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ORIGINAL REPORT

FUNCTIONAL EFFECTS OF ROBOTIC-ASSISTED LOCOMOTOR TREADMILL THERAPY IN CHILDREN WITH CEREBRAL PALSY

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Objective: **The aim of this study was to assess gait in children with spastic diplegic cerebral palsy rehabilitated with the use of Lokomat active orthosis.**

Design: **A randomized controlled trial.**

Subjects: **Fifty-two children with spastic diplegic cerebral palsy.**

Methods: **Temporospatial parameters of gait and selected kinematic parameters were assessed. Children from the study group used active orthosis in addition to following a programme of individual exercises. Children in the control group participated only in individual exercises.**

Results: **The difference between the initial and control examinations was statistically insignificant. After the programme was finished, there was a slight improvement in walking speed in both groups. Improvement in the mean walking speed was not significantly different between the groups ($p = 0.5905$). Range of motion decreased slightly in both groups, and the difference between mean amounts of change was not significant ($p = 0.8676$). There was significant improvement in maximal range of flexion in the hip joint ($p = 0.0065$) in the study. It was shown that with a decrease in the mean value of adduction in hip joint, the mean walking speed increased ($r = –0.53$, $p = 0.0011$).**

Conclusion: **There are several limitations to this study, therefore these results should be regarded as preliminary. Further research consistent with the above indications is needed to investigate the impact of this new treatment option in patients with cerebral palsy.**

Key words: robotic-assisted treadmill therapy; cerebral palsy; task-specific learning; children.

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INTRODUCTION

Cerebral palsy (CP) is the most common lifelong disability affecting motor development. For some decades, the overall incidence of CP in countries of the Western world has remained stable, at approximately 2–3 per 1,000 births (1, 2), with a higher prevalence among children born pre-term (3). The International Working Group on Definition and Classification of Cerebral Palsy defined cerebral palsy as: "… a group of permanent disorders of the development of movement and posture causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing foetal or infant brain" (4). This definition emphasizes motor impairment as the essential aspect of CP. Motor deficits of CP include negative phenomena, such as weakness, fatigue, and incoordination, and positive phenomena, such as spasticity, clonus, rigidity and spasms. Spasticity is a velocity-dependent, increased muscle tone with hyperreflexia resulting from hyperexcitability of the stretch reflex. It can lead to muscle stiffness, functional impairment, and atrophy. If not treated, it can progress to muscle fibrosis, contractures and musculoskeletal deformities (5). Abnormal gait is a common problem in children with CP. These children are at great risk of deterioration in their walking ability as they mature. Many treatment modalities have been developed in the past decade, depending on the age of the child and the nature and severity of their limited walking ability. Because of the importance of planning in the timing of interventions and the difficulty in predicting the outcome of different therapeutic regimens, it is essential to monitor the patient and perform gait analysis before and after an intervention (6). Better gait function, for example, in terms of higher speed, less pronounced tendency to fall, and better ability to walk on uneven surfaces, may improve the children's possibilities for participation (7). Acquisition of independent, effective, and safe gait is therefore the most important goal of rehabilitation in children with CP. The central nervous system (CNS), through mechanisms of brain plasticity, has the capacity to learn and adapt. Brain plasticity may be intensified by exercise, including movement activities, and the effect of motor learning depends on the intensity and regularity of performing these.

Recent advances in basic and clinical neuroscience give hope that the implementation of effective functional therapies based on enhanced activity will be crucial in improving the level of

