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Effect of robotic-assisted gait rehabilitation on dynamic equilibrium control in the gait of children with cerebral palsy

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ABSTRACT

Due to the intensity and repetition of movement, roboticassisted gait training therapy could have a beneficial effect on the recovery and improvement of postural and locomotor functions of the patient. This study sought to highlight the effects of robotic-assisted gait rehabilitation in gait of children with Cerebral Palsy (CP). We analyzed the different strategies before and after this rehabilitation which was used in order to generate forward motion while maintaining balance. Data were collected by a motion analysis system (Vicon® - Oxford Metrics, Oxford, UK). 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 roboticassisted gait training therapy using the driven gait orthosis Lokomat®Pediatric (Hocoma AG, Volketswil, Switzerland) compared to ii) a group of sixteen children without sessions of Lokomat®Pediatric (Control Group). Significant differences are observed for the TG between the preand post-test values of the locomotor parameters and of the kinetic data of the propulsive forces of the Center of Mass (COM) and of the Center of Pressure (COP) dynamic trajectory. This first study, although performed on a limited number of patients, shows the usefulness of this robotic gait rehabilitation mainly in the balance control in gait. Indeed after this rehabilitation, these children improve their gait that is especially characterized by a more appropriate time lag between the time instant of COM-COP trajectory divergence and the time instant when the forward propulsive forces became apparent.

1. Introduction

Walking may be defined as the forward displacement of the body requiring coordination between alternate successions of the swing phase and the stance phase. Consequently, walking can be summarized as the aptitude to produce and control propulsive forces through these alternating successions of double-support and single-support phases in order to move the body forward. To achieve this, it is necessary to create a distance between the Center Of Mass (COM) and the Center Of Pressure (COP) along the anteroposterior axis. The study of the distance between the COM and the COP trajectories provides information on the strategies used to control dynamic equilibrium and helps to explain the generation of the propulsive forces needed to walk [1–4]. This relationship between COM and COP constitutes a reliable indicator of strategies developed for children with typical development (TD) and cerebral palsy (CP) [4–6].

CP gait is generally characterized by a set of persistent movement and posture disorders [7]. This gait results in substantial postural instability and stiffness of the whole body, particularly of the upper part [8–12]. Indeed, they must control the disequilibrium generated by the decoupling between the projection of the COM and the COP during walking [6], which requires more energy than in TD children of the same age [13–15]. Therefore, the acquisition of new locomotor capacities represents one of the primary care objectives of these children.

In recent years, robot-assisted gait training (RAGT), such as the Lokomat® (Hocoma AG, Volketswil, Switzerland) was introduced in pediatric rehabilitation. These systems of rehabilitation assisted by robotics are based on sensorimotor learning principles, and are increasingly proposed as treatment modality for patients with locomotor disorders. Based on the body weight supported treadmill training principle, their main purpose consists of reacquiring functional gait through an intensive and repetitive simulation of the different phases of gait and sensory stimulation through visual and auditive feedbacks from different serious games (intensive task specific training) [16–21].

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Research that has been carried out in children with CP [22–30] shows general improvement of locomotor parameter values (mainly speed gait, frequency and stride length), endurance (6 min walking test) and of the performance of functional tasks (dimensions D and E of the Gross Motor Function Measure [31]). But, to the best of our knowledge, only one study [30] concluded that spatio-temporal parameters and kinematics, gait symmetry, Gait Gillette Index and COP data do not show statistical significant variations due to the robotic treatment. However, the authors specify that the lack of statistical significant improvement in clinical evaluation may be explained by the high number of children classified with Gross Motor Function Classification System (GMFCS) [32] level III and IV. Children were classified as moderately severe to severely involved, characterized by mobility that requires technical walking aids such as the walker, the manual wheelchair or motorized wheelchair.

The aim of this study was to highlight the effect of robotic-assisted gait rehabilitation on dynamic equilibrium control in the gait of children with CP, and more specifically on different strategies used in order to propel themselves forward while maintaining their balance. We make the assumption that robotic-assisted gait rehabilitation presents beneficial effects on recovery and improvement of postural and locomotor functions of the patient. These improvements result in a reorganization of gait pattern, which become less jerky. This translates to a decrease in braking upon heel strike increasing especially the displacement mean speed.

