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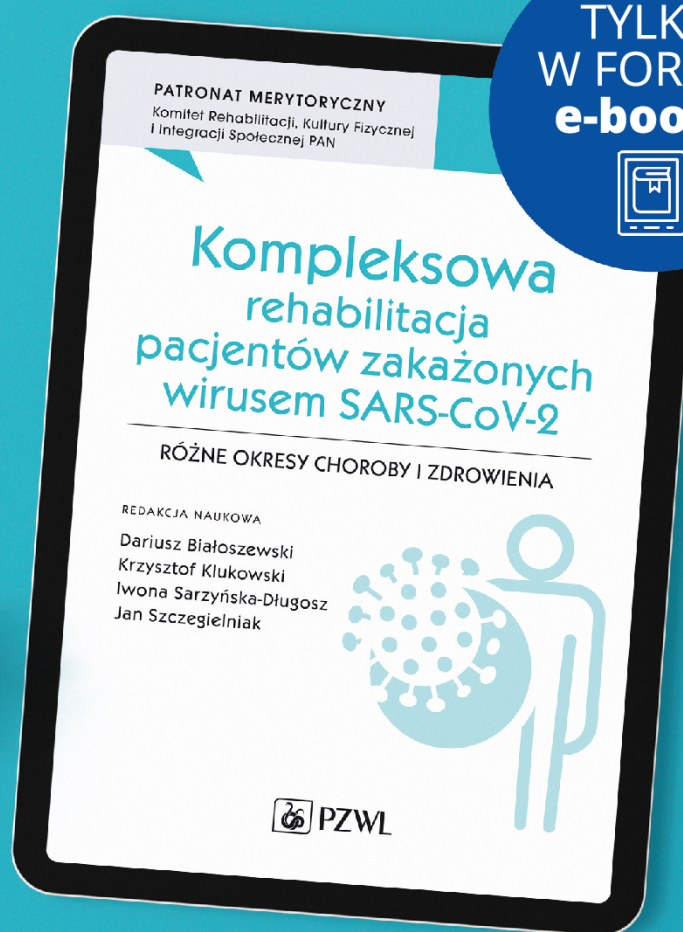
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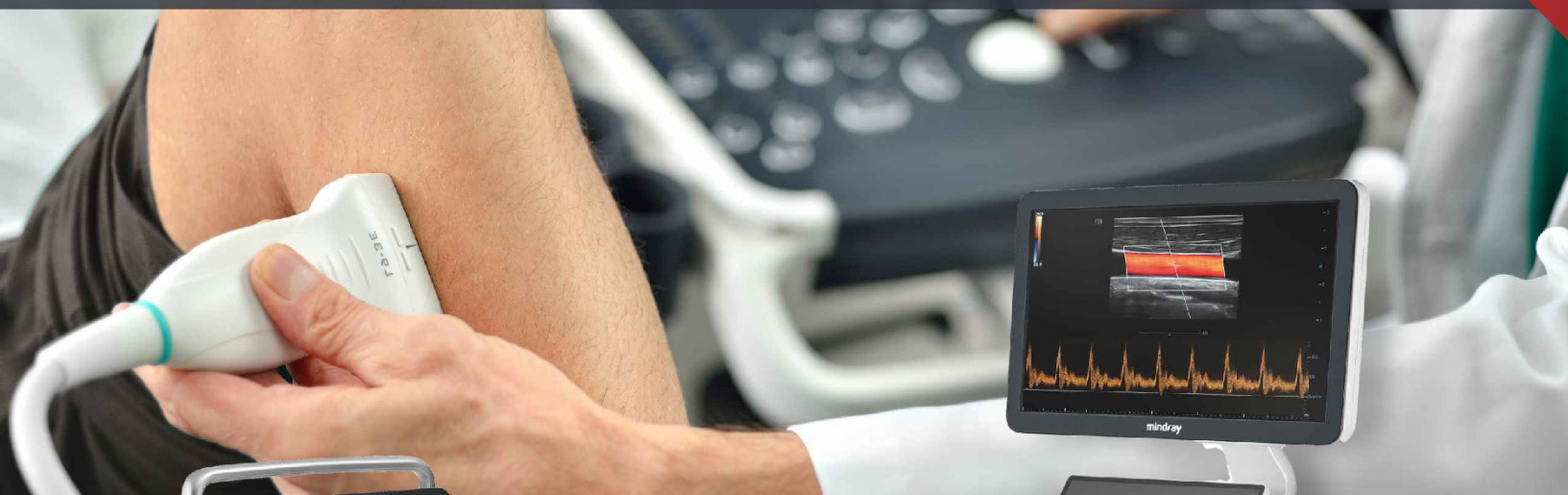
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26. Sympozjum Sekcji Rehabilitacji Kardiologicznej i Fizjologii Wysiłku Polskiego Towarzystwa Kardiologicznego

11-13 maja 2023, Wisła, Hotel STOK

www.rehabilitacja2023ptk.pl

Rehabilitacja kardiologiczna i fizjologia wysiłku – zapraszamy do rejestracji na wyjątkową konferencję w Wiśle

W dniach 11–13 maja w Hotelu Stok Wiśle odbędzie się wyjątkowe i interdyscyplinarne spotkanie specjalistów z całej Polski – 26. Sympozjum Sekcji Rehabilitacji Kardiologicznej i Fizjologii Wysiłku Polskiego Towarzystwa Kardiologicznego. Serdecznie zapraszamy do rejestracji.

26. Sympozjum Sekcji Rehabilitacji Kardiologicznej i Fizjologii Wysiłku Polskiego Towarzystwa Kardiologicznego to coroczne spotkanie specjalistów, zajmujących się rehabilitacją kardiologiczną, prewencją chorób układu krążenia i innymi formami aktywności fizycznej, która ma prowadzić do poprawy stanu naszego zdrowia.

Ta trzydniowa konferencja przeznaczona jest dla lekarzy kardiologów, specjalistów rehabilitacji medycznej oraz innych specjalności, którzy w swojej codziennej praktyce zajmują się rehabilitacją i fizjologią wysiłku, ale także dla fizjoterapeutów, pielęgniarek, techników i przedstawicieli innych zawodów medycznych, zainteresowanych tematyką spotkania, oraz studentów.

Jakie tematy zostaną poruszone podczas konferencji?

26. Sympozjum Sekcji Rehabilitacji Kardiologicznej i Fizjologii Wysiłku to konferencja, na którą zaproszeni zostali wybitni specjaliści z dziedziny kardiologii i nie tylko. Podczas wydarzenia wygłoszonych zostanie prawie 100 wykładów merytorycznych w ciągu aż 20 sesji. Uczestnicy będą mieli również szansę na udział w sesjach przypadków klinicznych, intensywnych warsztatach, a także panelach dyskusyjnych. To wydarzenie cechujące się dużą interdyscyplinarnością, dlatego z pewnością każdy znajdzie coś dla siebie.

Podczas wydarzenia kompleksowo pochylimy się nad dziedziną rehabilitacji kardiologicznej i fizjologii wysiłku. Wśród tematów wiodących znajdują się:

- rehabilitacja w dobie pandemii i po pandemii COVID-19;
- telerehebilitacja i rehabilitacja hybrydowa;
- rehabilitacja kardiologiczna w specyficznych grupach pacjentów;
- programy KOS-zawał i KONS;
- nowe standardy ESC, PTK i SRKiFW;
- Testy wysiłkowe i testy spiroergometryczne
- monitorowanie wysiłku fizycznego;
- prewencja pierwotna i wtórna chorób sercowo-naczyniowych;
- farmakoterapia pacjentów rehabilitowanych kardiologicznie i nie tylko;
- sport i aktywność sportowa w kardiologii;
- czynniki ryzyka chorób układu krążenia.

Program merytoryczny wydarzenia jest niezwykle bogaty i angażujący. Warto podkreślić także, iż na konferencji pojawią się specjalne sesje wykładów prowadzone przez zaproszone sekcje i asocjacje Polskiego Towarzystwa Kardiologicznego, m.in. Sekcję Kardiologii Sportowej, Asocjację Niewydolności Serca, Asocjację Elektrokardiologii Nieinwazyjnej i Telemedycyny, Sekcję Pielęgniarstwa Kardiologicznego i Pokrewnych Zawodów Medycznych, „Klub 30", Sekcję Farmakoterapii Sercowo-Naczyniowej, Sekcję Prewencji i Epidemiologii, a także Polskie Towarzystwo Medycyny Sportowej.

„Pandemia wymusiła na nas zmianę paradygmatu rehabilitacji kardiologicznej"

Organizatorami wydarzenia są wydawnictwo naukowe Evereth Publishing oraz Sekcja Rehabilitacji Kardiologicznej i Fizjologii Wysiłku Polskiego Towarzystwa Kardiologicznego (SRKiFW). Przewodniczącą Komitetu Naukowego jest prof. dr hab. n. med. Małgorzata Kurpesa, Wiceprzewodniczącymi – prof. dr hab. n. med. Anna Jagier, dr hab. n. med. Dominika Szalewska, a Komitetu Organizacyjnego – dr n. med. Bartosz Szafran.

Dr n. med. Agnieszka Mawlichanów, Przewodnicząca SRKiFW, podkreśla, iż ostatnie Sympozjum miało miejsce w 2019 r. w Wiśle. W tym czasie udało się zorganizować wydarzenie w formule online, jednak zdaniem Przewodniczącej obecnie „wszyscy spragnieni jesteśmy spotkania osobistego, wymiany doświadczeń i bezpośrednich rozmów, nie tylko na sali wykładowej, ale i w kuluarach".

