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Dynamics of indicators of vestibular dysfunction and walking locomotion in men aged 25-42 years with the consequences of a combat wound as a result of the influence of physical culture and sports rehabilitation

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Abstract

The purpose of the study was to investigate and evaluate the dynamics of basometry and stabilometry in men aged 25-42 with the consequences of a combat injury.

Material & Methods: examined 38 men aged 25-42 years with long-term consequences of closed craniocerebral injury in the late long-term period, which were divided into Gr1 (n=20) and Gr2 (n=18). Vestibular dysfunction, mobility was determined by the Bohannon and "TUG" tests. To determine the biomechanical characteristics of walking, a hardware-software basometric complex and methods of the Ukrainian Research Institute for Prosthetics, Prosthetic Engineering and Recovery were used.

Results: when developing a correctional and rehabilitation program, thanks to the concept of the ICF, Smart goals were set. At stage 1 of inpatient rehabilitation (28 days), the program is composed of components. For men in both groups, the normative component was the same. Kinesitherapy, classes on the C-mill system, on the «Cosmos» treadmill, and massage were prescribed. Persons Gr1 in the variable part were trained on the Redcord suspension system, Nordic walking and vestibular gymnastics. The men of Gr2 were prescribed a general training on a multifunctional block simulator, training walking. At the 2nd stage (42 days) the persons of both groups were exercising independently, however, the persons of Gr1, with the help of modern telecommunication technologies, were exercising under the supervision of a specialist in physical rehabilitation. The dynamics of the balance indicator according to the Bohann test indicated that the persons Gr1 balance indicator almost approached the normative value. In Gr2 positive changes were observed, however, after stage 2 the difference was only 0.44 points compared with the dynamics of stage 1 ($p>0,05$). The dynamics of functional mobility and balance according to the «TUG» test indicated that the average time to complete the test after stage 2 approached the standard value. In patients, Gr2 tended to decrease ($p>0,05$). Biomechanical studies of statics, namely the coefficient of resistance, rotation of pressure centers, the common center of pressure in the frontal and sagittal plane in men Gr1 acquired significant differences ($p<0,05$); in men Gr2 tended to improve ($p>0,05$). The main indicators of walking locomotion, namely the pace and speed in men Gr1 and Gr2, acquired a standard value ($p<0,05$). The walking rhythm coefficient and load asymmetry index in men Gr2 did not acquire the normative value ($p>0,05$), in comparison with the indices of men Gr1 ($p<0,05$), who were engaged under the supervision of a specialist in physical culture and sports rehabilitation.

Conclusions: the results of the study revealed a violation of walking in men aged 25-42 years with the consequences of a combat injury

in the form of temporal, kinematic and dynamic asymmetry. The analysis of the dynamics of the parameters of vestibular dysfunction and walking locomotion confirmed the advantages of the author's program.

Key words: combat injury, walking locomotion, vestibular dysfunction, Bohannon test, "TUG" test, stabilometry, basometry.

