Original article

Robotic-assisted gait training improves walking abilities in diplegic children with cerebral palsy

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ABSTRACT

The robotic-assisted gait training therapy (RAGT), based on intensity and repetition of movement, presents beneficial effects on recovery and improvement of postural and lo-comotor functions of the patient. This study sought to highlight the effect of this RAGT on the dynamic equilibrium control during walking in children with Cerebral Palsy (CP) by analyzing the different postural strategies of the fullbody (upper/lower body) before and after this RAGT in order to generate forward motion while maintaining balance. Data were collected by a motion analysis system (Vicon® — Oxford Metrics). Thirty children with bilateral spastic CP were evaluated using a full-body marker set which allows assessing both the lower and upper limb kinematics. The children were divided into two groups in such a way as to obtain a randomized controlled population: i) a group of fourteen children (Treated Group) underwent 20 sessions of RAGT using the driven gait orthosis Loko-mat®Pediatric (Hocoma) compared to ii) a group of sixteen children without sessions of Lokomat®Pediatric (Control Group) receiving only daily physiotherapy. Significant im-provements are observed between the TG pre- and post-test values of i) the kinematic data of the full-body in the sagittal and frontal planes and ii) the Gross Motor Function Measure test (D and E). This study shows the usefulness of this RAGT mainly in the balance control in gait. Indeed, the Treated Group use new dynamic strategies of gait that are especially characterized by a more appropriate control of the upper body associated with an improvement of the lower limbs kinematics.

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1.   Introduction

Cerebral palsy (CP) represents a group of non-progressive disorders due to lesions or abnormalities of the brain in the developing fetus or infant.[1] Children with cerebral palsy (CP) often have atypical body posture patterns and abnormal gait patterns resulting from functional strategies to compensate for primary anomalies that are directly attributable to damage to the central nervous system. These anomalies can lead in the longer term to adaptations in the motor control in these children.[2–4] The majority of these children have gait impairments. However, most clinical studies using quantitative gait analysis generally focus on lower limb strategy and tend to ignore upper body strategy (head and trunk movement, arm swing) which are greatly involved in maintaining dynamic balance during gait. To our knowledge, only few studies[5–11] have shown that CP gait is characterized by strong postural instability and stiffness of the whole body, particularly of its upper part with bloc patterns translating a decrease of rotation of trunk and head in relation to the pelvis. This stiffness of the upper body, and primarily the trunk, allows the child to control and to decrease the effect of lower limb movements on the head and therefore to stabilize the head during walking. This stabilization plays a very important role in the dynamic characteristics of walking.[12,13] The literature on full-body movement during gait in children with CP is more scarce, even nonexistent for comparative analysis before/after a robotic-assisted gait training therapy (RAGT) such as with the Lokomat® (Hocoma AG, Volketswil, Switzerland) which is increasingly introduced in pediatric rehabilitation (cf. Fig. 1).

This therapy is used in the treatment of children with CP in an attempt to improve standing and walking abilities. Based on the body weight supported treadmill training principle, its main purpose is to re-acquire functional gait through an intensive and repetitive gait pattern simulation for the lower limbs and a sensory stimulation through visual and auditive feedbacks of different serious games (task-oriented training).[3,14–18]

Few studies[19–26] have demonstrated positive results from the RAGT on the locomotor parameter values (mainly speed gait, frequency and stride length), on the gait endurance (6 min walking test) and on the performance of functional tasks (dimensions D and E of the Gross Motor Function Measure – GMFM). To the best of our knowledge, only one study[27] concludes that spatio-temporal parameters and kinematics, gait symmetry, Gait Gillette Index and COP data do not show statistically significant variations due to the robotic treatment. The authors precise that the lack of statistically significant improvement in clinical evaluation is probably due to the high number of children classified with Gross Motor Function Classification System (GMFCS) level III and IV (children are classified as moderately severe to severe, they use methods of mobility that require technical walking aids such as the walker, the manual wheelchair or motorized wheelchair). Another study[28] also found non-significant results (spatio-temporal and kinematics parameters) except for the range of pelvic motion in the frontal plane on the right side in the study group.

