0,01$) in the CG, and the average values of the angle of passive bending were 49,3 ± 7,9 ° ($p < 0,01$) in the MG and 54,5 ± 7,9 ° ($p < 0,01$) in the CG. According to the results obtained, the average value of active bending increased in the MG by 36.2°, and in the CG – by 27,4° compared to the initial measurement. Similar dynamics were observed in the indicators of passive bending, which improved in the MG by 39,6°, and in the CG by 34.6° compared to the initial result. And the average values of active extension changed in the MG by 34,2° compared to the CG, where changes occurred by 21,1°, passive extension – by 32,4°, while in the CG the values increased by 26,4°, although the increase in values was reliable in both groups ($p<0,05$). Thus, during the course of PT, the MG patients more quickly brought the flexion/extension amplitude closer to the upper limit of the norm (40/180°). The dynamics of goniometry values of the injured limb in the elbow joint during PT in patients with GWUL is presented in Figure 2.

Similar dynamics were observed in terms of amplitude indicators of active and passive pronation and active and passive supination, where MG indicators were closer to the norm in both pronation and supination indicators (90°/90°). Thus, mobility in the elbow joint of the wounded limb of the CG in persons with GWUL during the period of PT significantly improved, but did not reach the level of MG, in which more pronounced dynamics were observed.

To analyze and evaluate the effectiveness of PT for patients with GWUL, muscle strength in the upper limb was measured using the dynamometry method. It was shown that at the beginning of PT in patients with GWUL, the muscle strength indicators of both healthy and injured limbs in the MG and CG were almost the same. Thus, the indicators of the injured left limb in the MG were 18,5 ± 1,7 kg, and in the CG 18,8 ± 1,7 kg, and the right – 23,8 ± 2,0 kg and 23,6 ± 1,9, respectively, which was almost 2 times less compared to these indicators in the MG and CG healthy limbs. The dynamics of dynamometry indicators during PT in patients with GWUL is presented in Table 1

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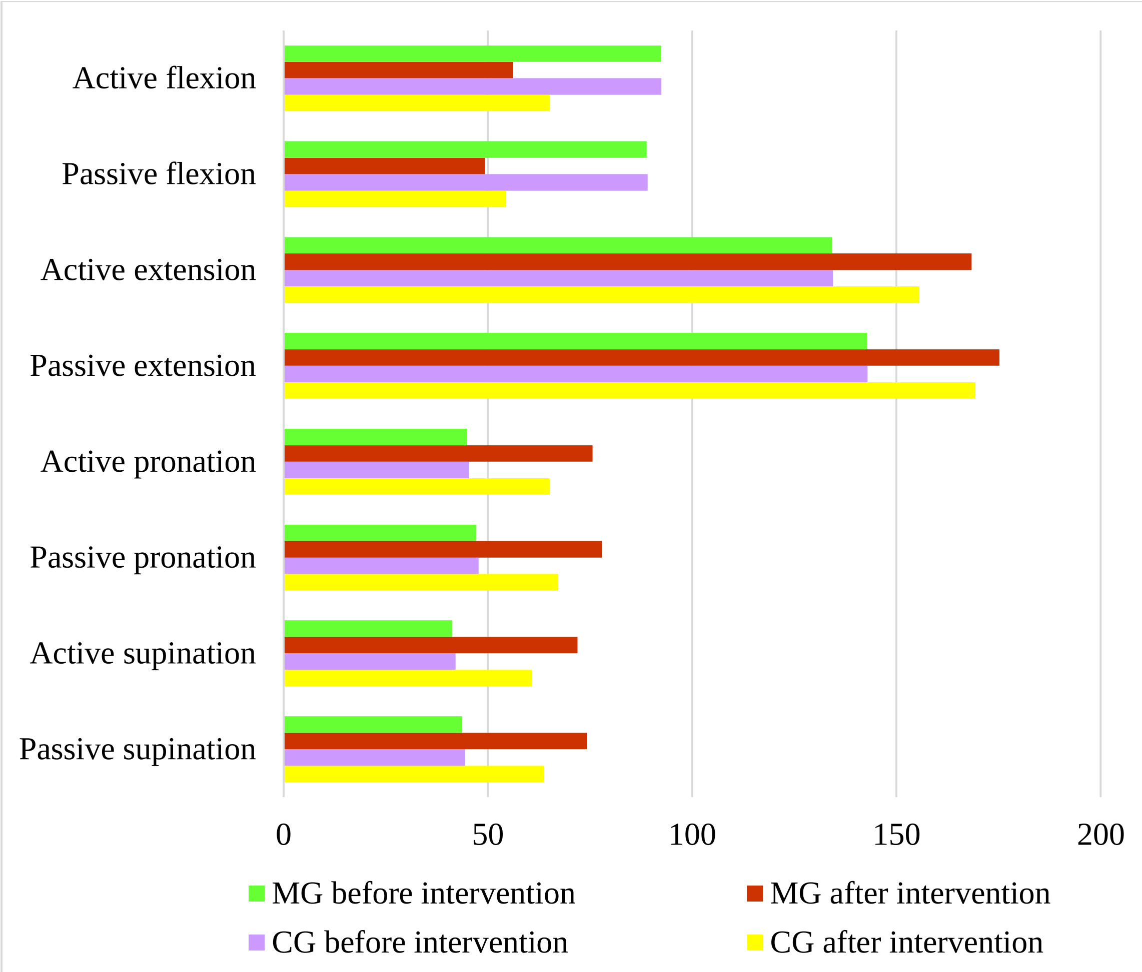

