The Fourth IEEE RAS/EMBS International Conference
on Biomedical Robotics and Biomechatronics
Roma, Italy. June 24-27, 2012

Efficacy of robotic-assisted gait training compared with intensive task-oriented physiotherapy for children with Cerebral Palsy

M. Romei, A. Montinaro, L. Piccinini, C. Maghini, C. Germiniasi, I. Bo, F. Molteni, A. C. Turconi

Abstract - The purpose of this study was to evaluate if adding paediatric robotic-assisted gait training (RAGT) to task-oriented physiotherapy (TOP) in children with Cerebral Palsy (CP) could improve gross motor abilities and gait compared to intensive TOP. Nineteen ambulatory children with Bilateral Spastic CP were assigned to two 10-week training groups. 9 children had 20 sessions of RAGT and 20 sessions of TOP, the other 10 children had 40 sessions only of TOP. The Gross Motor Function Measure, 6-Minute Walk Test and 3D Gait Analysis were assessed prior to, at the end of, and 3 months after the end of the treatment.

After the training and during the follow up, both groups improved their Gross Motor Function Measure scores, maintained their gait pattern and had unchanged 6-Minute Walk Test results. No between group differences were found in any outcome measures.

In conclusion, compared to intensive TOP alone, the addition of RAGT to TOP was demonstrated to be equally effective at improving gross motor abilities and maintaining gait pattern over time. The robotic rehabilitation allows care-providers to administer a standardized, controlled, dosed therapy, and appears to increase patient's motivation.

INTRODUCTION

Cerebral Palsy (CP) is the most frequent cause of motor, sensory and cognitive disability [1,2] and during childhood, the majority of children affected by CP follow physiotherapy training programs. Improving and maintaining walking function is often a primary focus in the management of CP children, since a decreased locomotor function is predictive of reduced capacity for activity, participation, and social interaction [3]. Several studies investigated the effect of different physiotherapy training programs aimed at improving walking and functional ability in children with CP [4-8], attesting to the emerging need for rigorous and evidence-based evaluation of physiotherapy treatments.

Manuscript received January 31, 2012.
This work was supported in part by the Mariani Foundation.
M.R. and A.M. are with the Bionegineering Laboratory of the I.R.C.C.S. "Eugenio Medea", Italy. (corresponding author phone: 0039-031-877351; e-mail: Marianna.romei@bp.Lnf.it).
L.P., C.M., C.G., A.C.T. are with the Functional Rehabilitation Units of the I.R.C.C.S. "Eugenio Medea", Italy
I.B. is with the Casa di Cura "Habilita", Zingonia (BG, Italy)
F.M., is with Ospedale Valduce, Costamasnaga (LC, Italy)

In recent years, clinicians and researchers have increasingly placed emphasis on promoting active therapies, including intensive, repetitive, and task specific training to enhance neuroplasticity. This interest is based on the principle that task-specific and repetitive practice is required to develop and improve a motor skill such as walking [8]. Based on the demonstrated evidence that functional training on a treadmill is effective in adults with neurological disorders [9-10], the potential benefit of similar training for improving walking in children with CP has begun to be investigated. Previous authors [4,8] found that the use of partial body weight-supported treadmill training is safe and feasible for children with CP and is as effective as practicing over ground walking.

Previously, a robotic-assisted gait training (RAGT) program, conducted on a driven gait orthosis (DGO) was developed for adults [11]. The program was found to be effective in restoring and improving walking abilities in adults after stroke and spinal cord injury [12-14]. Recently, a pediatric DGO for RAGT was developed, and several studies found it to be a feasible and promising therapeutic option for pediatric population[15-18].

The aim of this study was to investigate if adding paediatric RAGT to task-oriented physiotherapy (TOP) in children with CP could improve gross motor abilities and gait compared to intensive TOP alone. A further aim was also to detect possible subjective and objective benefits for children using this robotic device.

METHOD

- *Participants*

Nineteen children (8 males and 11 females, ranging in age from 4 to 16 years) with a diagnosis of spastic bilateral CP [1,2] participated in this study. The children were classified according to the Gross Motor Function Classification System [19] (GMFCS) and according to the Manual Ability Classification System [20] (MACS) for their daily object handling skills. At baseline and in the two following assessments, anthropometric data (height and weight) were recorded.

Inclusion criteria were: 1) ability to communicate pain, fear or discomfort, 2) ability to walk independently with or without the use of assistive devices or orthoses, 3) co-operation for assessment, 4) femur size of 21 to 35 cm for an appropriate use
of pediatric DGO, and 5) a regular routine in physiotherapy treatment before this study.

