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Software and Hardware Control System for Implementing the Balance Error Scoring System

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Abstract

Objectives. The study aimed to determine the degree of reliability and validity of the "Balance Error Scoring System" (BESS) for students after blast TBI implemented by the developed software and hardware control system.

Material and methods. The experiment was attended by 1st-year students (28) after blast TBI in remission, provided that there were no complications and post-concussion syndrome. The theoretical level of scientific research involved using the methods of analysis, synthesis, induction, deduction and interpretation. The developed software and hardware tools used the method of technical modelling. The experimental data presented in this study were obtained by using the BESS in the process of pedagogical testing, which was processed by methods of mathematical statistics.

Results. The result of our scientific research was the development of software and hardware control system for the implementation of BESS based on the integration of hardware and data processing algorithms. In the construction of the software-technical control system for the implementation of BESS, elements of the latest generation of electronic technology were used, namely: piezoelectric pressure sensors, Force-Sensitive Resistor, MPU-9250 sensor module – System-in-Package, which consists of a gyroscope, accelerometer and integrated Digital Motion Processor, as well as Arduino Mega board. For real-time data transmission to the PC screen and smartphone, wireless modules HC-05 (Bluetooth) or ESP32 (Wi-Fi) were used. To implement the tasks of processing BESS data, application software was developed, and neural network technology was used to process BESS results. Statistical processing of BESS results obtained by two methods of registering results revealed that the level of reliability and validity when the results were marked by an expert corresponded to the level of "low" and "medium". In the case of recording BESS results by the software-technical control system, the level of reliability and validity of the studied parameters reached the limit of "high".

Conclusions. The findings indicate that the use of advanced technologies and dependable automated control systems in inclusive physical education for the collection, careful study and analysis of test data ensures the generation of high-quality, trustworthy information, which serves as the basis for creating reliable and scientifically sound programs for restoring damaged functions after blast TBI.

Keywords: student, blast TBI, physical education, testing, inclusion, control, balance, reliability, validity.

Introduction

Problem statement. Since the beginning of the full-scale war, the aggression of the russian federation has had particularly severe consequences for the most vulnerable categories of the population, such as people affected by the war, as a result of injuries. In the situation of prolonged active hostilities on the territory of Ukraine and daily terrorist attacks, the scale of the catastrophe is increasing every day. This is a factor in the steady increase in the number of people who have sustained explosive injuries (Blavt et al., 2024).

According to (Chernenko, 2022; Ghandour et al., 2022), mild concussion due to blast injury (blast TBI) accounts

for half of all war injuries, which can be sustained equally by combatants and civilians. Blast injuries are the leading cause of TBI in war zones (Ling, Ecklund, & Bandak, 2015; Haydel, & Lauro, 2024). Moreover, mild TBI is almost 10 times more common than moderate and severe trauma (Dewan et al., 2019; Buckley, Oldham, & Caccese, 2016), but the exact prevalence is unknown (Kovacs, Leonessa, & Ling, 2014). With an additional 30% of latent cases (NAMS) added to this number, blast TBI has become a growing concern (DePalma, 2015).

Blast TBI has been called a «silent epidemic» because it contributes to disability and long-term disability among young people more than any other injury (Dewan et al., 2019; Marcus et al., 2019). It is recognized (Krueger, et al., 2021) as a factor of economic and social costs and deterioration of quality of life.

Along with the fact that the prevalence of blast TBI is a serious problem for the healthcare sector (Ling, & Ecklund, 2011), because the number of students after blast TBI in higher education institutions is growing (Blavt et al., 2024), this problem is becoming one of the central areas of higher education.

Analysis of recent research and publications. In higher education, the function of adaptation of students affected by the war and rehabilitation of damaged functions is entrusted to inclusive physical education (Blavt et al., 2023). At the same time, inclusion is recognized (Lieberman, Houston-Wilson, & Grenier, 2024; Barber, & Walters, 2024) as a norm of the modern educational environment.

It has been researched (Denby, et al., 2020; Sudhakar, et al., 2023; Du et al., 2023) that blast TBI causes varying degrees of injury severity. It has been proven (Zairinal, Malufti, & Ramli, 2023; Abebe, Alemu, & Sorato, 2024; Zhao et al., 2023) that such injuries are accompanied by significant disorders in the state of the body's functional systems, in particular, the vestibular system (Taylor et al., 2022; Akin et al., 2017; Wood et al., 2022).

In particular, vestibular dysfunction is a common consequence of blast TBI, which can prolong recovery time (Mucha, Fedor, & DeMarco, 2018; Akin et al., 2022; Alkathiry et al., 2019). It has been established (Kuo et al., 2021; Kontos et al., 2018; Zollman, 2021) that balance is a widely recognized marker of control over the recovery process after blast TBI.

