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Evaluation of the impact of exercise of gait on a treadmill on balance of people who suffered from cerebral stroke

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Purpose: The aim of the study is to define the impact of exercise on a treadmill on static balance and stability of posture in a group of patients after cerebral stroke rehabilitated in a late period, with an application of a treadmill with the function of visual biofeedback. *Methods:* The examination was carried out in a group of 46 people in a late period after ischemic cerebral stroke. The patients examined were randomly put to a group with intervention ($n = 23$), in which a rehabilitation programme with an application of a treadmill with the visual feedback function was realized and to a control group ($n = 23$). They evaluated balance in standing on both feet by means of a force plate, symmetry of load of lower limbs and dynamic balance in Up & Go test. *Results:* A statistically significant change of stabilometric parameters was observed only in the area of postural sways of the centre of pressure (COP). A significant improvement of the symmetry of load of lower limbs in standing ($p = 0.0266$) was diagnosed in the examined group after the end of the programme. After the end of the programme no significant difference between the group with intervention and the control group as for a change of balance of the examined patients was found. *Conclusions:* In the examined group in the chronic period after cs no significant improvement of stabilometrically evaluated balance was obtained, but improvement of the symmetry of load of lower limbs as well as improvement of dynamic balance were observed.

Key words: *balance, biofeedback, treadmill, cerebral stroke*

1. Introduction

The effects of cerebral stroke (cs) such as pareses, paralysis, abnormal field of vision and disorders of balance are the reason for defective function of gait, which leads to considerable limitation of activity and independence. Most of the patients who had a cerebral stroke, during the first 6 months after the stroke regain the ability of independent gait, but it is often impaired and inefficient, and it significantly limits functional activity and the quality of life. One of the main aims of rehabilitation of patients after cerebral stroke is reproduction of the function of gait and balance, since keeping balance in standing on both feet and on one foot is a necessary condition for independent and safe gait [15], [13].

Balance is a complex motoric function, which depends on mutual interaction of many sensomotor, environmental and functional processes [5], [14]. After cerebral stroke this function is often damaged, and its intensity depends on the scale of damage. In patients with paresis after cs in standing on both feet one observes asymmetry and shift of the limb load and the centre of gravity of the body towards the non-paretic limb [4], [12]. Disorder of symmetry of the limb load in standing affects the disorder of the symmetry of gait mainly by prolonging the phase of support on the non-paretic limb, prolonging the phase of shifting and reducing the length of step of the paretic limb [21].

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In the evaluation of static balance the analysis of involuntary postural sways of the centre of pressure (COP) of the body reflects the process of balance control in anteroposterior (A-P) and mediolateral (M-L) direction in calm standing [2]. In comparison with healthy persons, patients with hemiparesis after cs in standing have a wider scope of postural sways of COP with a bigger shift of load in the direction of the paretic limb [7].

Evaluation of postural sways of COP is directly connected with balance and gait of people after cs, it makes it possible to observe the process of rehabilitation, assess the efficiency of repair programmes and assess the risk of falling [20].

One of the forms of learning and improving gait is exercise on a treadmill using methods of visual biofeedback. Training on a treadmill influences improvement of parameters of gait and gives good effects both in the early and late period after the stroke [9], [11], [16], [18]. Including in teaching gait on a treadmill additional external visual and aural information about a proper model of gait and its parameters, i.e., speed, length of step and symmetry of phases of gait enable the patient not only to improve the symmetry of gait but also balance, coordination and strength and endurance of particular muscle groups [19], [22], [23]. Hesse proves that training on a treadmill causes improvement of the symmetry of gait, stimulates repetition and rhythmicity, which increases coordination, strength and endurance [8]. Biofeedback methods and techniques of virtual reality used in teaching gait provide the learner in a visual and acoustic form with additional processed kinematic, kinetic information or emg signals, which lets them correct the model of gait systematically.