Exclusion criteria were the contraindications for pediatric DGO previously established [15]. Children were also excluded if they had multi-level surgery less than six months before the onset of the study, or Botulinum Toxin A injections within the previous three months.
Approval for the study was obtained from the local Ethics Committees of the Institute and written consent was obtained from the parents/caregivers of each children.

- *Protocol*

RAGT was performed using the pediatric module of Lokomat® (Hocoma, Zurich, CH, Figure 1) and physiotherapy exercises (Figure 2) were carried out for all the children at the same Department of Functional Rehabilitation.
To evaluate the effect of the two different training programs RAGT+TOP and Intensive (greater number of sessions/week) TOP alone (ITOP), a baseline assessment (T0) was followed by two post-treatment outcome evaluations; the first one at the end of the treatment (T1) and the second one three months after the end (T2) of the treatment.
After the baseline evaluation, the children were allocated into two groups: 9 children were assigned to RAGT+TOP group and the other 10 children to ITOP group. For the allocation procedure, the first 9 consecutive recruited subjects were assigned to RAGT+TOP group and the following 10 subjects to ITOP group.
Both RAGT+TOP and ITOP training consisted of 40 rehabilitation sessions, each of 30 minutes, over a 10 week course. Children in the RAGT+TOP group had 20 sessions of RAGT (2 sessions/week) + 20 of task-oriented physiotherapy (2 sessions/week). Children in the ITOP group had 40 sessions exclusively of task-oriented physiotherapy (4 sessions/week).

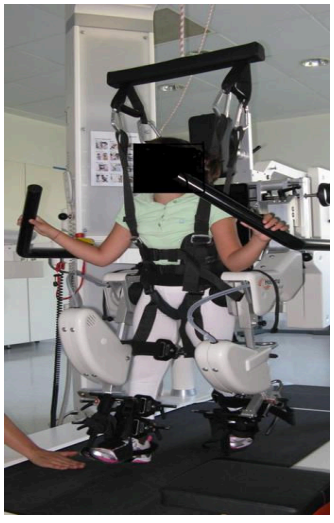
Figure 1. Robotic assisted gait training on pediatric Lokomat®

For the standardization of the RAGT protocol, children in the RAGT+TOP group were divided into two subgroups, according to their age: the 4 youngest children (4 to 6 yo) received RAGT on Monday and Thursday (and consequently on Tuesday and Friday they had TOP) and the 5 oldest children (8 to 9 yo) on Tuesday and Friday (and consequently on Monday and Thursday they had TOP). During each RAGT session, the children walked for 30 minutes with body-weight support fixed at 50% for the entire duration of the training and the leading force at 100%. The only parameter that was modified during the treatment sessions was the gait velocity, which was initially set at 1.2 km/h for all the children and was gradually increased to 1.6 km/h for the youngest children (10% every 5 sessions) and to 2.0 km/h for the oldest children (20% every 5 sessions). The gait velocity was held constant during a single treatment session. To maintain compliance during the treatment session, the children were allowed to watch their favorite cartoon on a TV when verbal encouragement of the therapists was not sufficient to sustain the therapy session. At the end of the training, the total time spent on RAGT and the total walked distance for each child were recorded, and then the RAGT+TOP group mean was calculated.

For standardization of TOP, a group of specific exercises for improving gait, balance and functional abilities, strengthening extensor muscle and stretching of flexor muscle was chosen. Children of both groups underwent the same TOP program with the same physical therapist. No hardware was used during physiotherapy.


Figure 2. Physiotherapy exercise

- *Outcome Measures*

A GMFM-certified therapist assessed the gross motor ability by applying the Gross Motor Function Measure-88[21] (GMFM-88). GMFM-66 scores were derived from the GMFM-88 by using the Gross Motor Ability Estimator software[21]. Each child's gross motor abilities were evaluated by analyzing GMFM-66 and GMFM-88 dimension D and E scores. Gait endurance was assessed by the 6-Minute Walk Test [22] (6minWT), during which the children were instructed to cover as much distance (dist) as possible within a 6-minute period. When the children were assessed through GMFM and 6minWT, they were allowed to wear their usual footwear/orthoses and to use their own walking aids. The information about orthoses and assistive devices were recorded by the therapist during the baseline evaluation in order to have the same condition in the following assessments.

Functional assessment included 3D-Gait Analysis (3DGA). The Movement Analysis Laboratory is equipped with an optoelectronic system of 8-infrared cameras working at 100 Hz (Elite, Bts, Italy), two force plates (Kistler, Switzerland) and a wireless 16-channel EMG system (FREEEMG, Bts, Italy). The children were asked to walk barefoot or to wear their usual orthoses and footwear, to utilize their regular walking aids and to walk at their preferred speed for at least 10 times on a walkway. Each child's walking condition was recorded during the baseline evaluation in order to replicate them in the following assessment.