– *Cztery lata w sporcie to pełna olimpiada, a w naszej dziedzinie kardiologii można powiedzieć – cała wieczność. Pandemia wymusiła na nas zmianę paradygmatu rehabilitacji kardiologicznej, między innymi stworzyła pole dla rozwoju modelu hybrydowego i monitorowanego telemedycznie. W tym czasie ukazało się wiele ważnych dokumentów, stworzonych przez polskie i europejskie towarzystwa kardiologiczne, dotyczące rehabilitacji, prewencji i aktywności fizycznej. Dynamicznie w naszym kraju rozwija się też program KOS-zawał, przynoszący liczne korzyści, ale też budzący kontrowersje. O tym wszystkim i jeszcze wielu innych sprawach pragniemy podyskutować w czasie naszego majowego spotkania* – zapowiedziała dr Mawlichanów.

Rejestracja na 26. Sympozjum Sekcji Rehabilitacji Kardiologicznej i Fizjologii Wysiłku możliwa jest na stronie internetowej konferencji rehabilitacja-2023ptk.pl/rejestracja/. Informacje na temat opłaty zjazdowej i wydarzeń towarzyszących znajdują się tutaj: rehabilitacja2023ptk.pl/oplata-konferencyjna/.

Informujemy jednocześnie, iż liczba miejsc na konferencji jest ograniczona, dlatego warto zarejestrować się już dzisiaj.
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Use of the posturography platform as a tool for quantitative assessment of imbalance and postural control in post-stroke patients in chronic phase

Wykorzystanie platformy posturograficznej jako narzędzia do ilościowej oceny zaburzeń równowagi oraz kontroli posturalnej u osób po udarze niedokrwiennym mózgu w fazie przewlekłej

Paulina Magdalena Ostrowska[(A,B,C,D,E,F)], **Rita Hansdorfer-Korzon**[(A,D,E,G)], **Rafał Studnicki**[(B,D)], **Dawid Spychała**[(F,G)]

Zakład Fizjoterapii, Gdański Uniwersytet Medyczny, Gdańsk / Department of Physiotherapy, Gdańsk Medical University, Gdańsk, Poland

Abstract

Background. Imbalance during standing, which is usually observed as an asymmetry in the weight shifting toward to the unaffected side of the body, is one of the most common factors affecting the independence and quality of life of post-stroke patients. Clinical assessment of imbalance in post-stroke patients is often conducted by visual observation using standardised tools (balance tests). However, quantitative analysis, using a posturographic platform, is more accurate and provides more information about the patient's functional status. The TYMO® device, used in this study, is a portable posturography platform that measures tilts of the body's center of mass and reports the results of the rehabilitation process. It enables an objective, direct and quantitative assessment of the patient's functional status. Such an assessment can contribute to significant effectiveness of physiotherapy and consequently improve the patient's quality of life and shorten the period of abstinence from work. Objective. Quantitative assessment of imbalance and postural control using a posturography platform (TYMO®) in patients after ischaemic stroke, in the chronic phase, as an important component of the functional diagnosis process and rehabilitation programme design. To emphasise the role of the posturography platform (TYMO®) as a tool for measuring static balance - symmetry of body weight distribution, and a tool for monitoring and reporting the results of physiotherapy treatment. Methods. In the current study, before and after two weeks of rehabilitation, quantitative measurements of balance on the TYMO® platform were made in a group of subjects (n = 60: adults, after ischemic stroke – first stroke episode, in chronic phase – up to 5 years after the stroke incident occurred) undergoing therapy using neurophysiological methods (PNF – Proprioceptive Neuromuscular Facilitation and NDT-Bobath – Neurodevelopmental Treatment according to the Bobath concept) and the SPIDER system (Strengthening Program for Intensive Developmental Exercises and activities for Reaching health capability). Measurements included: the distance marked by the patient's center of mass while performing the test, the medial-lateral and anterior-posterior tilts of the subject's body, the area of movement marked by the body's center of mass, the average speed at which the patient performed the movement to maintain the required position, and the distribution of the subject's weight. Based on the posturographic results obtained before therapy, it was possible to design a targeted rehabilitation programme. The magnitude of the difference in measurements before and after rehabilitation made it possible to assess the impact of the therapy on the patient's balance. In addition, it was a specific indicator of the accuracy of the selection of physiotherapeutic treatment (a large difference in the mean results before and after therapy reflected an improvement in the parameters of postural control, hence the effectiveness of the therapy) and determined the direction of the future rehabilitation programme. Results and conclusions. The parameters measured by the TYMO® platform are crucial in assessing the functional status of post-stroke patients, especially with regard to postural control or balance disorders. The results described confirm the validity of using quantitative assessment, using the posturography platform, as an important component of the functional diagnostic process and designing an rehabilitation programme. The TYMO® platform itself is a useful tool for measuring, monitoring and reporting the effects of physiotherapeutic treatment in post-stroke patients.

Key words:
stroke, body weight distribution, balance, quantitative assessment, posturographic platform

Streszczenie

Wstęp. Zaburzenia równowagi podczas stania, które zwykle obserwuje się jako asymetrię w przenoszeniu ciężaru ciała w kierunku strony niedotkniętej udarem, są jednym z najczęstszych czynników wpływających na niezależność i jakość życia osób po udarze mózgu. Kliniczna ocena zaburzeń równowagi u pacjentów poudarowych jest często dokonywana poprzez obserwację wzrokową przy użyciu standaryzowanych narzędzi (testy równowagi). Jednak analiza ilościowa, przy użyciu platformy posturograficznej, jest dokładniejsza i dostarcza więcej informacji na temat stanu funkcjonalnego pacjenta. Wykorzystane w niniejszym badaniu urządzenie TYMO® jest przenośną platformą posturograficzną, wykonującą pomiary wychyleń środka ciężkości ciała oraz raportującą wyniki procesu rehabilitacyjnego. Umożliwia przeprowadzenie obiektywnej, bezpośredniej oraz ilościowej oceny kontroli posturalnej chorego. Taka ocena może przełożyć się na znaczną efektywność fizjoterapii, a w konsekwencji poprawę jakości życia pacjenta oraz skrócenia okresu absencji zawodowej. Cel pracy. Ilościowa ocena zaburzeń równowagi oraz kontroli posturalnej, za pomocą platformy posturograficznej (TYMO®), u pacjentów po udarze niedokrwiennym mózgu, w fazie przewlekłej, jako ważna składowa procesu diagnostyki funkcjonalnej oraz projektowania programu usprawniania. Podkreślenie roli platformy posturograficznej (TYMO®) jako narzędzia do pomiarów równowagi statycznej – symetrii dystrybucji ciężaru ciała oraz narzędzia do monitorowania i raportowania wyników leczenia fizjoterapeutycznego. Metody. W obecnym badaniu, przed i po dwóch tygodniach rehabilitacji, dokonano ilościowych pomiarów równowagi na platformie TYMO® w grupie badanych (n = 60: osoby dorosłe, po udarze niedokrwiennym mózgu – pierwszy epizod udarowy, w fazie przewlekłej – do 5 lat od zaistniałego incydentu udarowego), poddanych terapii z wykorzystaniem metod neurofizjologicznych (PNF – Proprioceptive neuromuscular facilitation i NDT-Bobath – Neurodevelopmental treatment according to the Bobath concept) oraz systemu SPIDER (Strengthening Program for Intensive Developmental Exercises and activities for Reaching health capability). Pomiary dotyczyły: dystansu przebytego przez środek ciężkości ciała pacjenta podczas wykonywania testu, odchyleń przyśrodkowo-bocznych oraz przednio-tylnych ciała badanego, obszaru ruchu zaznaczonego przez środek ciężkości ciała, średniej prędkości, z jaką pacjent wykonywał ruch w celu utrzymania żądanej pozycji oraz rozkładu masy ciała badanego. Na podstawie wyników posturograficznych otrzymanych przed terapią możliwe było zaprojektowanie celowanego programu usprawniania. Wielkość różnicy pomiarów przed i po rehabilitacji umożliwiła ocenę wpływu terapii na równowagę chorego. Ponadto stanowiła swoisty wskaźnik trafności doboru leczenia fizjoterapeutycznego (duża różnica średnich wyników przed-po terapii odzwierciedlała poprawę parametrów kontroli posturalnej, czyli efektywność terapii) oraz wyznaczała kierunek przyszłego programu usprawniania. Wyniki i wnioski. Rejestrowane przez platformę TYMO® parametry są kluczowe w ocenie stanu funkcjonalnego pacjentów poudarowych, zwłaszcza w odniesieniu do kontroli posturalnej czy zaburzeń równowagi. Opisane wyniki potwierdzają zasadność stosowania oceny ilościowej przy użyciu platformy posturograficznej jako ważnej składowej procesu diagnostyki funkcjonalnej oraz projektowania programu usprawniania. Sama platforma TYMO® jest przydatnym narzędziem do pomiarów, monitorowania oraz raportowania efektów leczenia fizjoterapeutycznego u osób po udarze mózgu.

