



Defining Authenticity of the Y Balance Test Implemented by an Intellectual Programmed Tool in Inclusive Physical Education

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Abstract

Objectives. The study aimed to investigate the authenticity of the Y Balance Test for the lower quarter (LQYBT), implemented by a developed intelligent programmable tool for students after blast TBI with acoustic trauma.

Materials and methods. At the theoretical level, analysis, synthesis, systematization, and generalization were used, while at the empirical level, technical modeling, applied programming, a pedagogical experiment using the LQYBT, and mathematical statistics were employed. The study sample consisted of first-year students after mild blast TBI with acoustic trauma.

Results. The results are presented in a developed intelligent programmable tool for LQYBT implementation. The development of the tool involved using the MPU-6050 GY-521 module, which is placed into the sole of the footwear intended to perform LQYBT. Another element of the developed tool is “intelligent vectors”, which are placed on the axes of LQYBT execution and consist of a matrix of pressure sensors. This matrix registers pressure changes at the points of contact for the student's foot and automatically identifies loss of balance, foot movement, or errors related to changes in body position. Integrating information from the MPU-6050 GY-521 module and “intelligent vectors” is facilitated by using the Arduino Uno board comprising the ATmega328P microcontroller as the main processor and the ATmega16U2 microcontroller for communication with a PC via a USB port. The board recognizes signals and transmits them sequentially to a PC, where they are processed by the developed software and displayed on the screen. Wireless infrared communication is used to transmit the signal. A key feature of this smart tool is the use of artificial intelligence. The reliability and validity indicators of LQYBT after blast TBI with acoustic trauma, when the results are recorded by the teacher, correspond to the “average” and “acceptable” levels. When using the developed tool, they reached the “high” level.

Conclusions. The findings suggest that using an intelligent programmable tool for the implementation of LQYBT is a powerful means of monitoring the current state of balance in students after blast TBI with acoustic trauma in real time, its permanent analysis and forecasting, for making timely and adequate management decisions regarding the rehabilitation program in the process of inclusive physical education.

Keywords: students, blast TBI with acoustic trauma, physical education, inclusion, control, test authenticity, digitalization.

Introduction

Every day in Ukraine, the number of people who have become disabled due to war-related injuries is growing. In the context of Russia's war against Ukraine, the prevalence of blast traumatic brain injury (TBI) among both military personnel and civilians is reaching unprecedented levels, as the impact of the widespread use of the latest high-energy weapons is very significant for the entire body (Dzyak et al., 2023; Denby et al., 2020).

Blast TBI complicated by acoustic trauma is particularly common as a result of armed damage caused by blast waves (Akin et al., 2022; Li, 2023; Sudhakar et al., 2020). Acoustic trauma, particularly in veterans, is a factor in the increase in disability, with an annual rate of 13-18% (Aural Blast/Injury Acoustic Trauma and Hearing Loss, 2018).

At the same time, blast TBI with acoustic trauma has a cumulative effect, which has quite significant consequences for the health of victims (Alkathiry et al., 2019; Haarbauer-Krupa et al., 2021; Du et al., 2023). Despite this, timely and adequate care for blast TBI is crucial for preventing consequences and ensuring a speedy recovery (Blennow et al., 2016; Misyura, Ruban, & Mishin, 2022; Mullally, 2017).

Currently, an increasing number of individuals with blast TBI are participating in higher education. In the near future, given the current reality of Russia's ongoing military aggression in Ukraine, the rehabilitation of students of war injuries is becoming increasingly relevant (Blavt et al., 2024; Byshevets et al., 2024). The restoration of students' health during the learning process is ensured by the use of the potential of inclusive physical education (PE) in this process (Giuriato, 2023; Ben Rakaa, Bassiri, & Lotfi, 2025).

Given the need for sustainable development of the education sector to keep up with modern narratives, there's a clear need to modernize inclusive PE, considering the steady increase in the number of students with disabilities after blast TBI in higher education institutions.

Analysis of recent research and publications. Research (Bodnar, & Sofinsky, 2024) has shown that despite the war, Ukraine continues to implement important changes in the field of inclusive PE. It is indisputable (Keles, ten Braak, & Munthe, 2022) that quality education should contribute to improving health, and that good health is a prerequisite for obtaining a proper education (Lieberman, Houston-Wilson, & Grenier, 2024; Blavt et al., 2024).