However, all these studies[19–28] do not address the possible effect of RAGT on total-body kinematic gait parameters for these children and more particularly on the dynamic

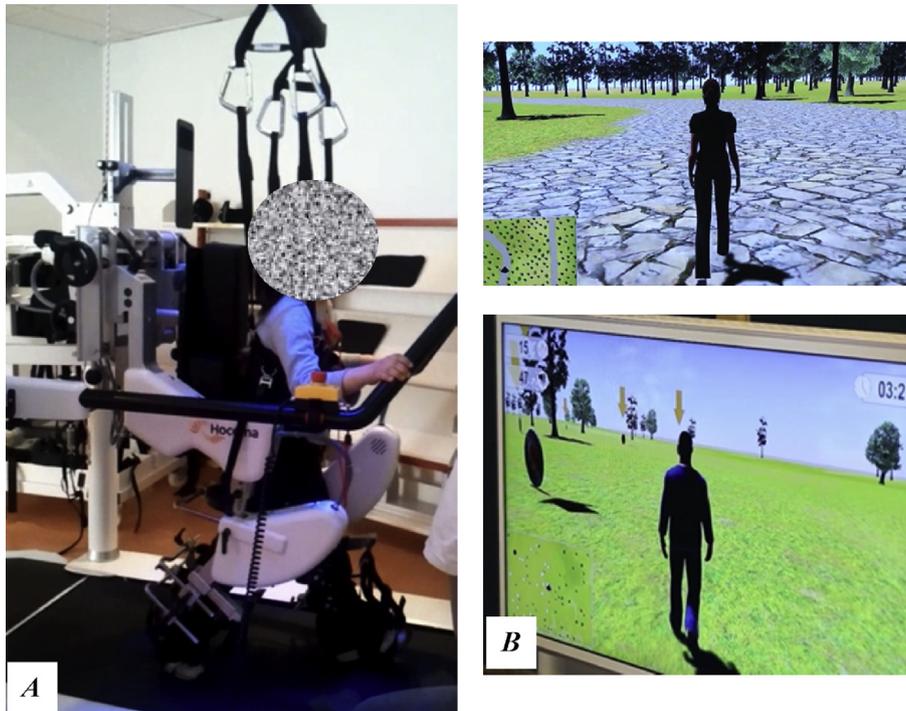**Fig. 1 – A: view of Lokomat®Pediatric; B: view of the visual interface during a session of robotic-assisted therapy. The Lokomat®Pediatric consists of a treadmill, a dynamic unloading system to relieve body weight, and two lightweight robotic actuators (exoskeleton), which are attached to the subject's legs.**

equilibrium control in gait. Therefore, the aim of this study was to evidence the effect of RAGT on dynamic equilibrium control in gait of children with CP, and more particularly on different strategies (upper/lower body) used during gait by these children in order to propel themselves forward while maintaining their balance. We make the assumption that RAGT presents beneficial effects on improvement of postural and locomotor functions of the patient resulting in a reorganization of gait pattern and full-body kinematic illustrating the dynamic equilibrium control in gait. This would translate in a better stabilization of the head, a better control of the displacement of the arms associated with an improvement in the kinematics of the lower limbs.