Анотація

Динаміка показників вестибулярної дисфункції та локомоцій ходьби чоловіків 25-42 років із наслідками бойової травми як результат впливу фізкультурно-спортивної реабілітації. Метою дослідження було дослідити та оцінити динаміку показників базометрії та стабілометрії чоловіків 25-42 років із наслідками бойової травми. **Матеріали і методи:** обстежено 38 чоловіків віком 25-42 років з віддаленими наслідками закритої черепно-мозкової травми у пізньому віддаленому періоді, які були розподілені на Гр1 (n=20) і Гр2 (n=18). Вестибулярну дисфункцію, мобільність визначали за тестами Bohannon і «TUG». Для визначення біомеханічних характеристик ходьби використовували апаратно-програмний базометричний комплекс та методики УкрНДІ протезування, протезобудування та відновлення працездатності. **Результати:** при розробці корекційно-реабілітаційної програми, завдяки концепції МКФ, були встановлені Smart цілі. На 1 етапі стаціонарної реабілітації (28 днів) програму складено з компонентів. Для чоловіків обох груп нормативний компонент був однаковий. Призначали кінезітерапію, заняття на системі C-mill, на біговій доріжці «Cosmos», масаж. Особам Гр1 в варіативній частині проводили тренування на подвісній системі Redcord, заняття зі скандинавської ходьби та вестибулярної гімнастики. Чоловікам Гр2 призначали загальне тренування на багатофункційному блочному тренажері, тренувальну ходьбу. На 2 етапі (42 дні) особи обох груп займалися самостійно, проте особи Гр1 за допомогою сучасних телекомунікаційних технологій займалися під контролем фахівця з фізичної реабілітації. Динаміка показника балансу за тестом Боханном вказала на те, що у осіб Гр1 показник балансу майже наблизився до нормативного значення. В Гр2 позитивні зміни спостерігали, проте після 2 етапу різниця складала всього 0,44 бали у порівнянні з динамікою 1 етапу (p>0,05). Динаміка функціональної рухливості та рівноваги за тестом «TUG» вказала, що середній час виконання тесту після 2 етапу наблизився до нормативного значення. У досліджуваних Гр2 мав тенденцію до зменшення (p>0,05). Біомеханічні дослідження статики, а саме коефіцієнт опірності, ротація центрів тиску, загального центра тиску у фронтальній та сагітальній площині у чоловіків Гр1 набули достовірних відмінностей (p<0,05); у чоловіків Гр2 мали тенденцію до покращення (p>0,05). Основні показники локомоцій ходьби, а саме темп та швидкість у чоловіків Гр1 і Гр2 набула нормативного значення (p<0,05). Коефіцієнт ритмічності ходьби та показник асиметрії навантаження у чоловіків Гр2 не набув нормативного значення (p>0,05), у порівнянні з показниками чоловіків Гр1 (p<0,05), які займалися під контролем фахівця з фізкультурно-спортивної реабілітації. **Висновки:** результати дослідження виявили порушення ходьби у чоловіків 25-42 років із наслідками бойової травми у вигляді часової, кінематичної та динамічної асиметрій. Проведений аналіз динаміки параметрів вестибулярної дисфункції та локомоцій ходьби підтвердив переваги авторської програми.

Ключові слова: бойова травма, локомоції ходьби, вестибулярна дисфункція, тест Боханнон, тест TUG, стабілометрія, базометрія.

Introduction

After the war in Ukraine, the number of people with disabilities will increase, including among young and middle-aged men. In this connection, the question arises of relevance in the development and implementation of correctional and rehabilitation programs for their speedy recovery and adaptation to a full life in society (Korshniak et al., 2016; Alsalaheen et al., 2017; Misiura et al., 2022). After a long break associated with military events in Ukraine, the return of amateur athletes to training is accompanied by an increase in the number of errors, impaired coordination of movements, and difficulty in the formation of new motor skills. In view of the fact that one of the main causes of such conditions in young men is the consequences of a mild closed craniocerebral injury (CTBI) caused by the action of a blast wave, the problem of restoring impaired coordination, balance and walking patterns of amateur athletes is extremely relevant today (Zabenko et al., 2017; Kletsenko et al., 2022; Ruban et al., 2022). The consequences of CTBI, first of all, depend on the properties of the traumatic object, which determines the characteristic structural changes in the brain and the corresponding clinical picture. Concussion of the brain from the action of a blast wave (mild TBI) has a number of differences from TBI in peacetime (sports and road traffic) in the form of an additional lesion of the vestibular apparatus (Ruban et al., 2019; Shvets et al., 2019).

In patients with sequelae of CTBI, postural instability or imbalance is a common symptom. Postural stability is a multisensory motor task that depends on reliable input from the vestibular, somatosensory, and visual systems. Postural control is modulated by vestibulospinal reflexes. The lateral vestibulospinal tract receives most of its input from the otolith organs and the cerebellum and contributes to the tonic contractions of the anti-gravity muscles of the lower extremities (Horlings et al., 2009; Biloshytskyi et al., 2016; Ruban et al., 2022).

Walking control integrates the resources of many

parts of the CNS, namely: motor centers that directly control locomotion, structural centers for controlling posture, balance, voluntary movements, cognitive processes, and musculoskeletal functions. Whitney et al. (2009), Horlings et al. (2009), Marchetti et al. (2011), Neamţu et al. (2014), Tramontano et al. (2018) proved that the mechanisms for controlling walking and the parameters of this process in a person mainly relate to the effects of pathological conditions on the walking pattern.