Instead, it has been studied (Murray et al., 2019; Akin et al., 2017; Akin, & Murnane, 2011; Leland et al., 2016) that postural instability is the main indicator of concussion. Recovery from dizziness and imbalance after mTBI is an area of ongoing research (Taylor et al., 2022; Romero et al., 2023; Alkathiry et al., 2019).

It has been argued (King et al., 2014; Leland et al., 2016; Prevention, mitigation, and treatment of blast injuries) that the persistence of imbalance symptoms after blast TBI is associated with the lack of constant control of this process. It has been determined (Joyce et al., 2022; Akin, & Murnane, 2011; Babu, Schutt, & Bojrab, 2019) that the diagnosis of disorders associated with blast TBI should be largely based on the results of objective testing to understand the effectiveness of interventions. On the other hand, it is believed (Fusco et al., 2020; Park, & Lee, 2014) that assessing test authenticity parameters provides an idea of the real effect of rehabilitation interventions.

At the same time, in inclusive physical education in accordance with the modern progress and direction of European educational integration, it seems possible to ensure the effectiveness of control in case of implantation of modern devices, programs and systems in the testing process (Colls, 2023; Blavt et al., 2023; Varga, & Révész, 2023).

The purpose of the study is to determine the degree of reliability and validity of the «Balance Error Scoring System» for students after blast TBI implemented using the developed software and hardware control system.

Materials and Methods

Research Methods

The choice of research methods was made following the principles of systematicity and structuredness at the empirical and theoretical stages, which were performed in the proper sequence The theoretical level of the study involved a practice-oriented approach, subject to the requirements of systematicity and the use of methods of analysis, synthesis, induction and deduction, and interpretation.

The identification, evaluation and generalization of scientific research data were carried out at the empirical level of the study. The experimental data in the study were obtained during testing, which was generalized, described, systematized and classified.

In choosing a test for measuring static balance, we were guided by the criteria that determine the usefulness of a test in certain studies. That is the possibility of its application in the conditions of physical education of students, as well as efficiency in terms of time and costs.

Traditionally, the «Balance Error Scoring System» (BESS) test is used to monitor the recovery process after mild TBI, which is a short, simple static balance test (Joyce et al., 2022). The BESS is a widely used tool for assessing mild TBI (Mathiasen et al., 2018), which is recognized as an effective modern tool (Caccese, & Kaminski, 2016; Napoli et al., 2016).

The test procedure. The balance testing consists of three stances on two different surfaces. The three stances are double leg stance, single leg stance and tandem stance. The two different surfaces include both a firm (ground) and foam surface. (Fig. 1).

The barefoot student should take a certain standing position with hands on hips and eyes closed with a constant foot position depending on the stance. The trial is 20 seconds. Count the number of errors from the proper stance (Balance_Error_Scoring_System).

The BESS is calculated by adding one error point for each error during the 6 20-second tests. The maximum number of errors for one exercise is 10. Errors include moving the hands away from the iliac crests, opening the eyes, stumbling or falling, abducting or flexing the hip more than 30 degrees, lifting the forefoot or heel above the test surface, and staying out of the proper test position for more than 5 seconds.

Fig. 1. Scheme of the BESS test

Study Participants

The 28 first-year students in remission after blast TBI took part in the experiment, from Lviv Polytechnic National University, Kamianets-Podilskyi National Ivan Ohiienko University and Kremenets Regional Humanitarian Pedagogical Institute named after Taras Shevchenko.

All students involved in the experiment had no complications. The limitations of this study were taken into account due to the small sample size and the age of the participants (from 19 to 23 years). The study sample included students exclusively after mild blast TBI with no post-concussion syndrome and musculoskeletal disorders that would affect balance indicators. The latter is justified by the need to interpret the effectiveness of BESS always in the context of all clinical information.

The students included in the study sample provided written consent to participate anonymously in the experiment, underwent a medical examination, and received the consent of a medical professional to participate in the experiment.

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 applied research was implemented as part of a university course on inclusive physical education. The comprehensive strategy for the implementation of the study included two stages. In the first stage, a software and hardware intelligent control system was created to implement BESS. In the second stage, the data on the test results were collected in two ways, processed and systematized.

To ensure that the BESS results were not misinterpreted, the testing was conducted anonymously by independent experts in the first case and with the use of a software and hardware control system in the second. In this way, in the second case, they tried to eliminate registration errors and, therefore, subjective interpretation of the collected data.