2. Methods

2.1. Participants

Thirty children with CP, aged 8–10 years, participated in the study. These children were recruited from the Unit of Clinical Movement Analysis of the Health Center – Rossetti Institute (PEP06). Inclusion criteria were: children with spastic diplegia with a jump gait; the ability to independently stand and walk or walk with assistance (e.g. walking stick); a classification of level II in the Gross Motor Function Classification System (GMFCS). At this level, the severity of motor impairment is moderate. Children may experience difficulty of walking and balancing on uneven terrain and inclines, they can walk with physical assistance mainly over long distances. The jump gait is defined as a knee bending disorder at the time of the ground attack by the foot. The foot is in plantar flexion with a tibial-tarsal angle always greater than $90°$, especially at the end of support. Hips and knees are in excess at the end of swing phase flexion and during the beginning of the stance phase. The children were divided into two groups in such a way as to obtain a randomized controlled population: i) Treated Group (TG) of 14 children (8 boys and 6 girls, mean ± SD age 8.3 ± 1.2 years) receiving twenty sessions of Lokomat®Pediatric, that is to say five intensive rehabilitation sessions per week of 40 min effective during four weeks ii) Control Group (CG) of 16 children (7 boys and 9 girls, mean ± SD age 9.6 ± 1.7 years) without sessions of Lokomat®Pediatric, receiving only daily physiotherapy. Children characteristics are presented in Table 1. Randomization and allocation into the two groups were made by drawing lots, limiting the selection biases. This was carried out by a specialist of physical and rehabilitation medicine, external to the study and attached to the health center. The evaluators were not aware of the assignment of children to study and control groups. A sample size calculation was performed so that the sample was the most representative of the population in relation to the dependant (kinematic data upper and lower body) and independent (group and treatment) variables of this study. The minimum sample size was eleven participants per group.

In order to observe the actual effects of this rehabilitation, none of the participants had undergone surgical treatment nor received injections of botulinum toxin at the latest one year before the intervention period. Only participants of the Control Group were received daily physical or occupational

Table 1 – Morphological and clinical characteristics of the children with CP of GMFCS level II.

	Treated Group	Control Group
Gender (female/male)	6/8	9/7
Age (years)	8.3 ± 1.2	9.6 ± 1.7
Height (m)	1.27 ± 0.17	1.31 ± 0.11
Weight (kg)	28.6 ± 1.21	29.8 ± 1.74
Brain pathology	PVL	PVL
Diagnostics	BS-CP	BS-CP
Walking aids/physical assistance	4 with stick	3 with stick
	2 with deambulator	2 with deambulator
	8 without aids	1 with ankle orthoses
		10 without aids
Walking speed (m s^{-1})	0.84 ± 0.17	0.85 ± 0.20
FAC	6 with score 3	7 with score 3
	8 with score 4	9 with score 4

Periventicular Leukomalacia (PVL); Bilateral spastic-Cerebral Palsy (BS-CP); Functional Ambulation Categories (FAC).

therapy during the same period. The participants and their legal guardians (parents or guardians) were informed of the progress of the study and gave their signed consents. Moreover, they were informed at the onset of the study that if they wished, they could stop the study at any time. The experiments were performed according to the Declaration of Helsinki. All subjects were recruited and agreed to the study, which was approved by the local ethics board.

2.2. Treatment intervention

The Treated Group received twenty sessions of Lokomat®Pediatric conducted over a four weeks period (5 sessions/week). Each session involved the child's installation in the device, this taking between 10 and 15 min for the physiotherapist. The extraction of the patient out of the device after the intervention needed less than 5 min. The duration of the therapy sessions was limited to 40 min of walking in the device. The same exercises were offered to the fourteen subjects with the same time, variation of speed, and game difficulties. The Lokomat® parameters were based on the measurement of limb length, the range of motion in the lower limb, muscle tone and body weight of the child. Body-weight support was started for all participants at 70% and then was gradually decreased at 40% over the sessions, according to the participant's functional capacity. Body-weight support was reduced as much as possible up to the point of when the knee started to collapse into flexion during stance phase due to the increased load of body weight. Walking speed was initially set at 0.7 km/h and gradually increased to 1.4 km/h. The therapist was always present at the child's sessions in order to follow the progression as well as to raise the child's awareness to correct gait patterns and posture during the training session.

The Control Group did not have sessions of Lokomat®Pediatric and only participated in exercises with a physiotherapist. These daily physiotherapy consisted of a passivo-active mobilization of the segments for 10 min followed by workshops of balance-posture working on the whole body with displacements on various grounds, graspings and displacements of objects, etc. The aim of these exercises was

to improve dynamic stability in various situations. The session ended with a calm return of 5 min. The total duration of the session was 40 min.