Słowa kluczowe:
udar mózgu, dystrybucja ciężaru ciała, równowaga, ocena ilościowa, platforma posturograficzna

Introduction

According to the World Health Organization (WHO), 15 million people are diagnosed with stroke each year, of whom about 6 million patients die, while about 5 million remain permanently disabled [1]. It is the leading cause of disability in Europe and the United States of America [2]. The best-documented motor deficit after stroke is a reduction in maximal muscle strength, especially on the side contralateral to the brain injury [3]. Studies by Horstman et al. have shown abnormal neuromuscular activation in post-stroke patients, which impairs their ability to stimulate appropriate muscles in both the limbs of the affected and unaffected sides, although the impairment tends to be greater in the affected limbs [4]. The above phenomenon is reflected in limitations of high functional ability (e.g., postural balance, walking or avoiding falls) [5].

Postural balance is defined as the ability to control the body's center of mass in relation to the base of support [6]. Imbalance while standing is one of the most common factors affecting the independence and quality of life of post-stroke patients [7]. Tyson et al. found that 83% of patients report balance problems, which are usually observed as asymmetry in weight shifting toward the unaffected side of the body [8]. Imbalance and reduced ability to shift weight symmetrically are also assumed to be factors contributing to falls in post-stroke patients [9]. A study by Patterson et al. found that 55.5% of post-stroke patients in the chronic phase demonstrate gait asymmetry [10]. In addition, the weakness of the plantar flexors in the group of patients described by the researchers is regarded as a limiting factor in gait speed. These muscles are important for various functional tasks, such as postural balance and locomotion, as they provide most of the force for gait progression [5,11]. In turn, gait speed is considered a predictor of disability severity [12]. Hence, regaining locomotor ability is the main goal of physiotherapeutic treatment after stroke, while the ability to shift body weight to the affected side is an indispensable element for the success of therapy [13]. In fact, it improves balance and maintains gait ergonomic and economy [14, 15].

Clinicians most often use qualitative analysis and observation-based balance scales (e.g., Berg Balance Scale, Trunk Control test, TUG test), as these tests do not require equipment expenditure and are easy to perform. Although non-instrumented tests can be useful in diagnosing postural disorders, they only provide a general picture of the level of postural control performance. A detailed analysis of the effectiveness of this control, and associated strategies, requires the use of instrumented tests.[16] However, quantitative analysis using spatiotemporal variables (e.g., speed, center of pressure [COP], displacement) is more accurate and provides more information about the patient's functional status. Correlations between balance scales based on observation and quantitative analysis, during standing balance, are low to moderate, suggesting that these two types of tests do not assess the same abilities of the subject [17]. Observation-based balance scales most often assess ability to perform a task, while quantitative tools assess physiological control through predictive, proactive or reactive mechanisms.

In addition, quantitative tools have the advantage of being based on continuous variables that cover a wider range of motor levels and have fewer ceiling and floor effects than observation-based balance scales (e.g., a patient who is unable to remain seated without assistance will not be able to perform a forward reaching test in that position – showing a floor effect, but the test will also show a ceiling effect for a patient whose dynamic balance in the seated position is within normal limits) [17, 18]. Platforms used to quantitatively measure tilts of the body's center of mass while standing interpret standing stability and postural control strategies [19]. Some of them (such as the TYMO® platform used in the study), also allow balance to be assessed under unstable ground conditions. The TYMO® device is equipped with a soft pad that increases the patient's sway during the test, which challenges the postural control system in relation to stable ground conditions [16].

The use of posturography platforms in clinical practice depends on the patient's ability to perform the task (subject must maintain the required standing position throughout the test on the measuring device) and on the ability of the tests to assess imbalances (a test that is too easy will not detect the patient's motor impairment, a test that is too difficult will not be able to be performed by the patient). Tests that are easiest to perform (such as on the TYMO® platform) have the disadvantage of covering a low range of motor levels, but in the case of post-stroke patients, maintaining standing position for a certain period of time can be challenging. Bruyneel et al. in their study conclude that quantitative assessment based on balance tests on posturographic platforms, allows a full psychometric analysis, which includes both reliability and validity of the results, in relation to observation-based balance scales - the minimum detectable change in value (MDC) for quantitative tools is higher than for observation-based balance scales such as the BBS or Brunel Balance Assessment [16].

In one of their studies, Ostrowska et al. evaluated the effect of therapy, using the SPIDER system, on weight-shifting symmetry, in chronic stroke patients. The results of the statistical analysis demonstrated a greater reduction in the tilt of the body's center of mass in therapy using the SPIDER system, compared to therapy in which the system was not used. In the above study, the TYMO® measurement platform was used to quantify the impact of therapy [20]. This study, in turn, presents a quantitative assessment of imbalance and postural control, using a posturographic platform (TYMO®), in patients after ischaemic stroke, in the chronic phase, as an important component of the functional diagnosis process and the planning and design of an rehabilitation programme. In study, using this platform, we quantified changes regarding postural control in patients before and after two weeks of rehabilitation using neurophysiological methods (PNF and NDT-Bobath) and the SPIDER system.

Materials and Methods
Subject of the study
The study was approved by the Independent Bioethics Committee for Scientific Research at the Medical University

of Gdansk (consent of 7 July 2021, Resolution No. NKBBN/507/2021), in cooperation with the NORMAN Neurological Rehabilitation Center in Koszalin. The study was conducted from August 2021 to August 2022. From a group of all post-stroke patients (n = 300) residing at the center at that time, patients meeting the inclusion criteria were selected. The size of the study group (SG): n = 60 adults after stroke in the chronic phase, meeting the inclusion criteria, undergoing therapy using neurophysiological methods and the SPIDER system. All patients participating in the study were informed in detail about the nature and procedure of the study and gave written voluntary consent to participate. Quantitative changes relating to patients' postural control before and after two weeks of rehabilitation were measured using the TYMO® posturography platform.

Evaluation protocol

Inclusion and exclusion criteria (Table 1.) were determined on the basis of a form using the following scales and tests: a questionnaire with functional tests based on the ICF, Barthel Scale, Rankin Scale, NIHSS Scale, Modified Ashworth Scale, FMA-LE test, mirror test, Berg Balance Test (BBS), to ensure the greatest homogeneity of the group. The patient's diagnosis was completed by a doctor, tests evaluating the patient's functional status were assessed by a physiotherapist.

Tab. 2. Intersex comparision of variables obtained on the basis of NRS, ODI and WHOQOL-BREF

Kryteria włączenia / Inclusion Criteria	Kryteria wyłączenia / Exclusion Criteria
1. Age 18+	1. Age below 18 years
2. Past ischemic stroke (first episode) as diagnosed by a doctor	2. Cerebral hemorrhagic stroke
3. First 5 years after stroke (chronic phase)	3. Confirmed second or subsequent stroke
4. Hemiparesis	4. Acute phase post-stroke or time since stroke greater than 5 years
5. Ability to move from sitting to standing (assessed by functional test)	5. Lower limb amputation
6. Ability to maintain standing position for the duration of the examination (assessed by functional test)	6. Comorbidities, diagnosed by a doctor, which may have a direct impact on therapeutic procedures, such as apalous state, cancer
7. FMA-LE score ≥ 16 points	7. Diagnosis of TIA in a patient
8. Lower limb spasticity (rectus femoris muscle, ischiofemoral muscle group, gastrocnemius muscle) ≤ 2 points according to the Modified Ashworth Scale	8. Medical diagnosis assessing the state of depression
	9. Medical diagnosis assessing the state of depression
9. NIHSS score ≤ 15 points	10. Inability to stand
10. MMSE score ≥ 24 points	11. FMA-LE score < 16 points
11. BBS ≥ 21 points	12. Lower limb spasticity (straight thigh muscle, ischiofemoral muscle group, gastrocnemius muscle) > 2 points according to the Modified Ashworth Scale
12. Modified Rankin Scale ≤ 3	
13. Barthel scale ≥ 55	13. NIHSS score > 15 points

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Kryteria włączenia / Inclusion Criteria	Kryteria wyłączenia / Exclusion Criteria
14. Informed agreement of the patient to participate in the trial after reading the study document in detail. In case of a patient with aphasia, consent of family or legal guardian 15. Consent for SPIDER therapy	14. MMSE < 24 pts. 15. BBS < 21 pts. 16. Modified Rankin Scale > 3 17. Barthel Scale < 55 18. Physician-diagnosed global aphasia 19. Use of botulinum toxin within 3 months of the start of the therapeutic program or during the program 20. Taking spasmolytic medication (e.g., Baclofen) during the program 21. Lack of informed consent from the patient for the implementation of therapy procedures 22. No consent to SPIDER therapy

TYMO® platform

TYMO® is a device for analyzing the transfer of the body's center of mass - it compares the symmetry of the active distribution of body weight and quantitatively assesses balance and postural adjustment in the standing position. TYMO® analysis includes information on:
• The length of time (in seconds) that balance can be maintained;
• Center Of Force Track (COFT), which is the total length (expressed in cm) of the Center Of Force Track (COF) during each measurement. Medio-Lateral indicates the total range of lateral sway of the body (right-mid-left), and Anterio-Posterior indicates the total range of forward and backward sway of the body (front-mid-backward);
• COF movement area (the area of the ellipse, expressed in cm^2, which contains 95% of all COF positions);
• The average velocity of the movements (expressed in cm/s) that must be made to maintain balance;
• A posture, viz., the distribution of weight and/or force from front to back and left to right. Depending on the weight shift, the values can be high (the more central, the better);
• Feedback pathways, which means movement control regulated by the visual, vestibular and somatosensory feedback loops. These values are presented in percentages and describe the (im)balance of sensory perceptions (feedback pathways);
• Frequency harmony: RQ is the harmony of the frequency parts of movement regulation and control. Frequency analysis of the body's swaying behavior provides insight into the individual use of postural subsystems. Centrally controlled (low frequency) gives a ratio for low frequencies and assesses the presence of centrally generated movement sequences that are controlled by the brain. Controlled reflex (high frequency) gives a ratio for medium and high frequencies and assesses the presence of movement sequences generated by the reflex [20, 23].