The issue of the quality of inclusive PE, which in higher education provides a rehabilitation function for students with disabilities, is the subject of a number of studies (Blavt, & Gurtova, 2024; Giuriato, 2023; Navas-Bonilla et al., 2025). After analyzing research initiatives (Lund, & Kirk, 2019; Kuntjoro et al., 2022; López-Pastor et al., 2012), it was found that monitoring the process PE provides valuable information about its effectiveness, helping to optimize the process of restoring health. According to the information (Akin et al., 2022; Mucha, Fedor, & DeMarco, 2018; Sudhakar et al., 2020), the consequences of changes that the brain undergoes during blast TBI can manifest themselves in various ways.

Many authors have addressed the issue of rehabilitation after a blast TBI (Shvets et al., 2020; Ng, & Lee, 2019; Perkins et al., 2022). According to the literature (Reilly, 2021; Misyura, Ruban, & Mishin 2022; Leland et al., 2016), the effects of blast TBI can lead to serious disorders in the

body and affect a person's working capacity, legal capacity and socialization, so it is important that treatment and rehabilitation are supervised.

Numerous studies have been devoted to the effects of blast TBI on the body (Kovacs, Leonessa, & Ling, 2014; Sepehry, Schultz, & Mallinson, 2024). First of all, acoustic trauma, which is defined as trauma caused by an acoustic blast wave, is considered by specialists (Shvets et al., 2020) to be a multiple trauma that falls under the concept of blast TBI. Motor disorders and sensory dysregulation are considered (Alkathiry et al., 2019; Mucha, Fedor, & DeMarco, 2018) to be the main types of disorders after blast TBI with acoustic trauma.

In particular, problems with hearing and the vestibular apparatus (acoustic trauma) (Alkathiry et al., 2019; Akin, & Murnane, 2011; Murray et al., 2019), vision, memory impairment, spatial coordination, attention, concentration, and reaction, and later with the musculoskeletal system and difficulty performing movements (Akin et al., 2022; Du et al., 2023; Denby et al., 2020).

Numerous studies focus on the role of assessment and testing in ensuring the effectiveness of PE (Baumgartner et al., 2015; Kuntjoro et al., 2022; López-Pastor et al., 2012). It has been proven (Lieberman, Houston-Wilson, & Grenier, 2024; González-Rivera et al., 2023) that systematic objective monitoring is a tool for avoiding bias and ensuring progress toward achieving goals in this process. Researchers see the solution to this issue in the creation of auxiliary tools that can provide reliable and rapid analysis of research parameters (Goodwin et al., 2003; Lund, & Kirk, 2019).

The purpose of the study research is to investigate the authenticity of the Y_Balance_Test for the lower quarter (LQYBT), implemented by a developed intelligent programmable tool for students after blast TBI with acoustic trauma.

Materials and Methods

Research Methods

The methodology of our study covers a two-level (theoretical and empirical) complex of scientific knowledge methods/The theoretical level of the study was practice-oriented while complying with the requirements of consistency and using methods of analysis, synthesis, induction, deduction, and interpretation.

At the empirical level, the following research methods were used: technical modeling to create an experimental prototype of the device, applied programming, pedagogical experiment, and mathematical statistics.

The choice of LQYBT for conducting a pedagogical experiment was guided by the need for simplicity of execution, practicality in use for measuring dynamic equilibrium, the absence of the need for complex equipment, and the possibility of repeated repetition.

The test procedure. The LQYBT has the student stand on one leg while reaching out in 3 different directions with the other lower extremity (Fig. 1). They are anterior, posteromedial and posterolateral. The maximal reach is measured by reading the distance at the edge of the reach indicator closest to the subject to the nearest half centimeter. The limb being tested is the stance limb (Physiopedia: Y Balance Test).

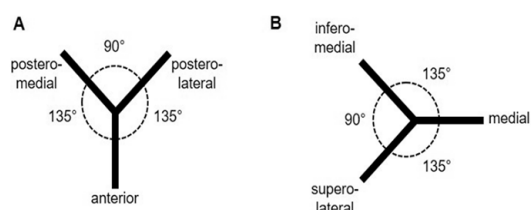


Fig. 1. Scheme of the LQYBT (Schwiertz, Beurskens, & Muehlbauer, 2020)

When performing LQYBT, the following should be observed: the supporting leg should not be lifted off the floor; the hands should be kept on the hips; the extended leg should not touch the floor; the standardization of returning to the starting position should be observed (Kattilakoski et al., 2023).