Results of many examinations show positive influence of balance exercise with the use of biofeedback on improvement of balance and gait and improvement of functional activity after stroke [1]. On the other hand, there is little information evaluating change of balance and statics of the body after training of gait, especially when it aims at reproduction of symmetry of the length and width of step with the application of biofeedback methods. The aim of the analysis is to define the impact of exercise on a treadmill on static balance and stability of posture in the group of people after cs treated in the late period with the application of a treadmill with the function of visual feedback. A hypothesis has been assumed that exercise on a treadmill with visualisation in real time of the symmetry, length and width of step will have an impact on improvement of stabilometric parameters of balance in standing on both feet and dynamic balance evaluated in a functional test. The results of the examination will provide essential information for planning programmes of rehabilitation of people after cerebral stroke.

2. Methods

2.1. Subjects

The examination was performed in a group of people who in 2010–2011 went through rehabilitation in Clinical Rehabilitation Ward of Province Hospital No. 2 in Rzeszów. Qualification criteria: first ischemic cerebral stroke (confirmed by CT or MR test), being able to keep balance in standing on both feet with closed eyes for at least 30 seconds, independent gait, period of getting better according to Brunnström 3 to 4, spastic tension of the paretic lower limb according to Ashworth ≤ 1 plus, level of disability 3 in Rankin Scale. People with insufficiency of the cardiovascular system, with disorders of cognitive functions (Mini Mental Scale > 24), with diseases of the organ of movement significantly limiting and disturbing gait and with disorders of the field of vision were not qualified. The examination did not comprise people who used other forms of physiotherapy during the programme.

All participants of the programme were very well informed about the aim and the course of the examination and they gave their written consent to take part in the examination. The examination protocol was confirmed by the Bioethical Committee of the Medical Department of Rzeszów University, Poland (No. 5/11/2009) and was accepted by the National Science Centre, Poland (No. N N404 249639) for realization within the project "Evaluation of the impact of biofeedback on reproduction of the functions of gait in patients with paresis after cerebral stroke".

People qualified for the programme were randomly included in a group with intervention and a control group. Randomization by means of a computer programme was done by a member of the research team who did not participate in the evaluation of the patients and did not conduct the exercise. Decoding of the qualification to the groups was done after finishing the programme.

2.2. Procedure

The programme was planned for 12 days for each participant. On the first day (Thursday and Friday of the week directly preceding the beginning of the programme) evaluation of static balance and evaluation of functionality of gait were performed. On the next 10 days (every day for two weeks, from Monday to Friday) the programme of exercise was carried out. On the last twelfth day of the programme (Monday and Tuesday in the first week after the end of the programme) a final examination was performed. The initial and final examinations were performed at the same time before noon, in the same room. The examination was performed by the same person (a member of the research team), who did not take part in the randomization and did not conduct the exercise.

For training on a treadmill they used a treadmill Gait Trainer 2 Biodex (Biodex, serial 0808501) with visualisation function in real time of the length of step (Fig. 1). The time of the exercise on the treadmill was from 15 minutes in the first training to 30 minutes in the subsequent trainings.

During the training the examined group had a biofeedback programme installed with visualisation of the length of step and an acoustic signal confirming correct fulfilment of the task. In the first exercise the speed of gait and the prescribed length of step were chosen individually for everyone in the way which would enable the person being trained to perform the task and walk keeping the symmetry of the length of step. The initial speed of gait for the examined group was 0.34 m/s and was increased in every following training. The increase of the speed of gait was accompanied by increase of the length of step. The participants from the control group trained on the same treadmill without biofeedback function. Trainings on a treadmill for all participants were preceded by preparation during individual exercises. The total day time of all exercise was 70 minutes altogether. The individual exercises comprised active and supported exercises of lower limbs, the beam exercise in sitting and standing and respiratory exercise.

2.3. Measurements

They assessed static balance in standing on both feet on a force platform, symmetry of load of lower limbs and they evaluated dynamic balance in the functional independence test Timed Up & Go. Stabilometric evaluation of balance was performed by means of a force platform Kistler (model 9260 AA). During the examination the patient was standing with the feet arranged at an angle of 30° and with the distance of 2 cm between the heels. During the examination the patients were standing without shoes and they were not using orthopaedic aids. The test with open eyes lasted 30 s, and the patient was to look at a point on the wall 2 meters from him/her. Just after the test with open eyes there was a test of standing with closed eyes for 30 seconds. They analysed the length of the path of movement of COP (mm), the surface area of movement of COP (mm^2), COP range scalar in anteroposterior (A-P) direction and COP range scalar in mediolateral (M-L) (mm) direction. Up & Go test was performed at a distance of 3 m. In the test the patients' task was to stand up from a chair without any assistance (a standard chair with a backrest, without an armrest), walk the distance of 3 metres, turn back in a designated place, come back to the chair and sit down without any assistance [17]. During the test the

Fig. 1. Training on the treadmill

examined moved at any speed and used their own orthopaedic equipment.