The essence of the empirical stage is to collect reliable information on the BESS results and ensure their availability.

Statistical Analysis

Statistical methods were applied given the need for the study that the selected outcome measure should be shown to verify a specific aspect of the quality under test (validity). At the same time, the repeatability of a certain set of research results (reliability) reflects the degree to which they can be reproduced in an identical study (AQR).

Validity, which characterizes the quality of validity, impartiality and correctness (Vocabulary). In the context of our study, it is important that a test has construct validity if it can discriminate between individuals known to have a particular condition (Portney, & Watkins, 2009).

Test-retest reliability and validity were determined by correlation analysis. The level of correlation was used as a measure for interpreting the research materials.

The organization and processing of empirical data was realized using special mathematical software SPSS Version 22.0 (IBM Corporation).

Results

It has been determined (Ponsford et al., 2024; Mucha, Fedor, & DeMarco, 2018) that TBI usually leads to short-term, spontaneously resolving neurological impairment that largely reflects functional rather than structural brain damage. Accordingly, balance, which is controlled by the combined input of the visual, vestibular, and somatosensory systems, is a fairly common consequence of TBI (Mullally, 2017). Deviations in Static balance, which is an indicator of the synthesized activity of the somatosensory, visual, and vestibular systems to achieve steadiness (Bell et al., 2011), may be symptoms of certain diseases (Marcus et al., 2019). Balance is assessed within the concept of coordination and is defined as the ability to keep the center of gravity of the body on a supporting surface (Ross et al., 2023).

Therefore, to implement BESS, we have developed a software and hardware control system. The system is based on the integration of hardware and data processing algorithms. Thus, we made it possible to accurately analyze the control data and eliminate the subjective influence of the human factor.

The basis of the software and hardware control system for the implementation of BESS is the Force Sensitive Resistor piezoelectric pressure sensors, which are placed in the soft mat used to perform BESS. The Force Sensitive Resistor continuously monitors the weight distribution, recording any deviations, such as the movement of the center of gravity or a minimal loss of balance (Politanskyi et al., 2024). The sensors used in the development are easy to use, characterized by low power and the ability to operate on batteries (which is extremely important in a situation of limited energy resources). Since the Force Sensitive Resistor operates on 5 volts, it can be connected directly to an Arduino, which is what we did.

Another key component of the software and hardware control system for implementing BESS is the MPU-9250 motion sensor module, which is placed on the student's body. The MPU-9250 is a System in Package consisting of a gyroscope, accelerometer, and integrated Digital Motion Processor. The module, which is attached to the student's belt or shoes, tracks body tilts and angular displacements in the front/back and left/right planes that occur during the test.

In our development, we used an improved version of the MPU-9250 with an activity detection and 9-axis calibration system – MotionFusion. MotionFusion algorithms process information from all sensors, forming a complete set of data on any displacements of the student's body that occur during the test. Analyzing this data allows us to detect minimal balance disorders. To integrate multiple sensors into one system, we used the Arduino Mega (the latest version of the top-of-the-line Arduino microcontroller board), which has a sufficient number of input ports to read signals from all connected sensors (Mykytyuk et al., 2024).

The signals received by the Force Sensitive Resistor and Digital Motion Processor when the student performs the BESS are sent to the Arduino Mega hardware computing platform, which acts as a hub for data collection. The Arduino

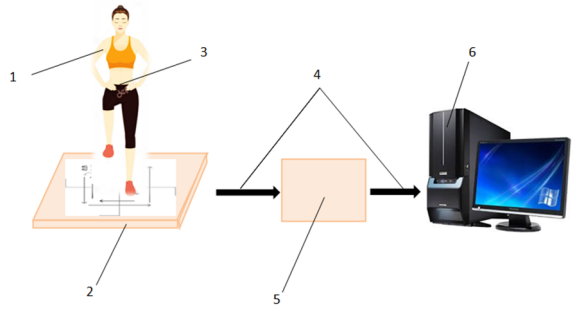

Fig. 2. Scheme of BESS implementation using a software and hardware control system: 1 – student, 2 – Force Sensitive Resistor, 3 – MPU-9250 motion sensor module, 4 – infrared communication lines, 5 – Arduino Mega hardware computing platform, 6 – PC

Mega board includes a microcontroller with I/O elements and a Processing/Wiring development environment that performs the primary processing of the Force Sensitive Resistor and System in Package signals and identifies changes in the weight load.

To transmit data in real-time, we used wireless modules such as HC-05 (Bluetooth) or ESP32 (Wi-Fi), which realize the presentation of results on a PC and smartphone screen.