Study Participants.

The study sample consisted of first-year students (24 male) after mild blast TBI with acoustic trauma who were involved in the study from Lviv Polytechnic National University, Lviv State University of Physical Culture named after Ivan Boberskyj, Kamianets-Podilskyi National Ivan Ohiienko University, Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv, Kremenets Taras Shevchenko Regional Academy of Humanities and Pedagogy.

Given that the authenticity of the test depends on the qualitative characteristics of the study sample (Baumgartner, et al, 2015), the inclusion criteria were set at 18-25 years of age and no impairment of vital body functions. The exclusion criterion was previous experience with LQYBT, to avoid the influence of the learning effect.

All students underwent a medical examination before the start of testing and signed a letter of consent to participate anonymously in the testing.

The study was planned and carried out following the principles of bioethics set forth by the World Medical Association (WMA-2013) in the Helsinki Declaration «Ethical Principles of Medical Research Involving Humans» and UNESCO in the «General Declaration on Bioethics and Human Rights».

Research Organization

The experiment was carried out in the process of inclusive PE. The essence of the comparative study was to conduct testing and record the results in two ways. In the first case, all testing and data collection was carried out by one teacher, and the distance was measured with a ruler. In the second case, the testing was carried out using a specially developed intelligent programmable control device.

Each student in the study sample was informed and familiarized in detail with the testing procedure, given specific instructions for performing the test, visually demonstrated, and provided explanations regarding incorrect performance.

Three directions of reach: anterior, posteromedial, and posterolateral, were to be performed. The students performed three attempts in the specified directions of reach,

To prove the authenticity of the test, its reliability and validity were determined. The conclusions of the study are based on a comparative analysis of the numerical values of the reliability and validity of the LQYBT, implemented using various measurement tools.

Statistical Analysis

The formation of generalized results and conclusions of the study involved the use of mathematical statistics methods. Correlation analysis was used to establish the level of authenticity, namely the numerical values of reliability and validity (Baumgartner et al, 2015).

Mathematical statistics methods were used to process, analyze, and interpret the experimental data using SPSS Version 22.0 (IBM Corporation).

Results

As proven (Shumway-Cook, & Horak, 1986), the predominant sensory signal for balance control is somatosensory information from the feet in contact with the supporting surface. Therefore, these positions should be taken into account when controlling stability in different conditions.

The results of the empirical stage of the study are presented in a developed intelligent programmable tool for LQYBT implementation. A compact and lightweight MPU-6050 GY-521 module was used to create the LQYBT implementation tool.

The MPU-6050 GY-521 module consists of a 3-axis accelerometer and a 3-axis gyroscope (Mykytyuk et al., 2024). This module is used to determine the position in space and angular displacements that indicate a loss of balance, such as a body tilt of more than 30°, which occurs during the performance of LQYBT. The module was placed in the sole of the footwear used to perform LQYBT (Fig. 2).

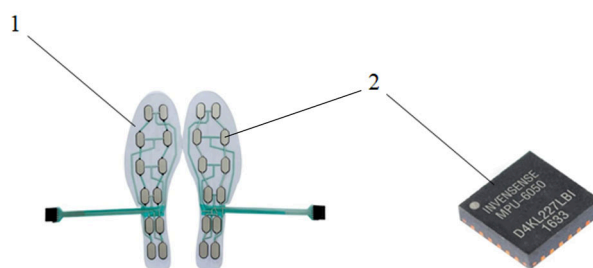


Fig. 2. Special footwear with a built-in MPU-6050 GY-521 module: 1 – special footwear, 2 – MPU-6050 GY-521 module

Another element of the developed tool is «intelligent vectors» which are placed on the axes of the LQYBT and consist of a matrix of pressure sensors located on the surface (Politanskyi et al., 2024). This matrix registers pressure changes at the points of contact of the student's foot and automatically identifies loss of balance, foot movement, or errors related to changes in body position.

