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ORIGINAL ARTICLE

ASSESSMENT OF POSTURAL CONTROL AND GAIT IN LATE POST-STROKE PATIENTS SUBJECTED TO TREADMILL TRAINING WITH CONTROLLED BODY BALANCE PERTURBATIONS. PILOT STUDY

OCENA KONTROLI POSTURALNEJ I CHODU U OSÓB W PÓŹNYM OKRESIE PO UDARZE MÓZGU PODDANYCH TRENINGOWI NA BIEŻNI RUCHOMEJ Z KONTROLOWANYMI PERTURBACJAMI RÓWNOWAGI. BADANIE PILOTOWE

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ABSTRACT

Introduction

One of the basic goals of post-stroke rehabilitation is the improvement of postural control and gait quality. Modern post-stroke rehabilitation implements treadmill training with controlled body balance perturbations (PBT).

Aim

This study aimed to assess the influence of the PBT treadmill training on activities of daily living (ADL), gait quality and postural control in people with chronic stroke.

Methods

Seventeen patients with stroke hospitalized in a rehabilitation centre were randomly allocated to 3-week PBT training. Functional independence was assessed using Fugl-Meyer Motor Assessment (FMA). ADL were assessed using Barthel Scale. Static and dynamic postural control was assessed using Berg Balance Scale (BBS), Timed Up And Go Test (TUG) and Functional Reach Test (FRT). Static postural control was assessed using stabilometric platform tests (Alfa and Gamma, Ac International East, Poland). The 10-meter walk test was used to evaluate gait. Spatial, temporal gait parameters were also assessed using the MyoMotion (Noraxon, USA).

Results

A significant improvement was found in the patients' motor functions (FMA; p = 0.01), independence in daily activities (Barthel Scale; p = 0.01), static and dynamic balance (BBS; p = 0.01). There was no statistically significant improvement in the dynamic balance (TUG; p = 0.15; and FRT; p = 0.19).

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Conclusions
Inclusion of perturbation training during rehabilitation of patients with chronic stroke improved ADL, gait quality and postural control.

Keywords: stroke, physical therapy, treadmill, body balance perturbations

STRESZCZENIE
Wstęp
Jednym z podstawowych celów rehabilitacji poudarowej jest poprawa kontroli posturalnej i jakości chodu. Nowoczesna rehabilitacja po udarze obejmuje rówież trening na bieżni ruchomej z kontrolowanymi perturbacjami równowagi (PBT).

Cel
Ocena wpływu treningu PBT na czynności dnia codziennego (ADL), jakość chodu i kontrolę posturalną u osób w późnym okresie po udarze mózgu.

Materiał i metody
Siedemnastu pacjentów po udarze hospitalizowanych w ośrodku rehabilitacyjnym zostało losowo przydzielonych do 3-tygodniowego treningu PBT. Niezależność funkcjonalną oceniono za pomocą skali Fugl-Meyer (FMA). ADL oceniono przy pomocy skali Barthel. Statyczną i dynamiczną kontrolę postawy oceniono za pomocą skali Berg (BBS), testu Wstań i idź (TUG) oraz testu sięgania (FRT). Statyczną kontrolę postawy oceniono za pomocą testów na platformie stabilometrycznej i dynamograficznej (Alfa i Gamma, Ac International East, Polska). Do oceny chodu zastosowano 10-metrowy test chodu. Przestrzenne i czasowe parametry chodu oceniono za pomocą przenośnego systemu analizy ruchu MyoMotion (Noraxon, USA).

Wyniki
Stwierdzono istotną poprawę w zakresie funkcji motorycznych (FMA; p = 0,01), samodzielności w czynnościach dnia codziennego (skala Barthel; p = 0,01), równowagi statycznej i dynamicznej (BBS; p = 0,01). Nie stwierdzono istotnej statystycznie poprawy w zakresie równowagi dynamicznej (TUG; p = 0,15; i FRT; p = 0,19).

Wnioski
Włączenie treningu na bieżni ruchomej z kontrolowanymi perturbacjami równowagi do rehabilitacji pacjentów w późnym okresie po udarze mózgu poprawiło ADL, jakość chodu i kontrolę postawy.

