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Original Article

Effects of sensorimotor foot training on the symmetry of weight distribution on the lower extremities of patients in the chronic phase after stroke

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Abstract. [Purpose] To assess the effects of sensorimotor foot stimulation on the symmetry of weight distribution on the feet of patients in the chronic post-stroke phase. [Subjects and Methods] This study was a prospective, single blind, randomized controlled trial. In the study we examined patients with chronic stroke (post-stroke duration > 1 year). They were randomly allocated to the study group (n=8) or to the control group (n=12). Both groups completed a standard six-week rehabilitation programme. In the study group, the standard rehabilitation programme was supplemented with sensorimotor foot stimulation training. Each patient underwent two assessments of symmetry of weight distribution on the lower extremities with and without visual control, on a treadmill, with stabilometry measurements, and under static conditions. [Results] Only the study group demonstrated a significant increase in the weight placed on the leg directly affected by stroke, and a reduction in asymmetry of weight-bearing on the lower extremities. [Conclusion] Sensorimotor stimulation of the feet enhanced of weight bearing on the foot on the side of the body directly affected by stroke, and a decreased asymmetry of weight distribution on the lower extremities of patients in the chronic post-stroke phase.
Key words: Rehabilitation, Sensorimotor foot training, Stroke

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INTRODUCTION

The rehabilitation of post-stroke patients targets at the performance of functional tasks and neuromuscular re-education. In 70–80% of cases the central goals of physical therapy management are to restore lost functions and preserve existing functions, and to prevent their further deterioration[1, 3)]. One of the greatest challenges faced by physical therapists is developing an effective procedure for the therapeutic management of patients, especially with regard to the improvement of balance and deep sensation. The maintenance of balance in patients over 65 years of age is more difficult due to their deterioration of vision, impaired sensory function, lower muscular strength and extended response time to destabilizing stimuli.

One of the crucial elements involved in the maintenance of body balance in the standing position are the feet. The feet are the first and usually the only point of contact between the body and the external environment. Proper foot function is ensured by sensory receptors which are present in great abundance on the plantar surface of the foot, and the motor system. Relevant information is transferred through feedback mechanisms to higher cognitive centres, which is followed by the planning of consecutive motor activities. The ability to maintain a free standing posture with a uniform distribution of weight on both feet is a prerequisite for more complex motor activities, such as walking, changes of body position and maintaining or regaining balance[2, 4–10)]. A study by Meyer showed that plantar cutaneous sensation is one of the main factors determining correct postural control under the eyes-closed conditions[11)]. Messages transferred from the feet allow continuous control and adjustment of the body's position in relation to the environment[12)]. Other elements playing a major role in maintaining body balance include the elasticity of soft tissues (skin) and the mechanics of the foot. In the elderly population, the absence of compensation in maintaining body balance is a consequence of the loss of skin elasticity and poor foot mechanics[4)]. It was proven that the weight-bearing symmetry of the feet while walking and standing changes after using foot stimulation in the form of shoe insoles. That study was conducted on post-stroke patients[13)]. It should be added that the majority of analyzed interventions were supplements to classical physiotherapy procedures. In many studies the posturographic platform

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Table 1. The criteria for inclusion or exclusion

Inclusion criteria	Exclusion criteria
- ischaemic cerebral stroke > 12 months - ability to assume and maintain an erect body posture > 30 s. - patient's consent to participation in the trial	- haemorrhagic stroke; - ischaemic stroke occurring < 12 months prior to enrolment; - coexistence of other diseases of the CNSe.g. Parkinson's disease, Alzheimer's disease, multiple sclerosis; - diabetes - injuries involving locomotor immobility (fractures, sprains) - break in the continuity of soft tissues in the foot - inability to maintain an erect body posture for at least 30 seconds - patients who lost balance more than once during the trial - visible postural imbalance - history of falls - headaches and dizziness - reluctance to participate in the trial

has been used to observe changes in parameters describing postural stability and the weight-bearing distribution on the feet after a therapeutic intervention[14]. Gok[15] observed positive changes in the parameters describing balance and functional performance of patients in the chronic phase after stroke after conducting training with biofeedback. A therapy oriented towards balance improvement should, therefore, seek to achieve a uniform weight distribution on both feet.