To integrate information from the MPU-6050 GY-521 module and «intelligent vectors» the development uses an Arduino Uno board, which consists of an ATmega328P

microcontroller as the main processor and an ATmega16U2 microcontroller for communication with a PC via a USB port. The board can be powered via USB or from an external power source. The type of source is selected automatically.

Importantly, the ATmega328 microcontroller on the board has a built-in bootloader, which allows new programs to be loaded into it without the need for an external programmer. The software for the intelligent tool was developed in the Delphi environment, which is used to run the test and determine the quality of its performance.

LQYBT using the developed intelligent programmable tool is implemented as follows (Fig. 3). The student puts on a special footwear with a built-in MPU-6050 GY-521 module and takes the starting position in the center of the vectors on which the pressure sensor matrices are located. The signals generated in the module and pressure sensors when the student performs the test task are transmitted to the Arduino Uno board. The signals are recognized by the board and transmitted sequentially to a PC, where they are processed by software and displayed on the screen using a user interface. Wireless infrared communication is used to transmit the signal.

A key feature of this intellectual tool is its ability to classify, plan, and predict the inclusive PE process based on test control data. To do this, it uses artificial intelligence technology, specifically neural networks for processing, such as sorting and searching large amounts of test data.

The analysis of the data obtained can be supplemented by visual tracking of the test process using a camera, for example, using a Raspberry Pi with an OpenCV module,

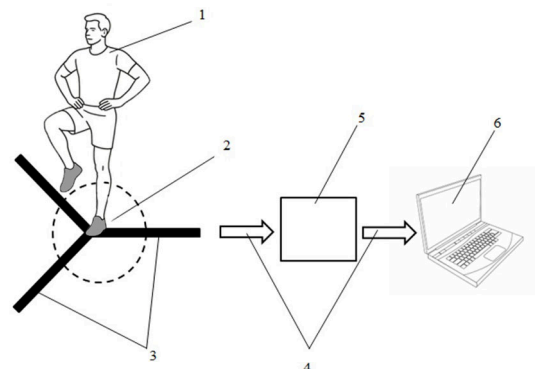


Fig. 3. Scheme of LQYBT implementation using an intelligent programmable tool: 1 – student, 2 – special footwear with a built-in MPU-6050 GY-521 module, 3 – “intelligent vectors” with a matrix of pressure sensors, 4 – infrared communication lines, 5 – Arduino Uno board, 6 – PC

which provides real-time recording of deviations in the performance of the test task. We visualize the results through a mobile application developed on the Blynk platform. The data can be presented in the form of graphs, tables, or 3D models of student movement.

A prominent characteristic of the developed control system is its ability to operate in energy-saving mode, which is extremely important in modern domestic realities.

The final stage of the study involved determining the numerical values of the authenticity indicators of LQYBT,

Table 1. Authenticity of the of the LQYBT for students after blast TBI with acoustic trauma when measured by a teacher(n = 24)

Test tasks	Statistical parameters and measurement results							
	X	S	As	Me	V(%)	reliability (rtt)	validity (rtt)	
posteromedial	r	91.1	5.0	0.13	89.9	31.3	0.447	0.211
	l	93.3	6,7	0.17	91.5	28.3	0.482	0.203
posterolateral	r	86.7	4.2	0.19	83.1	29.5	0.510	0.205
	l	81.7	6.8	0.21	78.4	30.3	0.560	0.198
anterior	r	69.1	4.2	0.49	67.7	31.5	0.484	0.191
	l	65.5	4.7	0.26	62.9	28.6	0.412	0.218

*Note: r – right leg, l – left leg, X – arithmetic mean, S – standard deviation, Me – median, V – coefficient of variation

Table 2. Authenticity of the of the LQYBT for students after blast TBI with acoustic trauma using the developed intelligent programmable tool (n = 24)

Test tasks	Statistical parameters and measurement results							
	X	S	As	Me	V(%)	reliability (rtt)	validity (rtt)	
posteromedial	r	95.7	5.7	0.18	91.9	22.3	0.876	0.501
	l	92.1	5.6	0.11	86.2	24.1	0.812	0.488
posterolateral	r	91.4	4.9	0.15	87.3	22.6	0.902	0.492
	l	88.9	3.3	0.13	86.4	26.1	0.897	0.512
anterior	r	72.5	6.2	0.49	69.2	21.5	0.879	0.465
	l	69.1	3.1	0.26	64.4	24.3	0.913	0.517

*Note: r – right leg, l – left leg, X – arithmetic mean, S – standard deviation, Me – median, V – coefficient of variation

implemented using various measurement tools. The results are presented in Table 1, 2.