Słowa kluczowe: udar mózgu, fizjoterapia, bieżnia, trening zaburzeń równowagi ciała

Introduction

According to data from World Health Organization (WHO), stroke is the 2nd most common cause of death and the 3rd most common cause of disability in the world (Johnson *et al.*, 2016). Worldwide, about 10 million people experience a stroke every year (Feigin *et al.*, 2017). The incidence of stroke in Poland is estimated at an average of 150 per 100 thousand inhabitants annually, with an observed constant increase in the number of new cases (Antecki *et al.*, 2018). According to data from the National Health Fund in Poland, the costs of ischemic stroke hospitalization increased by 10% in the period from 2013 to 2018, from

PLN 571.8 million (EUR 124.9 million) to PLN 630.4 million (EUR 137.7 million) and rehabilitation expenses increased by 30% from PLN 159.6 million (EUR 34.8 million) to PLN 207.6 million (EUR 45.3 million) (Raport NFZ o zdrowiu, 2019).

Physical activity plays an important role in the prevention and treatment of stroke (Stewart *et al.,* 2019). In post-stroke rehabilitation, special attention is paid to physical exercise, which can improve the quality of gait and postural control and can reduce the risk of falls and injuries in patients (Alawieh *et al.,* 2018).

Balance and gait in stroke patients

Stroke survivors have difficulties maintaining static and dynamic body balance. In static conditions, patients with stroke show an increased deflection of the body's center of gravity towards the affected side, which is caused by the asymmetry of loads on the lower limbs as a result of hemiplegia (Bonan *et al.,* 2015; Tasseel-Ponche *et al.,* 2015). The affected lower limb is generally loaded to a degree not exceeding 40% of the body weight (de Haart *et al.,* 2004; Bonan *et al.,* 2015). Lower limb load asymmetry is long-lasting and persists even when the functional status of patients improves (Kamphuis *et al.,* 2013).

The dynamic balance is also disturbed in stroke patients. During exercises targeting balance, the amplitude and speed of the deflections of the body's center of gravity towards the paresis increases (Weerdesteyn *et al.,* 2008; Handelzalts *et al.,* 2019). While walking, the length of the stride is reduced, and the control of the body's center of gravity is disturbed, especially at the end of the gait phase (Honeycutt *et al.,* 2016). Defensive balance reactions against falling that involve a rapid limb movement, i.e., in the form of additional steps, are delayed, and the patient has difficulty in performing them with both a paresis and a healthy lower limb, which increases the risk of falls (Mansfield *et al.,* 2013; Inness *et al.,* 2016; Salot *et al.,* 2016). The patterns of muscle activation are disturbed (especially in the paretic limb), as a result of which patients' defense reactions to imbalances are delayed and uncoordinated (de Kam *et al.,* 2018). Poor postural and motor control in stroke survivors results in reduced speed, symmetry and gait efficiency (Hollands *et al.,* 2016; Bower *et al.,* 2019; Yadav *et al.,* 2020). The described disorders of muscle excitability, posture control and gait increase the risk of falls in people with stroke (Hollands *et al.,* 2016; Bower *et al.,* 2019; Yadav *et al.,* 2020).

Post-stroke rehabilitation training

In post-stroke rehabilitation, ground-based gait and body balance training is used to improve gait quality and postural control and prevent falls. There are also group and individual balance and sensorimotor exercises, as well as aerobic and resistance exercises (Verheyden *et al.,* 2013). Exercises based on modern technologies are also increasingly used in post-stroke rehabilitation. These include rehabilitation robots, walking exercises on treadmills and balance exercises on platforms with stable and unstable surfaces. Exercises on platforms and treadmills are often enriched with feedback using virtual reality (Veerbeek *et al.,* 2014; Bo and Shuming, 2016; Gallego Hernández *et al.,* 2021; Lamberti *et al.,* 2021).