2.3.   Outcome measurements

An eight infrared camera Vicon® system (Oxford Metrics, Oxford, UK) was used to record three-dimensional total-body kinematic data to a sampling frequency of 200 Hz with the Plug-In-Gait marker-set.[29] A total of 34 reflective markers were positioned on the skin overlying specific bony landmarks or anatomical positions of the children's upper and lower body according to the Davis protocol (head, trunk and pelvis and bilaterally on the arms, thighs, shanks and feet) in order to enabling reconstruction of the segmental axes and their respective joint centers. Gait analysis was performed while the subjects walked barefoot along a 10 m straight and level walkway at a self-selected speed in a minimum of ten trials.

The assessments (Clinical gait analysis and GMFM test) were performed twice, before and after the treatment intervention. Clinical gait analysis and the GMFM test were performed for Treated Group three days before (T0) and three days after (T1) a robotic-assisted gait rehabilitation of twenty intensive sessions with Lokomat®Pediatric. For Control Group, clinical gait analysis and the GMFM test were performed at the start (T0) and at the end (T1) of this period of four weeks.

The GMFM test (GMFM − 66 score) is a rating scale of global motor function in children with CP.[30] We examined for this study mainly the dimensions D (standing abilities − GMFM-D score) and E (walking/running/climbing abilities − GMFM-E score). These two dimensions allow to evaluate motor skills such as walking on level ground and/or on mat, unipodal and bipodal balance (postural stability), up and down stairs, etc.

2.4.   Data analysis and statistical methods

Data was processed using VICON-Nexus® acquisition software (Oxford Metrics, Oxford, UK) and Motion Inspector® software (Biometrics France, Orsay, France) in order to reconstruct an appropriate biomechanical model for each subject reflecting the trajectory of the reflective markers and permitting the calculation of the upper body kinematics (shoulder angles in the frontal plane, head angles in the frontal and sagittal planes, elbow, thorax and pelvis angles in the sagittal plane) and lower body kinematics (hip, knee and ankle angles in the sagittal plane). For the upper body kinematic parameters, the head kinematic corresponds to the maximum and minimum amplitudes of the head angle relative to the orbitomeatal and horizontal axes (head pitch for sagittal plane and head roll for frontal plane) and the trunk according to the protocol used by Wallard and colleagues.[8] The shoulder kinematic measure corresponds to the angle elevation representing the opening angle between the humerus and the thorax in the frontal plane (abduction/adduction angle). The elbow kinematic measure corresponds to the flexion/extension angle. The angle of the trunk reflects the relative movement between the thorax and pelvis (anteroposterior movement). For the lower body kinematic parameters, the hip and knee kinematics measure correspond to the

flexion/extension angles, and the ankle kinematic measure corresponds to plantar-flexion and dorsi-flexion.

For each kinematic parameter, the maximum (peak angle) and minimum (minimum angle) values were calculated for each gait cycle (stance and swing phases). The results are detailed in Tables 2 and 3.

After establishing that each variable was normally distributed (according to a Shapiro−Wilk test), a two way ANOVA with repeated measures was conducted using the R software both for GMFM test and for the kinematic data in order to quantify the effect of robotic-assisted gait rehabilitation on dynamic equilibrium control in gait children with CP. The statistical model used was the ANOVA type III, namely two fixed factors which are the "group" effect (Treatment Group vs. Control Group) and the "treatment" effect (T0 vs. T1) correlated with the dependent variables (kinematic data and GMFM test). This analysis enabled us to identify two types of comparisons: i) an intergroup comparison corresponding to the variances of the means between the groups and ii) an intragroup comparisons corresponding to the variances of the observations around the mean of the group, and thus to explain the effect of a specific intervention on the kinematic and functional parameters. In all cases, results were considered statistically significant where p-values ≤ 0.05.

3.   Results

3.1.   Kinematic data

The full-body kinematic analysis allows to evidence the ability of the subject to generate and control its dynamic equilibrium during gait and thus analyze the dynamic strategies and coordination between the upper and lower body created by the subject to move forward.

The intergroup comparison corresponds to the observed values on the one hand between T0 for the TG and T0 for the CG and on the other hand between T1 for the TG and T1 for the CG. The intergroup comparison shows no significant differences at T0. However, at T1 we observe significant differences for both the upper body kinematics parameters (head, shoulder and elbow) and the lower body kinematics parameters (knee and ankle). Data for the thorax, pelvis and hip angles show no significant differences.

