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# Impact of a short walking exercise on gait kinematics in children with cerebral palsy who walk in a crouch gait

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ABSTRACT

*Background:* Crouch gait results in an increase of the joint stress due to an excessive knee flexion. Daily walking exercises, even when performed at a self-selected speed, may result in a decrease of the extensor muscle strength which could lead to a more severe crouch gait pattern. The aim of this study was to assess the impact of a short walking exercise on gait kinematics in children with cerebral palsy who walk with a crouch gait.
*Methods:* Seven children with cerebral palsy who walk with a crouch gait were asked to walk for 6 min at a self-selected speed. The spatio-temporal and kinematic measures, as well as the center of mass position were compared before and after the exercise.
*Findings:* There was no significant difference between walking speed before and after the walking exercise. Knee flexion and the maximal ankle dorsiflexion increased after the walking exercise. The vertical position of the center of mass decreased. No significant difference was found at the hip.
*Interpretation:* Children with cerebral palsy who walk with a crouch gait were more crouched after a 6-min walking exercise performed at their self-selected speed. These gait modifications could be due to fatigue of the extensor muscle groups. This study highlighted that a short walking exercise, corresponding to daily mobility, results in gait pattern modifications. Since therapies in children with cerebral palsy aim to improve motor function in everyday life situations, it could be relevant to evaluate gait adaptation after a few minutes of walking exercise.


## 1. Introduction

Cerebral palsy (CP) represents a group of non-progressive disorders due to lesions or abnormalities of the brain in the developing foetus or infant (Bax et al., 2005). CP is related to abnormal motor control resulting in posture and movement disorders (Beckung et al., 2008). These impairments are often associated with abnormal muscle tone, deformities, and muscle weakness (Gage et al., 2009), which result in deterioration of functional abilities including walking (Scrutton et al., 2004).

Crouch gait, characterized by an excessive hip and knee flexion (Rodda et al., 2004), is one of the most common walking pattern in children with bilateral CP (Wren et al., 2005). This flexed-knee gait results in an increase of the joint stress which also increases with crouch gait severity (Steele et al., 2012a). The larger internal extension moments required to maintain this posture, especially at the knee joint (Lin et al., 2000), represent a potentially harmful muscle stress. Moreover, excessive mechanical stress around this joint may lead to skeletal deformities during growth (Carter, 1987), patellar stress fractures (Perry et al., 1975; Topoleski et al., 2000), and pain (Rethlefsen et al., 2015). Finally, children who walk in a crouch gait are prone to a long-term degradation of their walking ability (Bell et al., 2002). Hence, limiting excessive lower extremity flexion during walking may reduce secondary adaptations and preserve mobility function and quality of life.

Given the increased muscle force requirement related to crouch gait (Hicks et al., 2008; Steele et al., 2012b), children with CP may also be prone to early onset of fatigue. Several studies evaluated muscle fatigue in children with CP (Eken et al., 2013; Leunkeu et al., 2010; Moreau et al., 2016; Stackhouse et al., 2005) and reported opposing results concerning muscle fatigability. Moreover none of these studies evaluated muscle fatigue induced by a weight-bearing exercise, such as walking. In children who walk in crouch gait, decreased muscle strength due to fatigue of the extensor muscle groups could in turn result in a more severe crouch gait. Such an adaptation could be anticipated even during short

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walking distances due to the muscle weakness related to CP (Steele et al., 2012b). A better understanding of gait adaptation during short walking exercise could therefore provide relevant information that could aid in identifying potential harmful musculoskeletal adaptations in children with CP who walk in crouch gait. As far as the authors know, gait pattern modifications induced by a continuous walking exercise practiced at a self-selected speed have never been reported in children with CP. The aim of this study was to evaluate the impact of a short walking exercise on gait kinematics in children with CP who walk in a crouched posture. It was hypothesized that the children would walk with a more severe crouch gait after a short walking exercise.

## 2. Methods

### 2.1. Participants

The study included seven youth with bilateral spastic CP who walk in crouch gait (age: 12 (3) years; weight: 34 (9) kg; height: 146 (18) cm). Participants were selected from a database of children who have undergone gait analysis at the LAM-CRME of Sainte-Justine Hospital in Montreal between 2013 and 2015. All children who fulfilled the selection criteria were included in the present study. Inclusion criteria were a diagnosis of spastic bilateral CP, the ability to walk for 6 min with or without support, and the presence of bilateral knee flexion greater than 15° throughout the stance phase of gait (Steele et al., 2013). Exclusion criteria were surgery intervention during the last 12 months and inability to walk without orthosis. Children were classified in Gross Motor Function Classification System (GMFCS) levels II ($n = 4$) and III ($n = 3$), meaning they were ambulatory, but they had limitations in basic walking skills (Rosenbaum et al., 2002). The participants with GMFCS level III required external support during walking, unlike those with GMFCS level II. All participants' characteristics are reported in Table 1. This study was approved by the Research Ethics Board of Sainte-Justine Hospital.