Perturbation-based balance training (PBT)

In modern post-stroke rehabilitation, exercises on platforms and treadmills with controlled body balance perturbations (PBT) are also implemented. These perturbations are achieved in various ways. For example, mechanisms and devices are used to accelerate and slow down the speed of a running belt, which allows for an anterior-posterior disturbance, or there are mechanisms that cause a running treadmill belt to move in lateral and medial directions. The speeds, accelerations, ranges and sequences of perturbations vary, allowing for gradation of difficulty during exercise. According to clinical studies (McCrum *et al.,* 2017; Allin *et al.,* 2020; Harper *et al.,* 2021), exercises during which the patient is repeatedly exposed to body balance perturbations result in training defensive techniques against falling, such as faster reaction time, improved gait quality and improved postural control. It is also believed that PBT requires fewer training sessions than conventional balance training to achieve improved postural control (van Duijnhoven *et al.,* 2016).

According to the authors of systematic reviews of clinical trials, PBT is used to reduce the risk of falls in elderly people and patients with neurodegenerative diseases (Mansfield *et al.,* 2015; Gerards *et al.,* 2017). In a cohort study by Mansfield *et al.* (2017), PBT decreased the risk of falls in early post-stroke patients. Similar results were also obtained in the chronic post-stroke phase (Mansfield *et al.,* 2018).

The results of clinical trials using PBT to improve postural control and gait quality and reduce the risk of falls in people with stroke are promising; nonetheless, there are few studies in which the PBT methodology and the results obtained are varied. Therefore, there is a need for further studies and the results of which will clearly answer the questions of whether and to what extent PBT can improve the quality of gait and postural control in people after stroke. The research will also determine the most effective PBT methods in patients after stroke.

Aim

The aim of the study was to obtain knowledge on the impact of treadmill exercise with controlled body balance perturbations on daily functions, quality of gait and postural control in people in the late period after stroke.

Participants and methods

A three-week, single-group pilot trial was conducted in the Medical and Rehabilitation Center Solanki in Inowroclaw (Poland). The study protocol was approved by Bioethics Committee for Scientific Research at the Jerzy Kukuczka Academy of Physical Education in Katowice, Poland (Resolution No. 5/2020).

The participants were enrolled in the trial by a physician and were informed in writing about the study purpose and design, and that they could withdraw at any time without prejudice to further treatment.

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Setting and participants

All participants were treated at the same rehabilitation center. Their eligibility for the trial was assessed by a physician against the following inclusion criteria: age 18+, history and clinical presentation of stroke (ischemic; hemorrhagic) occurring > 6 months previously, independent gait over 10 m (acceptable gait support with a cane or a walker), gait speed minimum 0.4 km/h, the spasticity of the affected lower limb classified between 0 and 2 according to the Modified Ashworth Spasticity Scale, written consent to participate in the study. The exclusion criteria included contraindications to physical exercise presented in the study, subarachnoid hemorrhage, other than stroke conditions affecting gait and balance.

Measures

A baseline assessment was performed on the day before the 3-week treatment cycle. The final clinical assessment was performed the day after the end of the 3-week rehabilitation treatment.

Patients'demographics were obtained from standard interviews, physical examinations and medical records. Patients were assessed for neurologic status by the National Institutes of Health Stroke Scale (NIHSS). Functional independence was assessed using Fugl-Meyer Motor Assessment (FMA). Brunnström Recovery Scale and Ashworth Scale were used to assess motor functions and muscle spasticity. Activities of daily living (ADL) were assessed using the 100-point Barthel Scale.

Static and dynamic postural control was assessed using Berg Balance Scale (BBS), Timed Up And Go Test (TUG) and Functional Reach Test (FRT). Static balance of the body (COP path length [cm²] and COP surface area [cm²]) was also assessed on a stabilometric platform (Alfa, Ac International East, Poland), on which forces and torques were registered with a sampling frequency of 62 Hz. During measurements, the participants were standing still with eyes open, feet shoulder-width apart, and arms hanging at their sides. Measurement lasted 30 seconds and was repeated three times for reliability (the average result from all 3 measurements was taken as the final result).