The intragroup comparison corresponds for its part to the observed values between T0 and T1 for each group. For CG, no data shows significant differences. On the other hand, significant differences are shown for intragroup comparison data for TG for head (in both planes), shoulder, elbow, knee and ankle.

3.2.   Gross Motor Function Measure (GMFM) test

This analysis shows significant differences (cf. Fig. 2) for both the intergroup comparison at T1 (T1-TG/T1-CG) (dimension D: 60.58% ± 14.71 for T1-TG vs 55.74% ± 15.02 for T1-CG, p-value 0.048; dimension E: 50.87% ± 15.82 for T1-TG vs 43.61% ± 12.59 for T1-CG, p-value 0.026), and for the intragroup comparison (T0/T1 − TG) (dimension D: 53.89% ± 16.02 vs 60.58% ± 14.71, p-

Table 2 – Mean and standard deviation (std) values of upper-body kinematics parameters in the sagittal plane for the pre (T0) and post (T1) rehabilitation and the frontal plane for the head (head roll) and the shoulder elevation.

| | Treated Group (TG) | | | | Control Group (CG) | | | | p-Values | | | |
| | T0 | | T1 | | T0 | | T1 | | Intergroup comparison | | Intragroup comparison | |
	Mean	std	Mean	std	Mean	std	Mean	std	T0-TG/T0-CG	T1-TG/T1-CG	T0/T1 (TG)	T0/T1 (CG)
Head pitch (sagittal plane)												
Mean peak angle (°)	7.8	1.0	10.8	1.6	7.7	2.9	7.6	1.7	1.000	**0.005**	**0.012**	0.951
Mean minimum angle (°)	−3.7	1.3	−6.4	2.0	−4.4	3.5	−4.2	9.6	0.176	**0.017**	**0.032**	0.796
Head roll (frontal plane)												
Mean peak angle (°)	6.3	2.9	4.8	3.0	6.4	1.9	5.1	2.0	0.991	**0.031**	**0.035**	0.297
Mean minimum angle (°)	−7.5	5.2	−5.7	2.8	−8.6	7.0	−7.8	2.5	0.916	**0.028**	**0.021**	0.364
Shoulder elevation												
Mean peak angle (°)	41.8	5.0	38.2	2.3	40.9	7.2	40.7	5.3	0.971	**0.046**	**0.031**	0.724
Mean minimum angle (°)	26.4	3.6	24.5	4.2	28.3	6.2	27.4	7.8	0.150	**0.033**	**0.039**	0.854
Elbow flexion (+)/extension (−)												
Mean peak angle (°)	71.5	5.7	69.4	8.0	71.3	4.4	73.5	9.1	0.925	**0.013**	**0.049**	0.147
Mean minimum angle (°)	49.6	7.3	47.2	7.6	49.4	11.5	49.7	12.3	1.000	**0.025**	**0.046**	0.739
Thorax												
Peak angle in stance (°)	3.8	5.1	3.4	4.9	3.7	4.1	3.5	7.9	0.952	0.126	0.155	0.701
Peak angle in swing (°)	3.9	2.3	3.5	4.7	3.9	4.5	3.8	5.3	0.801	0.053	0.251	0.486
Minimum angle in stance (°)	−5.2	4.8	−3.8	1.7	−4.8	4.4	−4.6	6.3	1.000	0.061	0.405	0.988
Minimum angle in swing (°)	−4.6	6.3	−2.8	4.9	−4.2	3.7	−3.9	4.7	1.000	0.203	0.143	0.561
Pelvis												
Peak angle in stance (°)	15.9	5.1	14.2	6.4	15.2	6.3	15.1	8.4	0.771	0.308	0.142	0.637
Peak angle in swing (°)	14.4	3.3	12.9	4.7	15.9	7.2	14.6	9.1	0.430	0.531	0.403	0.501
Minimum angle in stance (°)	10.6	3.7	9.8	4.3	11.2	7.1	10.3	5.1	1.000	0.108	0.498	0.314
Minimum angle in swing (°)	9.9	4.7	8.6	5.3	9.8	4.9	9.3	6.7	0.975	0.082	0.508	0.472

Significant p-values (<0.05) are highlighted in bold.

value 0.037; dimension E: 42.23% ± 14.65 vs 50.87% ± 15.82, p-value 0.033).