Each patient, before therapy and after two weeks of training, was given the task of maintaining a standing position on the TYMO® platform - standing barefoot, with eyes open. Visual information is an important component of balance, even when standing quietly, as evidenced by the fact that both the amplitude

and variability of body sway increase under closed-eye conditions [24]. Thus the decision to test under active visual control. Before the test, each subject was instructed to distribute his body weight symmetrically on both lower limbs during the test. The test was composed of two parts: in the first, the patient stood directly on the platform (stable ground), while in the second, the patient stood on a soft pad placed on the platform (unstable ground).The two-part nature of the test was aimed at testing patients' postural control strategies under stable and unstable ground conditions. Static standing on an unstable surface modifies biomechanical variables in the foot and in the ankle capsular and ligamentous system, resulting in a change in the distribution of pressure on the foot [16]. The test of maintaining the above-described position, both without the pad (M1) and with the pad (M3), lasted 30 seconds.

The device recorded tilts of the body's center of mass in a specific direction. Measurements included: the distance marked by the patient's center of mass while performing the test , the medial-lateral and anterior-posterior tilts of the subject's body, the area of movement marked by the body's center of mass, the average speed at which the patient performed the movement to maintain the required position, and the distribution of the subject's weight (Figure 1.). Based on the posturographic results obtained before therapy, it was possible to design a targeted rehabilitation programme. The results obtained after therapy made it possible to assess the impact of this therapy on the patient's functional status (balance). In addition, the magnitude of the difference in the results before and after rehabilitation was an indicator of the accuracy of the selection of therapy (a large difference in mean measurements before and after therapy reflected an improvement in postural control parameters – proving the effectiveness of the therapy) and determined the direction of the future rehabilitation programme.
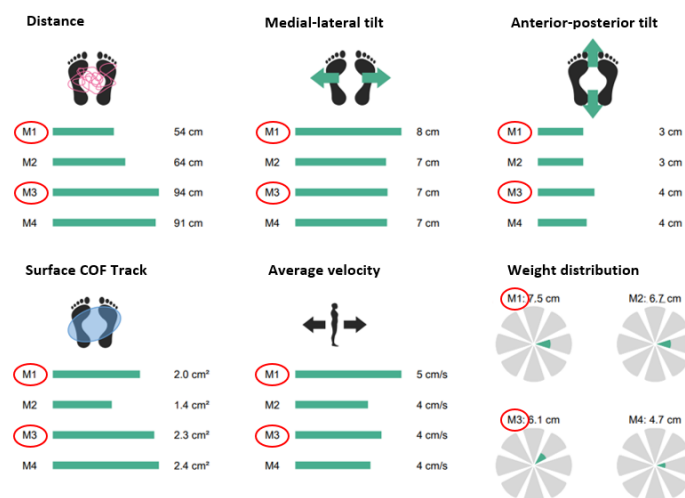
Figure 1. An example of analysis of the center of mass distribution from TYMO® platform (M1 – eyes open + without TYMO® pad, M2 – eyes closed + without TYMO® pad, M3 – eyes open + with TYMO® pad, M4 – eyes closed + with TYMO® pad). The current study analyzed the results of measurements circled in red (M1 and M3). [TYMO® Balance test report from TyroS® software Version 4.1].

Physiotherapy treatment program
Physiotherapeutic treatment of the study group (SG) was based on manual therapy, balance training and postural control, sensory and functional techniques using neurophysiological methods (PNF, NDT-Bobath), exercises on equipment (stationary bicycle, treadmill) and using the SPIDER system. To promote cortical plasticity, patients were taught postural stability (to strengthen existing neuronal pathways, on the one hand, and initiate functional and structural changes, on the other, resulting in the expression of neuroplasticity [21]). The results of Seok Hyun Nam et al. suggest that forced weight shifting to the affected lower limb can be an effective method for improving gait ability in post-stroke patients [22]. Also, Seoung Hoon Park et al. noted that lateral weight shifting to the affected side is a key component in post-stroke physiotherapeutic treatment [3]. Therefore, the main component of the therapy of the present study was to force a shift of body weight to the lower limb of the hemiparesis in order to inhibit the mechanism of learned disuse of this limb (training using the SPIDER system). As a result, there was an activation of the muscles of the loaded lower limb, an increase in the muscle tone of the paresis side, an improvement in sensation (both superficial and deep) of the paresis foot and a lengthening of the support phase of the paresis lower limb, resulting in an improvement in weight transfer symmetry and a reduction in balance disorders [20].

Results
Statistical analysis
Tests of normality were performed using the Shapiro–Wilk Test. These tests did not indicate the normality of the distribution. However, since n > 30, the t-test could be used (robustness of the test for non-compliance with the normality condition). Indeed, the t distribution can be approximated by a normal distribution, because the sample size in this case (n = 60) is large. The effect magnitude of the therapy was determined using d-Cohen. Descriptive statistics were performed using the Student's t-test. Data management and analysis were performed in three programs: Microsoft Excel 2007 (Microsoft: Redmond, WA, USA) + add-ons, StatSoft Statistica V12 Advanced Package (StatSoft: Tulsa, OK, USA) and PQStat 1.8.0.476. The statistical significance level was set at $p < 0.05$ (one-tailed).

Demographic and functional characteristics of patients
The final study sample included 60 participants, of whom 30% were women and 70% were men, ranging in age from 24 to 80, with a mean age of 59 (SD = 14.7) (Table 2.).

Table 2. Demographic and functional characteristics of the study participants

	Average/Value	Standard deviation	Minimum	Maximum
Gender				
F	18 (30%)			
M	42 (70%)			

	Average/Value	Standard deviation	Minimum	Maximum
Age	59	14.7	24	80
Hemiparesis side				
P/R	29 (48%)			
L	31 (52%)			
Modified Ashworth Scale				
2	56			
1+	4			
Barthel Scale	65	6.5	55	85
Superficial sensation				
N	57 (95%)			
P	3 (5%)			
Deep sensitivity				
(+/-)	24 (40%)			
(+)	32 (53%)			
(-)	4 (7%)			
BBS	25	1.9	21	30
NIHSS	7	1.4	4	11
Rankin Scale	3	0	3	3
FMA LE	16	0.9	16	20

Description of results

Table 3. presents a summarisation of the mean results obtained during tests on the TYMO® platform, prior to the application of rehabilitation (under both stable - M1 and unstable - M3 ground conditions). The following values, characterising the postural control of the patients, demonstrate balance problems in this group of subjects: a large distance marked by the patient's centre of mass during the test, indicating the large number of movements the patient had to make to maintain the required position; a large tilt of the body's centre of mass (towards the unaffected side) and an asymmetric distribution of body weight (also towards the unaffected side), indicating an inability or unwillingness to transfer body weight to the unaffected side; a slow motor response, reflected in the low velocity of movement with which the patient tried to stay in the tested position, indicating a slow response of the postural control mechanisms. The results presented were the basis for the design of the physiotherapeutic treatment described in subsection 2.4 of this study (Physiotherapy treatment program).

Table 3. Mean values obtained during testing on the TYMO® platform, before the applied therapy (M1 – without the pad, M3 – with the pad)

	M1	M3
Mean distance before rehabilitation [cm]	54.416667	78.616667
Mean medial-lateral tilt before rehabilitation [cm]	3.916667	4.916667
Mean anterior-posterior tilt before rehabilitation [cm]	3.433333	5.15
Mean surface COF track before rehabilitation [cm²]	0.753333	1.993333
Average velocity before rehabilitation [cm/s]	4.483333	4.366667
Average weight distribution before rehabilitation [cm]	4.29	5.308333

Distance

Measured in centimeters using the TYMO® platform without a pad (M1), the mean distance after rehabilitation (47.6 cm) is significantly smaller than the mean distance before rehabilitation (54.42 cm), measured in the same way (whereas the t-statistic is less than 0 (−2.24462) and the one-sided p-value is 0.014283, which is smaller than the assumed α=0.05). The absolute difference in means before and after rehabilitation is 6.82cm, which means the average distance of M1 after rehabilitation decreased by 12.5%. Also, measured in centimeters using the TYMO® platform with a pad (M3), the mean distance after rehabilitation (56.67cm) is significantly smaller than the mean distance before rehabilitation (78.62cm), measured in the same way (whereas the t-statistic is less than 0 (−4.852264) and the one-sided p-value is 0.000005, which is smaller than the assumed α = 0.05). The absolute difference in the mean before and after rehabilitation is 21.95 cm, which means the average distance of M3 after rehabilitation decreased by 28% (Table 4.). For both M1 and M3, there was a reduction in the mean distance after physiotherapy treatment. This proves that the subjects' postural stability improved, as their body center of mass marked a shorter distance after rehabilitation with regard to the pre-rehabilitation state (during the test, the patients made fewer movements to maintain the required position).