Since the feet play a crucial role in the process of maintaining body balance[7], it is our opinion that sensorimotor foot stimulation (SFS) should be utilised in physiotherapy for post-stroke patients. Sensorimotor stimulation encompasses a range of therapeutic procedures performed in the immediate foot region, aimed at improving sensory function and increasing the elasticity of tissues within the feet. Therefore, the aim of study is to assess the effect of sensorimotor foot stimulation on the symmetry of weight distribution on the feet in patients in the chronic post-stroke phase. The hypothesis of this study was that supplementing the process of rehabilitation by sensorimotor foot stimulation training would markedly increase the weight placed on the foot directly affected by stroke, and would be more effective at correcting the disproportionate distribution of weight on both extremities than the standard rehabilitation regime.

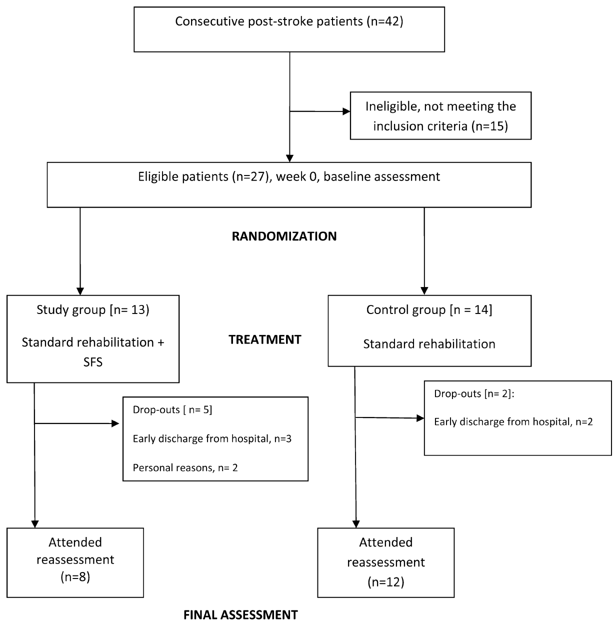

Fig. 1. Flow diagram showing the passage of participants through the trial

SUBJECTS AND METHODS

This study performed an assessment of the effects of SFS on the symmetry of weight-bearing on the feet post-stroke patients.Itwas conducted in the rehabilitation department of rehabilitation hospital in Poznań. The study was planned for the years 2013–2015 and was carried out with the approval of the Bioethics Committee of the University of Medical Sciences Poznań. During this period a representative group of 80 patients with chronic stroke in the rehabilitation department will be examined. Since few studies describing the mechanism of direct stimulation of the foot and its influence on the symmetry of weight-bearing on the feet and postural stability have been conducted, the present study is presented as a pilot study, after completing the first year of intervention. A total of 42 patients with ischaemic cerebral stroke were examined.

The inclusion and exclusion criteria are listed in Table 1.

All the post-stroke patients staying in the rehabilitation centre were subjected to a preliminary examination. During the study, there were a total of 42 post-stroke patients in the facility. Fifteen (35.7%) of them were immediately excluded, as they failed to meet the study inclusion criteria or there were other contra indications to their participation.

The patients who were enrolled in the study were then randomly assigned to the study group (SG, n=13) or the control group (CG, n=14). The procedure of randomization was carried out using 28 unmarked envelopes.

During the course of the study, five patients from the SG dropped out due to their unscheduled discharge from the hospital and two patients in the CG were excluded due to their early discharge from the hospital (Fig. 1).

All the trials were conducted with the consent of the

Bioethics Committee, the director of the facility in which the study was performed, and the Head of the Rehabilitation Department. All the patients gave their consent to participation in the trial.

All the patients [SG and CG] with a history of ischaemic cerebral stroke who met the trial inclusion criteria received a standard six-week therapeutic rehabilitation programme. SFS was an additional element of the programme for the the SG only.

The standard programme of therapeutic rehabilitation comprised the following components:

- individual therapy with a physical therapist (45-minute sessions in the CG five times a week; 30-minute sessions in the SG five times a week + 15-minute SFS) based on Neuro Development Treatment Bobath (NDT), priopriorecepive neuromuscular facilitation (PNF) and other recognized physical rehabilitation concepts;

- other kinesitherapeutic procedures (45-minute sessions twice a day, five times a week for both groups). The module of kinesitherapeutic procedures encompassed active non-weight bearing exercises, active resistance exercises, treadmill walking, pedalling exercises for upper and lower extremities on a cycloergometer, walking exercises and others. A total of six kinesitherapeutic procedures were recommended.

- two physical therapy procedures five times a week.

All the physical therapy procedures were prescribed by the attending physician, a specialist in motor rehabilitation.

The sensorimotor training programme consisted of 25 sessions of 20 minutes each.

