CME ARTICLE • 2011 SERIES • NUMBER 2

Improved Gait After Repetitive Locomotor Training in Children with Cerebral Palsy

ABSTRACT

Smania N, Bonetti P, Gandolfi M, Cosentino A, Waldner A, Hesse S, Werner C, Bisoffi G, Geroin C, Munari D: Improved gait after repetitive locomotor training in children with cerebral palsy. Am J Phys Med Rehabil 2011;90:137–149.

Objective: The aim of this study was to evaluate the effectiveness of repetitive locomotor training with an electromechanical gait trainer in children with cerebral palsy.

Design: In this randomized controlled trial, 18 ambulatory children with diplegic or tetraplegic cerebral palsy were randomly assigned to an experimental group or a control group. The experimental group received 30 mins of repetitive locomotor training with an applied technology (Gait Trainer GT I) plus 10 mins of passive joint mobilization and stretching exercises. The control group received 40 mins of conventional physiotherapy. Each subject underwent a total of 10 treatment sessions over a 2-wk period. Performance on the 10-m walk test, 6-min walk test, WeeFIM scale, and gait analysis was evaluated by a blinded rater before and after treatment and at 1-mo follow-up.

Results: The experimental group showed significant posttreatment improvement on the 10-m walk test, 6-min walk test, hip kinematics, gait speed, and step length, all of which were maintained at the 1-mo follow-up assessment. No significant changes in performance parameters were observed in the control group.

Conclusions: Repetitive locomotor training with an electromechanical gait trainer may improve gait velocity, endurance, spatiotemporal, and kinematic gait parameters in patients with cerebral palsy.

Key Words: Development, Robotics, Rehabilitation, Brain Damage, Walking, Randomized Control Trial

CME Objectives:

Upon completion of this article, the reader should be able to: 1) Identify the leading cause of gait impairments in children with Cerebral Palsy; 2) Describe the potential benefits of repetitive locomotor training on gait mechanics in children with Cerebral Palsy; 3) Describe the potential effects of repetitive locomotor training on disability and energy expenditure during gait in children with Cerebral palsy.

Level: Advanced

Accreditation: The Association of Academic Physiatrists is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians. The Association of Academic Physiatrists designates this activity for a maximum of 1.5 *AMA PRA Category 1 Credit(s)*™. Physicians should only claim credit commensurate with the extent of their participation in the activity.

Authors:

Nicola Smania, MD
Paola Bonetti, MD
Marialuisa Gandolfi, MD
Alessandro Cosentino, MD
Andreas Waldner, MD
Stefan Hesse, MD
Cordula Werner, MSC
Giulia Bisoffi, ST
Christian Geroin, PT
Daniele Munari, PT

Affiliations:

From the Neuromotor and Cognitive Rehabilitation Center, Department of Neurological, Neuropsychological, Morphological and Motor Sciences, University of Verona, Italy (NS, PB, MG, CG, DM); Rehabilitation Unit "C. Santi," Polyfunctional Centre Don Calabria, Verona, Italy (AC); Villa Melitta, Bolzano, Italy (AW); Medical Park Berlin, Charité-University Medicine, Berlin, Germany (SH, CW); and Statistics Unit, University Hospital of Verona, Italy (GB).

0894-9115/11/9002-0137/0
American Journal of Physical Medicine & Rehabilitation

DOI: 10.1097/PHM.0b013e318201741e

Correspondence:

All correspondence and requests for reprints should be addressed to: Nicola Smania, MD, Neuromotor and Cognitive Rehabilitation Center, Department of Neurological, Neuropsychological, Morphological and Motor Sciences, University of Verona, P.le Ludovico Antonio Scuro, 10, 37134 Verona, Italy.

Disclosures:

Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article. Supported by a grant from the CariVerona Fondation (PACIS), Verona, Italy.

Cerebral palsy (CP) describes a group of chronic conditions affecting body movement and muscle coordination caused by damage to one or more areas of the brain, usually occurring during fetal development or infancy.[1] The motor disorders of CP are often accompanied by disturbances of sensation, cognition, communication, perception, behavior, and/or a seizure disorder.[2] One of the most disabling mobility impairments in CP is gait impairment, clinically characterized by reduced speed and endurance, as well as reduced step, stride length, and toe clearance during gait.[3,4]

Recently, gait rehabilitation methods in patients with neurologic impairment 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.[5] The rationale for these approaches originates from animal studies, which have shown that repetition of gait movements may enhance spinal and supraspinal locomotor circuits.[6]

Previous studies in gait rehabilitation in patients with CP were carried out by using partial body-weight support treadmill training (PBWSTT) and robotic-assisted treadmill therapy. Most of these studies consisted of single-case, small, or unselected patient samples and/or uncontrolled trials.[7–11] In a recent randomized control trial study, Willoughby et al.[12] 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 of 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 carryover of improvements to overground walking.[12] Despite their potential, these technologies have practical limitations in their routine application: PBWSTT requires the assistance of one or two physiotherapists to control the patient's weight shift and lower limb position during training,[13] and proper placement of the patient onto the machine (Lokomat; Hokoma Inc, Volketswill, Switzerland) for robotic-assisted treadmill training is time-consuming.[14]

More recently, several studies have focused on the use of a new electromechanical gait trainer (Gait Trainer GT I; Reha-Stim, Berlin, Germany)[15] in adult patients who have experienced a stroke. These studies have shown that training with this device may significantly improve gait performance.[16,17] Despite the clinical impact of this new rehabilitative procedure, to date, no studies have been conducted on its use in children with CP.

The primary aim of the present randomized controlled trial was to evaluate whether repetitive locomotor training with the Gait Trainer GT I can improve walking speed and endurance in tetraplegic or diplegic ambulatory children with CP. The secondary aim was to assess whether training can also have a positive impact on kinematic and spatiotemporal gait parameters and on disability.