Table 4. The results of the statistical analysis of the average distance before and after rehabilitation (M1 – without TYMO® Pad, M3 – with TYMO® Pad

	M1	M3
Mean distance before rehabilitation [cm]	54.416667	78.616667
Mean distance after rehabilitation [cm]	47.6	56.666667
Absolute difference in averages before and after rehabilitation [cm]	6.816667 (12.5%)	21.95 (28%)
Statistics t	−2.244462	−4.852264
Value p one-sided	0.014283	0.000005

Figure 2. shows a comparison, in the form of a box plot, of the statistical analysis distribution of the average distance (measured in cm) marked by the patients' body center of mass during the test: before therapy without a pad (A), before therapy with a pad (B), after therapy without a pad (C) and after therapy with a pad (D). This graph illustrates the difference in median, minimum and maximum values . The minimum and maximum values for boxes A and C are in similar ranges, but the shift in the median of box C (47.6 cm) relative to the median of box A (54.42 cm) reflects a reduction in the distance of patients' center of mass after therapy (6.82cm). The minimum and maximum values for boxes B and D are also in similar ranges (however, a greater disparity is noticeable with respect to boxes A and C), and in this case, too, the shift of the median of box D (56.67cm) relative to the median of box B (78.62 cm) is evidence of a reduction in the distance of the body's center of mass of patients after therapy (21.95 cm).
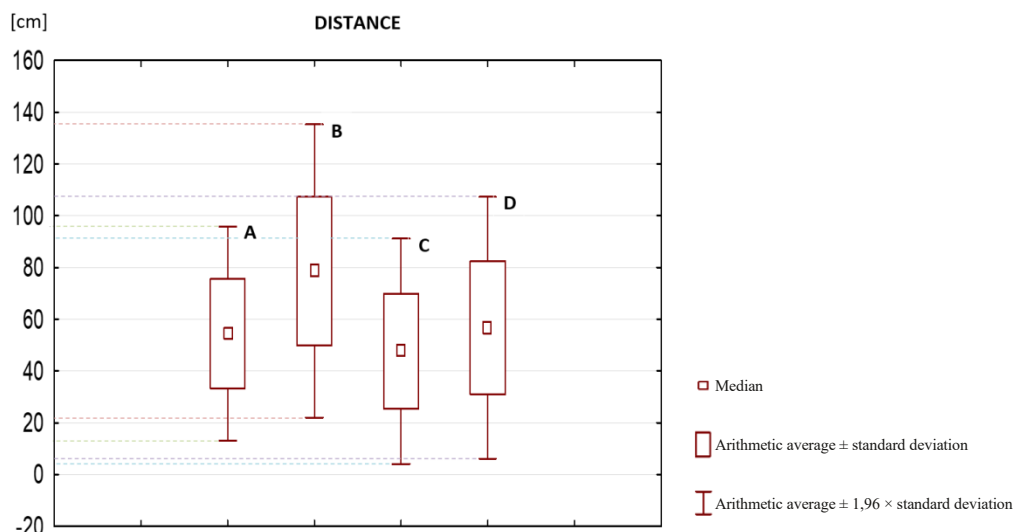
Figure 2. A box plot showing distribution of statistical analysis of average distance: A – before rehabilitation M1, B – before rehabilitation M3, C – after rehabilitation M1, D – after rehabilitation M3.

Medial-lateral tilt

Measured in centimeters using the TYMO® platform without a pad (M1), the mean medial-lateral tilt after rehabilitation (2.32 cm) is significantly smaller than the mean medial-lateral tilt before rehabilitation (3.92 cm), measured in the same way (whereas the t-statistic is less than 0 (-6.412329) and the one-sided p-value is < 0.000001, which is smaller than the assumed $\alpha = 0.05$). The absolute difference in means before and after rehabilitation is 1.6 cm, which means the average medial-lateral tilt of M1 after rehabilitation decreased by 41%. Measured in centimeters using the TYMO® platform with a pad (M3), the mean medial-lateral tilt after rehabilitation (2.93 cm) is also significantly smaller than the mean medial-lateral tilt before rehabilitation (4.92 cm), measured in the same way (whereas the t-statistic is less than 0 (-5.425933) and the one-sided p-value is 0.000001, which is smaller than the assumed $\alpha=0.05$). The absolute difference in the means before and after rehabilitation is 1.98 cm, which means the average medial-lateral tilt of M3 after rehabilitation decreased by as much as 40% (Table 5.). For both M1 and M3, there was a reduction in the mean medial-lateral tilt after physiotherapy treatment. This proves that the balance of the subjects improved (centralization of the body's center of mass).

Table 5. The results of the statistical analysis of the average medial-lateral tilt before and after rehabilitation (M1 – without TYMO® Pad, M3 – with TYMO® Pad)

	M1	M3
Mean medial-lateral tilt before rehabilitation [cm]	3.916667	4.916667
Mean medial-lateral tilt after rehabilitation [cm]	2.316667	2.933333
Absolute difference in averages before and after rehabilitation [cm]	1.6 (41%)	1.983 (40%)
Statistics t	-6.412329	-5.425933
Value p one-sided	< 0.000001	0.000001

Figure 3. shows a comparison, in the form of a box plot, of the statistical analysis distribution of patients' mean medial-lateral body tilt (measured in cm) during the test: before therapy without a pad (A), before therapy with a pad (B), after therapy without a pad (C) and after therapy with a pad (D). The shift in the median of box C (2.32 cm) relative to the median of box A (3.92 cm) reflects a reduction in the mean medial-lateral body tilt after therapy (1.6 cm). The situation is similar for boxes B and D: a shift in the median of box D (2.9 cm) relative to the median of box B (4.92 cm) also reflects a reduction in the mean medial-lateral tilt after therapy (1.98 cm).

Figure 3. A box plot showing distribution of statistical analysis of average medial-lateral tilt: A – before rehabilitation M1, B – before rehabilitation M3, C – after rehabilitation M1, D – after rehabilitation M3

Anterior-posterior tilt

Measured in centimeters using the TYMO® platform without a pad (M1), the mean anterior-posterior tilt after rehabilitation (2.63 cm) is significantly smaller than the mean anterior-posterior tilt before rehabilitation (3.43 cm), measured in the same way (whereas the t-statistic is less than 0 (-4.087538) and the one-sided p-value is 0.000067, which is smaller than the assumed $\alpha = 0.05$). The absolute difference in the means before and after rehabilitation is 0.8 cm, which means the average anterior-posterior tilt of M1 after rehabilitation decreased by 23%. On the other hand, measured in centimeters using the TYMO® platform with a pad (M3), the mean anterior-posterior tilt after rehabilitation (3.98 cm), is also significantly smaller than the mean anterior-posterior tilt before rehabilitation (5.15 cm), measured in the same way (whereas the t-statistic is less than 0 (-4.676364) and the one-sided p-value is 0.000009, which is smaller than the assumed $\alpha = 0.05$). The absolute difference in the means before and after rehabilitation is 1.17 cm, which means the average anterior-posterior tilt of M3 after rehabilitation decreased by 22.5% (Table 6.). For both M1 and M3, there was a reduction in the mean anterior-posterior tilt (centralization of the body's center of mass) after physiotherapy treatment, demonstrating a reduction in the patients' imbalance during the test.

Table 6. The results of the statistical analysis of the average anterior-posterior tilt before and after rehabilitation (M1 – without TYMO® Pad, M3 – with TYMO® Pad).

	M1	M3
Mean anterior-posterior tilt before rehabilitation [cm]	3.433333	5.15
Mean anterior-posterior tilt after rehabilitation [cm]	2.633333	3.983333
Absolute difference in averages before and after rehabilitation [cm]	0,8 (23%)	1.166667 (22,5%)
Statistics t	−4.087538	−4.676364
Value p one-sided	0.000067	0.000009

Figure 4. shows a comparison, in the form of a box plot, of the statistical analysis distribution of the patients' mean anterior-posterior body tilt (measured in cm) during the test: before therapy without a pad (A), before therapy with a pad (B), after therapy without a pad (C) and after therapy with a pad (D). The shift of the median of box C (2.6 cm) relative to the median of box A (3.4 cm), as well as the median of box D (4cm) relative to the median of box B (5.2 cm), reflects a reduction in the mean anterior-posterior body tilt of patients after therapy (M1 – 0.8 cm, M3 – 1.2 cm).
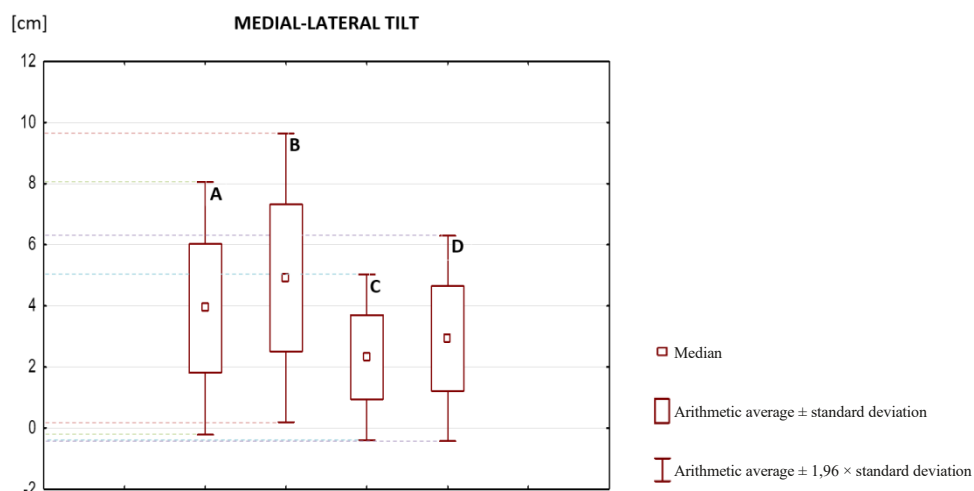