The symmetry of load of lower limbs in standing was calculated on the basis of the values of load of lower limbs in standing evaluated with the application of a set of two tensometric platforms. The result of the measurement as the value of load in kilograms was obtained for every limb as an averaging value of a 10-second attempt of independent standing. The symmetry ratio (sr) was calculated dividing the higher value by the lower one independently of the side of paresis. Value 1.0 indicates full symmetry of load of lower limbs in standing.

2.4. Statistical analysis

The statistical analysis of the results was carried out by means of the programme Statistica ver. 10.0 (StatSoft, Poland). The normality of the distribution of the features examined was evaluated by means of the Shapiro–Wilk test. They assessed the significance of the effects of rehabilitation by means of Wilcoxon's statistical test. Then they compared the level of the effects of rehabilitation as referred to the kind of therapy. They presented the values of descriptive statistics (especially mean values) of the measurements taken in both groups for every examination as well as the difference between particular examinations (of the effect of rehabilitation). The evaluation of the significance of the differences in the level of fitness and the effects of rehabilitation in both groups compared was carried out by means of the Mann–Whitney test. The test result $p < 0.05$ was assumed as a statistically significant level.

3. Results

On the basis of qualification 46 people were comprised in the examination. They were randomly qualified to a group with intervention ($n = 23$) and to a control group ($n = 23$). The flow of participants is demonstrated in Fig. 2. The average age of the participants was 61.5 years (median of age in group with intervention 60.5 years, median of age in control group 61.0) and did not diversify the groups in a statistically significant way. The time from the occurrence of the stroke in both groups was characterised by a big range. The time median from the stroke in the examined group was 36 months (mean 46 months) and in the control group 18 months (mean 40.2 months). The people from the examined group and the control group did not significantly differ before the beginning of the programme. A demographic and clinical characteristics in the initial examination are shown in Table 1.

No statistically significant change of the length of the path of movement of COP both on the level of the whole group of participants ($p > 0.05$) and in the