No significant differences were shown for both the intergroup comparison at T0 (T0-TG/T0-CG) (dimension D: 53.89% ± 16.02 for T0-TG vs 53.81% ± 14.67 for T0-CG, p-value 0.073; dimension E: 42.23% ± 14.65 for T0-TG vs 42.51 ± 13.09 for T0-CG, p-value 0.09), and for the intragroup comparison (T0/T1 − CG) (dimension D: 53.81% ± 14.67 vs 55.74% ± 15.02, p-value 0.053; dimension E: 42.51 ± 13.09 vs 43.61% ± 12.59, p-value 0.098).

4. Discussion

The aim of this study was to analyze and to evidence the effect of robotic-assisted gait rehabilitation on walking abilities in

Table 3 – Mean and standard deviation (std) values of lower-body kinematics parameters in the sagittal plane for the pre (T0) and post (T1) rehabilitation.

| | Treated Group (TG) | | | | Control Group (CG) | | | | p-Values | | | |
| | T0 | | T1 | | T0 | | T1 | | Intergroup comparison | | Intragroup comparison | |
	Mean	std	Mean	std	Mean	std	Mean	std	T0-TG/T0-CG	T1-TG/T1-CG	T0/T1 (TG)	T0/T1 (CG)
Hip												
Angle at the initial contact (°)	40.2	3.2	38.4	4.7	41.6	5.2	40.8	7.2	0.131	0.251	0.141	0.109
Minimum angle in stance (°)	−9.7	5.0	−10.8	3.0	−8.2	7.3	−9.8	6.1	0.247	0.312	0.110	0.107
Peak angle in swing (°)	45.1	6.1	43.8	4.1	45.8	5.8	45.1	5.4	0.801	0.148	0.195	0.218
Knee												
Angle at the initial contact (°)	18.2	6.2	16.8	4.3	17.9	8.7	17.2	3.4	1.000	**0.035**	**0.045**	0.813
Minimum angle in stance (°)	10.4	7.6	8.1	6.9	11.6	6.4	10.9	4.8	1.000	**0.014**	**0.043**	0.956
Peak angle in stance (°)	37.3	1.5	35.9	2.7	38.1	8.6	37.5	3.7	0.957	**0.025**	**0.041**	0.713
Peak angle in swing (°)	56.4	3.6	58.2	4.8	54.8	6.5	57.4	3.3	0.642	**0.046**	**0.037**	0.811
Minimum angle in swing (°)	13.9	7.4	11.8	5.0	14.6	4.8	14.8	3.9	0.703	**0.024**	**0.040**	0.956
Ankle												
Angle at the initial contact (°)	1.3	1.5	0.8	2.1	1.3	2.5	1.1	1.8	1.000	**0.026**	**0.050**	1.000
Peak angle in stance (°)	10.8	5.7	12.6	3.3	11.7	5.8	11.9	10.8	1.000	**0.048**	**0.042**	1.000
Minimum angle in stance (°)	−11.5	1.9	−13.0	1.5	−11.2	6.6	−12.3	5.3	0.905	**0.013**	**0.036**	1.000
Peak angle in swing (°)	2.7	3.7	3.1	2.5	2.8	3.8	2.7	7.4	1.000	**0.037**	**0.040**	1.000