The distribution of lower limb loads (left leg weight distribution [%] and right leg weight distribution [%]) was also assessed using a dynamographic platform (Gamma, Ac International East, Poland). During measurements, the participants were standing quietly, with eyes open, feet shoulder-width apart, and arms hanging at their sides for 30 seconds.

The 10-meter walk test (10MWT) was used to evaluate the gait. Spatial-temporal gait parameters (foot rotation [degree]; step length [cm and difference]; stride length [cm]; step-width [cm]; velocity [km/h]; step time [ms and difference]; stride time [ms]; cadence [no. steps/min]; stance and swing phases [%] and double-stance phase [%]) were also assessed using the MyoMotion device (Noraxon, USA), which enables three-plane motion analysis (3D) with the use of inertial sensors. During the test, the patient walked at his preferred pace for 30 seconds on a treadmill (Zebris FDM-T; Rehawalk, MaxxusDaum h / p Cosmos Force).

Interventions

The treatment of the patients lasted 3 weeks, during which daily (from Monday to Saturday), for 2.5 hours a day, post-stroke therapy based on the principles of best clinical practices was carried out. Exercises to improve movement patterns and normalize postural tension were used, including body balance exercises on an unstable platform (Sigma Balance Platform; Ac International East, Poland) for 15 minutes a day.

Additionally, every day (from Monday to Saturday) for these 3 weeks, the patients underwent gait training on a treadmill with special software that allowed body perturbations during walking (Balance Tutor; Medi-Touch, Israel). The duration of the treadmill exercises and the difficulty of the exercises were gradually increased according to the following scheme: 1–3 days – the exercises lasted 10 minutes, including a 7-minute walk forward and a 3-minute walk, during which the patient was thrown off balance towards the affected side every 30 seconds (the length of the lateral shifts of the treadmill was 7–10 cm); day 4–6 – the exercises lasted 15 minutes, including a 10-minute walk, in which every 30 seconds the patient was thrown forward and backward (anterior-posterior shifts of the treadmill were 10 cm) and a 5-minute walk in which every 30 seconds, the patient was upset sideways (lateral shifts of the treadmill were 15 cm); 7–20 days - the exercises lasted 20 minutes, including a 13-minute walk, in which every 30 seconds the patient was thrown forward and backward (anterior-posterior shifts of the treadmill were 15 cm) and a 7-minute walk during which every 30 seconds 30 seconds the patient was sideways unbalanced (lateral shifts of the treadmill were 18–20 cm).

Statistical analysis

Variables were examined for normality of distribution by the Shapiro-Wilk test. In variables that had non-normal distribution, the within-group results obtained pre- and post-intervention were compared with the Wilcoxon signed-rank test. In variables that had normal distribution, the within-group results obtained pre- and post-intervention were compared with the Student's T-Test for dependent samples. The level of significance was set at $P \leq 0.05$. All computations were made in STATISTICA v.13.1 (StatSoft, Inc., USA).

Results

Between 10 May 2021 and 15 December 2021, 24 patients were screened for the trial. Twenty of them met the inclusion criteria and were enrolled. Three patients (12.5%) withdrew from the study for health reasons unrelated to the study. The remaining 17 patients (8 women and 9 men) completed the study. Patients' age ranged from 45 to 77 years (mean 63.47 ± 10.98 years).

The time since the occurrence ranged from 6 to 18 months (mean 12.76 ± 4.15 months). All patients experienced ischemic stroke. All the patients were right-handed. 10 patients (58.8%) had left-sided paralysis, and 7 patients had right-sided paralysis. Detailed characteristics of the patients at baseline are presented in Table 1.

statistically significant changes in the lower limb load distribution were found on the dynamographic platform (p = 0.37) (Table 2).

There was a statistically significant improvement in selected gait parameters, including increased walking velocity (p = 0.04), decreased step length difference between the left and the right leg (p = 0.01), elongation of stride length (p = 0.02), shortening of the stance phase on the left leg (p = 0.03) and extension of the single support phase on the right leg and the swing phase on the left leg (p = 0.03) (Table 3).

Table 1. Sample characterization before treatment.