Figure 4. A box plot showing distribution of statistical analysis of average anterior-posterior tilt: A – before rehabilitation M1, B – before rehabilitation M3, C – after rehabilitation M1, D – after rehabilitation M3

Surface COF track
Measured in square centimeters using the TYMO® platform without a pad (M1), the mean surface COF track after rehabilitation (0.47cm^2) is significantly smaller than the mean surface COF track before rehabilitation (0.75 cm^2), measured in the same way (whereas the t-statistic is less than 0 (−2.468395) and the one-sided p-value is

0.008245, which is smaller than the assumed α = 0.05). The absolute difference in means before and after rehabilitation is 0.29 cm^2, which means, the average surface COF track M1 after rehabilitation decreased by 39%. Also, measured in square centimeters using the TYMO® platform with a pad (M3), the mean surface COF track after rehabilitation (0.8 cm^2) is significantly smaller than the mean surface COF track before rehabilitation (1.99 cm^2) measured in the same way (whereas the t-statistic is less than 0 (−4.158085) and the one-sided p-value is 0.000053, which is smaller than the assumed α =0 .05). The absolute difference in the averages before and after rehabilitation is 1.2 cm^2, which means, the average surface COF track M3 after rehabilitation decreased by 60% (Table 7.). In both M1 and M3, there was a reduction in the mean surface COF track after physiotherapy treatment. This confirms the previously discussed measurements, as the reduction in surface COF track is a reflection of the reduction in distance and the tilt of the patients' center of mass during the test. This proves an improvement in the subjects' postural stability, as after rehabilitation their body's center of mass marked a smaller tilt area with respect to the pre-rehabilitation state (during the test the patients made fewer swings to maintain the required position).

Table 7. The results of the statistical analysis of the average surface COF track before and after rehabilitation (M1 – without TYMO® Pad, M3 – with TYMO® Pad).

	M1	M3
Mean surface COF track before rehabilitation [cm^2]	0.753333	1.993333
Mean surface COF track after rehabilitation [cm^2]	0.465	0.796667
Absolute difference in averages before and after rehabilitation [cm^2]	0.288333 (39%)	1.196667 (60%)
Statistics t	−2.468395	−4.158085
Value p one-sided	0.008245	0.000053

Figure 5. shows a comparison, in the form of a box plot, of the statistical analysis distribution of the mean surface of movement (measured in cm2), marked by the subjects' center of mass, when performing the test: before therapy without a pad (A), before therapy with a pad (B), after therapy without a pad (C) and after therapy with a pad (D). The minimum and maximum values for boxes A and C are in similar ranges, but the shift in the median of box C (0.47 cm^2) relative to the median of box A (0.75 cm^2) reflects a reduction in the mean surface COF track after therapy (0.29 cm^2). The range of box D is contained within the range of box B – the ranges overlap, but also here the shift of the median of box D (0.8 cm^2) relative to the median of box B (2 cm^2) reflects a reduction in the mean surface COF track after therapy (1.2 cm^2).

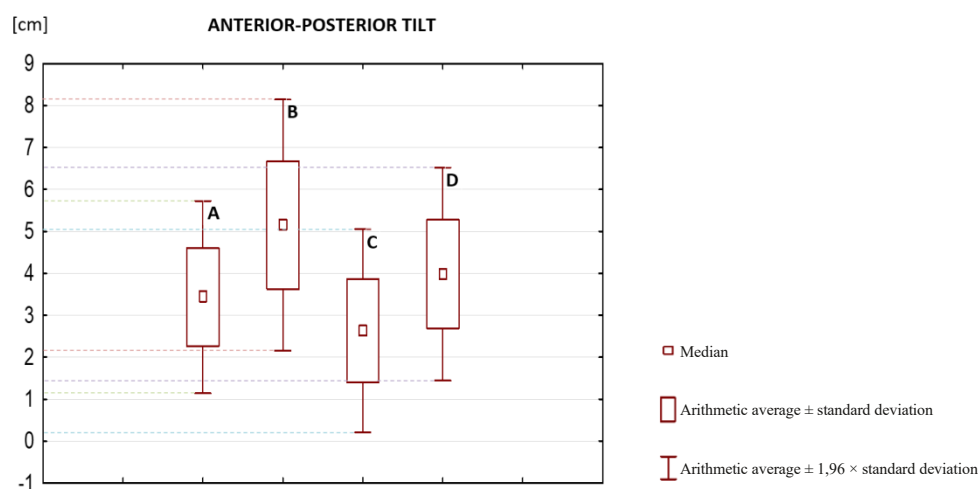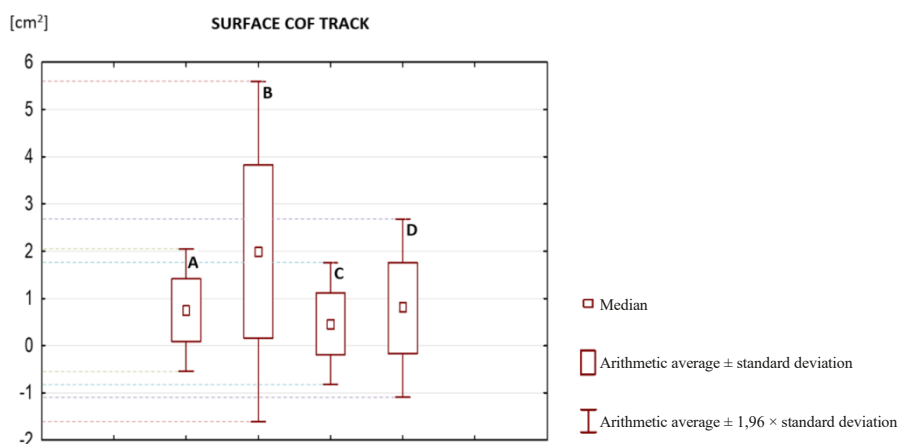**Figure 5. A box plot showing distribution of statistical analysis of average surface COF track: A – before rehabilitation M1, B – before rehabilitation M3, C – after rehabilitation M1, D – after rehabilitation M3**

Average velocity

Measured in centimeters per second using the TYMO® platform without a pad (M1), the mean movement velocity after rehabilitation (5.33 cm/s) is significantly greater than the mean movement velocity before rehabilitation (4.48 cm/s), measured in the same way (whereas the t-statistic is greater than 0 (4.310548) and the one-sided p-value is 0.000031, which is smaller than the assumed $\alpha = 0.05$). The absolute difference in the averages before and after rehabilitation is 0.85 cm/s, which means, the average movement velocity of M1 after rehabilitation increased by 19%. Measured in centimeters per second using a TYMO® platform with a pad (M3), the average movement velocity after rehabilitation (4.77 cm/s) is also significantly higher than the average movement velocity before rehabilitation (4.37 cm/s), measured in the same way (whereas the t-statistic is greater than 0 (1.85614) and the one-sided p-value is 0.034215, which is smaller than the assumed $\alpha = 0.05$). The absolute difference in the averages before and after rehabilitation is 0.4 cm/s, which means, the average movement velocity of M3 after rehabilitation increased by 9% (Table 8.). For both M1 and M3, there was an increase in average movement velocity after physiotherapy treatment (an increase in the velocity of motor responses). This proves an improvement in the patients' balance during the test, reflected in an improvement in the velocity of postural control responses.

Table 8. The results of the statistical analysis of the average velocity before and after rehabilitation (M1 – without TYMO® Pad, M3 – with TYMO® Pad)

	M1	M3
Average movement velocity before rehabilitation [cm/s]	4.483333	4.366667
Average movement velocity after rehabilitation [cm/s]	5.333333	4.766667
Absolute difference in averages before and after rehabilitation [cm/s]	0.85 (19%)	0.4 (9%)
Statistics t	4.310548	1.85614
Value p one-sided	0.000031	0.034215

Figure 6. shows a comparison, in the form of a box plot, of the statistical analysis distribution of the average velocity (measured in cm/s) with which the patient performed the movement to maintain the required position during the test: before therapy without a pad (A), before therapy with a pad (B), after therapy without a pad (C) and after therapy with a pad (D). A shift in the median of box C (5.3 cm/s) relative to the median of box A (4.48 cm/s) reflects an increase in the average velocity of movement after therapy (0.85cm/s). The situation is similar for boxes B and D: a shift of the median of box D (4.77 cm/s) relative to the median of box B (4.37 cm/s) also reflects an increase in the average velocity of movement after therapy (0.4 cm/s).
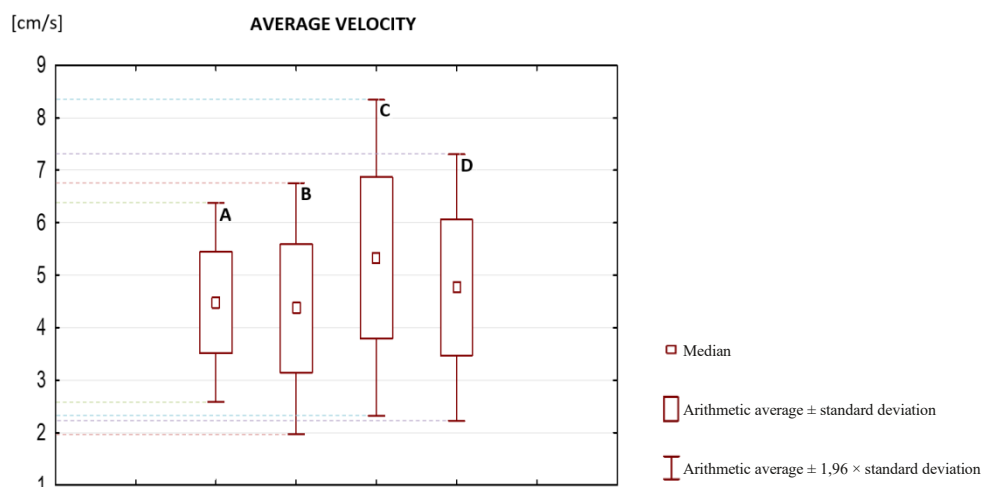