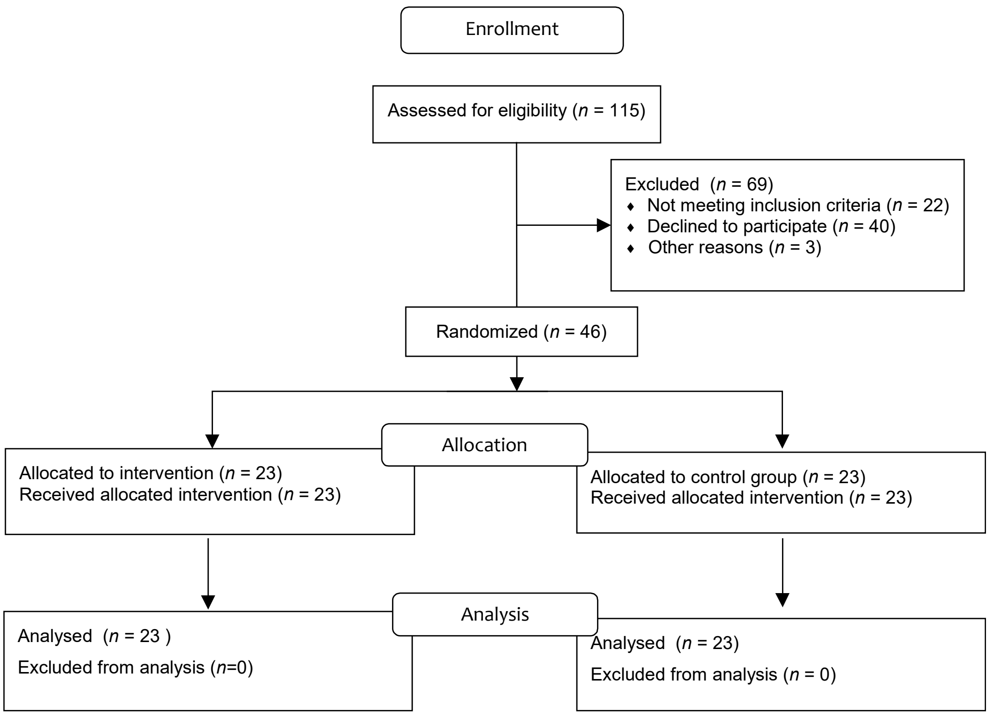

Fig. 2. Flow of participants through the trial

separately analysed control group and the group with intervention was observed. There are also no grounds for conclusions concerning the existence of differences between the groups. In the examination with closed eyes the length of the path of COP increased considerably in both groups in comparison with the results of the examination with open eyes ($p < 0.001$), but it was not shown that the examined group obtained a significant difference between the results from the control examination and the first examination. No significant difference was shown between the change in the examined group and the group with intervention (Table 2).

In the analysis of the size of the surface area of the movement of COP in the test with open eyes they observed slight increase of the mean surface area of movement of COP in the group with intervention and decrease in the control group. The difference in each group was not statistically significant. Also as for the change between the groups no statistically significant difference was found (Table 3). In the test with closed eyes in the group with intervention statistically sig-

Table 1. Demographic characteristics and clinical evaluation in the initial examination of the participants of the programme

	Group with intervention (*n* = 23) Mean (SD)	Control group (*n* = 23) Mean (SD)	*P*
Age/years/ [range]	59.9 (11.4) [38–77]	61.5 (10.8) [42–79]	*0.4378*
Sex women/men, *n* [%]	7 (32)/16 (68)	9 (40)/14 (60)	–
Time from the stroke/months/ [range]	46.1 (43.0) [8–180]	40.2 (40.8) [8–180]	*0.0587*
Left-side paresis, *n* [%]	20 (84)	13 (56)	–
Right-side paresis, *n* [%]	3 (16)	10 (44)	–
EO COP Length [cm]	5.82 (4.2)	4.85 (2.3)	*0.9137*
EC COP Length [cm]	9.08 (7.3)	7.06 (5.6)	*0.3398*
EO Sway Area [cm^2]	4.31 (3.6)	6.69 (9.7)	*0.3912*
EC Sway Area [cm^2]	8.03 (9.5)	9.21 (6.7)	*0.8566*
COP EO A-P Range Scalar [cm]	0.24 (0.1)	0.249 (0.2)	*0.7087*
COP EO M-L Range Scalar [cm]	0.17 (0.1)	0.224 (0.1)	*0.0620*
COP EC A-P Range Scalar [cm]	0.31 (0.2)	0.274 (0.2)	*0.4616*
COP EC M-L Range Scalar [cm]	0.22 (0.12)	0.23 (0.1)	*0.6731*
Ws ratio	1.49 (0.5)	1.51 (0.63)	*0.5674*
Up & Go test [s]	16.5 (7.7)	18.6 (8.2)	*0.1579*

SD – standard deviation, EO – eyes open, EC – eyes closed, A-P – anteroposterior, M-L – medial-lateral, Ws ratio – weight symmetry ratio, p-result of Wilcoxon's test.

Table 2. Values of analysed parameters in the initial and final examination after the end of the programme and the value of improvement in the examined group and in the control group