Characteristics	Intervention group (n = 17)
Gender: Females / Males [number of Pts]	8 / 9
Age: mean (SD) [years]	63.47(10.98)
BMI: mean (SD) [kg/m²]	28.25 (4.29)
Ischemic stroke / hemorrhagic stroke [number of Pts]	17 / 0
Time since stroke: mean (SD) [months]	12.76 (4.15)
Right-handedness / left-handedness [number of Pts]	17 / 0
Side affected [left/right] [number of Pts]	10 / 7
Brunnström Recovery Scale: III / IV / V [number of Pts]	3 / 8 / 6
Modified Ashworth Spasticity Scale: 0 / I / II [number of Pts]	10 / 5 / 2
National Institutes of Health Stroke Scale: mean (SD) [points]	2.06 (2.49)
Fugl-Meyer Motor Assessment: mean (SD) [points]	56.77 (11.01)
Barthel Scale: mean (SD) [points]	96.47 (4.93)

Pts – patients

Study outcomes

17 patients (8 women and 9 men) completed the study. A statistically significant improvement in the patients' motor functions (Fugl-Meyer Motor Assessment; p = 0.01) and a statistically significant increase in independence in daily activities (Barthel Scale p = 0.01) were noted after treatment (Table 2).

Clinical evaluation carried out using the Berg Balance Scale showed a statistically significant improvement in the static and dynamic balance (p = 0.01). However, there was no statistically significant improvement in the dynamic balance assessed in the TUG (p = 0.15) and FRT (p = 0.19). In the assessment of static balance carried out on the stabilometric platform, no statistically significant changes in the size of the surface area and the path length of COP were observed (p = 1.00 and p = 0.46, respectively) (Table 2). No

Discussion

In 17 chronic stroke patients who underwent a 3-week conventional post-stroke rehabilitation in combination with perturbation-based balance training, a statistically significant increase was observed in independence in daily activities and improvement in gait quality (including increased velocity and stride length, shortening the stance phase and lengthening the swing phase). Rehabilitation treatment did not affect the load distribution of the lower limbs.

Treadmill exercises with controlled body balance perturbations combined with conventional rehabilitation may also improve postural control in patients in the late post-stroke phase; nevertheless, in our study, this thesis is only confirmed by the results of static and dynamic balance assessment by the BBS. Other clinical tests (TUG and FRT and tests

Table 2. Treatment effects on functional independence and balance.

Characteristics N=17	Before treatment	After treatment	p-value
	Mean (SD); median (lower-upper quartile)		
Fugl-Meyer Motor Assessment [points]	56.77 (11.01); 58 (55–66)	61.77 (6.42); 65 (56–66)	**0.01***
Barthel Scale [points]	96.47 (4.93); 100 (95–100)	99.41 (1.66); 100 (100–100)	**0.01****
Berg Balance Scale [points]	47.29 (6.87); 48 (42–55)	52.41 (4.44); 55 (50–56)	**0.01***
Timed Up And Go Test [sec]	10.35 (2.98); 10 (8–12)	9.65 (2.15); 9 (8–11)	0.15*
Functional Reach Test [cm]	36,18 (11.41); 35 (29–40)	39.00 (9.05); 37 (33–46)	0.19*
COP path length [cm²]	42.54 (101.47); 16.77 (8.02–26.10)	40.12 (85.11); 16.80 (11.74–26.36)	1.00**
COP surface area [cm²]	3.53 (4.86); 1.44 (0.84–3.19)	3.49 (7.11); 1.25 (0.88–1.60)	0.46**
Left leg weight distribution [%]	49.53 (2.96); 50 (48–52)	50.41 (2.55); 50 (50–50)	0.37**
Right leg weight distribution [%]	50.47 (2.96); 50 (48–52)	49.59 (2.55); 50 (50–50)	0.37**

COP – center of foot pressure: *Student's T-Test; **Wilcoxon test

Table 3. Treatment effects on gait.