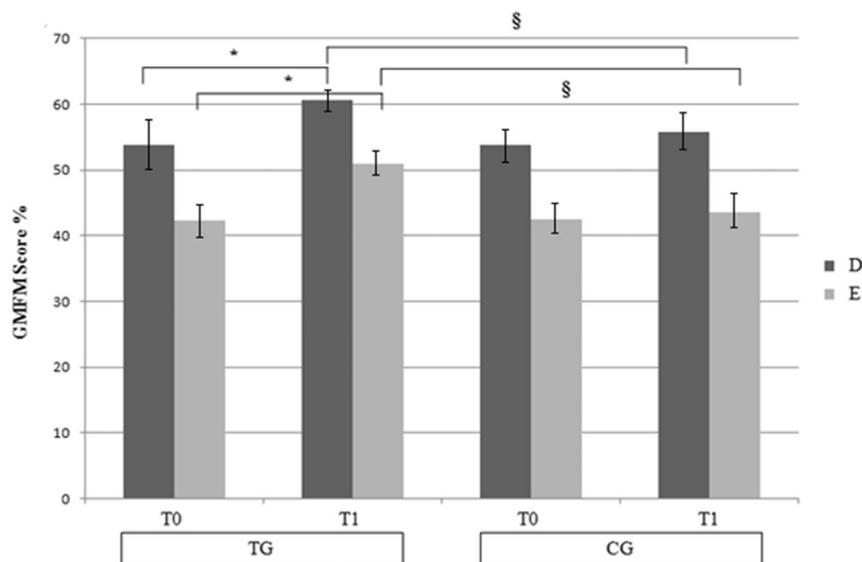Significant p-values (<0.05) are highlighted in bold.

Fig. 2 − Histogram showing the results after the therapy in the dimension D (standing) and E (walking/running/climbing) of the GMFM test. * corresponds to significant improvements in intragroup comparison (T0/T1 TG). § corresponds to significant improvements in intergroup comparison (T1-TG/T1-CG).

children CP with spastic diplegia. This study, though performed on a limited number of patients, nevertheless shows modification of postural and locomotor functions resulting in a reorganization of full-body kinematic. This is especially characterized by a better control of the upper body associated with an improvement of the lower limbs kinematics which is similar to the values observed in typically developing children.

Upper and lower limb movement during walking provides information about balance control and gait stability. Although the upper body (head, arms and trunk) is considered as "the passenger part" of the gait,[31] it plays an important role during gait. An altered gait pattern implies mainly movements of compensations to help maintain balance and stability. Children with CP (spastic diplegia), who have poor balance control during gait[7] use their arms for compensation[32,33] with increased shoulder movements in the frontal plane (elevation angle) and increased elbow movements in the sagittal plane (flexion/extension angle). These arm postures are similar to the description of the guard position that toddlers exhibit during the first weeks of walking.[34,35] Altered arm posture in children with CP is related to balance control during walking.[34] CP gait is characterized by stiffness of the upper body with bloc pattern, particularly of the head relative to the trunk reducing the head degrees of freedom to control.[8,12,13] CP children show a tendency to place the chin as close to the chest as possible in order to reduce these degrees of freedom between the head and the trunk (there is no dissociation of the head-trunk which move as a single segment).[8] Indeed, this bloc pattern illustrates a particular organization of the head and the gaze orientation translating into a tendency to look downward and not forward which results in significant head movement.[8,12,13]

In our study, the gait analysis of full-body kinematic and the GMFM test have shown at T0 for both groups these same attitudes whether for the arm postures (cf. Table 2) with more shoulder elevation and elbow flexion or for the particular organization of the head with increased head movements (cf. Table 2). This reflects probably a poor trunk control which aims to reduce as much as possible the effect of lower limb movements during gait. The observed results at T0 on thirty CP children confirm those reported by previous studies.[7,8,12,13,32−35]

Furthermore, the observed results also show that children belonging to the Treated Group were seen to adopt new gait strategies compared to the Control Group.

The intragroup comparison (T0/T1-TG) results translate a statistically significant improvement in the dynamic equilibrium control in gait of the whole body. The children of the TG adopt new dynamic strategies of gait that are especially characterized by a more appropriate control of the upper body associated with a significant improvement of the lower body. For the upper body (cf. Table 2), these children show a new organization of the head and the gaze orientation illustrated by significant improvement of the stabilization of the head whether for the frontal plane (head roll) or the sagittal plane (head pitch). This type of organization, referred to as "positional anchoring" of the gaze,[36] is a fundamental component of the vestibule-ocular balance process. This head stability is essential for the proper integration of vestibular and visual information needed in functions related to balance.[12] The stabilization of the head observed in the TG after the robotic-assisted gait rehabilitation can be explained by the fact that during the Lokomat®Pediatric sessions, the children must raise their head and stabilize their gaze on the screen in front of them in order to interact with the different serious games which are proposed. Moreover, this new organization of the head is associated with better control of arm postures and arm swinging during walking. Indeed, the TG children show a significant decrease of arm flexion associated with a significant decrease of shoulder elevation. This better control is correlated with the results observed for the lower limbs (cf. Table 3)