	Intervention		control		
	Pre intervention Mean (SD)	Post intervention Mean (SD)	Pre intervention Mean (SD)	Post intervention Mean (SD)	*p*
EO COP Length [cm]	5.82 (4.2)	5.76 (5.3)	4.85 (2.3)	5.5 (7.4)	*0.3649*
EC COP Length [cm]	9.08 (2.8)	8.69 (4.7)	7.06 (5.6)	7.77 (5.1)	*0.2605*
EO Sway Area [cm^2]	4.31 (3.6)	4.4 (2.1)	6.69 (5.6)	6.05 (4.1)	*0.2928*
EC Sway Area [cm^2]	8.03 (9.5)	9.18 (8.6)*	9.21 (7.7)	6.76 (6.7)*	*0.8756*
COP EO A-P Range Scalar [cm]	0.24 (0.1)	0.21 (0.1)	24.9 (0.2)	0.26 (0.1)	*0.1706*
COP EO M-L Range Scalar [cm]	0.17 (0.1)	0.21 (0.1)	0.22 (0.1)	0.23 (0.1)	*0.9520*
COP EC A-P Range Scalar [cm]	0.31 (0.2)	0.28 (0.1)	0.27 (0.2)	0.32 (0.1)	*0.2307*
COP EC M-L Range Scalar [cm]	0.22 (0.1)	0.31 (0.2)	0.23 (0.1)	0.25 (0.2)	*0.3522*
Ws ratio	1.49 (0.5)	1.24 (0.4) *	1.51 (0.6)	1.38 (0.5)	*0.1933*
Up&Go [s]	16.5 (7.7)	12.0 (4.0) ***	18.6 (7.2)	14.4 (6.6) ***	*0.0807*

EO – eyes open, EC – eyes closed, A-P – anteroposterior, M-L – medial-lateral, SD – standard deviation, Ws – weight symmetry ratio, *p* – result of Wilcoxon's test,*– result of Mann–Withney's test * – < 0.05, ** – $p < 0.01$, *** – $p < 0.001$.

Table 3. Mean values of the change of the examined parameters of balance

	Intervention group Mean (SD)	Control group Mean (SD)	*p*
EO COP Length [cm]	–0.06 (2.6)	0.64 (2.8)	*0.9328*
EC COP Length [cm]	–0.39 (6.6)	0.72 (2.6)	*0.7632*
EO Sway Area [cm^2]	0.09 (4.0)	–0.64 (9.7)	*0.6731*
EC Sway Area [cm^2]	1.15 (10.1)	2.5 (5.3)	*0.7449*
COP EO A-P Range Scalar [cm]	–0.02 (0.1)	0.01 (0.2)	*0.4186*
COP EO M-L Range Scalar [cm]	0.04 (0.1)	0.002 (0.1)	*0.4616*
COP EC A-P Range Scalar [cm]	–0.03 (0.2)	0.05 (0.1)	*0.1419*
COP EC M-L Range Scalar [cm]	0.09 (0.2)	0.04 (0.2)	*0.8946*
Ws ratio	–0.25 (0.3)	–0.13 (0.4)	*0.0765*
Up & Go (s),	–4.5 (5.0)	–4.2 (2.4)	*0.4882*

EO – eyes open, EC – eyes closed, A-P – anterio-posterior, M-L – medial-lateral, SD – standard deviation, Ws – weight symmetry ratio, *p* – result of Mann–Whitney test.

nificant increase of the surface area of COP in comparison with the initial examination was observed and in the control group statistically significant decrease of postural sways of COP was found (Table 2). The difference between the groups was not statistically significant (Table 3).

The amplitude of postural sways of COP towards A-P in the group with intervention decreased both in the trial with open and closed eyes, but the difference was not statistically significant ($p > 0.05$). However, in the control group an increase of the amplitude of postural sways of COP towards A-P in both trials was found. The difference was not statistically significant. Also there was no statistically significant difference between the mean value of the change in the group with intervention and the control group (Table 3). In the direction of L-M in the group with intervention they found an increase of the amplitude of postural sways of COP in the trial with open and closed eyes and in the control group the amplitude of postural sways in the direction of L-M decreased (Table 2). The differences in each group were not statistically significant and the difference between the mean value of the change between the groups was also not significant (Table 3).

In the initial examination in both groups they found disturbance of symmetry of load of the lower limbs in standing, with overloading of the non paretic limb. After the end of the programme they found improvement of the symmetry of load of the lower limbs in standing. In the group with intervention the improvement was statistically significant ($p = 0.0266$). The difference of the mean value of improvement of the ratio of symmetry between the groups was not statistically significant (Table 2, Table 3).