Characteristics N = 17	Before treatment	After treatment	p-value*
	Mean (SD); median (lower-upper quartile)		
Foot rotation of left leg [degree]	7.41 (6.87); 7.30 (6.6–12.10)	7.41 (5.76); 6.8 (3.9–12.2)	0.99
Foot rotation of right leg [degree]	9.49 (4.50); 9.1 (6.6–12.3)	9.07 (5.22); 9.1 (5.3–13.2)	0.27
Step length on left leg [cm]	29.94 (7.42); 30 (25–34)	33.24 (9.52); 33 (24–42)	0.05
Step length on right leg [cm]	27.53 (6.28); 26 (22–32)	30.82 (10.84); 34 (21–37)	0.15
Step length difference between left and right leg [%]	−6.18 (15.93); −1.8 (−12.9–2.2)	1.04 (11.87); −1.8 (−8.8–9.9)	**0.01**
Stride length [cm]	57.53 (12.39); 60 (45–65)	66.47 (17.54); 66 (51–81)	**0.02**
Step-width [cm]	13.65 (4.83); 13 (11–17)	14.53 (4.4); 16 (11–18)	0.26
Velocity [km/h]	1.45 (0.23); 1.5 (1.4–1.5)	1.64 (0.4); 1.6 (1.5–1.9)	**0.04**
Step time on left leg [ms]	738.18 (127.39); 702 (659–829)	754.82 (122.44); 743 (686–780)	0.55
Step time on right leg [ms]	714.71 (132.65); 686 (654–781)	715.12 (86.6); 701 (642–738)	0.99
Step time difference between left and right leg [%]	−3.09 (6.52); −3.3 (−6.8–1.5)	−4.54 (8.1); −4 (−6.8–0)	0.37
Stride time [ms]	1452.77 (253.79); 1367 (1349–1585)	1469.94 (196.75); 1439 (1344–1509)	0.73
Cadence [no. steps/min]	85.24 (14.63); 88 (76–89)	83.06 (9.93); 83 (80–89)	0.41
Stance phase on left leg [%]	68.95 (2.71); 68.9 (67.2–71.0)	67.58 (2.86); 68.1 (66.3–69.8)	**0.03**
Stance phase on right leg [%]	70.08 (2.94); 70.1 (67.7–73.1)	70.02 (3.08); 69.7 (68.7–72.9)	0.89
Stance phase difference between left and right leg [%]	1.67 (4.16); 0.9 (−1.6–2.8)	3.85 (7.19); 2.2 (−0.8–5.8)	0.07
Single support phase on left leg [%]	29.48 (3.13); 29.5 (26.9–32.2)	29.95 (3.13); 30.3 (27.1–31.3)	0.40
Single support phase on right leg [%]	31.04 (2.75); 31.2 (28.8–32.4)	32.39 (2.84); 31.8 (30.3–33.8)	**0.03**
Single support phase difference between left and right leg [%]	6.07 (11.62); 3.5 (−3.1–15.5)	9.45 (16.79); 3.3 (−1.5–15.5)	0.29
Swing phase on left leg [%]	31.06 (2.72); 31.2 (29.0–32.8)	32.42 (2.86); 31.9 (30.2–33.7)	**0.03**
Swing phase on right leg [%]	30.49 (3.25); 30,5 (26.9–32.3)	29.95 (3.1); 30.3 (27.1–31.3)	0.47
Swing phase difference between left and right leg [%]	−3.29 (8.57); −1.8 (−7.4–3.3)	−6.81 (12.93); −4.30 (−13–1.4)	0.10
Double-stance phase [%]	39.31 (4.86); 40.2 (35.3–42.6)	39.64 (8.69); 38.4 (35.1–41.8)	0.88