MATERIALS AND METHODS

Subjects

Eighteen participants were recruited among 31 children with CP attending the Developmental Age Unit, "C. Santi," Polyfunctional Centre Don Calabria, Verona, Italy, from January 2009 to October 2009.

Inclusion criteria were bilateral lower limb (diplegic or tetraplegic) CP, 10 to 18 yrs of age, and Gross Motor Function Classification System[18] levels II to IV. The children needed to walk by themselves or with the use of an assistance device for at least 10 m, maintain a sitting position without assistance, follow instructions, and participate in the rehabilitative program. Exclusion criteria were lower limb spasticity of >2 or higher on the Modified Ashworth Scale,[19] severe lower limb contractures, cardiovascular diseases, orthopedic surgery or neurosurgery in the past 12 mos, or Botulinum toxin injections within 6 mos before the beginning of the study. Before the start of the study, participants were allocated to the experimental group or the control group via computerized randomization. The randomization sequence was generated by a research assistant not involved with the study, and the group allocation was concealed using sealed, numbered envelopes. The randomization list was locked in a desk drawer accessible only to the principal investigator.[20]

Written informed consent was obtained from the children's parents and the children themselves. The ethics committee of the Department of Neurological and Vision Sciences, University of Verona, approved the study protocol.

Training

Before the start of the study, the authors designed experimental and control group treatment protocols and instructed two physiotherapists in their use. One physiotherapist treated the experimental group and the other treated the control group. The participants were treated individually on an outpatient basis in a rehabilitative gym at the C. Santi Medical Centre.

Both training programs consisted of ten 40-min daily sessions for 2 wks (5 days/wk).

During the study period, participants received no physiotherapy other than that scheduled in the study protocol.

Experimental Group Training

Each participant received 30 mins of repetitive locomotor therapy on the Gait Trainer GT I, followed by 10 mins of passive joint mobilization and stretching exercises by a physiotherapist.

The Gait Trainer GT I

The gait trainer consists of a double crank and rocker gear system, composed of two footplates positioned on two bars (coupler), two rockers, and two cranks that provide the propulsion. While using the gait trainer, individuals are secured in a harness and positioned on two footplates, whose movements simulate stance and swing phase, with a ratio of 60% to 40% between the two phases.[15] A servo-controlled motor assists gait movement by controlling the gear velocity and comparing it with the preselected velocity. The rotation of the planetary gear system, equaling one gait cycle, controls the movement of the center of mass (CoM) in the vertical and horizontal directions. Two cranks, one for the vertical and one for the horizontal movement CoM control, are attached to the planetary gear system. A transmission gear installed between the planetary gear and the crank controlling the vertical CoM displacement provides a double frequency of the vertical CoM movement within one gait cycle. A rope attached to the crank controlling the vertical CoM displacement served as the central suspension of the subject. A second rope connected to the crank controlling the horizontal CoM displacement was attached to the left lateral aspect of the subject harness at the level of the pelvic crest (Fig. 1).[15]

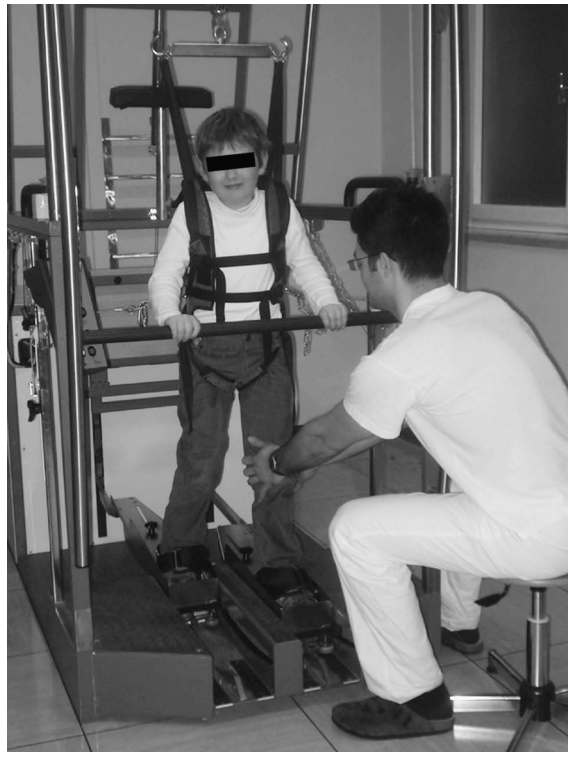

FIGURE 1 *Training of a 6-yr-old on the Gangtrainer GT I.*

Training Procedures

The child was positioned on the gait trainer. Step length and gait speed were individually set according to the gait parameters recorded at the pretreatment gait analysis. Walking speed was gradually increased over the course of the 2 wks if the children completed the last previous training session without discomfort or complaints of fatigue. The partial body-weight support was progressively decreased from 30% to 0% over the duration of the sessions. The criterion for the reduction was the child's ability to avoid his/her knee collapsing into flexion during the stance phase because of the increased load of body weight. Each participant was supervised during therapy sessions by only one physiotherapist who corrected knee motion manually, when needed. No patients required the assistance of two physiotherapists. The machine was stopped if pain or other problems such as muscle cramps occurred.

Control Group Training

Conventional training consisted of the repetition of three different sets of exercises: (1) passive joint mobilization and stretching of the lower limb muscles with the patient lying on a physiotherapy mat in the supine position; (2) strengthening exercises, including leg-press exercises and sit-to-stand and stand-to-sit exercises. In the first session,

the correct performance of the leg-press exercise required strict supervision by the physiotherapist: the participants lay in the supine position and were asked to slowly push their feet against the physiotherapist's chest and to slowly bend them back again; in the subsequent sessions, these exercises were performed by using a leg-press machine with resistance specifically adapted for the child's ability; (3) balance and gait exercises. The balance exercises were carried out with the participant sitting on a bench and in the standing position, with a front support or against a wall. Gait exercises consisted of guided ground walking (e.g., side stepping) with the assistance of the physiotherapist. Each set of exercises lasted 10, 15, and 15 mins, respectively. During the entire sessions, the physiotherapist stood near the children to ensure safety and prevent potential falls.