In Up & Go test in the whole group as well as in the examined group and in the control group separately they observed significant changes (shorter time of doing the test). A bigger improvement was obtained by people from the examined group, but the difference between the mean value of the improvement in the group with intervention and the control group was not statistically significant (Table 2, Table 3).

4. Discussion

The aim of the analysis was to evaluate the impact of exercise on a treadmill on the balance of patients with hemiparesis after cerebral stroke.

In the examination they used visual time-space feedback, which showed the exercising person in the real time the area in which the feet should be placed during gait. For most of the people the task required changing the mechanism of gait by prolonging the step made by the non paretic limb with simultaneous shortening of the step made by the paretic limb and prolonging the time of supporting phase on the paretic limb with simultaneous shortening of the supporting phase on the non paretic limb. These changes require from the exercising person active shifting of the weight of the body to the limbs during gait, which requires better coordination and balance. It was the basis for the assumed hypothesis that a planned training on a treadmill affects an improvement of dynamic and static balance of people who suffered from cerebral stroke.

Yang [25] evaluated effects of learning gait on a treadmill with the application of virtual reality in a randomised examination in a group of 14 people who had had a stroke. The authors evaluated static balance on force platforms, symmetry of load of lower limbs, the number of steps made with the paretic limb and the load of the foot of the paretic limb in standing, shifting from sitting to standing and gait. The author showed that neither traditional training on a treadmill nor training on a treadmill with the use of virtual reality had had significant influence on static balance of the examined but training with virtual reality influenced significantly bigger shift of COP in medial-lateral direction and improvement of the symmetry of load of limbs in standing up and gait. A similar examination in a group of people in the chronic period after stroke was carried out by Cho [3]. In a 16-people group he showed that people using virtual techniques had obtained bigger improvement of balance evaluated on the Berg scale and Up&Go test in comparison with the group with conventional exercise. On the other hand, in a randomised examination whose aim was to evaluate the impact of learning gait with the application of techniques of virtual reality, Cho and the co-authors did not show any significant change in static balance but a significant improvement in the examined group was diagnosed in evaluation of dynamic balance.

The stabilometric examination showed no significant change of static balance either in the group with intervention or in the control group. A change of little statistical significance was observed in the trial with closed eyes as referred to the mean surface of the area of postural sways of COP. In the control group they showed a decrease of the area of postural sways ($p = 0.0447$) and in the group with intervention an increase ($p = 0.0511$). At the same time, in the evaluation of the load of lower limbs in standing they observed a decrease of the asymmetry of load ($p = 0.0266$) in the group with intervention with no significant change in the control group. The obtained result concerning a change of the surface area of postural sways of COP can be interpreted as worsening in the group with intervention and improvement in the control group, but with simultaneous decrease of overloading the non paretic limb and an improvement of symmetry of load of the limbs in standing observed in the group with intervention the result should be interpreted as positive and in accordance with the expectation. A clinical confirmation of the improvement is a simultaneous statistically significant shortening of the time of doing Up&Go test. Thus, after the end of the programme the participants from the group with intervention were standing with smaller asymmetry of load of the lower limbs, had better dynamic balance in spite of the worse result of the evaluation of static balance. Very small changes were found in the length of the path of COP and the amplitude of postural sways of COP in A-P direction. In the group with intervention the amplitude of postural sways of COP in the medial-lateral direction prolonged. The change after the end of the programme was not statistically significant and it was not significantly different from the change in the control group. In spite of the lack of a homologous improvement of static balance, in all participants of the programme they observed a considerable functional improvement of gait and balance assessed in Up & Go test. A statistically significant improvement of functional efficiency of gait was obtained by patients in the late period after stroke, which is consistent with the results of many studies in which they showed that training on a treadmill affects improvement of gait and balance both in the early and late period after stroke [6], [9].

5. Conclusions

In the examined group of people in the chronic period after cs no significant improvement of stabilometrically evaluated balance was obtained, but an improvement of symmetry of load of the lower limbs and an improvement of dynamic balance was found. The results of the examination let us suppose that the applied method of time-space biofeedback is a good form of supporting the process of re-education of balance and gait of people who had stroke.

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