functioning in children with CP (8, 9). Current concepts of motor learning assume that repetitive, task-specific training, enabled by a driven gait orthosis, may be a cost-effective means allowing for an improvement in walking ability (10, 11). One of the latest solutions in this area is the Lokomat (Hocoma AG, Volketswil, Switzerland), which was designed for adults and shown to facilitate significant improvements in individuals with spinal cord injury (12–14). A paediatric device for children age 4 years and over has been available since 2006; however, there are only a few studies assessing body-weight-supported treadmill therapy applied to paediatric patients. This orthosis is an exoskeleton, i.e. two-leg braces that allow the patient to achieve a physiological step movement using both legs. The device is driven by integrated computer-controlled miniature motors, while the hip and knee joints are constantly monitored by software. A walking speed of between 1 and 3.2 km/h can be selected and adjusted during the training session. Dorsiflexion of the ankle joint is achieved using an elastic foot lifter. Paediatric Lokomat is adapted to the individual patient's anatomy. A dynamic body weight support system can take the strain of the patient's body weight to such an extent that a controlled stance phase can be achieved. To ensure patient safety while training, a range of safety features has been implemented, which stop the device immediately in the event of any anomalies.

Other studies (15, 16) found no advantage in the use of Lokomat compared with conventional therapy, and systematic reviews regard the evidence as controversial (17), therefore further research is required.

METHODS

Subjects

Children with CP, aged 6–13 years, participated in the study. Inclusion criteria were: children with spastic diplegia; the ability to independently stand and walk or walk with assistance; a classification of level II–III in the Gross Motor Function Classification System (GMFCS); and no disorders of higher mental functions. Exclusion criteria were: children treated with botulinum toxin during the last 6 months; children treated surgically within a 1-year period before the date of the examination; active drug-resistant epilepsy; anatomical leg length discrepancy larger than 2 cm (due to the Lokomat system limitations); fixed contractures; bone and joint deformities; bone-articular instability (joint dislocation); baclofen therapy using an implanted infusion pump; inhibiting casts during the last 6 months; significant amblyopia and hearing loss; inflammation of the skin and open skin lesions around the trunk or limb; contra-indications for training on a treadmill; and lack of patient cooperation. A total of 52 children meeting the inclusion criteria, were enrolled in the study. Children were randomly assigned to two groups of equal size. The study group consisted of 26 children participating in the rehabilitation programme using the Lokomat system (Table I). In the control group, 9 children completed the programme (17 children resigned from participation in the project for various reasons). The subjects' characteristics are shown in Table I.

Outcome measurements

The assessment was performed twice, before and after the therapeutic programme. Gait analysis was performed by means of the BTS Smart motion analysis system (BTS Bioengineering, Milan, Italy), by a team of people who did not participate in the exercises and were not aware of the assignment of children to study and control groups. Temporospatial and kinematic gait parameters obtained from 3-dimensional gait analysis were examined (Table II).

Table I. *Participants' characteristics*

	Randomized ($n=35$)		
Characteristics	Exp ($n=26$)	Con ($n=9$)	p-value
Age, years, mean, [median] (SD)	10.1 [10.5] (2.2)	11.0 [11.0] (2.3)	0.3052
Gender: males/females, *n* (%)	19/16 (54/46)		
GMFCS 2, *n* (%)	15 (58)	8 (89)	
GMFCS 3, *n* (%)	11 (42)	1 (11)	0.0893

GMFCS: Gross Motor Function Classification System; SD: standard deviation; Exp: Lokomat study group; Con: control group.

Treatment intervention

Children from the study group used active orthosis (the Lokomat system, Hocoma Company, Volketswil, Switzerland), and followed a programme based on individual exercises under the guidance of a physiotherapist. The control group did not use active orthosis and only participated in individual exercises with a physiotherapist. Both the study group and the control group participated in 20 therapeutic sessions. Individual exercises in both groups were aimed at improving motor control, increasing stability in the sitting and upright positions, and developing walking skills. The overall time assigned for exercise in both groups was the same. The Lokomat is a device that allows for gait training in the conditions of dynamic unloading accompanied by gait pattern simulation for the lower limbs, with an option to set gait parameters (velocity, step length). For each exercise, the parameters of training were selected individually and were based on the measurement of the length of limbs, the range of motion in the joints of the lower limbs, muscle tone, and body weight. The value of body weight support was selected taking into account the child's ability to walk, endurance, strength, and commitment to walking. A single training session was 45 min long. During the session, children were continuously provided with additional information, delivered verbally by the physiotherapist supervising the exercise, and in the form of graphical visualization showing their walking pattern on a monitor screen. This study was approved by the Local Bioethical Board (number KNW/0022/KB1/36/II/09, Medical University of Silesia in Katowice, Poland).