The developed software and hardware control system for the implementation of BESS provides for the collection and processing of test data in real-time. Application software was developed to implement the tasks of BESS data processing, and neural network technology was used to process the BESS results data.

In the second stage of the study, when the BESS data were collected in two ways, they were processed and systematized. The results of statistical processing of BESS data are presented in Tables 1 and 2.

Thus, according to the results of the statistical processing of the BESS results, the following was found: the level of reliability and validity, when the results were noted by the expert, corresponded to the level of «low» and «medium». However, when the results were recorded by the software and hardware control system, the level of reliability and validity of the studied BESS parameters reached the «high» level.

Table 1. Reliability and validity of the BESS for students after blast TBI in the firm surface (n = 28)

Statistical parameters	BESS tasks and measurement results in the firm surface (к-сть помилок)					
	Double Leg Stance		Single Leg Stance		Tandem Stance	
	E	ПТІС	E	ПТІС	E	ПТІС
Mean	3.67	3.21	4.1	3.3	2.95	1.93
± SD	3.01	2.01	2.88	1.93	2.15	1.82
Median	3.01	2.93	3.88	3.01	2.31	1.55
V (%)	31.24	20.51	30.9	23.14	35.94	22.81
			rtt			
reliability	0.401	0.899	0.376	0.917	0.482	0.904
validity	0.216	0.583	0.212	0.611	0.233	0.678

*Note: E – experts, CS – software and hardware control system

Table 2. Reliability and validity of the BESS for students after blast TBI in the foam surface (n - 28)

Statistical parameters	BESS tasks and measurement results in the foam surface (к-сть помилок)					
	Double Leg Stance		Single Leg Stance		Tandem Stance	
	E	ПТІС	E	ПТІС	E	ПТІС
Mean	5.12	4.17	5.32	3.45	4.18	5.33
± SD	2.21	1.18	2.34	2.21	2.09	2.13
Median	3.88	3.02	3.56	2.14	3.02	4.55
V (%)	34.11	25.51	31.43	20.85	31.21	19.28
rtt						
reliability	0.488	0.919	0.418	0.955	0.433	0.917
validity	0.189	0.612	0.201	0.688	0.223	0.654

*Note: E – experts, CS – software and hardware control system

Dicussion

Our scientific research is justified by the fact that testing in physical education is an effective tool for assessing various aspects of students' physical and personal development (Colls, 2023). We support the thesis that motor skills assessment is positioned as a tool to promote inclusive education by recognizing the unique abilities and challenges of each student (Barber, & Walters, 2024; Blavt, & Gurtova, 2024).

Our study expands on the importance of balance as a component in concussion assessment (Murray et al., 2019; Matuszak et al., 2016), which can serve as a guide for rehabilitation in individuals after TBI (Taylor et al., 2022). We support the need for a comprehensive assessment of vestibular function and balance in individuals following blast-related injury (Akin et al., 2022; Wood et al., 2022).

Determining validity and reliability are considered (Ng, & Samsudin, 2024; Barlow et al., 2011) to be necessary steps in evaluating an instrument. This is in line with the findings that manually obtained balance scores cannot be accurate and do not detect changes that cannot be recognized by the naked eye (Rochefort et al., 2017; Prangley, Aggerholm, & Cinelli, 2017; Ross et al., 2023).

The study is in line with the current state of the art in the field: it is consistent with the data (Blavt et al., 2024; Fusco et al., 2020; Mykytyuk et al., 2022) that the use of computerized programmable devices in testing is an effective means of achieving objectivity in the testing process. Our research is motivated by the need to develop an inexpensive and widely available balance test instrument (Park, & Lee, 2014; Alberts et al., 2015), given that the balance test provides important information such as a standard for assessing functional recovery (Park, & Lee, 2014; Bell et al., 2011).

Our study is in line with the results of scientific research (Fusco et al., 2020; Park, & Lee, 2014; Ross et al., 2023) that computerized instrumented devices have the potential to become the mainstream devices for balance assessment (Caccese, & Kaminski, 2016).

It has been reported that the use of technical means (Goldie, Bach, & Evans, 1989), in particular, portable sensors (King, et al., 2014; Napoli, et al., 2016) in balance control, including after TBI, ensures the objectivity of measurements.

Our study confirms the results (Bell et al., 2011; Ross, Hoch, Malvasi, Cameron, & Roach, 2023; Caccese, & Kaminski, 2016) that the reliability of the overall BESS assessment ranges from poor to medium when performed by a specialist.