Testing

Before and after treatment and at 1-mo follow-up, the participants were evaluated by the same examiner who was unaware of treatment allocation. The assessment procedures, consisting of clinical and instrumental evaluations, were carried out at the C. Santi Medical Centre: the clinical tests took place in a spacious and silent environment to avoid the child potentially becoming distracted, whereas the instrumented evaluations were conducted in the Gait Analysis Laboratory. All the assessments were administered in the same sequence (clinical and instrumented evaluations) and at the same time of day, in the afternoon, around 3 p.m. During testing, the participants were allowed to wear their usual footwear and orthoses and use their gait-assistive devices.

Primary Outcomes

10-m Walk Test:

This is a validated test for the clinical evaluation of walking speed.[21] The subject was asked to walk at her/his self-selected walking speed along the central 10 m of a 14-m linoleum-covered walkway. A digital stopwatch was used to time the walks.

6-Min Walk Test:

This is a validated test for the clinical evaluation of walking endurance that involves respiratory, cardiovascular, skeletal, nervous, and muscular system competences/skills.[22] The subject was asked to walk at her/his self-selected walking speed in the gym along an oval track 20 m in length marked out with masking tape. The distance walked during the test was calculated with a tape measure.

Secondary Outcomes

Functional Independence Measure for Children (WeeFIM):

This widely used scale for the evaluation of disability in children with CP[23] investigates three main domains: self-care, mobility, and cognition (score, 18–126; high, best performance).

Gait Analysis:

Three-dimensional gait analysis (Vicon; Oxford Metrics, Oxford, UK) by means of a motion capture system consisting of six infrared cameras was carried out according to a standard marker placement protocol.[24] The participants were required to walk at their self-selected speeds. The data from at least four trials were collected. The gait parameters were sagittal plane kinematics (joint angles of the hip, knee, and ankle at initial contact; middle stance; and initial swing and middle swing) and spatiotemporal gait parameters (speed, cadence, and step length).

Statistical Analysis

We calculated effect sizes between the two independent groups (Cohen *d*) and used 95% confidence intervals. Because our data were not normally distributed (after visual and descriptive inspection), we used nonparametric tests for inferential statistics. The Mann-Whitney *U* test was used for testing differences between groups at baseline, the Friedman test was used to analyze changes in performance within groups, and Wilcoxon's signed rank tests were used to compare changes between groups from pretreatment/posttreatment and pretreatment/follow-up measures. The Mann-Whitney *U* test was used for between-group comparisons. For this purpose, we computed the differences (Δ) between pretreatment and posttreatment performance and between pretreatment and follow-up performance for all outcome measures. We set the alpha level for significance at 0.05; however, to adjust for multiple comparison, we used a Bonferroni[25] correction ($\alpha = 0.025$). All statistical analysis was carried out using the SPSS for Macintosh statistical package, version 16.0.

RESULTS

No children withdrew from the study. Participant demographics and clinical characteristics are reported in Table 1.

At baseline, there were no statically significant differences between the two groups in age, performance on the 10-m walk test and the 6-min walk test, or WeeFIM scores (age, $Z = -0.13$, $P = 0.89$; 10-m walk test, $Z = -0.08$, $P = 0.93$; 6-min walk

TABLE 1 Patients' demographics and pretreatment, posttreatment, and 1-mo FU performance in the 6-min walk test, the 10-m walk test, and WeeFIM

						10-m Walk Test, m/sec			6-Min Walk Test, m			WeeFIM		
Patient no.	Sex	Age, yr/mo	Diagnosis	GMFCS	Walking Aids	Pre	Post	FU	Pre	Post	FU	Pre	Post	FU
Experimental group														
1	F	11	ST	I	None	0.99	1.05	1.18	308	393	395	115	116	116
2	F	11/1	SD	IV	Walker	0.76	0.77	0.75	205	262	288	85	85	85
3	M	14/4	ST	I	None	1.35	1.54	1.59	451	590	550	94	94	94
4	M	14/4	SD	I	None	1.12	1.16	1.18	400	462	462	117	117	117
5	M	17/6	ST	II	None	1.10	1.32	1.45	368	412	423	84	84	84
6	F	13/2	SD	IV	Walker	0.82	0.85	0.96	302	362	378	112	116	116
7	F	10/1	SD	IV	Walker	0.53	0.68	0.60	144	208	186	62	62	62
8	F	15/8	SD	II	None	0.74	0.76	0.77	360	378	380	63	63	63
9	M	17/8	ST	IV	Walker, AFO	0.61	0.63	0.64	90	180	190	102	104	104
	5F/4M													
Mean		13/88				0.89	0.97	1.01	292	360	361	92.66	93.44	93.44
SD		2.83				0.27	0.31	0.36	121.44	128.71	120.81	20.94	21.68	21.68
Range (min-max)						0.53–1.35	0.63–1.54	0.60–1.59	90–451	180–590	186–550	62–117	62–117	62–117
Control group														
10	M	10/4	SD	IV	Walker, AFO	0.39	0.38	0.39	321	403	400	86	86	86
11	M	14/1	SD	III	Walker, AFO	0.91	0.89	0.88	322	312	314	111	112	112
12	F	8/9	SD	III	None	0.83	0.84	0.84	319	350	347	85	85	85
13	F	15/4	SD	I	None	1.00	0.92	0.92	317	284	281	94	94	94
14	M	12/1	SD	I	Walker	1.12	1.11	1.10	403	290	300	117	117	117
15	F	15/8	SD	III	Walker, AFO	1.11	1.02	1.02	259	322	318	84	84	84
16	M	10/7	ST	IV	Walker, AFO	1.00	0.91	0.85	350	319	318	112	113	113
17	M	10	ST	IV	Walker, AFO	0.57	0.63	0.62	284	270	272	62	62	62
18	M	17/8	ST	I	None	0.69	0.72	0.72	290	321	320	83	83	83
	3F/6M													
Mean		12/79				0.85	0.82	0.82	318	319	319	92.67	92.89	92.89
SD		3.08				0.25	0.22	0.21	41.3	39.60	37.73	17.73	18	18
Range (min-max)						0.39–1.12	0.38–1.11	0.39–1.10	259–403	270–403	272–400	62–117	62–117	62–117