Statistical analysis

Analysis of the results shows the distribution of values for all investigated parameters during the initial and final examination, as well as

Table II. *Temporospatial and kinematic gait parameters analysed in the study*

Temporospatial parameters
Stance phase length (% of gait cycle)
Double support length (% of gait cycle)
Mean step width (m)
Mean gait speed (m/s)
Mean step length (m)
Kinematic parameters
Range of pelvic motion in coronal plane (º)
Range of pelvic motion in sagittal plane (º)
Range of pelvic motion in transverse plane (º)
Value of hip adduction at initial contact phase (º)
Maximum value of hip extension during stance phase (º)
Maximum value of hip flexion during swing phase (º)
Range of hip motion in sagittal plane (º)

Table III. *Results of the observed temporospatial parameters in the study and control groups*

Gait parameters	Initial measurement			Final measurement			Difference		
	Study group Mean (SD)	Controls Mean (SD)	*p*-value	Study group Mean (SD)	Controls Mean (SD)	*p*-value	Study group Mean (SD)	Controls Mean (SD)	*p*-value
Length of stance phase, % of gait cycle									
Right side	67.8 (6.9)	67.9 (7.8)	0.9262	67.9 (6.6)	68.2 (7.9)	0.8676	0.2 (4.0)	0.3 (3.8)	0.9262
Left side	68.3 (6.6)	65.1 (7.1)	0.2547	68.5 (7.4)	66.8 (7.1)	0.5157	0.2 (4.7)	1.7 (3.5)	0.1966
Step length, m									
Right side	0.26 (0.07)	0.28 (0.09)	0.5905	0.27 (0.09)	0.28 (0.1)	0.5157	0.01 (0.08)	0.00 (0.11)	0.4918
Left side	0.28 (0.09)	0.27 (0.11)	0.9852	0.29 (0.10)	0.29 (0.11)	1.0000	0.02 (0.10)	0.02 (0.10)	0.5650
Step width, m	0.19 (0.04)	0.18 (0.04)	0.8096	0.18 (0.04)	0.20 (0.03)	0.5157	0.00 (0.03)	0.01 (0.03)	0.3616
Length of double support phase of gait cycle	18.1 (7.3)	16.3 (8.2)	0.4918	18.8 (6.8)	16.8 (7.7)	0.4239	0.7 (5.7)	0.5 (4.7)	1.0000
Gait velocity, m/s	0.34 (0.14)	0.35 (0.14)	0.8096	0.36 (0.18)	0.39 (0.18)	0.7247	0.02 (0.12)	0.04 (0.11)	0.5905

SD: standard deviation.

the change in their values following rehabilitation. Selected descriptive statistics were used to describe the distribution of data. The significance of rehabilitation outcomes was measured with the Wilcoxon test. These comparisons are related to the entire cohort, both the control group and the study group.

Subsequent analyses compared the level of measured parameters (in both examinations), as well as the level of rehabilitation outcomes in the study group and in the control group. The significance of differences between these two groups was assessed with the non-parametric Mann-Whitney *U* test, precise version for small samples. The assumed statistically significant level was $p \leq 0.05$. The correlation level for the studied feature was assessed using Spearman's rank correlation coefficient.

RESULTS

The two groups did not differ significantly in terms of the temporospatial gait parameters (Table III). The stance phase for both the right and the left lower extremity was slightly longer in all subjects. After the programme was completed, the stance phase did not change visibly in the study group, while in the control group, the phase of standing on the left lower extremity was longer. The difference between the initial and final measurements in both groups was statistically insignificant. Similarly, the change understood as a difference found between the measurements was not material. In the initial measurement, the two groups were not significantly differentiated by the mean gait speed ($p = 0.8096$). After the programme was completed, the mean gait speed was found to have increased slightly in both groups, with the increase in the control group being the most notable. The improvement in the mean gait speed did not differ significantly between the groups ($p = 0.5905$).