Normal human walking is a series of rhythmic and alternating movements of the limbs and torso, leading to a forward movement of the body's center of gravity. In order for walking to be efficient, it is best that the center of mass of the body moves as little as possible. Under conditions of normal walking, the common center of mass (CCM) of the human body makes rhythmic up and down movements while moving forward. The highest point is reached when the supporting leg rests on the entire foot. The lowest point is in the two-support period, when both feet are in contact with the ground. This vertical displacement of the CCM is approximately 50 mm. The main mechanism that determines the effectiveness of walking is the movement of the CCM (Misiura, 2023).

The essence of the rehabilitation activities that should be carried out in a comprehensive rehabilitation for persons affected by hostilities is most fully expressed in one of the WHO definitions: "Rehabilitation and adaptation are effective in providing opportunities for people with disabilities to return to or stay at home or in the community, to live independently, receive education, participate in labor and civil relations. The possibility of rehabilitation (access to rehabilitation) and adaptation can reduce the consequences of illness or injury, improve health and quality of life, and reduce health care seeking". This problem is also gaining urgency from an economic point of view, because in most cases, CTBI during hostilities will be received by people of working age, who eventually become disabled. There is a negative relationship between vestibular dysfunction and recovery, however, in scientific publications there is evidence of the effectiveness of the use of vestibular rehabilitation (Whitney et al., 2009; Herdman et al., 2013; Voronova et al., 2021; Ruban et al., 2021).

Purpose of the study: to investigate and evaluate the dynamics of basometry and stabilometry indicators of men aged 25-42 years with the consequences of a combat injury.

Material and methods of research

Participants

Under observation were 38 men aged 25-42 years with long-term consequences of a closed craniocerebral injury in the late long-term period. The cause of disability was wounds and contusions associated with military operations. The patients were randomly divided into two groups: Gr1 (n=20) and Gr2 (n=18). All the studied complications after TBI were: persistent headache, dizziness, decreased muscle strength in the lower extremities, impaired coordination, balance and walking pattern. The duration of the post-traumatic period is from six months. All patients were involved in amateur sports before the injury.

Methods

The determination of vestibular dysfunction in patients in the long-term period was performed using the Bohannon test, the "TUG" test (Kim et al., 2021; Misiura, 2023).

According to the Bohannon test, the level of stability of the vertical posture was determined with different support areas.

The "TUG" test assessed mobility, balance, walking ability and risk of falling. According to the concept of the ICF, this test determines the level of activity (Kletsenko et al., 2022).

To study the support ability and postural stability when standing, a hardware-software basometric complex and the methods of basometry and stabilometry were used (Saleeva et al., 2003, 2007).

Basometry is a method for determining the patient's support ability when standing, while determining the level of load of each limb in relation to the total weight, the ratio of the load of the limbs (resistance coefficient).

Stabilometry is a technique for determining stability, that is, measuring the coordinates of the migration of the projection of the common center of pressure (CCP) or the resulting vector of the reaction of the support on the horizontal plane, which characterizes the ability to maintain a stable state in a standing position. During the study, a graphical linear registration of oscillations of the common center of pressure occurs separately in the frontal (right-to-left) and sagittal (forward-backward) planes and the calculation of the average amplitude of the oscillations is performed. After conducting stabilometric studies, the fluctuations of the CCP in the frontal and sagittal planes, which characterize the stability when the patient is standing, were studied.

The study of walking parameters was carried out using a hardware-software complex for studying the dynamic characteristics of walking, which consisted in measuring the values of the parameters of the support reaction vectors in time when the patient was walking. The main indicators of locomotion were determined: walking speed, rhythm coefficient, load asymmetry.

Procedure

The study was conducted on the basis of the Ukrainian Research Institute of Prosthetics, Prosthetics and Rehabilitation of Kharkiv (2019-2021).

The correctional rehabilitation program for restoring the walking pattern after brain contusion by means of physical culture and sports was com-

posed of 2 stages.