GMFCS, Gross Motor Function Classification System; Pre, baseline; Post, posttreatment; FU, follow-up; ST, spastic tetraparesis; SD, spastic diplegic; AFO, ankle-foot orthosis.

TABLE 2 Patients' performance and treatment effects in all outcome measures

		Pre-Post			Pre-1 Mo FU		
	Group	95% CI, Mean (LB; UB)	Effect Size (BG)	*P* (*Z*)	95% CI, Mean (LB; UB)	Effect Size (BG)	*P* (*Z*)
10-m WT	Experimental	−0.08 (−0.14; −0.02)	0.558	0.008 (−2.67)[a]	−0.12 (−0.21; −0.02)	0.644	0.011 (−2.54)[a]
	Control	0.02 (0.01; −0.06)		0.214 (−1.24)	0.03 (0.01; 0.08)		0.314 (−1.00)
6-min WT	Experimental	−68.78 (−94.73; −42.82)	0.438	0.008 (−2.66)[a]	−69.33 (−90.04; −48.63)	0.474	0.008 (−2.66)[a]
	Control	−0.67 (−45.92; 44.59)		0.095 (−0.59)	−0.56 (−43.13; 42.02)		0.095 (−0.59)
WeeFIM	Experimental	−0.78 (−1.85; 0.29)	0.027	0.109 (−1.60)	−0.78 (−1.85; 0.29)	0.027	0.109 (−1.60)
	Control	−0.22 (−0.56; 0.12)		0.157 (−1.4)	−0.22 (−0.56; 0.12)		0.157 (−1.4)
Hip							
Initial contact	Experimental	0.78 (−0.62; 2.20)	0.192	0.109 (−1.60)	2.71 (−1.88; −3.53)	−0.12	0.008 (−2.66)[a]
	Control	0.05 (−2.12; 2.22)		0.214 (−1.24)	0.15 (−2.03; 2.34)		0.139 (−1.48)
Middle stance	Experimental	2.02 (0.94; 3.1)	−0.023	0.011 (−2.54)[a]	3.18 (1.11; 5.27)	−0.210	0.008 (−2.66)[a]
	Control	0.22 (−0.03; 0.49)		0.008 (−1.71)	0.091 (−0.21; 0.39)		0.441 (−0.77)
Initial swing	Experimental	0.93 (0.03; 1.84)	0.025	0.024 (−2.24)[a]	2.25 (0.92; 3.4)	0.114	0.008 (−2.66)[a]
	Control	0.08 (−0.01; 0.18)		0.86 (−1.71)	0.01 (−0.40; 0.40)		0.767 (−0.29)
Middle swing	Experimental	3.23 (0.13; 6.33)	−0.356	0.051 (−1.95)	3.32 (0.12; 6.76)	−0.335	0.066 (−1.83)
	Control	0.23 (−0.43; 0.89)		0.484 (−0.70)	−0.09 (−0.54; 0.36)		0.374 (−0.89)
Knee							
Initial contact	Experimental	1.66 (−2.35; 5.68)	−0.356	0.249 (−1.15)	−0.46 (−6.47; 5.54)	0.043	0.917 (−0.10)
	Control	−0.02 (−0.25; 0.21)		0.714 (−0.36)	−0.07 (−0.32; 0.16)		0.131 (−1.51)
Middle stance	Experimental	1.82 (−0.47; 4.12)	−0.169	0.43 (−2.02)	−0.17 (−3.30; 2.953)	0.019	0.893 (−0.13)
	Control	−0.12 (−0.30; 0.05)		0.130 (−1.51)	−0.01 (−0.18; 0.15)		0.20 (−2.33)
Initial swing	Experimental	1.27 (−1.78; 4.34)	−0.045	0.917 (−0.10)	2.38 (−3.91; 8.67)	−0.158	0.735 (−0.33)
	Control	0.07 (−0.11; 0.27)		0.339 (−0.95)	0.11 (−0.06; 0.28)		0.174 (−1.36)
Middle swing	Experimental	2.06 (−1.50; 5.61)	−0.116	0.172 (−1.36)	2.07 (−3.89; 8.05)	−0.124	0.31 (−1.01)
	Control	−0.08 (−0.25; 0.09)		0.349 (−0.93)	−0.03 (−0.20; 0.14)		0.776 (−0.28)
Ankle							
Initial contact	Experimental	2.83 (−1.64; 7.31)	−0.371	0.285 (−1.06)	3.04 (−1.8; 7.88)	−0.404	0.285 (−1.06)
	Control	−0.06 (−0.41; 0.28)		0.888 (−0.141)	−0.14 (−0.46; 0.17)		0.497 (−0.67)
Middle stance	Experimental	2.82 (−2.82; −8.46)	−0.363	0.273 (−1.09)	3.30 (−3.43; 10.03)	−0.449	0.273 (−1.09)
	Control	−0.08 (−0.21; 0.04)		0.167 (−1.38)	−0.21 (−0.32; −0.09)		0.178 (−1.45)
Initial swing	Experimental	1.88 (2.72; −6.47)	−0.182	1.00 (0.00)	1.98 (−2.96; 6.92)	0.066	1.00 (0.00)
	Control	−0.17 (−0.48; 0.15)		0.231 (−1.19)	−0.17 (−0.43; 0.10)		0.182 (−1.33)
Middle swing	Experimental	2.69 (−2.90; 8.28)	−0.250	0.109 (−1.60)	2.71 (−2.87; 8.29)	−0.244	0.144 (−1.461)
	Control	−0.13 (−0.25; −0.02)		0.036 (−2.10)	−0.03 (−0.17; 0.10)		0.570 (−0.56)
Gait speed	Experimental	−0.05 (−0.09; −0.01)	0.905	0.028 (−2.19)[a]	−0.11 (−0.16; −0.05)	1.058	0.008 (−2.26)[a]
	Control	0.10 (0.07; 0.13)		0.347 (−2.66)	0.10 (0.07; 0.14)		0.198 (−2.66)
Cadence	Experimental	0.76 (−4.38; 5.91)	−0.201	0.575 (−0.56)	−1.53 (−6.90; 3.84)	−0.055	0.515 (−0.65)
	Control	−4.49 (−11.16; 2.18)		0.173 (−1.36)	−4.49 (−11.16; 2.18)		0.173 (−1.36)
Step length	Experimental	0.02 (0.4; 0.00)	0.555	0.024 (−2.25)[a]	0.02 (0.04; 0.00)	0.630	0.011 (−2.53)[a]
	Control	−0.0.1 (−0.02; 0.00)		1 (0.00)	−0.01 (−0.03 −0.00)		1 (0.00)