2. Methods

2.1. Participants

Gait analysis data was obtained from 30 children aged 8–10 years. These children were recruited from the Unit of Clinical Movement Analysis of the Health Center − Rossetti Institute (PEP06). Inclusion criteria were: children with bilateral spastic with a jump knee gait pattern; being able to independently walk without or with assistance (*e.g.* walking stick) on at least 60 m; classified as GMFCS level II. At this level, the severity of motor impairment is moderate. Children may experience difficulty walking and balancing on uneven terrain and inclines and they may require physical assistance when walking over long distances. The jump knee gait pattern [33] is defined as a knee bending disorder at the time of foot contact with the ground. 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 excessive flexion at the end of swing phase flexion and during the beginning of the stance phase. Finally, 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. Randomization and allocation into the two groups were made by drawing lots, limiting the selection biases.

The children were divided into two groups to obtain a randomized controlled population: i) Treated Group (TG) including 14 children (8 boys and 6 girls, mean ± SD age 8.3 ± 1.2 years) receiving only twenty sessions of Lokomat®Pediatric ii) Control Group (CG) including 16 children (7 boys and 9 girls, mean ± SD age 9.6 ± 1.7 years) without sessions of Lokomat®Pediatric. The CG received only daily physical or occupational therapy with a physiotherapist. The characteristics of the children of the two groups are presented in Table 1.

The participants and their legal guardians (parents or guardians) were informed of the progress of the study and gave their signed consents. 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. Procedure

Data was collected by a motion analysis system with 8 infrared cameras recording at a frequency of 200 Hz (VICON® − Oxford Metrics, Oxford, UK) and 4 force platforms (AMTI®, 0.60 × 0.60 m) in order to provide a clinical gait analysis. The children were equipped with 34 reflective markers that were aligned to anatomical landmarks on the head, trunk, pelvis and bilaterally on the arms, thighs, lower legs and feet. Following the full body Plug-In-Gait protocol [34], it enabled the reconstruction of the segmental axes and of their respective joint centers. The participants walked barefoot without walking aids at their preferred speed for a minimum of ten trials on a 10 m x 0.60 m gait track.

Table 1
Morphological and clinical characteristics of the children. Periventicular Leukomalacia (PVL).

	Treated Group	Control Group
Gender	8 boys and 6 girls	7 boys and 9 girls
Age (years)	8.3 years ± 1.2	9.6 years ± 1.7
Height (m)	1.21m ± 0.17	1.23m ± 0.11
Weight (kg)	18.6 kg ± 1.21	19.8 kg ± 1.74

Clinical gait analysis and GMFM test were performed for the Treated Group three days before (T0) and three days after (T1) a robotic rehabilitation. The treatment consisted of twenty Lokomat®Pediatric sessions with a duration of 40 min, spread over a period of four weeks. The same exercises were offered to the fourteen participants with the same time, variation of speed, and game difficulties. For all participants, the initial body-weight support was 70%, and was then gradually decreased to 40% over the sessions, according to the participant's functional capacity. Body-weight support was reduced as much as possible until the knee started to collapse into flexion during stance phase due to the increased load of body weight. 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. For the Control Group, clinical gait analysis and GMFM test were performed at the start (T0) and at the end (T1) of this four week period.

The GMFM test (GMFM–66 score) was performed in order 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. This test is a rating scale of global motor function in children with CP [31]. We examined for this study mainly the dimensions D (standing abilities–GMFM-D score) and E (walking/running/climbing abilities–GMFM-E score).

2.3. 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, for each subject, an appropriate biomechanical model of the trajectory of the reflective markers. This reconstruction allowed to calculate the trajectory of the COM [3] for each participant. The progress of the COP in the anteroposterior and mediolateral axes was extracted using forces platform data. The COP was computed from the reaction forces and torques of an equivalent platform calculated as the sum of the four platforms used (reference to König’s theorem). These results were subsequently used to calculate i) COM (from VICON-Nexus®)–COP (from platform data) trajectory relative to the propulsive forces [6] and ii) the time lag resulting at the time-instant of COM-COP trajectory divergence and the time-instant when the propulsive forces created become apparent around the anteroposterior (Y) and mediolateral (X) axes in each group at T0 and T1.

After checking each variable for normal distribution (according to a Shapiro-Wilk test), the following statistical analyses (intragroup and intergroup comparisons) were conducted using the R software: (i) for