Stage 1 (28 days) was held on the basis of the Ukrainian Research Institute of Prosthetics, Prosthesis Construction and Recovery. Using the philosophy of the International Classification of Functioning, Disabilities and Health (ICF) Smart Goals are set: restoration of range of motion in the joints of the lower extremities to the standard value; increase in the strength of the muscles of the trunk and lower extremities; restoring balance in a standing position; increase in walking speed; improving the tolerance of the cardiovascular system to physical activity.

Stage 2 (42 days), long-term goals according to the concept of the ICF – return to amateur sports.

The dynamics of all characteristics was monitored after each stage.

The research related to human use has been complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki.

Statistical analysis

Statistical data processing was carried out using the Statistica 13 software. The data are presented as: X – arithmetic mean value; σ – standard deviation – an indicator of the dispersion of the values of a random variable about its mathematical expectation; m – representativeness error. The significance of differences in the obtained results was checked using Student's t-test. The α value coefficient was set at <0,05.

Results of the study

The training stage corresponds to the recovery phase, where the elimination of residual damage occurs, permanent compensations are fixed and improved. The objectives of this period were the maximum possible resumption of physical activity; increased tolerance to physical activity; formation of high-quality permanent compensations; social and labor adaptation (Honcharov et al., 2020; Lubetzky et al., 2022).

The correctional rehabilitation program for restoring the walking pattern after brain contusion by means of physical culture and sports was composed of 2 stages: Stage 1 (28 days) was held on the basis of the Ukrainian Research Institute of Prosthetics, Prosthesis Construction and Recovery. Using the philosophy of the International Classification of Functioning, Disabilities and Health (ICF) Smart Goals are set: restoration of range of motion in the joints of the lower extremities to the standard value; increase in the strength of the muscles of the trunk and lower extremities; restoring balance in a standing position; increase in walking speed; improving the tolerance of the cardiovascular system to physical activity.

At the 1st stage, the normative component of the program for persons Gr1 and Gr2 was the same: Kinesitherapy, group classes; Worked interactive system C-mill; Computer program "Rehabilitation & robotowolk" on the treadmill "Cosmos"; Massage.

The variable component of the program for patients Gr1 and Gr2 had differences.

The men of Group 1 were trained according to the developed program: training on the Redcord suspension system according to the Neurac method; Nordic walking; Vestibular gymnastics.

The men of Gr2 underwent a course of rehabilitation according to the protocol for managing patients of the Ukrainian Research Institute of Prosthetics, Prosthetic Construction and Recovery: General training on a multifunctional block simulator; Training walking.

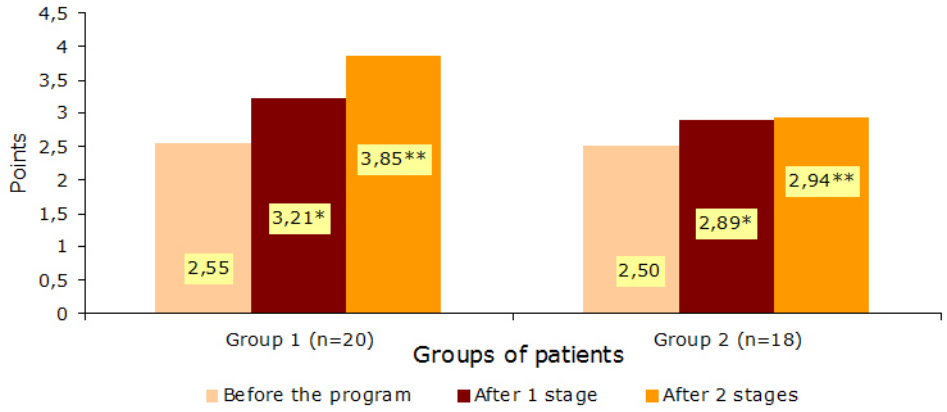
Stage 2 (42 days), long-term goals according to the concept of the ICF – return to amateur sports. The men of both groups worked independently. However, Gr1 persons, with the help of modern telecommunication technologies, were engaged under the supervision of a specialist in physical rehabilitation: Vestibular gymnastics; Nordic walking; Classes on simulators for the selected sport.

Men Gr2 were engaged independently according to the recommendations of the Ukrainian Research Institute of Prosthetics, Prosthetic Construction and Recovery without the supervision of a specialist.