P and *Z* values were identified from the Wilcoxon's test.

Pre, baseline; Post, posttreatment; FU, follow-up; CI, confidence interval; LB, lower bound; UB, upper bound; BG, between groups; WT, walk test.

[a]Statistically significant.

test: $Z = -0.13$, $P = 0.89$; WeeFIM, $Z = -0.22$, $P = 0.82$) (Table 1).

Primary Outcomes

In the experimental group, overall significant changes in performance in the different evaluation sessions were found in regard to all primary outcome measures (10-m walk test, $df = 2$, $X = 11.56$, $P = 0.003$; 6-min walk test, $df = 2$, $X = 12.51$, $P = 0.001$). Within-group comparisons showed that changes in performance were significant at both the posttreatment and follow-up evaluations (see Table 2 for details). In the control group, no significant changes in the primary outcome measures were found at any of the evaluation sessions (statistics in Table 2).

A between-group comparison showed that the effects of the experimental and the control treatments were significantly different in all primary outcome measures (see Table 3 for details).

Secondary Outcomes

No significant changes in WeeFIM scores were found in either group (see Table 2 for details).

In regard to gait analysis, the experimental group showed significant changes in the joint angles of the hip during initial contact, middle stance, and initial swing, as well as in gait speed and step length at all assessments (hip kinematics–initial contact, $df = 2$, $X = 14.222$, $P = 0.001$; middle stance, $df = 2$, $X = 11.556$, $P = 0.003$; initial swing, $df = 2$, $X = 13.886$, $P = 0.001$; spatiotemporal parameters–gait speed, $df = 2$, $X = 13{,}771$, $P = 0.001$; step length, $df = 2$, $X = 9.188$, $P = 0.010$).

Before-after comparisons showed improved hip extension at middle stance, initial swing, gait speed, and step length (see Table 2 for details). Before-follow-up comparisons showed increased hip extension at different phases of the gait cycle and increased gait speed and step length. No changes in performance of the control group were seen (see Table 2 for details).

Between-groups analysis showed a significant difference in the rate of hip extension at different phases of the gait cycle, in gait speed, and in step length (see Table 2 for details).

TABLE 3 Comparison of treatment effects between the experimental and control groups

	Pre-Post	Pre-1 Mo FU
	P (*Z*)	*P* (*Z*)
10-m WT	0.007 (−2.69)[a]	0.004 (−2.87)[a]
6-min WT	0.015 (−2.43)[a]	0.007 (−2.669)[a]
WeeFIM	0.466 (−0.72)	0.466 (−0.72)
Hip		
Initial contact	0.58 (−1.89)	0.005 (−2.78)[a]
Middle stance	0.009 (−2.60)[a]	0.000 (−3.40)[a]
Initial swing	0.03 (−2.16)	0.004 (−2.87)[a]
Middle swing	0.85 (−1.72)	0.035 (−2.42)[a]
Knee		
Initial contact	0.120 (−1.55)	0.351 (−0.93)
Middle stance	0.529 (−2.90)	0.855 (−0.18)
Initial swing	0.329 (−0.97)	0.559 (−0.58)
Middle swing	0.045 (−2.00)	0.184 (−1.33)
Ankle		
Initial contact	1.00 (0.00)	0.380 (−0.87)
Middle stance	0.096 (−1.66)	0.018 (−2.37)
Initial swing	0.236 (−1.18)	0.466 (−0.72)
Middle swing	0.113 (−2.48)	0.279 (−1.08)
Gait speed	0.000 (−3.58)[a]	0.000 (−3.58)[a]
Cadence	0.145 (−1.45)	0.757 (−0.30)
Step length	0.004 (−2.89)[a]	0.001 (−3.51)[a]

The *P* value and the corresponding *Z* value were identified from the Mann-Whitney *U* test.

Pre, baseline; Post, posttreatment; FU, follow-up.

[a]Statistically significant.