Every session had the same structure, including preparation of the foot for weight bearing, repetition of the key exercises practised during the previous therapeutic session, and the main therapeutic intervention.

The daily schedule of therapeutic interventions:

Days 1–3: improving elasticity of soft tissues in the tarsal joint and the foot,

Days 4–9: facilitating and improving sensory function in the foot area,

Days 10–13: learning and refining selective movements in the tarsal joint,

Days 14–18: learning and improving symmetrical weight distribution on both feet during rising to the standing position and in the standing posture with and without visual control,

Days 19–25: learning and improving symmetrical load distribution on both feet during rising to the standing position and while standing on surfaces having different textures.

The main objectives of the underlying training were:

1) improving the elasticity of soft tissues in the tarsal joint and the foot by stroking, rubbing, and scratching the dorsal and plantar surfaces of the foot in a predetermined sequence and direction;

2) facilitating and improving the sensory function in the foot region, by using objects with various facture and temperature with visual control;

3) learning and refining selective movements in the tarsal joint by patient's observations of the foot and repetition of commands after stimulating the muscles to contract;

4) learning and improving symmetrical weight distribution on both feet during rising to the standing position and in the standing posture with and without visual control; and

5) learning and improving symmetrical load distribution on both feet during rising to the standing position and while standing on surfaces of different textures.

All the measurements and tests were performed by an experienced physical therapist, in a quiet and peaceful location. The functional evaluation of the patients was conducted on the first and the last day of their stay in the rehabilitation facility. The physical therapist who performed the functional evaluation was not aware of the assignment of patients to the respective trial groups.

Weight distribution on the feet was assessed using the Zebris FDM-TDL treadmill with Win FDM-T software and a stance analysis module[16)]. The device has an integrated matrix of 5,376 pressure sensors, which form a measuring surface with a length of 94.8 cm and a width of 40.6 cm. The force measurement range is 1–100 N/cm^2, and the signal sampling frequency is 100 Hz. The test was performed in silence, since auditory stimuli are known to interfere with postural reflexes[17)]. During the measurements, the patients stood on the platform barefoot, with their feet rotated outwards (at a 14-degree angle), and by their the heels 4 cm apart and aligned. The patients assumed and maintained the standing posture with their arms sides and the head in the natural position for 30 seconds[4, 12, 18)].

A total of 10 measurements were performed. For the initial five measurements the patients had their eyes open (EO), and for the next five measurements they were requested to close them (eyes closed, EC). Each patients received the same verbal instructions during the tests. The patient were told to stay still until hearing the next verbal instruction. During the test performed under the EO condition, the patient's eyes were focused on a reference point located on a wall 1 m in front of them. After each measurement the patient was requested to step off the treadmill, so that calibration could be performed[19)]. Throughout the entire duration of the tests the operator stood behind the patient.

A trial was not taken into account in the case of an unexpected loss of balance, sneezing or moving, etc. The trial was repeated once. The study was discontinued and the patient was excluded from further procedure in the case of having to repeat the trial > 1. The aim of the test was to assess the difference in weight distribution on the right and left foot under static conditions.

Student t-test was performed to compare the mean values of the characteristics determined on different dates, and the mean increases in the value of different characteristics between consecutive dates. Since the study groups were small, a non-parametric test (Wilcoxon matched-pairs test) was also used

Mann-Whitney U test was used to determine the significance of the differences found between the groups.

Significance in all the tests was accepted for values of $p<0.05$. The statistical analyses were conducted using the STATISTICA 2009 software package.

RESULTS

The comparison of the variables defining somatic characteristics in the study group and in the control group was

Table 2. Basic characteristics of the patient groups

Characteristics / group	SG	CG
Gender [male/female]	5/3	7/8
Age [years]	62.3 ± 9.4	67.7 ± 9.2
Body weight [kg]	75.6 ± 9.3	74. 8 ± 10.2
Height [cm]	1.7 ± 0.1	1.7 ± 0.1
BMI [kg/m^2]	25.6 ± 1.7	26.9 ± 3.1
Time after stroke [years]	4.4 ± 3.1	4.1 ± 2.8
Lesion type [ischaemic/haemorrhagic]	8/0	12/0
Hemiparetic side [right/left]	2/6	5/7

mean (SD)
There were no significant differences between the groups.