The dynamics of all characteristics was monitored after each stage. The average balance indicator in the standing position according to the Bohann test in the primary study in persons Gr1 and Gr2 indicated instability to more maintain their standing position, independently on both legs. The difference in indicators compared to the standard value was 1,45 points in men of Gr1 and 1.5 points in men of Gr2 ($p<0,05$). After stage 1 of the program, the studied Gr1 and Gr2 determined positive dynamics, the difference compared to the primary indicator, which acquired the value of 0,66 points ($p<0,05$) and 0,39 points ($p>0,05$). Dynamics of indicators of the 2nd stage in men Gr1 indicated that the balance score on the Bohann test was almost close to the normative value (4 points) ($p<0,05$). In patients Gr2 positive changes were observed, however, after stage 2 the difference was only 0,44 points compared with the dynamics of stage 1 ($p>0,05$). The dynamics of balance indicators in the standing position after the Bohann test is shown in Figure 1.

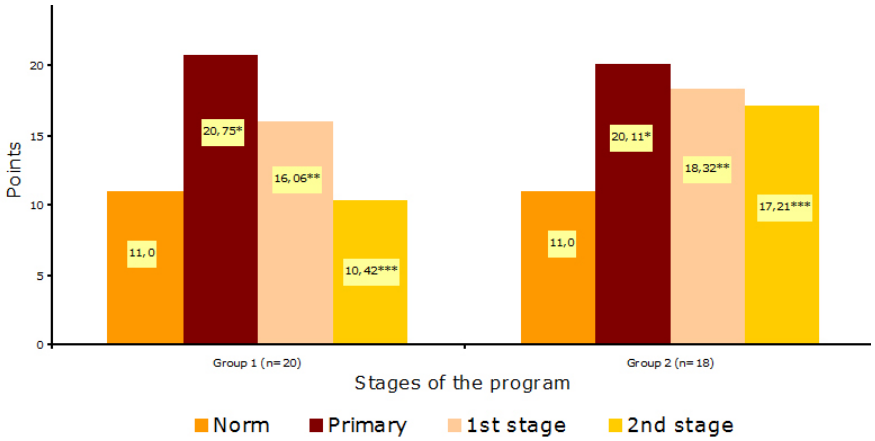
Changes in statistically significant dynamics, in our opinion, occurred due to the appointment of vestibular gymnastics in the variable part of the program.

The TUG test assessed functional mobility, balance, walking, and risk of falling. The normative value of the fall risk index for vestibular disorders is >11 seconds. Primary testing in the studied patients Gr1 and Gr2 indicated a statistically significant decrease in the obtained data compared with the normative indicator ($p<0,05$). The average time to complete



* – the difference between the primary indicators and indicators of stage 1 in Gr1 and Gr2;
** – difference between primary indicators and indicators of Stage 2 in Gr1 and Gr2.

Figure 1. Dynamics of balance indicators according to the Bohann test of patients Gr1 (n=20) and Gr2 (n=18), in points



* – difference between primary indicators and normative value in Gr1 and Gr2;
** – difference between primary indicators and indicators of stage 1 in Gr1 and Gr2;
*** – difference between primary indicators and indicators of stage 2 in Gr1 and Gr2.

Figure 2. Dynamics of functional mobility and balance according to the «TUG» test of patients Gr1 (n=20) and Gr2 (n=18), in points

the test after stage 1 in men of Gr1 decreased by 4,69±1,17 s ($p<0,05$); after stage 2 approached the standard value. In the studied Gr2 after the 1st stage decreased by 1,79±0,51 ($p>0,05$), after the 2nd stage it decreased by another 1,11±1,21 s ($p>0,05$). The dynamics of functional mobility and balance according to the "TUG" test of both studied groups is shown in Figure 2.