because when balance during walking improves, arm guard positions are expected to decrease.[34] The results show a significant improvement of knee and ankle kinematic that is similar to the values observed in typically developing children. These children have improved gait patterns particularly at the level of the angle at the initial contact and in stance phase for the knee and ankle. These improvements seem coherent with the aim of the Lokomat®Pediatric which consists to rehabilitate functional gait through an intensive and repetitive simulation of the different phases of gait. Finally, the kinematic of thorax, pelvis (cf. Table 2) and hip (cf. Table 3) show no significant differences. These no significant differences can be explained by the fact that the Lokomat®Pediatric, by the exoskeleton fastening and the suspension harness on the child, blocks the hip articulation and the lower trunk.

For the intergroup comparison (T1-TG/T1-CG), except for the kinematic of thorax, pelvis (cf. Table 2) and hip (cf. Table 3), all the differences were significant. This confirms the interest of a robotic gait rehabilitation with intensive and repetitive movement added to a traditional physiotherapy rehabilitation.

The GMFM D and E data (cf. Fig. 2) are in agreement with the kinematic data. The results show task-specific improvements in gait parameters as measured by the dimension E of the GMFM. The improvement in the standing dimension (D) of the GMFM was equally as good as in the walking dimension (E) of the GMFM. This suggests an additional effect on the stabilization of posture beyond the task-specific improvement of walking parameters.[23] The GMFM D and E data correlated with the kinematic with better alternating steps, and with a decrease in daily use of technical walking aids. The improvements of these results were consistent with the perception of the patients, parents and caregivers who most often reported increased endurance, improved balance control in gait, and reduction of walking aids. The intragroup results for CG (T0/T1) show no significant differences. Moreover, for the intergroup comparisons (T1-TG/T1-CG), all the differences were significant. Overall, these first results show a dynamic and active postural control in gait by these children with an increased dynamic and smooth control between the successive phases of balance (stance phase) and imbalance (swing phase).

The results of this experiment then confirm our original hypothesis, namely that robotic gait rehabilitation presents beneficial effect on improvement of postural and locomotor functions of the patient. These improvements result in a reorganization of gait pattern which become more and more similar to that which was observed in typically developing children.[7,8,12,13,32—35]

In this study, we sought to achieve homogeneity in the division of the two groups (TG and CG) in order to have the same cognitive and motor learning levels in order to compare the actual effects of such a robotic gait rehabilitation. This study assessed the effect of Lokomat®Pediatric directly after therapy but not a few months later for logistical reasons. There was no long-term follow-up, therefore, the results do not provide any indication that benefits are maintained or on the necessity to repeat Lokomat®Pediatric regularly or to use it continuously. This limitation could be addressed by evaluating the evolution of improvements over time. Some authors[21,23] have shown a sustainability of the effect of

Lokomat®. Furthermore, it would be relevant and interesting to carry out other tests such as spasticity tests and muscle tone of the upper limbs (the trunk or the head for example) but also tests for controlling the posture of the trunk in relation to the lower limbs during dynamic activities in order to better understand post-intervention improvements in overall postural control. The cognitive abilities have not been evaluated; it would be interesting to take this aspect into account in a future study. Nevertheless, the results of this study dealing with the use of robotic rehabilitation have proved its real interest in the therapeutic and clinical treatment of children with CP. Moreover, it can be appropriate to provide the means to confirm more strongly the benefits of this assisted process. It is important to enrich the overall biomechanical data by taking into account other factors (for example, EMG data/ muscle strength or else mechanical work/energy expenditure). From our point of view, these are important elements for understanding the different strategies used by children with CP in gait production.

Conflict of interest

None declared.

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