Table 3. Percentage differences in weight distribution on the directly affected lower extremity (DL) and healthy leg (HL) at baseline and after the completion of the rehabilitation period

EYES OPEN	Differences in weight distribution on the NL and DL (% - N/cm^2) – mean ± SD		Reduction of the differences in weight distribution on the NL and DL and the terms (% - N/cm^2) – mean ± SD Eyes open
	Baseline test–eyes open	End test–eyes open	
Study group (n=8)	30.6 ± 19.6%	17.8 ± 15.2% *	12.2 ± 12.9% #
Control group (N=12)	20.1 ± 18.4%	18.7 ± 18.2%	2.4 ± 4.9%
EYES CLOSED	Differences in weight distribution on the NL and DL (% - N/cm^2) – mean ± SD		Reduction of the differences in weight distribution on the NL and DL and the terms (% - N/cm^2) – mean ± SD Eyes closed
	Baseline test–eyes closed	End test–eyes closed	
Study group (n=8)	26.9 ± 16.9%	18.1 ± 17.3% *	8.1 ± 7.2%
Control group (N=12)	18.9 ± 20.9%	16.5 ± 18.8%	2.4 ± 9.6%

*p <0.05 − versus baseline test
# p <0.05 versus control group

performed using the Mann-Whitney U test. The analysis of the significance of the differences existing between the groups revealed that they were statistically insignificant. The groups proved to be uniform in terms of age, body weight, height and BMI (Table 2).

To evaluate the changes arising from the rehabilitation and sensorimotor foot stimulation programme, changes in weight distribution on the lower extremities were determined. The changes in weight distribution on the feet were evaluated in two tests of the lower extremity directly affected by stroke ("dysfunctional leg", DL) and of the healthy lower extremity (not directly affected by stroke, "healthy leg", HL). The changes in weight distribution on the extremities were assessed in tests with subject`s eyes open and closed

The results are presented in Tables 3 and 4.

The patients in the SG and in the CG unevenly distributed weight on their lower extremities, and tendied to carry their body weight on the healthy leg. This tendency was observed both in the eyes-open and eyes-closed tests, prior to and after the rehabilitation regime in both groups of patients. A significant reduction of the difference in weight distribution on the feet between the DL and HL was only observed in the study group (SG) − both in the eyes-open and eyes-closed tests. In addition, in the eyes-open test, the difference was significantly reduced compared to the control group.

The load on the DL increased significantly only in the study group, both in the eyes-open and eyes-closed tests. Moreover, the increase in load on the DL in the eyes-open test in the SG was statistically significant in comparison to the CG.

DISCUSSION

Few studies have investigated the effects of active or passive stimulation of the foot of post-stroke patients[20]. It is necessary to constantly search for new methods of rehabilitating patients with a history of stroke, and examine the effectiveness of such methods. Our present study highlights the need of conducting high-quality studies using large homogeneous groups in the field of active stimulation.

An earlier study by Forghany et al.[21] showed that an abnormal or asymmetrical foot posture was observed in a minority of stroke patients. The present study found there was considerable asymmetry of weight distribution on the feet both in the study group and in the control group, even after completing the rehabilitation programme. It was also demonstrated that sensorimotor training of the foot can contribute to increasing the weight distribution on the foot affected by the stroke reducing the weight-bearing imbalance between the legs, under static conditions.

Table 4. Load on the lower extremity directly affected by stroke (DL) and differences in the increase of the total load on the DL prior to and after completing the rehabilitation programme.

EYES OPEN	Load on the DL (% - N/cm^2)–mean ± SD		Increase in the total load on the DL (% - N/cm^2)–mean ± SD Eyes open
	Baseline test–eyes open	End test–eyes open	
Study group (n=8)	34.7 ± 6.7%	41.4 ± 7.6%*	6.5 ± 6.7% #
Control group (N=12)	39.9 ± 9.2%	40 ± 9.2%	0.7 ± 4.9%
EYES CLOSED	Load on the DL (% - N/cm^2)–mean ± SD		Increase in the total load on the DL (% - N/cm^2)–mean ± SD Eyes closed
	Baseline test–eyes closed	End test–eyes closed	
Study group (n=8)	36.5 ± 8.5%	40.6 ± 8.7%*	4.1 ± 3.6%
Control group (N=12)	40.5 ± 10.5%	41.7 ± 9.4%	1.2 ± 4.8%

*# p <0.05 versus control group
p <0.05 − versus baseline test

The sensorimotor foot stimulation (SFS) was a training item complementing a comprehensive rehabilitation programme based on highly specialized physical therapy procedures. In addition to the comprehensive rehabilitation programme carried out in the hospital, SFS provided the additional beneficial effect of reducing the asymmetry of weight distribution on the feet of post-stroke patients.