The reliability and validity indicators of LQYBT after blast TBI with acoustic trauma, when the results were recorded by the teacher, corresponded to the “average” and ‘acceptable’ levels. When using the developed intelligent programmable tool, the numerical values were significantly higher and reached the “high” level.

Discussion

Our study is based on the assertion that ensuring the effectiveness of student rehabilitation after blast TBI in the process of inclusive PE requires constant monitoring of the state of recovery in dynamics and analysis of this process (Lund, & Kirk, 2019; Misyura, Ruban, & Mishin, 2022). Therefore, we support scientific approaches (Kuntjoro et al., 2022; López-Pastor et al., 2012; González-Rivera et al., 2023) that objective monitoring of inclusive PE is the basis for the effectiveness of the methods used and their timely correction. Information has been expanded (Blavt, et al., 2023; Perkins et al., 2022) on the importance of periodically assessing parameters that have been damaged as a result of injuries, in particular blast TBI (Li, 2023; King et al., 2014; Mucha, Fedor, & DeMarco, 2018). This confirms the ideas (Lieberman, Houston-Wilson, & Grenier, 2024; López-Pastor et al., 2012) about using assessment results as a basis for improving and individualizing the rehabilitation process and physical education itself.

At the same time, we agree with the view (King et al., 2014; Salafi et al., 2023; Yilin et al., 2024) that the testing process should eliminate the influence of human factors as much as possible to meet the requirements of impartiality. It is test reliability that is recognized as a factor in the objectivity of data on the effectiveness of the control process (Marchenko, Ivashchenko, & Kupreichenko, 2023; Ng, & Samsudin, 2024; Putro et al., 2025).

Our scientific research expands on the data (Asongu, Orim, & Nting, 2019; Navas-Bonilla et al., 2025; Mokmin, & Rassy, 2024) on ensuring the effectiveness of the inclusive educational process, seeing the solution to this issue in constructive technological solutions and applied programming.

In line with the results of our scientific research (Gao, Guan, & Tan, 2025; Goodwin et al., 2003) on the transformation of the inclusive physical education process and its implementation in accordance with the individual needs of each student, based on our previous studies (Blavt et al., 2024), which are based on the development of automated control systems using the high-tech capabilities of modern digital technologies.

In our study, we took into account information that scientists see the restoration of balance as the key to improving quality of life and maximizing the recovery of lost functions (Reilly, 2021; Misyura, Ruban, & Mishin, 2022). Our study expands on existing findings on vestibular effects after blast TBI (Haarbauer-Krupa et al., 2021; Blavt et al., 2024), which is a new area of assessment and research that may contribute to predicting long-term outcomes. At the same time, testing postural stability is becoming increasingly important for assessing motor function after TBI (Guskiewicz, 2001; Merritt et al., 2017; King et al., 2014).

Our study is based on information (Schwiertz et al., 2019) about the widespread use of LQYBT to control

dynamic balance in various populations. The list includes: individuals with chronic ankle instability (Olmsted et al., 2002); military personnel with closed head injuries and barotrauma (Shvets et al., 2020); healthy early adolescent female athletes (Greenberg et al., 2019); student-athletes and general college students (Engquist et al., 2015); in healthy adults (Powden, Dodds, & Gabriel, 2019); healthy trained and untrained youth (Schwiertz, Beurskens, & Muehlbauer, 2020); male collegiate soccer players (Plisky et al., 2009); in adolescent athletes (Linek et al., 2017); in healthy female and male adolescents from grade 6 to 11 (Schwiertz et al., 2019); in high school athletes (Smith et al., 2018); in recreationally active healthy adults (Bubić, & Kozinc, 2023).

Despite a significant list of studies on establishing the authenticity of LQYBT, no study has sought to establish the level of authenticity of LQYBT for students after blast TBI with acoustic trauma. We were guided by information (Plisky et al., 2021) about the need to take into account the characteristics of the study sample when interpreting the LQYBT test results. This is consistent with the opinion that before a test can be used in practice, its reliability in a specific population should be determined (Maricot et al., 2024; Merritt et al., 2017; Marchenko, Ivashchenko, & Kupreichenko, 2023).