Biomechanical studies of statics were performed in all patients with impaired walking function as a result of brain contusion. All subjects showed a decrease in all stability parameters when standing. In patients of both groups, there is a decrease in the coefficient of resistance. So, in patients Gr1 the average indicator of the coefficient of resistance differed from the normative value by 0,23±0,03, in men Gr2 by 0,19±0,01 ($p<0,05$). We noticed a pronounced asymmetry of the posture, which is confirmed by the rotation of the pressure centers of the extremities in Gr1 to $1,14^0$ and in Gr2 by $1,11^0$ ($p<0,05$). In both groups, there is an increase in the displacement of the common center of pressure (CCP) both in the frontal and sagittal planes compared to the standard value. Fluctuations of CCP in the sagittal and frontal planes acquired significant differences compared to the standard value ($p<0,05$). In Gr1 patients, after the first stage, all the studied parameters changed statistically significantly ($p<0,05$), after the 2nd stage of work according to the developed program, they approached the normative value ($p<0,05$). In Gr2 men, after the 1st stage, the dynamics was positive, but without significant changes ($p>0,05$). After stage 2, the parameters of the resistance coefficient, rotation of pressure centers, fluctuations of the CCP in the frontal and sagittal plane tended to improve ($p>0,05$). Only the indicators of the displacement of the CCP in the frontal and sagittal planes approached the standard value ($p<0,05$). Table 1 presents the parameters of stabilometry in

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Table 1. Dynamics of stabilometric parameters of patients Gr1 (n=20) and Gr2 (n=18)

Parameters	Gr1 (n=20) X±σ			Gr2 (n=18) X±σ			Normative indicator
	primary	1 stage	2 stage	primary	1 stage	2 stage	
Stability factor	0,75±0,05*	0,86±0,03	0,94±0,03**	0,79±0,03	0,75±0,05*	0,80±0,03	0,98 ±0,02
Rotation of pressure centers, deg	–1,60±0,30*	–1,12±0,92	-0,98±0,81	–1,57±0,18	–1,29±1,33*	-1,26±1,30	-0,46±0,44
Displacement of the CCP in the frontal plane, mm	–3,76±2,13*	–3,00±1,76	–2,69±1,62**	-3,84±2,12	-3,32±1,94*	–2,88±1,74**	–2,86±1,00
Displacement of CCP in the sagittal plane, mm	–6,12±4,87*	–4,81±4,14	–4,30±3,84**	-6,14±5,0	-5,22±4,25*	–5,11±4,16**	–5,08±1,61
Fluctuations of the CCP in the frontal plane, mm	3,36±0,40*	2,85±0,26	2,58±0,37**	3,39±0,30	3,19±0,16*	3,07±0,14	2,04±0,31
Fluctuations of CCP in the sagittal plane, mm	7,69±0,55*	6,34±1,61	5,96±1,68**	7,79±0,07	7,59±0,52*	7,52±0,45	6,10±0,41

* – statistical significance in comparison with the normative indicator; ** – statistical significance of the dynamics of indicators in Gr1 and Gr2 after stage 2.