The range of pelvic motion in the sagittal plane measured in the initial examination was similar in both groups for both the right and left side (Table IV). The range of motion decreased slightly in both groups, and the difference between the mean values of the change was not statistically significant ($p = 0.8676$). In the frontal plane, both the initial and final examination showed a smaller range of motion on the left side, while there was no statistically significant difference between the groups in the initial examination. In the final examination, the study group demonstrated a significantly greater increase in the mean value of the range in pelvic motion in the frontal plane on the right side, and, statistically, the change in the study group was found to be significantly larger ($p = 0.0130$).

The assessment of selected ranges of motion in the hip joints did not demonstrate statistically significant changes after completing the therapeutic programme, or any differences between the study group and the control group (Table V). Analysis of

Table IV. *Mean values and standard deviations (SD) of the observed range of pelvic motion in the study and control groups, the difference between measurements, and the results of statistical testing*

Gait parameters	Initial measurement			Final measurement			Difference		
	Study group Mean (SD)	Controls Mean (SD)	*p*-value	Study group Mean (SD)	Controls Mean (SD)	*p*-value	Study group Mean (SD)	Controls Mean (SD)	*p*-value
Range of pelvic motion in sagittal plane, º									
Right side	8.6 (2.8)	8.7 (1.4)	0.9557	8.5 (2.9)	8.4 (1.5)	0.7247	–0.2 (3.2)	–0.3 (1.5)	0.8676
Left side	8.8 (3.0)	8.4 (1.8)	0.6970	8.3 (3.8)	8.6 (1.6)	0.2709	–0.5 (4.3)	0.2 (2.5)	0.4025
Range of pelvic motion in coronal plane, º									
Right side	8.8 (5.2)	8.9 (4.0)	0.8968	13.8 (7.7)	8.2 (6.2)	0.0312	4.9 (8.5)	–0.7 (3.0)	0.0130
Left side	7.7 (2.8)	7.5 (1.6)	0.7810	8.5 (3.1)	6.6 (2.1)	0.1186	0.8 (2.7)	–0.9 (2.0)	0.0556
Range of pelvic motion in transverse plane, º									
Right side	17.0 (7.7)	15.3 (8.9)	0.5157	13.9 (8.1)	15.6 (9.0)	0.5650	–3.1 (9.9)	0.3 (4.1)	0.2709
Left side	18.1 (6.3)	18.5 (6.9)	0.8676	18.3 (6.1)	17.4 (7.4)	0.4239	0.2 (4.9)	–1.0 (3.3)	0.5650

the change in the mean value of the maximum flexion in the hip joint during the swing phase showed a statistically significant increase in the range of motion for the entire study group and control group ($p = 0.0065$).

The values of kinematic and temporospatial parameters were checked for correlations. The analysis took into account the values measured before the rehabilitation and the outcomes of the training. Before rehabilitation, there were no significant correlations between the range of pelvic motion and temporospatial parameters of gait. On the other hand, a number of statistically significant relationships between the range of motion in the hip joints and the temporospatial parameters were noted. A weak positive correlation was shown between the mean value of adduction in the right hip joint at initial contact phase and both the length of the stance phase on the left lower limb ($r = 0.48$, $p = 0.0033$) and the length of the double support phase ($r = 0.47$, $p = 0.0048$). It was also shown that, as the mean value of adduction in the hip joint decreases, the mean value of walking increases ($r = –0.53$, $p = 0.0011$). It was shown in the study group that, as the range of motion in the hip joint increases, the walking speed ($r = 0.48$, $p = 0.0035$) and step length also increase ($r = 0.62$, $p = 0.0001$). Other relationships analysed in the initial study were statistically non-significant. A significant relationship in the control study has only been shown between the range of motion of the hip joint in the sagittal plane and step length ($r = 0.68$, $p = 0.0000$).