Figure 2. Dynamics of goniometry indicators of the wounded limb in the elbow joint during PT of persons with GWUL, degrees

Table 1. Dynamics of dynamometry indicators during PT in patients with GWUL, M±SD

Indicators	MG (n=36)		CG (n=36)	
	Before intervention	After intervention	Before intervention	After intervention
Injured left limb, kg	18,5±1,7	27,4±2,1*	18,8±1,7	23,9±1,7*
Injured right limb, kg	23,8±2,0	32,9±2,1*	23,6±1,9	27,7±1,9*
Healthy left limb, kg.	32,6±1,7	36,5±1,9*	32,8±1,9	35,0±1,8*
Healthy right limb, kg	42,4±1,7	47,6±1,8*	41,6±1,6	44,5±1,6*
Strength index of injured arm, %	33,5±3,1	45,0±3,6**	33,0±2,2	40,0±2,9*
Strength index of healthy arm, %	44,6±2,8	55,6±3,9**	43,5±2,9	50,5±2,9**

*Note. *Significant difference in the main group (MG) and the control group (CG) before and after PT*

When assessing the results of changes in muscle strength in the upper limbs of the case patients after the course of PT, positive dynamics of increasing muscle strength of the hand and forearm in both groups were revealed. Thus, the indicators of the injured left limb in the MG after PT were 27,4 ± 2,1 ($p < 0,01$) and in the CG – 23,9 ± 1,7 kg ($p < 0,05$) and the indicators of the injured right limb in the MG – 32,9 ± 2,0 ($p < 0,05$) kg and in the CG – 27,7 ± 1,9 ($p < 0,05$), respectively. Similar results were revealed when assessing the strength index of the muscles of the upper limbs.

Discussion

The treatment and subsequent recovery of military personnel who have received various types of wounds to the extremities remains an urgent problem, especially as a result of the ongoing military operations in Ukraine and there is an increase in the number of victims with varying degrees and localization of gunshot wounds. This, in turn, requires an improved approach not only to restore the health of military personnel with the consequences of gunshot wounds of the upper limb, but also to quickly return to their working capacity and combat readiness to perform their professional duties (Saiko et al. 2012; Bilyi et al. 2017; Naumenko et al. 2018; Lysun, 2019).

The experience of Canadian physical therapists who developed a problem-based model of civil-military rehabilitation for wounded soldiers involved in the conflict in Afghanistan within the framework of the CFHS (Canadian Forces Health Service) shows the need to take into account the special needs of each military personnel for their subsequent service (Enemark Larsen et al., 2018).

Moore et al. (2005) [167], Lototsky et al. (2016) note that the issue of using modern PT tools that are similar in their impact on the professional actions of military personnel and can serve as an important means of restoring lost skills after injury is important.

Muñoz-Cespedes et al. (2005) summarized the methodological issues associated with functional neuroimaging and relevant to the study of neuronal plasticity and recovery after rehabilitation.

Clinical examples of adaptive neural plasticity include the reorganization of cortical finger maps in response to string instrument practice and induced movement therapy to improve hemiparesis following stroke or cerebral palsy (Johnston, 2009).

Kopp et al. (2008) reviewed neuropsychological assessment tools and intervention programs in activities of daily living, vocational rehabilitation, and social integration.

Prigatano et al. (2021) note that neuropsychological rehabilitation is entering a new era that involves collaboration with neuroimaging and related neuroplasticity research.

Kerr 1 et al. (2011) viewed experiences as influencing neural circuits, shaping neural reorganization and functional outcomes, where behavioral interventions (e.g., rehabilitation training) can stimulate functionally beneficial neural reorganization.

Kleim (2011) notes that the field of neurorehabilitation is now beginning to receive new developments in neurobiologically based therapies that target key behavioral and neural signals that stimulate neural plasticity. Understanding the relationship between the mechanisms of neural plasticity and behavioral changes may contribute to the development of new, more effective functional outcomes for clinical rehabilitation of various injuries and diseases.

Our research confirmed the opinion of Moore et al. (2005), Kerr 1 et al. (2011), Lototsky et al. (2016) on the effectiveness of using PT programs taking into account the principles of neuroplasticity in military personnel with gunshot wounds to the upper limb. We supplemented the study of Epstein et al. (2010), Allami (2017), on the level of activity of daily life and its importance for military personnel.

Conclusion

The application of the principles of neuroplasticity in the PT program in the MG contributed to the improvement of the functional state of military personnel, as well as their professional and social capabilities and is applicable to wider practical implementation in specialized medical and rehabilitation institutions.

The prospect of further research is to study the effectiveness of the use of PT measures for injuries of the lower extremities among combatants.

Author's contribution

Conceptualization, N.S. and H.B.; methodology, O.L. and N.B.; check, N.S. and H.B.; formal analysis, O.L. and N.B.; investigation, N.S.; data curation, H.B., N.S.; writing – rough preparation, N.S. and N.B.; writing – review and editing, O.L. and H.B.; supervision, H.B.; project administration, N.S. All authors have read and agreed with the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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