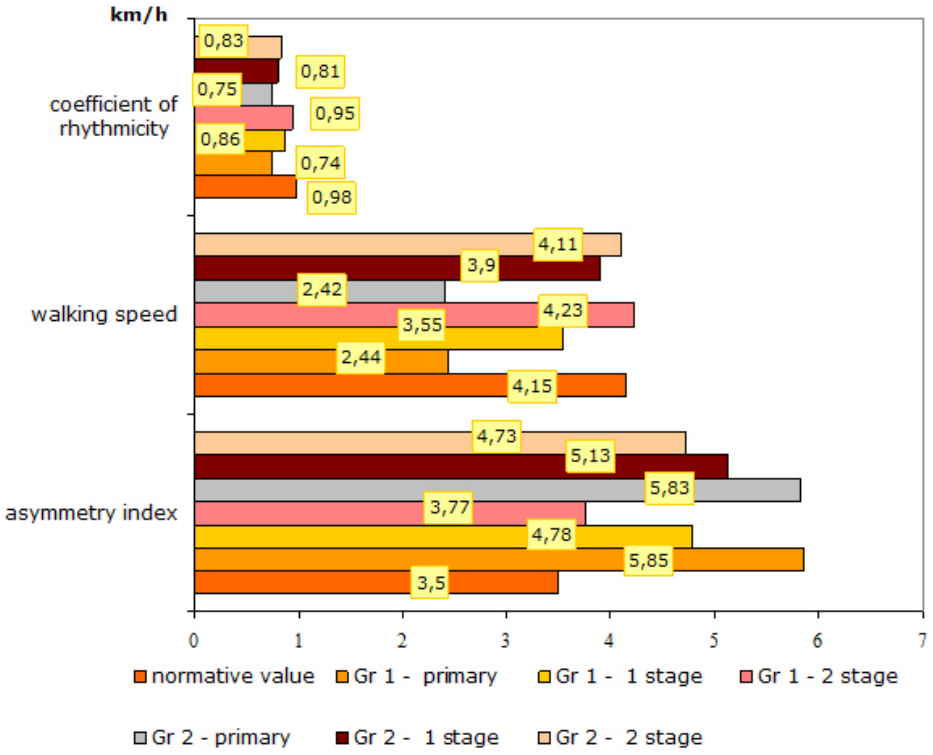

Figure 3. Dynamics of parameters of walking characteristics of patients Gr1 (n=20) and Gr2 (n=18)

patients of both groups.

The primary study of the dynamic characteristics of walking in patients of both groups indicated a deterioration in the main indicators of locomotion, namely the pace and speed of walking, which were statistically significantly reduced (p<0,05). Also, a statistically significant walking disorder was noted in the form of temporal, kinematic and dynamic asymmetries in patients Gr1 and Gr2 (p<0,05). Figure 3 shows the indices of walking locomotion in patients of both groups.

Initial studies of walking locomotion in men Gr1 and Gr2 indicated a significant decrease in all parameters compared with the standard value (p<0,05). After the 1st stage of observation in men Gr1 and Gr2, all the studied parameters significantly changed (p<0,05), but have not yet acquired a normative value. After the 2nd stage in men of Gr1, the parameters of walking speed, rhythmicity coefficient and load asymmetry acquired the normative value (p<0,05); in men of Group 2, the walking speed acquired a standard value (p<0,05),

the rhythm coefficient almost did not change compared with the indicator after the 1st stage of the program (p>0,05), the load asymmetry indicator statistically significantly decreased (p< 0.05), but did not acquire a standard value (p>0,05). That is, after the 2nd stage of observations, a more positive effect on the parameters of walking locomotion occurred in Gr1, who were engaged under the supervision of a specialist in physical culture and sports rehabilitation with the help of modern telecommunication technologies.

Thus, the study confirmed the benefits of the author's program, which resulted in an improvement in vestibular dysfunction and gait locomotion in patients Gr1, since the statistical significance was (p<0,05).

Discussion

The results of this work confirmed the opinion of many scientists that when building a correctional and rehabilitation program, the main principle is an individual approach. From the point of view of rehabilitation management, the methodology of SMART goals is the formation of the patient's individual space (Honcharov et al., 2020; Voronova et al., 2021; Kletsenko et al., 2022; Ruban et al., 2022).

We agree with the opinion of Marchetti et al. (2011) that understanding the relationship between vestibular dysfunction and actual balance scores can improve the recovery process and overall health-related quality of life of patients.

Based on the results of the scientific work of Tishchenko (2017), we confirm that walking is not a fully automated process, but requires the use of a variety of additional CNS resources. When choosing means of kinesitherapy, attention should be paid to those means, the mechanism of therapeutic action of which is neuro-reflex.

We confirm the results of the preliminary work by Misyura et al. (2022) that it is the individual selection of physical exercises, the development of correctional and rehabilitation programs, and a multidisciplinary approach that positively affect the vestibular coordination and walking pattern of amateur athletes with the consequences of brain contusion, even in the late period, and bring their return to sports activities closer.

Conclusion

Thus, the results of the study revealed walking disorders in men aged 25-42 with the consequences of a combat injury in the form of temporal, kinematic and dynamic asymmetries. The developed correction and rehabilitation program with an emphasis on vestibular gymnastics had a positive effect on the biomechanical characteristics of walking. The analysis of the dynamics of the parameters of vestibular dysfunction and walking locomotion confirmed the advantages of the author's program.

Author's contribution

Conceptualization, V.M. and L.R.; methodology, V.M. and O.H.; software, L.R.; check, Y.G., V.M.and L.R.; formal analysis, V.M.; investigation, V.M.; resources, L.R.; data curation, V.M.; writing – rough preparation, V.M.; writing – review and editing, L.R.; visualization, L.R.; supervision, L.R.; project administration, L.R.; receiving funding, Y.G. 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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