*Student's T-Test for dependent samples

performed on a stabilometric platform) did not show statistically significant changes in postural control. An increase in postural control confirmed by stabilometric tests was, in turn, noted in a 2017 study by Sergeenko *et al.* (2017), who used the same methodology of treadmill PBT as in our study. The study (Sergeenko *et al.*, 2017) covered 72 chronic stroke patients with an average of 6.8 ± 0.4 months after stroke in the experimental group (EG) and 6.4 ± 0.2 months in the control group (CG). Most patients (n = 57; 79.2%) experienced ischemic stroke, and the rest suffered from hemorrhagic stroke (n = 15; 20.8%). The EG group consisted of 37 people with a mean age of 58.0 ± 5.3 years, and the CG group consisted of 35 patients at a mean age of 56.0 ± 4.8 years. All patients underwent a 3-week rehabilitation, including drug treatment, medical resort treatment (magnetotherapy, massage, paraffin treatment), and physical training (cyclic mechanotherapy and gymnastics). In addition, patients in the EG group during the treatment underwent eighteen 20-minute training sessions conducted 6 days a week on the BalanceTutor treadmill (MediTouch, Israel). Postural control evaluation was performed with the stabilometric system MBN Stabilo (MBN Medical Research Firm, Russia). After treatment, the decreases in the COP sway area and COP velocity in the EG were statistically significantly greater than in the CG (COP sway with eyes opened p = 0.0476 and eyes closed p = 0.0072, and COP velocity with eyes opened p = 0.0176 and eyes closed p = 0.0037). According to the authors (34), the reduction of these parameters indicated an improvement in static postural control. Additionally, Tinetti Gait and Balance scores also improved in the EG versus CG (p = 0.0513 and p = 0.0274, respectively).

The results of other clinical trials, including PBT treadmill exercises, also indicate an improvement in postural control (Dusane and Bhatt, 2020; Esmaeili *et al.*, 2020) and an improvement in balance reactions against falling in patients in the late post-stroke period (Dusane and Bhatt, 2020; Esmaeili *et al.*, 2020). In a study by Osman *et al.* (2021), similarly to our study, an increase in walking speed was noted in chronic stroke survivors after PBT treadmill training. However, not all studies indicate an improvement in gait after treadmill PBT exercises in this group of patients (Dusane and Bhatt, 2020; Punt *et al.*, 2019).

In a pilot study conducted by Esmaeili *et al.* (2020), 18 patients (16 males; 2 females) in the chronic phase of stroke with reduced dynamic balance abilities participated. In 10 patients (mean age 58 ± 6.7 years) (EG – experimental group), a split-belt treadmill (Bertec Fit®) was used in PBT. Perturbations were carried out in the gait cycle by changing the speed of each belt independently. A certain number of perturbations per one gait cycle were provided for each training, and the duration of the training depended on the number of perturbations and the walking speed of a given patient. Eight participants (mean age 57.5 ± 18 years) (in the control group – CG) only walked on the treadmill at their comfortable walking speed. The duration of the training sessions for each participant in the CG group was adjusted to the time of a participant in the EG group with a similar overground speed. In both groups, the participants attended 9 training sessions over 3 weeks. The Mini-BES Test was used to assess balance abilities in dynamic conditions. The test consisted of fourteen tasks, categorized into four subsystems (anticipatory activity, reactive postural control, sensory orientation and dynamic gait). 10-Meter Walk Test was also used to evaluate gait speed at comfortable and fast overground speeds. After the therapy, a statistically significant improvement was observed in the balance abilities in the EG versus the CG (p = 0.007). There were no statistically significant differences in walking speed between the groups, both in the pace preferred by the patient (p = 0.594) and the maximum pace (p = 0.424).

In a single group study by Osman *et al.* (2021), 12 chronic (> 6 months) post-stroke patients of the average age of 61.5 ± 10.58 years participated. These patients were treated for 10 weeks with PBT treadmill exercises with two side-by-side independent belts (R-Mill treadmill, Motekforce Link, Netherlands). While walking on the treadmill, the patients were secured against falling by means of an appropriate harness. The protocol consisted of a maximum of 15 ninety-second walking trials, each with three 30-second periods (preperturbation, perturbation, recovery). A perturbation was induced once during the perturbation period by increasing the treadmill belt speed by a specified value for 0.25 s and then returning it to its previous speed. A constant acceleration of 15 m/s speed was done for all speed changes. Within the perturbation period, the perturbations were applied at the mid-stance of the unaffected leg during a randomly preselected gait cycle. After treatment, the patients' treadmill walking speed increased significantly, both at the pace preferred by the patient ($p = 0.003$) and at the maximum pace ($p = 0.010$). The number of falls while walking on the treadmill has also decreased ($p = 0.015$), and the number of recoveries has increased ($p = 0.001$). The authors concluded that treadmill PBT might improve gait and body balance responses protecting against falling in stroke patients.