The reliability of the BESS has been studied for specific populations, in particular, in Military Cadets (Bell, 2011; Ross et al., 2023); middle school and high school population (Barlow et al., 2011); undergraduate students (Planchet et al., 2023); among NCAA Division-I Football Athletes (Mathiasen et al, 2018); in healthy young athletes (Valovich McLeod et al., 2004); in concussed athletes on the sidelines (Caccese, & Kaminski, 2016); a healthy population (Tao et al., 2020); with moderate-to-severe TBI (Joyce et al., 2022); in US military personnel (Kontos et al., 2021).

We first investigated the use of BESS to assess the state of balance for students after blast TBI and experimentally established the level of reliability and validity of BESS, which was implemented using a software and hardware control system for the implementation of BESS.

Conclusions

Most of the changes in national educational policy were aimed at adapting higher education to the new military realities. Important developments in this area are aimed at rethinking the educational process of vulnerable categories of students, in particular those who received TBI blasts as a result of russia's full-scale invasion of Ukraine.

A software and hardware control system was developed to implement BESS for students after blast TBI based on the integration of modern hardware and data processing algorithms. Application software has been developed to implement the tasks of BESS data processing, and neural network technology has been used to process the BESS results data.

The presented software and hardware control system for the implementation of BESS provides for the collection and processing of test control data in real-time, which is a factor in their relevance and will be especially noticeable in short-term studies. Its use ensures the objectivity, accuracy and reliability of the control process.

Establishing a measure of reliability and validity of the BESS for students after blast TBI proves the advantage of automated controls in ensuring the impartiality and reliability of the testing process. According to the empirical data obtained from the experiment, the level of the studied BESS indicators measured using the software and hardware intelligent control system for students after blast TBI reached the "high" mark.

The use of advanced technologies and reliable automated control systems in the practice of inclusive physical education for the collection, thorough study and analysis of test data provides the generation of high-quality reliable data, which is the basis for the creation of effective scientifically based programs for the restoration of damaged functions after blast TBI.

Conflicts of Interest

No conflicts of interest exist.

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Програмно-технічна система контролю для реалізації системи підрахунку помилок балансу

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Реферат. Стаття: 9 с., 2 табл., 2 рис., 69 джерел.

Мета дослідження у визначені ступеню надійності та валідності «Системи підрахунку помилок балансу» для студентів після вибухової черепно-мозкової травми реалізованого розробленою програмно-технічною системою контролю.

Матеріал та методи. У експерименті прийняли участь студенти І-го курсу навчання після вибухової черепно-мозкової травми у стані ремісії, за умови відсутності ускладнень та постконтузійного синдрому. Теоретичний рівень наукового пошуку передбачав застосування методів аналізу, синтезу, індукції та дедукції, інтерпретації. У створені програмно-технічного засобу застосовано метод технічного моделювання. Експериментальні дані у досліджені отримані шляхом використання «Системи підрахунку помилок балансу» у процесі педагогічного тестування, які оброблено методами математичної статистики.

Результати. Підсумком нашого наукового пошуку є розроблення програмно-технічної системи контролю реалізації BESS на основі інтеграції апаратного забезпечення та алгоритмів обробки даних. У побудові програмно-технічної системи контролю для реалізації BESS використано елементи останнього покоління електронної техніки, а саме: п'єзоелектричні сенсори тиску Force Sensitive Resistor, сенсорний модуль MPU-9250 – System in Package (SiP), який складається з гіроскопа, акселерометра й інтегрованого Digital Motion Processor (DMP), плату Arduino Mega. Для передачі даних у реальному часі на екран ПК та смартфону нами використано бездротові модулі HC-05 (Bluetooth) або ESP32 (Wi-Fi). Для реалізації завдань опрацювання даних BESS розроблено прикладне програмне забезпечення, а для обробки даних результатів BESS використано технологію нейромережі. Статистичним опрацюванням результатів BESS, які отримано двома способами реєстрації результатів з›ясовано, що рівень надійності та валідності коли результати відмічались експертом відповідні рівню «низький» та «середній». У разі запису результатів BESS програмно-технічною системою контролю рівень досліджуваних параметрів надійності та валідності досягав межі «високий».

Висновки. Використання у практиці у інклюзивному фізичному вихованні передових технологій та надійних автоматизованих систем керування для збору, ретельного вивчення та аналізу даних тестових випробувань забезпечують генерування високоякісних достеменних даних, що є основою у створенні надійних та науково обґрунтованих програм відновлення ушкоджених функцій після вибухової черепно-мозкової травми.

Ключові слова: студенти, вибухова черепно-мозкова травма, фізичне виховання, тестування, інклюзія, контроль, баланс, надійність, валідність.

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