DISCUSSION

Our results demonstrate that repetitive locomotor gait training with an electromechanical body-weight support machine can significantly improve gait velocity and endurance in ambulatory children with diplegic and tetraplegic CP and that the improvements can be maintained for at least 1 mo post-treatment. Improvements were also seen in proximal lower limb gait kinematics and in spatiotemporal parameters (gait speed and step length). The results obtained displayed that the magnitude of treatment effect was small to medium among the primary outcomes, further supporting the value of our experimental approach. No changes were seen in disability. There was no adverse event that led to a missed training session. No joint pain or muscle spasms were reported during or after the GT I training program.

Our study showed that the children in the experimental group significantly improved their gait velocity after treatment (10-m walk test and gait analysis). There are several reasons for this effect of treatment. First, children showed significant post-treatment changes in hip kinematics in the sagittal plane, with increased hip extension during middle stance and initial swing. This may have been because of the fact that during training with the GT I machine, the footplates forced the children to extend their hips.[15] The leg movement imposed by the machine has a maximal fulcrum at the hip level, and backward pelvis displacements are blocked by a rear bar, thus forcing the patient to extend the hip joint. As a result, training might have progressively enhanced the extensibility of the hip flexor muscles and periarticular hip joint tissues, leading to increased hip movement. Another possible

explanation for the improvement in gait velocity may have been the increased muscle strength present after training.[26] It has been demonstrated that muscle weakness is a primary limiting factor in ambulation in children with CP.[26–28] Although muscle strength was not specifically tested in this study, previous studies have shown that adult stroke patients trained with the GT I machine significantly increased their performance on the Motricity Index Test (lower limb section).[13] This effect on muscle strength is further confirmed by the fact that trained patients in previous studies usually experience a feeling of muscle fatigue after treatment, indicating that training on the GT I machine not only acts as a passive guide for movements but also requires active involvement of the lower limb muscles.[15]

A second main result of the present study was that the children in the experimental group had improved gait endurance after training. This improvement could have resulted from the previously described effects on gait kinematics and strength. However, a reduction in energy expenditure[29] related to the decrease in co-contraction muscle[30,31] and the improvement in movement efficacy during gait[29] may have also contributed to this improvement. This may lead to an optimization of cardiovascular performance. To date, no studies have investigated the effect of body-weight support gait-training approaches on energy expenditure in children with CP. Future research on this topic in the neuromotor rehabilitation of children with CP is needed.

The question arises as to the possible delayed effects of training. It is worth noting that at the 1-mo follow-up, the participants in the experimental group showed a trend toward continued improvement in gait kinematics and gait velocity. After training, the children may have been more motivated to practice gait during daily life activities. This hypothesis was supported by informal interviews conducted with the children's parents.

As shown by the WeeFIM results, the children in the experimental group showed no reduction in activities of daily life after training. Although gait is an important activity of daily life, this result may be explained by the fact that the WeeFIM is not sensitive enough to point out significant changes in the overall performance of activities of daily life. Furthermore, a potential ceiling effect may be an additional explanation of the small changes in score seen in children with higher scores in the WeeFIM.

No improvements in the primary and secondary outcomes were obtained in the control group. This could be because of the different level in the Gross Motor Function Classification System and in the gait-assistive devices required in the experimental and control group.

Most studies on body-weight support gait-training techniques discuss the effects of PBWSTT and Lokomat robotic training. PBWSTT differs in several ways from the GT machine approach. The major disadvantage of PBWSST is that the trunk and the lower limbs are difficult to control during exercise. Hence, the more severe the mobility impairment, the more physical effort is demanded from the child. In addition, at least two physiotherapists are needed to assist trunk and limb movements during the gait cycle.[13] Two reviews[7,8] on the limited studies investigating the effect of PBWSTT on gait parameters in children with CP concluded that, currently, there is no evidence that children with CP benefit from PBWSTT. This lack of evidence was attributed to small sample size, disparate ability levels of participants, and low-quality experimental design.

A recently developed pediatric version of the Lokomat consists of a robotic-driven exoskeleton[11] that moves the lower limbs to reproduce normal walking. Lower limb movements are synchronized with a treadmill. The few studies examining the effect of this device on children with CP demonstrated positive effects on gait velocity and endurance in clinical tests.[9–11] However, these studies were limited because of small sample size, lack of a randomized control trial design, and lack of instrumental evaluations.

Some limitations of the present study must be acknowledged. First, no measure of muscle strength, energy expenditure, or quality-of-life was performed. Second, a longer session time (1 mo) could have led to a more significant improvement in children performances. Third, the fact that only one physiotherapist treated the control group and only one physiotherapist treated the treatment group makes it difficult to determine if group differences are related to the interventions or rather to a characteristic of the assigned therapist. Fourth, a great variability in the Gross Motor Function Classification System scores was evident in our sample of patients. Finally, a longer follow-up period (3–6 mos) is needed to determine the long-term effects of a gait-training program with this device. Nonetheless, our results strongly suggest that repetitive locomotor training on a body-weight support electromechanical machine may improve gait speed and endurance in children with CP.

ACKNOWLEDGMENTS

We thank the participants and their family for their dedication to and participation in this study. Also, we are grateful to the staff of the Developmental Age Unit, C. Santi Medical Centre, Don Calabria Institute, Verona, Italy, for their helpful collaboration.