Dusane *et al.* (2020) conducted a single group study with 12 community-dwelling post-stroke (> 6 months) patients. All the participants received slip-like (12 m/s^2) or trip-like (16.75 m/s^2) perturbations using the ActiveStep (Simbex) treadmill. The patients stood with their feet shoulder-width apart. A safety harness was firmly attached to prevent the patients from touching the treadmill belt at the time of the fall. All the participants were instructed to try to avoid falls. Each patient underwent three consecutive training sessions at one time: slip-like block training, trip-like block training, and mixed slip- and trip-like training. During each training session, postural stability (position and velocity of center-of-mass, CoM), step count, trunk angle and compensatory step length were examined. Slip-like block training resulted in anteriorly positioned center-of-mass, increased step length and reduced compensatory step count ($p < 0.05$). Trip-like block training resulted in reductions in step length and step count, and trunk angle ($p < 0.05$). However, the position of CoM was unchanged ($p > 0.05$). With mixed training, a decrease in step length for slip-like perturbations was noted, but a continued decrease in trunk angle and step length was observed on trip-like perturbations ($p < 0.05$). However, the position of CoM and the step count remained unchanged for both. According to the authors (Dusane *et al.*, 2020), a development of favorable reactive responses in people with chronic stroke to counteract treadmill-based trip-like and slip-like stance perturbations was observed after the block perturbation training. During the mixed block, previously obtained adaptive changes in reactive responses from slip-block training were not held. On trip-like perturbations trip, block-induced adaptation succeeded in showing further betterment.

In a single group study by Punt *et al.* (2019), 10 patients (7 men, 3 women) at least one year after stroke participated, who had fallen at least once in the last six months. Patients participated in ten 30 minutes-1 hour exercise sessions over a six-week period. The time of a training session depends on the participant's physical condition. Training on a treadmill equipped with the Gait Real-time Analysis Interactive Lab (GRAIL, Motekforce Link B.V., The Netherlands) system was used. Accelerometry was used to assess daily-life gait characteristics. Firstly, the patients became familiarized with how to walk on the treadmill. The authors assessed steady-state gait characteristics during sixty consecutive strides at a gait speed of 0.41m/s. Secondly, all perturbations were executed at the mentioned gait speed (0.41m/s). The perturbation protocol consisted of two separate trials. Each trial comprised 16 perturbations, and each perturbation was followed by a wash-out period of on average 15 seconds. Foot contact triggers the semi-random perturbations. The perturbation type was fixed, but the triggering at the left or right foot placement was random. Each trial lasted for 4 minutes. As much as possible breaks were taken between trials to avoid fatigue. Medio-lateral and anterior-posterior decelerating perturbations were implemented.

In the following trainings, the intensity of the perturbations was gradually increased. More stable gait on the treadmill and, thus, lower predicted fall risk was observed. However, a more stable gait on the treadmill did not transfer to a more stable gait in daily life.

Our study and the other cited trials indicate that treadmill PBT can improve the quality of gait and postural control and reduce the risk of falls in people in the chronic post-stroke phase. However, it should be noted that our study and the studies cited by other authors can be considered only as preliminary studies (a pilot study; a single group study) with a small size of the study groups. Therefore, the results of these studies should be verified by high-quality randomized control trials.

Limitations

Limitations and weaknesses of the study: small size of the study group, no control group, no blinding, parallel medical resort treatment, and no long-term assessment of the effects (no follow-up).

Conclusion

The results of the study allow the conclusion that standard post-stroke rehabilitation enriched with treadmill exercises with controlled body balance perturbations improves everyday functioning and contributes to the improvement of gait in people in the late phase after stroke. There are also indications that PBT may improve postural control in chronic stroke survivors. However, PBT does not affect the distribution of loads on the lower limbs in chronic stroke patients. The results of our study should be verified in high-quality randomized clinical trials.

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