A 3DGA-experienced PM&R physician selected the most representative trials of each child for further analysis and parameter calculation. Walking speed, step length, stride length and cadence (all normalized in respect to height), and duration of stance phase (expressed as percentage of the gait cycle) were measured. From 16 kinematic parameters the Gillette Gait Index [23] (GGI) was calculated as a summary of the gait deviation from the normal walking pattern. Greater deviations from normal are reflected by a larger GGI; whit normal gait measuring 15.

The relatives or caregivers were asked to evaluate the walking ability of their children by filling in the Functional Assessment Questionnaire [24] (FAQ).

- *Statistical Analysis*

For all the outcome measures, mean values (M) $\pm$ standard deviation (SD) were calculated for the RAGT+TOP and ITOP groups. Student T test for unpaired samples was applied to analyze pre-treatment homogeneity of the two training groups (RAGT+TOP and ITOP) at baseline (T0). A general linear model for repeated measures with time [3 levels] as a within-subjects factor and training group [2 levels] as a between-subjects factor was performed. The level of significance was set at $p<0.05$ for all statistical comparisons.

To determine whether individual patients improved or declined, minimal detectable change values for GMFM-66 score and dist of 6minWT with 95% as confidence level of choice (MDC_{95} [25]) were calculated by using the respective test-retest data already available in Literature [22,25].

Values in text and tables are group M $\pm$ SD. All computations were performed with SPSS version 11.0 for Windows; SPSS, Chicago, IL.

RESULTS

All the recruited children completed the training programs and performed all the three evaluation sessions (T0, T1 and T2).

At baseline, no statistically significant differences in age, height and weight between children of RAGT+TOP and ITOP groups were found (Table 1).

Table 1. Patients' anthropometric data

	RAGT+TOP	ITOP
Age (years)	6.9±2.1	9.3±3.9
Height (cm)	119.7±14.5	134.7±20.9
Weight (kg)	24.8±8.0	32.3±14.3

The distribution of children requiring assistive devices or orthoses during walking was similar between the two groups: in RAGT+TOP group two children walked with AFO+cane, one child with cane and three children with AFOs, in the ITOP group two children walked with AFO+cane and two children with AFOs. According to GMFCS levels, in the RAGT+TOP group there were 3 children with level I, 5 with level II and one with level III. In the ITOP group there were 3 children with level I, 6 with level II and one with level III.

At the end of the RAGT+TOP treatment, the mean total distance walked per patient during the RAGT was 13862±1105 m (range: 12574 – 14921 m) and the total time walked per patient was 600 minutes.

At the end of the study both RAGT+TOP and ITOP groups showed significant improvement in the GMFM-66 score and in GMFM-88 dimensions D and E (Table 2). The between groups comparison showed no differences in the treatment effect on GMFM-66 score either at T1 or at T2 ($p>0.05$).

MDC_{95} value for GMFM-66 score was $\pm$ 3.26, slightly higher than the value previously found[25] in a smaller group of children with CP. An increase of 3.26 or more represents an improvement in functional ability, whereas a decrease of 3.26 or more represents a worsening. Changes of less than 3.26 score were considered to be within measurement error range. At both the T1 and T2 sessions, no child presented a decrease in GMFM-66 greater than 3.26 compared to baseline (T0). At the end of the study (T2) 5 patients of RAGT+TOP group and 3 patients of ITOP group had GMFM-66 score increase of more than 3.26 greater than baseline.

For the parameter dist of 6mWT no statistically significant changes were found for either group after the training (Table 2). Between-groups analysis revealed no differences in the walked distance either at T1 or at T2.

MDC_{95} value for dist was $\pm$ 59.5 m, which was similar to that previously calculated by Thompson and colleagues [22]. At the T1 session, one child in the RAGT+TOP group and one in the ITOP group increased their dist values more than 59.5 m when compared with the value at T0. At T2 the number of patients that had clinically significant increases in their walked distance was 3 for the RAGT+TOP group and one for the ITOP group. Only one child belonging to the ITOP group had a clinically significant reduction in walked distance at T2.