### 2.2. Six-minute walking exercise (6mwe)

Children were asked to walk barefoot for 6 min at their self-selected comfortable speed around a 25-m path. This exercise differs from the 6-min walking test (Guyatt et al., 1985; Maher et al., 2008), since children were not asked to walk the maximal distance within 6 min. They were asked to walk continuously at their self-selected speed for 6 min. This exercise was considered as representative of possible daily walking distances (Graham et al., 2004). Standardized encouragements were provided at the third minute.

### 2.3. Measurements

The kinematic gait analysis was performed before and at the end of the 6mwe. Reflective markers, corresponding to the plug-in-gait kinematic model (Vicon Motion Systems, Oxford, UK), were placed on each participant by the same experienced assessor. Markers were not removed throughout the protocol. The "before" 6mwe measures were taken while children walked barefoot along a 10-m walkway before the 6mwe. The "after" measures were taken during the last lap of the 6mwe, on the 10-m straight part of the path. The conditions for gait analysis, before and after the 6mwe, were the same, and both walks were performed at a self-selected comfortable speed. A 12-camera motion capture system (T40Sx Vicon, Oxford) sampled at 100 Hz was used to measure the marker displacements. The data were further analyzed with Nexus 1.8.5 and Polygon 4.1 softwares (Vicon Motion System, Oxford, UK) to obtain the trunk, pelvic and lower limbs joint angles, as well as the center of mass (COM) vertical displacements. The three dimensional trajectories were filtered using the Vicon Woltring routine (Woltring, 1986). The average of three gait cycles was used for the analyses. Since the objective was to evaluate gait adaptation at the end of the 6mwe without allowing any rest period, gait was recorded during the last lap of the exercise. The motion capture during this last lap was performed along the 10-m straight part of the path. At least three gait cycles were captured and averaged for all participants, as done in other studies (Ferrari et al., 2008; Hong and Brueggemann, 2000). This procedure allowed to evaluate the adaptation of gait during a continuous walking exercise.

The outcome measurements were (1) the walking speed, cadence, and step length; (2) the maximal and minimal flexion-extension angles of the trunk, pelvis, hip, knee, and ankle during stance; (3) the flexion-extension angles of the trunk, pelvis, hip, knee and ankle at initial contact; (4) the maximal, minimal and mean vertical position of the body COM, normalized to children's height, during the entire gait cycle, and;(5) the Gait deviation index (GDI) (Schwartz and Rozumalski, 2008), which is based on lower limb kinematics and indicates the deviation of a patient's gait compared to typically developing children.

### 2.4. Statistical analysis

All data sets were tested for normative distribution by using the Shapiro–Wilk test. Values were summarized using descriptive statistics. Either paired Student's T-tests or Wilcoxon signed-rank tests were used to compare the measurement variables between "before" and "after" the 6mwe, depending on the normality of the distribution. In all cases, the alpha level of statistical significance was set at p value inferior to 0.05. No correction for multiple comparisons was conducted. However, the effect size was reported along with exact p values. Effect size was calculated by dividing the difference between the means for the outcome variable by the pooled SD and was interpreted in accordance with Cohen's guidelines: 0.20 as small, 0.50 as moderate, and 0.80 as large. Statistical analysis of the GDI, the spatio-temporal data, and the hip, knee, and ankle joint angles were based on 14 limbs. The trunk, pelvis and COM changes were based on seven participants, except the COM and the trunk data which were based on six participants because of trunk missing markers after the 6mwe in one participant.

## 3. Results

All children completed the 6mwe. During the 6mwe, children with CP walked a mean distance of 276 (122) m. The GDI and walking speed did not change significantly after the 6mwe ($p > 0.05$) when compared to the before exercise values. The pelvic anteversion at initial contact was significantly decreased by 3.1° at the end of the walking exercise ($p < 0.05$). The minimal and maximal knee angles as well as the maximal ankle angle during stance phase were significantly increased by 6.2°, 5.8°, and 1.9° respectively ($p < 0.05$) at the end of the walking exercise. No significant difference was observed at the hip angles. The maximal, minimal and mean vertical COM position were significantly different at the end of the 6mwe when compared to beforehand ($p < 0.05$). The spatio-temporal and kinematic gait parameters before and at the end of the 6mwe are reported in Table 2 as well as the effect sizes.

**Table 1**
Participants' characteristics. *Abbreviations*: *F- Female*; *GMFCS – Gross Motor Function Classification System*; *M – Male.*

| Participants | Gender | Age (years) | Mass (kg) | Height (cm) | GMFCS | Assistive device |
|---|---|---|---|---|---|---|
| 1 | F | 9.0 | 21 | 124 | III | Walker |
| 2 | M | 9.7 | 30 | 133 | II | None |
| 3 | M | 10.4 | 31 | 134 | II | None |
| 4 | F | 11.8 | 35 | 137 | III | Walker |
| 5 | M | 14.0 | 43 | 165 | II | None |
| 6 | M | 15.0 | 47 | 165 | II | None |
| 7 | M | 16.1 | 32 | 163 | III | Canes |
| Mean | - | 12.3 | 34 | 146 | - | - |