Conclusions

The process of transforming inclusive education is now inevitable, given the trend toward an increase in the number of students with disabilities due to the ongoing hostilities in Ukraine. In order to meet today's challenges, higher education institutions must do everything possible to ensure the accessibility of all areas of the educational process so that students with disabilities are provided with the conditions for proper rehabilitation of their health during the learning process.

Seeing the solution to the issue of ensuring the effectiveness of the rehabilitation process for persons with disabilities in constructive and technological solutions and applied programming, we ensure the modernization of this process and its implementation on a scientifically sound basis, following the individual needs of each student after blast TBI with acoustic trauma.

The use of an intelligent programmable tool for the implementation of LQYBT is a powerful means of monitoring the current state of balance of students after blast TBI with acerbic trauma in real time, its permanent analysis and forecasting, for making timely and adequate management decisions in the process of inclusive PE. This is confirmed by the numerical values of the authenticity characteristics of LQYBT when the results are recorded by an intelligent programmable tool. In contrast, when the results are recorded by a teacher, the level of authenticity of LQYBT is significantly lower.

Thus, through objective real-time monitoring, high-quality calculations, and data analytics, we ensure the objectivity of monitoring students with post-blast TBI in the process of inclusive PE.

Conflict of Interest

If the authors have any conflicts of interest to declare.

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Визначення автентичності тесту «Y баланс» реалізованого інтелектуальним програмованим інструментом у інклюзивному фізичному вихованні

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 2 табл., 3 рис., 66 джерел.

Мета дослідження полягала у дослідженні автентичності тесту Y- балансу для нижньої частини тіла (LQYBT), реалізованого розробленим інтелектуальним програмованим інструментом для студентів після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою.

Матеріал та методи. На теоретичному рівні використано аналізу, синтезу, систематизації, узагальнення; емпіричному – технічного моделювання, прикладного програмування, педагогічного експерименту з використанням LQYBT, математичної статистики. Досліджувана вибірка складалась із 24 студентів 1-го курсу після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою.

Результати представляємо у розробленому інтелектуальному програмованому інструменту для реалізації LQYBT. Для створення інструменту використали модуль MPU-6050 GY-521, який розміщено у підшві взуття для виконання LQYBT. Ще одним елементом розробленого інструменту є «інтелектуальні вектори», які розмістили на осях виконання LQYBT і які складаються з матриці датчиків тиску. Така матриця реєструє зміни тиску в точках дотику ноги студента та автоматично ідентифікує втрату рівноваги, пересування ноги або помилки, пов'язані зі зміною положення тіла.

LQYBT з використанням розробленого інтелектуального програмованого інструменту реалізується наступним чином. Студент одягає спеціальне взуття з вбудованим модулем MPU-6050 GY-521 та займає вихідне положення у центрі «інтелектуальних векторів», на яких розміщено матриці датчиків тиску. Сигнали, які виникають у модулі та у датчиках тиску при виконанні тестового завдання студентом, передаються на плату Arduino Uno. У платі сигнали розпізнаються та передаються послідовно на ПК, де обробляються програмним забезпеченням та відображаються на екрані з допомогою програмного інтерфейсу користувача. У розробці використано технологію штучного інтелекту, а саме нейромережі для обробки, як от сортування та пошуку великих обсягів даних тестування.

Отримані показники надійності та валідності LQYBT після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою, у разі фіксації результатів викладачем, відповідні рівню «середній» та «прийнятний». У разі використання розробленого інструменту – досягли рівня «високий».

Висновки. Використання інтелектуального програмованого інструменту для реалізації LQYBT є потужним засобом моніторингу поточного стану рівноваги студентів після легкої вибухової черепно-мозкової травми, ускладненою акуборотравмою, в режимі реального часу, його перманентного аналізу й прогнозування, для прийняття своєчасних і адекватних управлінських рішень у інклюзивному фізичному вихованні.

Ключові слова: студент, вибухова черепно-мозкова травма, акуборотравма, фізичне виховання, інклюзія, контроль, автентичність тесту, цифровізація.

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