REFERENCES

1. Rosenbaum P, Paneth N, Leviton A, et al: A report: the definition and classification of cerebral palsy. 2006. *Dev Med Child Neurol* 2007;109:S8–14
2. Bax M, Goldstein M, Rosenbaum M, et al: Executive Committee for the Definition of Cerebral Palsy. Proposed definition and classification of cerebral palsy. *Dev Med Child Neurol* 2005;47:571–6
3. Pirpiris M, Wilkinson AJ, Rodda J, et al: Walking speed in children and young adults with neuromuscular disease: comparison between two assessment methods. *J Pediatr Orthop* 2003;23:302–7
4. Jean L. Gait: development and analysis. In: Campbell KS, Vander Linden DW, Palisano RJ, eds. *Physical Therapy for Children*. Elsevier Health Sciences, 2006:161–90
5. Hesse S: Locomotor therapy in neurorehabilitation. *NeuroRehabilitation* 2001;16:133–9
6. Scivoletto G, Ivanenko Y, Morganti B, et al: Plasticity of spinal centers in spinal cord injury patients: new concepts for gait evaluation and training. *Neurorehabil Neural Repair* 2007;21:358–65
7. Mutlu A, Krosschell K, Spira DG: Treadmill training with partial body-weight support in children with cerebral palsy: a systematic review. *Dev Med Child Neurol* 2009;51:268–75
8. Damiano DL, DeJong SL: A systematic review of the effectiveness of treadmill training and body weight support in pediatric rehabilitation. *J Neurol Phys Ther* 2009;33:27–44
9. Meyer-Heim A, Borggraefe I, Ammann-Reiffer C, et al: Feasibility of robotic-assisted locomotor training in children with central gait impairment. *Dev Med Child Neurol* 2007;49:900–6
10. Borggraefe I, Meyer-Heim A, Kumar A, et al: Improved gait parameters after robotic-assisted locomotor treadmill therapy in a 6-year-old child with cerebral palsy. *Mov Disord* 2008;23:280–3
11. Meyer-Heim A, Ammann-Reiffer C, Schmartz A, et al: Improvement of walking abilities after robotic-assisted locomotion training in children with cerebral palsy. *Arch Dis Child* 2009;94:615–20
12. Willoughby KL, Dodd KJ, Shields N, Foley S: Efficacy of partial body weight-supported treadmill training compared with overground walking practice for children with cerebral palsy: a randomized controlled trial. *Arch Phys Med Rehabil* 2010;91:333–9
13. Dias D, Lains J, Pereira A, et al: Can we improve gait skills in chronic hemiplegics? A randomised control trial with gait trainer. *Eura Medicophys* 2007;43: 499–504
14. Colombo G, Joerg M, Schreier R, Dietz V: Treadmill training of paraplegic patients using a robotic orthosis. *J Rehabil Res Dev* 2000;37:693–700
15. Hesse S, Uhlenbrock D: A mechanized gait trainer for restoration of gait. *J Rehabil Res Dev* 2000;37:701–8
16. Pohl M, Werner C, Holzgraefe M, et al: Repetitive locomotor training and physiotherapy improve walking and basic activities of daily living after stroke: a single-blind, randomized multicentre trial (DEutsche GAngtrainerStudie, DEGAS). *Clin Rehabil* 2007;21: 17–27
17. Mehrholz J, Werner C, Kugler J, et al: Electromechanical-assisted training for walking after stroke. *Cochrane Database Syst Rev* 2007;17: CD006185
18. Palisano RJ, Hanna SE, Rosenbaum PL, et al: Validation of a model of gross motor function for children with cerebral palsy. *Phys Ther* 2000;80:974–85
19. Bohannon RW, Smith MB: Interrater reliability of a Modified Ashworth Scale of muscle spasticity. *Phys Ther* 1987;67:206–7
20. Bryant TN, Machin D: Statistical methods. In: Wilson BA, McLellan DL, eds. *Rehabilitation Studies Handbook*. Cambridge, United Kingdom: Cambridge University Press; 1997:189–204
21. Wade DT: *Measurement in Neurological Rehabilitation*. Oxford, United Kingdom: Oxford University Press; 1992
22. Maher CA, Williams MT, Olds TS: The six-minute walk test for children with cerebral palsy. *Int J Rehabil Res* 2008;31:185–8
23. Ottenbacher KJ, Taylor ET, Msall ME, et al: The stability and equivalence reliability of the functional independence measure for children (WeeFIM). *Dev Med Child Neurol* 1996;38:907–16
24. Davis RB, Ounpuu S, Tyburski DJ: A gait analysis data collection and reduction technique. *Hum Mov Sci* 1991;10:575–87
25. Shaffer JP: Multiple hypothesis testing. *Annu Rev Psychol* 1995;46:561–84
26. Bottos M, Gericke C: Ambulatory capacity in cerebral palsy: prognostic criteria and consequences for intervention. *Dev Med Child Neurol* 2003;45:786–90
27. Gormley ME Jr: Treatment of neuromuscular and musculoskeletal problems in cerebral palsy. *Pediatr Rehabil* 2001;4:5–16
28. Eagleton M, Iams A, McDowell J, et al: The effects of strength training on gait in adolescents with cerebral palsy. *Pediatr Phys Ther* 2004;16:22–30
29. Waters RL, Mulroy S: The energy expenditure of normal and pathologic gait. *Gait Posture* 1999;9:207–31
30. Unnithan VB, Dowling JJ, Frost G, et al: Role of cocontraction in the O_2 cost of walking in children with cerebral palsy. *Med Sci Sports Exerc* 1996;28: 1498–504
31. Piccinini L, Cimolin V, Galli M, Berti M, Crivellini M, Turconi AC: Quantification of energy expenditure during gait in children affected by cerebral palsy. *Eura Medicophys* 2007;43:7–12

INSTRUCTIONS TO OBTAIN CATEGORY 1 CME CREDITS:

1. Read the Designated CME Articles in this issue.
2. Read the following CME Self-Assessment Exam Questions.
3. Photocopy and complete the CME Self-Assessment Exam Answering Sheet and CME Evaluation.
4. Send the completed Answering Sheet and Evaluation to: CME Department, AAP National Office, 7250 Parkway Drive, Suite 130, Hanover, MD 21076.

AMERICAN JOURNAL OF PHYSICAL MEDICINE & REHABILITATION

Vol. 90, No. 2 • February 2011

This is an adult learning experience and there is no requirement for obtaining a certain score. The objective is to have each participant learn from the total experience of studying the article, taking the exam, and being able to immediately receive feedback with the correct answers. For complete information, please see "Instructions for Obtaining Continuing Medical Education Credit" at the front of this issue.