The physical exercise prescribed for the patients was instrumental in the increasing the force with exerted by the DL foot pressed on the ground. The initially disproportionate distribution of weight on both extremities was found to have decreased both under the eyes-open and eyes-closed conditions, which demonstrates there was an improvement in the proprioceptive sense of the foot. It seems that our proposed method was more effective than the sensory stimulation of the feet reported by Lynch et al.[22], who assessed the effects of the sensory retraining protocol involving the discrimination of different textures, sensation, postural control and gait. Our proposed method also appears more effective than the passive exercise regime based on a portable device discussed by Rudwig et al[23]. There were no significant differences between the study groups in the two studies.

Another line of research focuses on the assessment of a variety of physical therapeutic modalities applied in the foot region, and their effects on postural stability and the body's centre of gravity. Chen et al.[24] assessed the outcomes of thermal stimulation on the motor and balance functions of post-stroke patients. They showed thermal stimulation had positive impact on the motor function of the affected leg and on body balance. In the study by Magnusson et al.[25], patients in the treatment group received galvanic stimulation and sensory stimulation based on traditional Chinese acupressure. They demonstrated there was an enhancement of postural function and quality of daily life, which was maintained after more than two years after stroke.

Until now no studies have focused focusing specifically on the effects of sensorimotor foot stimulation on the symmetry of weight distribution on the feet of stroke patients. However, it is worthwhile to mention studies investigating the importance of the plantar surface of the foot and its role in postural stability in groups of healthy individuals. Kavounoudias et al.[12] showed the importance of the foot sole in correcting irregularities between body posture and body balance. Plantar skin, together with other senses, enables control and planning of body posture by the central nervous system. The experiment involved the stimulation of the mechanoreceptors in the foot with vibrations of high frequency and amplitude. Nurse et al.[26] demonstrated the contribution of sensory feedback from the feet to body posture maintenance, and the importance of sensory stimulation for the activity of muscles during gait. These studies were based on the exposure of the plantar surface of the foot and lower leg muscles to cold (ice).

In post-stroke patients, most studies have focused on forms of rehabilitation which have a direct influence on the maintenance of balance. Srivastava et al.[27] examined a larger group of 45 patients aged 22–65. They demonstrated there was a beneficial effect of training based on visual feedback using the Biodex Balance Master on the sense of balance. Tyson et al.[28] studied a total of 29 stroke patients aged 28–82. A major improvement in the parameters defining the speed of gait, balance and the force of plantar flexion was noted after TENS stimulation. The studies discussed above were notable for the large age ranges of their participants.

The participants of our study were aged 51–80. Thus, the age range of our study group were quite homogeneous compared to these earlier studies.

Another strong point of our study was the fact that we selected a group of patients in the chronic, but quite narrow, period following the stroke episode (more than a year; mean: 4.2 years; range: 1–9 years). This fact may facilitate future comparisons, e.g. focusing on the outcomes of sensorimotor foot stimulation in the acute phase of the disease in contrast to the chronic phase. In the study by Geiger et al.[29], 13 outpatients with hemiplegia whose age ranged from 30 to 77 years were examined. The subjectswere 15 to 538 days post-stroke, which means that they included both patients in the acute and chronic post-stroke stages. Harris et al.[30] studied a group of 99 patients aged 50–93, who were 1 to 24 years post-stroke. A question thus arises whether such a large age span − and an even greater divergence in the post-stroke periods under analysis − may be a limitation affecting the conclusions drawn from the studies.

The present study provides valuable insights into the rehabilitation of patients in the chronic post-stroke phase. Nevertheless, it also had certain limitations, such as the small number of participants and the lack of functional tests to verify the impact of therapeutic interventions on daily activities; therefore, it should be treated as a pilot study. Attempts should be made in the future to conduct studies of larger numbers of subjects. These two items definitely warrant further investigation in future studies on sensorimotor foot training.

Our present study proved the validity of the therapeutic modality used. Thus, the problem under study, i.e. the assessment of the effects of sensorimotor foot training on the symmetry of weight distribution on the lower extremities, seems a legitimate research effort. A more even weight distribution enhances the potential for balance control in the standing position in patients aged between 54 and 80.

Finally it is in our opinion that sensorimotor stimulation of the feet of thepatients in the chronic post-stroke phase elicited an increase in the load on the side of the body directly affected by stroke, and a decrease in weight distribution asymmetry between the feet in the standing position, with their eyes both open and closed.

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