DISCUSSION

Walking ability, which is extremely important for quality of life and participation in social and economic life, can be adversely affected by neurological disorders. Rehabilitation of patients with such disorders should include gait training, due to evidence that the desired function or movement has to be developed in a task-specific training programme (18, 19).

Recently, gait rehabilitation methods in patients with neurological impairments have relied on technological devices, which drive the patient's gait in a body-weight support condition and emphasize the beneficial role of repetitive practice (11). The rationale for these approaches originates from animal studies, which have shown that repetition of gait movements may enhance spinal and supraspinal locomotor circuits (20).

Recently published systematic reviews examine the effects of partial body weight supported treadmill training (PBWSTT) in individuals with CP, spinal cord injury, and acquired brain injury (for example, after stroke). Several studies have demonstrated improvements in locomotor ability in different patient populations receiving robot-assisted gait training (12–14, 21–23). However, the evidence so far is controversial. Randomized controlled trials have shown the effectiveness of PBWSTT, as well as promising effects on functional and motor outcomes in patients after stroke (13, 24). In contrast, a multicentre randomized clinical trial found that conventional gait training appeared to be more effective for stroke patients than PBWSTT (25). There is also a growing body of literature showing that PBWSTT is feasible for use in children with cerebral palsy, and can be considered a safe treatment method, beneficially impacting the capacity to stand and walk, as demonstrated by gross motor function measurements (GMFM) (26, 27).

In the literature, protocols for PBWSTT vary. Session frequencies range from 2 to 5 times per week (28, 29), session durations vary, with most studies reporting 20–30 min of treadmill walking at each session (28), and length of treatment varies from 2 weeks to 5 months (28, 29). There is insufficient evidence to support any single frequency, duration of each session or length of treatment, or discontinuation of PBWSTT.

In contrast, other results (27–31) suggest that evidence to support PBWSTT in children with CP is limited. Studies include heterogeneous age groups with varying GMFCS levels, and most are of low quality. Most of these studies consisted

Table V. *Mean values and standard deviations (SD) of the observed range of hip motion in the study and control groups, the difference between measurements, and the results of statistical testing*

	Initial measurement			Final measurement			Difference		
Gait parameters	Study group Mean (SD)	Controls Mean (SD)	*p*-value	Study group Mean (SD)	Controls Mean (SD)	*p*-value	Study group Mean (SD)	Controls Mean (SD)	*p*-value
Range of hip adduction at the initial contact of the heel with the floor, º									
Right side	–6.8 (6.4)	–6.9 (6.0	0.6697	–5.0 (6.2	–6.8 (7.1	0.5905	1.8 (5.6	0.1 (3.9)	0.4918
Left side	–4.5 (6.9)	–8.5 (3.1)	0.0556	–5.7 (5.3)	–5.0 (7.4)	0.8096	–1.1 (4.8)	3.6 (8.1)	0.1013
Maximum range of hip extension during stance phase, º									
Right side	–8.9 (10.9)	–3.5 (8.5)	0.1837	–9.2 (12.1)	–6.1 (7.1)	0.6697	–0.2 (9.0)	–2.5 (5.1)	0.2877
Left side	–12.4 (11.5)	–7.4 (12.6)	0.2547	–11.2 (11.0)	–10.1 (10.6)	0.8676	1.2 (8.0)	–2.8 (5.5)	0.1280
Maximum value of hip flexion during swing phase, º									
Right side	48.6 (10.9)	42.2 (9.4)	0.1097	49.4 (10.7)	45.3 (12.1)	0.2709	0.8 (8.1)	3.1 (3.1)	0.1714
Left side	45.6 (11.5)	43.6 (7.7)	0.3052	49.2 (12.3)	46.7 (46.7)	0.4025	3.7 (15.1)	3.1 (4.6)	0.9262
Total range of hip motion in sagittal plane, º									
Right side	39.2 (10.5)	38.4 (13.5)	0.8968	40.3 (12.8)	38.1 (10.9)	0.6697	1.0 (6.5)	–0.4 (4.4)	0.6970
Left side	37.2 (12.8)	36.7 (13.2)	0.7527	38.9 (10.4)	37.7 (11.5)	0.6697	1.7 (9.1)	1.0 (4.3)	0.6970