Every question must be completed on the exam answering sheet to be eligible for CME credit. Leaving any item unanswered will make void the participant's response. This CME activity must be completed and postmarked by December 31, 2012. The documentation received will be compiled throughout the calendar year, and once a year in January, participants will receive a certificate indicating CME credits earned for the prior year of work. This CME activity was planned and produced in accordance with the ACCME Essentials.

CME Self-Assessment Exam Questions

CME Article 2011 Series Number 2: *N. Smania, et al.*

1. In this study, which was used for repetitive locomotor training in children with Cerebral Palsy?
   A. A robotic-driven exoskeleton
   B. A treadmill device
   C. An electromechanical body-weight support gait trainer
   D. Lower limbs orthoses

2. In this study, which of the following may explain the velocity improvements after repetitive locomotor training?
   A. Increased hip extension during the middle stance and initial swing
   B. Increased knee flexion during swing phase
   C. Decreased ankle dorsiflexion during swing phase
   D. Increased ankle dorsiflexion during stance phase

3. Which of the following represent the scientific rationale for repetitive locomotor training in gait rehabilitation?
   A. Repetition of gait movements may enhance supraspinal circuits
   B. Repetition of gait movements may enhance spinal and supraspinal locomotor circuits
   C. Repetition of gait movements may increase the primary motor cortex excitability
   D. Repetition of gait movements may decrease lower limb spasticity

4. Which of the following represent gait impairment in children with Cerebral Palsy?
   A. Increased step, stride length, toe clearance, gait speed and endurance.
   B. Increased ankle dorsiflexion during phases of gait
   C. Reduced step and stride length, toe clearance, gait speed and endurance.
   D. Increase hip flexion, stride length, toe cleareance and endurance

5. In this study the improvement in gait endurance seen in the experimental group may result from
   A. Improved gait mechanics
   B. Improved strength
   C. Improved movement efficiency and reduction of energy expenditure
   D. All of the above.

(Continued next page)

The answers to any essay questions must be typed or computer printed on a separate piece of paper and attached to this page.

After finishing this exam:

1. Check your answers with the correct answers on page 174.
2. Photocopy and complete the CME Evaluation and Certification on the next page and mail to CME Department, AAP National Office, 7250 Parkway Drive, Suite 130, Hanover, MD 21076.
3. This educational activity must be completed and postmarked by December 31, 2012. AAP Members may complete and submit this CME Answering Sheet and the following Standardized CME Activity Evaluation page and Certification page online through the members-only section of the AAP web page at www.physiatry.org.

AMERICAN JOURNAL OF PHYSICAL MEDICINE & REHABILITATION

Please photocopy this form and complete the information required for each CME Activity.

Journal Issue Month and Year _____
Volume Number _____ Issue Number _____
CME Article Number _____
CME Article Author's Name _____

Circle the appropriate answers.

1.	A	B	C	D
2.	A	B	C	D
3.	A	B	C	D
4.	A	B	C	D
5.	A	B	C	D

Please photocopy this form and complete the information required for each CME Activity.

Journal Issue Month and Year_____ Volume Number _____ Issue Number _____
CME Article Number _____ CME Article Author's Name_____

	Agree	Neutral	Disagree	Not Applicable
The CME activity was consistent with the stated objectives.	☐	☐	☐	☐
The activity prepared me to achieve its stated objectives.	☐	☐	☐	☐
The activity enhanced my professional skills.	☐	☐	☐	☐
The activity confirmed the effectiveness of previous skills.	☐	☐	☐	☐
I learned new techniques or skills.	☐	☐	☐	☐
I learned new diagnostic strategies.	☐	☐	☐	☐
The activity was free of industry bias.	☐	☐	☐	☐
I acquired new skills and competencies not listed above – *please list here:*	☐	☐	☐	☐

These new skills will improve my work performance and professional competencies in the following areas:

(Check all that apply):

- ☐ Provision of patient care
- ☐ Communication with patients and families
- ☐ Teaching and educational tasks
- ☐ Administrative duties
- ☐ Research endeavors
- ☐ Team and co-worker interactions
- ☐ Medical knowledge
- ☐ Practice-based learning and improvement
- ☐ Interpersonal and communication skills
- ☐ Professionalism
- ☐ Systems-based practice
- ☐ Other – *please list here:*

Please provide additional comments about the Activity and make any suggestions for improvement:

Please list any topics you would like to see presented in the future:

CME ACTIVITY CERTIFICATION

Please photocopy this form and complete the information required for each CME Activity.

Journal Issue Month and Year_____ Volume Number _____ Issue Number _____
CME Article Number _____ CME Article Author's Name_____

I, _____ certify that I have met the criteria for CME credit by studying the designated materials, by responding to the self-assessment questions, by reviewing those parts of the article dealing with any question(s) answered incorrectly, and by referring to the supplemental materials listed in the references.

This educational activity is designated for 1½ category 1 CME credits.

Indicate total credits claimed: _____ (maximum of 1½ credits)

Signature of Participant _____ Date _____

Are you a member of the AAP? ☐ Yes ☐ No

Do you have an individual subscription to the *Journal*? ☐ Yes ☐ No

If you are not an AAP member or a Journal subscriber, have you enclosed payment of $15 with your exam? ☐ Yes ☐ No

Payment Options: ☐ Check (Payable to AAP) ☐ VISA ☐ Mastercard

Card # _____ Exp. date _____ Amount $ _____

Signature _____

Please provide your name as it should appear on your certificate of credit and also provide your mailing address.

Name _____ Position _____

Institution _____

Street Address _____

City, State, Zip _____

Phone _____ Fax _____ Email _____

Office Use _____