Figure 6. A box plot showing distribution of statistical analysis of average velocity: A – before rehabilitation M1, B – before rehabilitation M3, C – after rehabilitation M1, D – after rehabilitation M3

Weight distribution

Measured in centimeters using the TYMO® platform without the pad (M1), the mean weight distribution after rehabilitation (2.14 cm) is significantly smaller than the mean weight distribution before rehabilitation (4.3 cm), measured in the same way (whereas the t-statistic is less than 0 (-13.654225) and the one-sided p-value is < 0.000001, which is smaller than the assumed $\alpha = 0.05$). The absolute difference in means before and after rehabilitation is 2.15cm, which means, the mean distribution of body weight of M1 after rehabilitation decreased by 50%. On the other hand, measured in centimeters using the TYMO® platform with a pad (M3), the average weight distribution after rehabilitation (3.73 cm), is also significantly smaller than the average weight distribution before rehabilitation (5.31 cm), measured in the same way (whereas the t-statistic is less than 0 (-6.298663) and the one-sided p-value is < 0.000001, which is smaller than the assumed $\alpha = 0.05$). The absolute difference in means before and after rehabilitation is 1.58 cm, which means, the mean weight distribution of M3 after rehabilitation decreased by 30% (Table 9.). In both M1 and M3, there was a reduction in the mean weight distribution after physiotherapy treatment. This demonstrates an improvement in the symmetry of the body weight distribution during the test, and thus an improvement in the subjects' balance.

Table 9. The results of the statistical analysis of the average weight distribution before and after rehabilitation (M1 – without TYMO® Pad, M3 – with TYMO® Pad)

	M1	M3
Average weight distribution before rehabilitation [cm]	4.29	5.308333
Average weight distribution after rehabilitation [cm]	2.14	3.73
Absolute difference in averages before and after rehabilitation [cm]	2.15 (50%)	1.578333 (30%)
Statistics t	−13.654225	−6.298663
Value p one-sided	< 0.000001	< 0.000001

Figure 7. shows a comparison, in the form of a box plot, of the statistical analysis distribution of the mean distribution of body weight (measured in cm) during the performance of the test: before therapy without a pad (A), before therapy with a pad (B), after therapy without a pad (C) and after therapy with a pad (D). This graph illustrates the difference in median, minimum and maximum values. The shift in the median of box C (2.1 cm) relative to the median of box A (4.3 cm), as well as the median of box D (3.7 cm) relative to the median of box B (5.3cm), reflects a reduction in the mean weight distribution of patients after therapy (M1 – 2.2 cm, M3 – 1.6 cm).
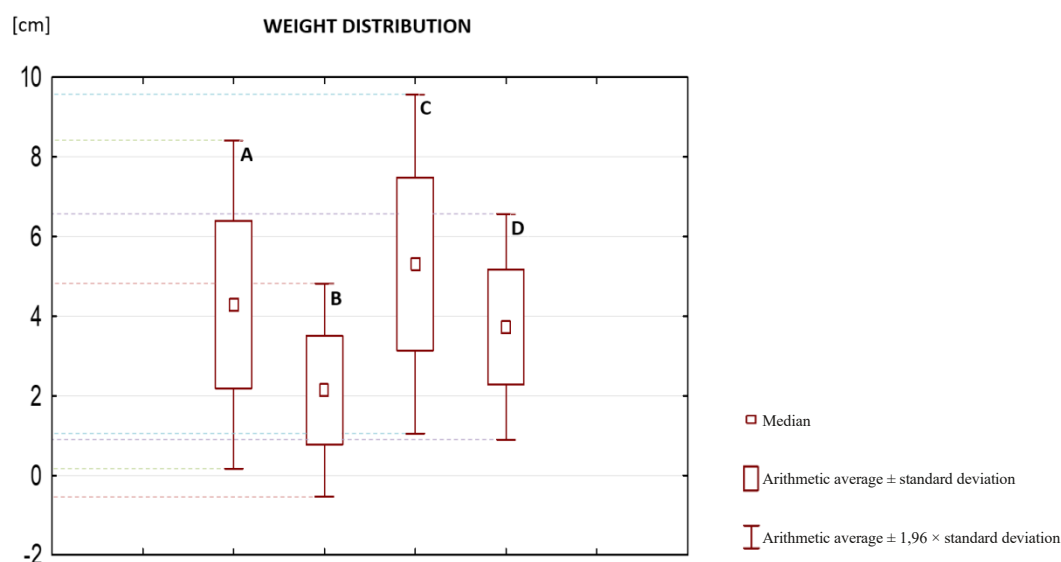
Figure 7. A box plot showing distribution of statistical analysis of average weight distribution: A – before rehabilitation M1, B – before rehabilitation M3, C – after rehabilitation M1, D – after rehabilitation M3

Medial-lateral tilt in relation to the paresis side
Measured in centimeters using the TYMO® platform without a pad, the mean medial-lateral tilt, before rehabilitation, is significantly smaller for those with right-sided hemiparesis (3,45 cm) than the mean medial-lateral tilt measured in the same way in the left hemiparesis group (4.35 cm) (whereas the t-statistic is less than 0 (−1.689322) and the one-sided p-value is 0.048264, which is less than the

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assumed α = 0.05) (Table 10.). This can be explained by motor dominance on the right side – the recovery potential is higher in patients with right-sided hemiparesis [25].

Table 10. The results of the statistical analysis of the average medial-lateral tilt before rehabilitation (M1 – without TYMO® Pad) in patients with left-sided (L) and right-sided (R) hemiparesis

	M1	M3
Mean medial-lateral tilt before rehabilitation M1 [cm]	4.354839	3.448276
Absolute difference in average L and P [cm]	0.906563	
Statistics t	−1.689322	
Value p one-sided	0.048264	

Figure 8. shows a comparison, in the form of a box plot, of the statistical analysis distribution of the mean medial-lateral tilt (measured in cm) during performing the test without a pad, before rehabilitation, in patients with left-sided (L) and right-sided (P) hemiparesis. The minimum and maximum values for the L and R boxes are in different ranges, reflecting a large difference in medial-lateral tilt with respect to the side of hemiparesis. A difference of 21% (0.9 cm), between the median medial-lateral tilt for left-sided hemiparesis (box L: median = 4.35 cm) and right-sided hemiparesis (box R: median = 3.45 cm) reflects greater problems with maintaining postural stability in patients with left-sided hemiparesis.

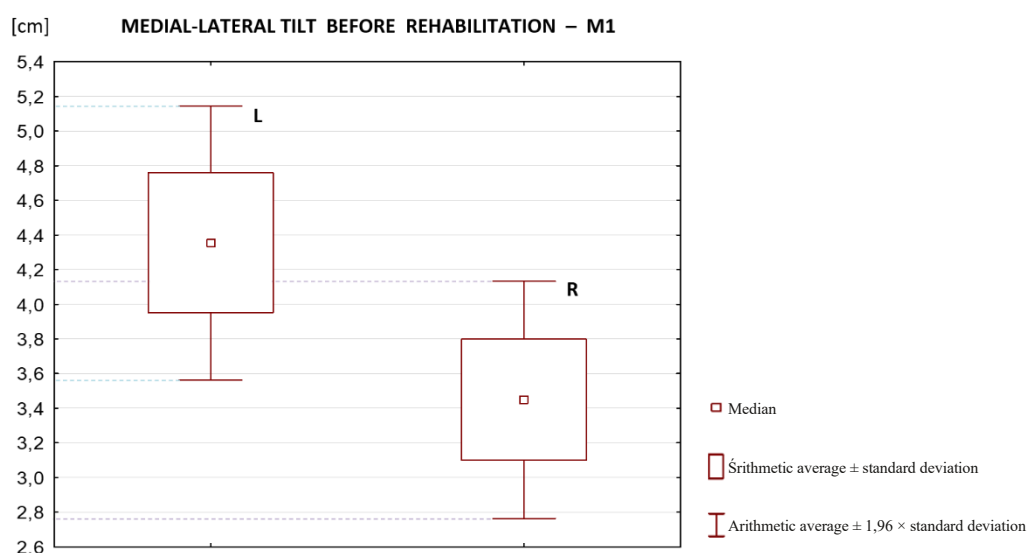**Figure 8. A box plot showing distribution of statistical analysis of average medial-lateral tilt before rehabilitation (M1) in patients with left-sided (L) hemiparesis versus right-sided (R) hemiparesis**

The effect magnitude of the treatment was determined using d-Cohen, with a score of approximately: 0.2 – small effect magnitude; 0.5 – medium effect magnitude; 0.8 – large effect magnitude (Table 11.).