of single-case, small, or unselected patient samples, and/or uncontrolled trials (27, 30, 32).

In our study, there was no improvement in the temporospatial and kinematic gait parameters in children with CP who participated in the rehabilitation programme using Lokomat active orthosis. The only statistically significant parameter whose value improved in the study group was the range of pelvic motion in the coronal plane on the right side.

Some of the results, such as a shortening of the period of time of double stance phase for the left lower limb (1.1% decrease in time) in the study group, and the increase in this parameter (2.1% increase in time) in the control group, for the left lower limb also, were not statistically significant, although the relatively low value of the level of statistical significance ($p = 0.0726$) may be appropriate to investigate this relationship on a larger sample and over a longer duration of training.

Damiano (28) and Mattern-Baxter (29) indicate that PBWSTT intervention may be beneficial; however, PBWSTT effects could not be isolated in a number of reviewed studies secondary to co-intervention or continuation of other therapies during PBWSTT (28, 30). Despite its shortcomings, trends demonstrate PBWSTT may improve walking speed, walking endurance, gross motor function, and functional mobility status (27, 28–30). In a recent randomized control trial study, Willoughby et al. (31) showed that PBWSTT was no more effective than overground walking for improving walking speed and endurance in children with CP. They concluded that the progressive reduction in body-weight support, along with the addition of concurrent overground walking practice to a treadmill training protocol, may increase the intensity of training and assist with the carryover of improvements to overground walking.

These results may be explained by different patient populations, or may be caused by different methods of enhancing activity during training interventions and protocols (e.g. reducing body-weight support, increasing gait speed, reducing guidance force). Overall, training efficacy depends on a number of different parameters. Findings related to PBWSTT need to be interpreted cautiously and examined in greater detail in order to exploit its beneficial effect fully in each specific patient population.

Another possible explanation for the limited effectiveness of robotic devices might be the patient's passivity in the driven gait orthosis. Studies have shown that active involvement in the production of a motor pattern resulted in greater motor learning and retention than did passive movement (33, 34). Comparison of PBWSTT with manually assisted treadmill training has shown that muscular activity in patients and healthy controls were reduced when walking with a robotic device (35, 36). An important issue in PBWSTT might be connected with preventing passivity and improving active performance in the rehabilitation training of patients.

The use of PBWSTT in patients with CNS disorders has many benefits. These include: providing a safe environment to practice walking (37), making repetitive training more feasible, increasing safety of standing and ambulation training, and decreasing the work reducing the number of therapists (28, 39). However, the limitations and controversial findings in published research suggest the need for further studies. There are some indications that increased training intensity might lead to less ambiguous results (38, 39).

CONCLUSION

There were no statistically significant changes in gait parameters in the two groups of children after the 4-week physiotherapy programme. Children using the Lokomat did not show a significantly greater improvement in the investigated parameters compared with a group of children engaged in conventional physiotherapy without the use of the Lokomat. The pilot study showed an improvement in stabilometric parameters, including the normalization of load symmetry of the lower limbs. The lack of changes in the evaluated gait parameters, with a simultaneous improvement in the load symmetry of the lower limbs, as shown in the static test, may indicate a need to extend the duration of exercises necessary to achieve improvement. Due to several limitations (small group size, number of therapeutic sessions, and duration of therapy session) these results should be regarded as preliminary. Further studies consistent with the above indications are needed in order to investigate the impact of this new treatment option in patients with CP.

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