Table 2.Outcome measures

		RAGT+TOP	ITOP
GMFM-66	T0	71.7±14.4	69.2±8.5
	T1	73.5±13.6	70.5±8.1
	T2	74.2±12.0	72.0±9.3
GMFM-88 dim D	T0	85.6±10.9	84.7±10.5
	T1	89.4±10.4	87.3±8.6
	T2	90.4±9.6	88.8±8.7
GMFM-88 dim E	T0	64.7±26.1	70.7±19.4
	T1	68.9±23.2	73.9±18.7
	T2	71.7±21.4	75.0±18.4
dist (6mWT, [m])	T0	298.7±168.9	331.5±111.3
	T1	312.0±144.4	339.2±111.2
	T2	323.0±156.4	339.4±119.2
Gait Gillette Index	T0	163.4±125.2	134.6±88.8
	T1	172.0±133.3	164.6±97.6
	T2	174.2±129.2	161.3±90.4

When analyzing 3DGA data, no significant changes for stride parameters (walking speed, step length, stride length and cadence) normalized in respect to subject's height were found for either group. Stance phase duration did not change after the training or in the follow up period for either group.
There were no significant within- or between group changes in GGI for either group after the training.
For the caregivers' functional evaluation (FAQ) no within- or between groups changes were found, though an increasing trend was noted for both the groups.

DISCUSSION

The main finding of this study is that the combination of RAGT and TOP was as effective as ITOP alone in the improvement of gross motor abilities and in the maintenance of the gait pattern over time. These results were demonstrated by all outcome measures: GMFM-66 and dimensions D and E of GMFM-88, Gait Analysis and GGI and 6-Minute Walk Test.
It's noteworthy to report that all patients completed the trial and RAGT was well tolerated. Compared to traditional physiotherapy, RAGT seemed to be more motivating for all the children. In addition, the robotic device allows administration of a standardized controlled dose therapy.
Literature does not provide well defined and unique protocols for the use of RAGT in children with CP. Therefore a protocol using the same treatment parameters for all patients without a specific personalization was implemented. In this study, the leading force was fixed at 100%, and this infers that children's movement was mostly passive during the RAGT. According to motor learning principles, an active participation in combination with task specificity should lead to more benefit in improving walking function[4]. Furthermore, the gait velocity on RAGT was increased 10% every 5 sessions for the youngest children and 20% every 5 sessions for the oldest, and this may limit the potential improvement in children who could have walked faster and/or increased their velocity more rapidly.

We chose to compare RAGT+TOP vs ITOP instead of RAGT alone vs ITOP considering RAGT a complementary therapy. Physical therapy has to be considered the most important rehabilitation approach in these patients. Furthermore, RAGT does not allow all the degrees of freedom that are typically exhibited by kids with CP during walking. This confirm the need to combine robotic gait training with physical therapy.

The results of this study related to 6-Minute Walk Test show no changes in gait endurance. Only one previous study [15] where RAGT was used as a training program reported a clinically significant improvement in 6-Minute Walk Test. In that study, however, children affected by a variety of neurological pathologies were involved (Cerebral Palsy, Traumatic Brain Injury, Stroke, Guillain-Barrè syndrome, incomplete paraplegia, haemorrhagic encephalitis, dystonia) and the number of training sessions ranged from 3 to 20. Other previous studies showed changes in the walked distance of 6-Minute Walk Test comparable to those shown in the present study.

Because of the nature and the specificity of RAGT, an improvement in gait pattern for the children of the RAGT+TOP group was expected, and therefore 3DGA was performed as a relevant measurement for the outcome evaluation. This represents a strength of this study and an important difference with the previous studies of RAGT efficacy in children with Cerebral Palsy, in which only clinical functional scales and gait endurance test were applied. GGI data obtained for the RAGT+TOP group indicated that the repetitive execution of walking movement performed by the DGO is only effective in maintaining the gait pattern over time. No improvements in gait were observed.
Moreover, this study included a proper control group receiving an equal amount of ITOP therapy, whereas in many previous assessments of RAGT, controls were not assessed [16-18]. Based on the results of this study, it appears that a control group is necessary to evaluate the true benefits of RAGT.

The allocation procedure can be considered a limitation of the study, even though this seems not to influence the final results.

The introduction of the DGO device in physiotherapy treatment had a positive impact on children's and family's daily life. During a post-training interview, parents reported that after RAGT children's functional skills in self-care at home had increased and their need for caregiver assistance in self-care and mobility had decreased. In addition, during the RAGT the children appeared highly motivated because of the novelty of the treatment and the feeling of walking. No child missed sessions or reported difficulties with their progress at school.

In conclusion, our results suggest that RAGT can be safely introduced in rehabilitation training program for children with CP, and can constitute a valid alternative of TOP exercises. The RAGT therapy was feasible to

implement, well-accepted by children, and could be considered as a new therapy for increasing children's compliance and motivation during the rehabilitation program. These data are only subjective. We didn't evaluation a pre and post training attention span.

As no guidelines regarding RAGT in children with CP exist, and no general recommendations are yet available regarding length and intensity of the treatment, the present study standardized the RAGT parameters in order to limit the numbers of factors that could influence the treatment effects.

Further studies are needed in order to more extensively investigate the RAGT effect in children with CP by increasing the number of involved children and by identifying the most effective set of RAGT parameters.

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