Table 11. Presentation of treatment effect magnitudes (d-Cohen)

	d-Cohena / d-Cohen
Distance post-pre rehabilitation M1 [cm]	0.32
Distance post-pre rehabilitation M3 [cm]	0.81
Medial-lateral tilt post-pre rehabilitation M1 [cm]	0.9
Medial-lateral tilt post-pre rehabilitation M3 [cm]	0.96
Anterior-posterior tilt post-pre rehabilitation M1 [cm]	0.67
Anterior-posterior tilt post-pre rehabilitation M3 [cm]	0.83
Surface COF track post-pre rehabilitation M1 [cm^2]	0.44
Surface COF track post-pre rehabilitation M3 [cm^2]	0.82
Average velocity post-pre rehabilitation M1 [cm/s]	0.67
Average velocity post-pre rehabilitation M3 [cm/s]	0.32
Distribution of body weight post-pre rehabilitation M1 [cm]	1.22
Distribution of body weight post-pre rehabilitation M3 [cm]	0.86

There was a significant improvement in stability and postural control (adjustment of postural strategies) under unstable ground conditions. This is evidenced by the values of the difference of the mean before and after rehabilitation with the pad (M3) greater than the corresponding values without the pad (M1) (Figure 9.).
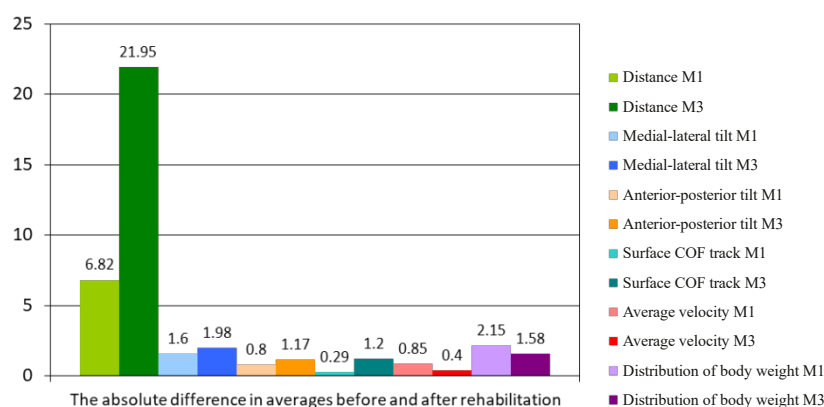
Figure 9. The absolute difference in averages before and after rehabilitation (M1 – without TYMO® Pad, M3 – with TYMO® Pad)

Discussion

Improving balance and returning gait function is an important factor in the quality of life of stroke survivors [26]. Clinical evaluation of balance disorders in post-stroke patients is often assessed by visual observation using standardized tools (balance tests). Individual determinants, the characteristics of the task and the environmental conditions in which the task is performed are important factors to consider when assessing postural control. However, due to the complex na-

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ture of this control, clinical evaluation is a difficult task (even for assessing quiet standing). Quantitative posturography uses force plates to monitor the trajectory of the center of pressure (COP). It reflects the sway of the body while standing and the ability of the nervous and musculoskeletal systems to integrate information from multiple sensory systems (including visual, somatosensory and vestibular) to maintain balance. Changes in the postural control system are reflected in changes in COP characteristics and parameters, so these are key variables for monitoring the postural control system.

Individuals who have experienced central nervous system damage in the form of a stroke may demonstrate difficulties in sensory processing and/or motor planning. In these patients, the inability of peripheral sensory receptors to receive information about the environment can result in impaired postural control [24]. Symmetry of body weight distribution, as a component of postural control, is assumed to be an important factor in the assessment of motor deficits and functional status impairment in post-stroke patients. In studies in which posturographic platforms were used, it has been proven that patients show increased swaying activity and lateral displacement of the body's center of mass toward the unaffected lower limb while standing quietly. They present greater motor variability with slower motor responses during external interventions and delays and compensations in postural control responses [27]. In addition, during standing quietly, their body's center of mass demonstrates movements over a greater range (larger tilts of the body from side to side and from front to back), making them more prone to falling. Greater sway while standing has also been observed in patients with impaired proprioception of the area of the ankle joints [2].

The above-described parameters of impaired postural control also characterize the functional status of the entire SG patient population of the current study before physiotherapy treatment: mean distance marked by the body's center of mass during testing: M1 – 54.4 cm, M3 – 78.6 cm, mean medial-lateral tilt: M1 – 3.9 cm, M3 – 4.9 cm, mean anterior-posterior tilt: M1 – 3.4 cm, M3 – 5.2 cm, mean weight distribution: M1 – 4.3 cm, M3 – 5.3 cm. However, after rehabilitation, the results of measurements registered by the TYMO® platform showed a reduction in the above-mentioned parameters, indicating an improvement in the postural stability of the patients: mean distance marked by the body's center of mass during testing: M1 – 47.6cm (13% reduction), M3 – 56.7 cm (28% reduction), mean medial-lateral tilt: M1 – 2.3 cm, M3 – 2.9 cm (40% reduction in both cases), mean anterior-posterior tilt: M1 – 2.6 cm, M3 – 4 cm (23% reduction in both cases), mean weight distribution: M1 – 2.1 cm (50% reduction), M3 – 3.7 cm (30% reduction). In turn, the average speed of movement after rehabilitation increased: M1 – 5.3 cm, M3 – 4.8 cm, compared to pre-improvement measurements: M1 – 4.5 cm, M3 – 4.4 cm (increase by: M1 – 19%, M3 – 9%). This proves an improvement in patients' balance during the test, reflected in improved velocity of motor responses and postural control responses.

Studies have shown that therapy that increases the ability to shift body weight symmetrically (equal distribution of body weight on the affected and unaffected lower limb) leads to

increased stability during gait and improves sensation in the affected foot [28–30]. This phenomenon occurs because the repetitive feedback from the loaded receptors during therapy is used as feedback to strengthen the extensors during gait [28, 31]. Thus, forced weight-shifting to the affected lower limb leads to improvements in gait parameters and ground pressure distribution in post-stroke patients [32]. However, about 30% of patients have problems with abnormal, asymmetrical positions of the feet (with almost equal amounts of pronation and supination) while standing [33]. All specific phenomena of cortical origin are effects of neuromotor control, and are also related with effects of foot morphofunction. Morphofunctional changes in the foot also imply an influence on the proprioceptive system. For this reason, it is so important to return function of proprioceptive system, which increases the chances of better transfer of afferent information, thereby reducing the risk of falling [34]. The medial-lateral stability assessed in this study is mainly related to the activity of the mechanoreceptors of the sole skin of the feet, which provide the central nervous system with information about the positioning of the feet on the ground and the tilt of the patient's body over the feet. Deficits in soleus skin sensation may be one of the factors explaining large medial-lateral shifts of the body's center of mass [2]. In the Connell study, it was shown that 89% of post-stroke patients have somatosensory deficits, resulting in impaired postural control [35]. In the group of the current study, patients with superficial sensory disorders (hypoesthesia) were 95% of the population (n = 57/60), while deep sensory disturbances presented 93% of the population (n = 56/60). Hence, the mean medial-lateral tilt before rehabilitation (both M1 and M3) was 40% greater than measurements taken after training (sensory improvement). In addition, before rehabilitation, the mean medial-lateral tilt of M1 (3.9 cm) was greater than the mean anterior-posterior tilt of M1 (3.4 cm) ($p < 0.05$). The study by Moisan et al. explains that post-stroke patients lose balance with a smaller forward shift of the body's center of mass in relation to the lateral shift. This phenomenon is reflected in the size of steps during the gait of post-stroke patients - steps are smaller than physiological ones, as larger steps increase the risk of falls [2].

The above data prove that a detailed understanding of the impaired features of kinetic and kinematic postural regulation in standing is beneficial in developing appropriate therapeutic strategies for post-stroke patients [6]. Posturographic analysis provides important information that is not possible to reflect in clinical tests and scales, which argues for its use in assessing balance in this group of patients [36]. Platforms, such as TYMO®, provide an objective, direct, quantitative assessment of parameters related to postural control.

The mechanism of spontaneous learning occurring in post-stroke patients could be seen as a limitation, affecting the reliability of the results of the present study. However, the chronic phase, which characterises the SG population, is somehow a guarantee that the effects of spontaneous learning in this group of patients, did not significantly affect the results of the study. The phenomenon of spontaneous learning and memory is severely limited (stability-mobility dilemma) in post-stroke patients in the chronic phase. These patients have maladaptive compensatory mechanisms (which are reflected in moving in fixed, pathological movement patterns), which are the result of new synaptic con-

nections, often functionally inappropriate and maladaptive, formed immediately after the stroke incident. The growth and location of such abnormal synapses on target neurons is characteristic especially in the later period after brain injury. The lack of surviving synaptic fields in the chronic phase further impedes proper spontaneous learning. In this case, only supervised, comprehensive neurorehabilitation can transform effective learning and encoding in the brain centres.[37] This is different for post-stroke patients in the acute phase, where the phenomenon of spontaneous learning is incomparably more intense, and where this fact may be a limitation of studies with similar themes.

Conclusions

The above results demonstrate the validity of using a posturography platform (in this case TYMO®) to quantitatively assess imbalance and as a tool for monitoring and reporting the effects of physiotherapy treatment in post-stroke patients in the chronic phase. The parameters registered by the platform are crucial in assessing the functional status of post-stroke patients, especially with regard to postural control or balance disorders. Analysis of the results obtained with the TYMO® device also supports the planning and design of rehabilitation goals. It also indicates the accuracy of therapy selection and is useful in determining the direction of a future rehabilitation program. As a result, such an evaluation can turn into a significant effectiveness of physiotherapy and, consequently, improve the patient's quality of life, and contribute to a shorter period of abstinence from work.

Adres do korespondencji / Corresponding author

Rita Hansdorfer-Korzon

e-mail: rita.hansdorfer-korzon@gumed.edu.pl

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