Gait & Posture 40 (2014) 43–47

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Balance control in gait children with cerebral palsy

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ARTICLE INFO

Article history:
Received 28 June 2013
Received in revised form 5 February 2014
Accepted 9 February 2014

Keywords:
Child gait
Balance control
Cerebral palsy
Posturokinetic capacity

ABSTRACT

This study sought to highlight the balance control process during gait in children with cerebral palsy (CP) by analyzing the different strategies used in order to generate forward motion while maintaining balance. Data were collected using a motion analysis system in order to provide a clinical gait analysis for 16 children with CP and 16 children with typical development. Significant differences between the two groups are observed in terms of kinetic data of the propulsive forces of the center of mass (COM) and of the center of pressure (COP) dynamic trajectory and for locomotor parameters. The imbalance generated by divergent trajectories of COM and COP produce the propulsive forces responsible for human gait initiation. Moreover, we observe in children with CP an "en bloc" postural strategy resulting in increasing divergence between trajectories of COM–COP. This particular strategy of the children with CP is characterized by a greater time duration between the moment of COM–COP trajectory divergence and the moment where the forward propulsive forces became apparent.

1. Introduction

Human gait involves complex movement and requires coordination between successions of the swing phase and the stance phase that induce oscillations of the head and trunk observable in the sagittal and frontal planes [1–6]. The subject must constantly maintain postural balance while propelling himself forward to move in space. Gait may essentially be perceived as a continual state of imbalance created by the relationship between two particular parameters: the center of mass (COM) and the center of pressure (COP). The COP corresponds to the point of application of the resultant of the ground reaction forces. COM corresponds to the point of application of the resultant of the forces exerted on the subject and COM allows to summarize the whole mechanical system. Healthy patterns of human gait are typically characterized by dynamic equilibrium that entails a fluid and ongoing regulation of the distance (or gap) between the COM and the COP trajectories.

The study of multisegmental movements (head, trunk and hip), and the COM relative to the COP provides information on the strategies used to control dynamic equilibrium [7–9]. Moreover, the gap between the COM and the COP trajectories allows to explain the generation of the dynamic forces (*e.g.*, propulsive forces) needed to walk [10]. This relationship between COM and COP constitutes therefore a reliable indicator of strategies developed by children with typical development (TD) and cerebral palsy (CP).

In the case of cerebral palsy (CP), gait and postural control are impaired according to the site and extent of the brain damage. This often results in a set of persistent movement and posture disorders [11], preventing the expression of fluid movement patterns. Such motor disorders are often complex, incorporating different compensatory strategies that should be identified and understood in order to determine effective therapeutic treatment strategies. Despite this, few studies [12,13] have sought to quantify the potential segmental coordination and motor strategies used to maintain dynamic stability in children with CP. One prior study [13] has focused on the stability and control of a particular segment, such as the head or the trunk. It was proposed that this process of stabilization constitutes the frame of reference for organizing movements [14–20], thus reducing the number of degrees of freedom [21]. This prior study [13] showed that children with CP develop an "en bloc" postural strategy [14] in which the head and the trunk move as a single segment, causing the whole body to swing from left to right. These variables show the presence of a particularly pronounced head roll for these children, which

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http://dx.doi.org/10.1016/j.gaitpost.2014.02.009
0966-6362/

probably enable them to develop "en bloc" compensatory strategies in gait production by reducing the number of degrees of freedom to control.

These studies lead to the question of the dynamic organization of gait, that is to say the COM–COP imbalance which allows, by production of propulsive forces, the forward movement of the subject. The aim of this study was to characterize the different strategies used during gait by children with CP in order to propel themselves forward while maintaining their balance. It was hypothesized that the children with CP, having an inherently different postural organization to that of children with TD (*cf. supra*), would produce a greater difference between the COM and COP trajectories along the anteroposterior and mediolateral axes.

2. Methods

2.1. Participants

Gait analysis data were obtained from 16 children with TD (7 boys and 9 girls, mean ± SD age 11 ± 1.5 years) and 16 children with CP (8 boys and 8 girls, mean age 11 ± 1.2 years) at GMFCS (Gross Motor Function Classification System) level II with a jump gait [22,23]. All subjects were receiving daily physiotherapy interventions and had not undergone surgical treatment or received recent injections botulinum toxin at the time of assessment.

Each participant needed to be able to walk at least 60 m to be included in the study.

2.2. Procedure

Data were collected by a motion analysis system with 8 infrared cameras, sampling frequency of 200 Hz (VICON® – Oxford Metrics, Oxford, UK) and 4 force platforms (AMTI®, 0.60 m × 0.60 m) in order to provide a clinical gait analysis.

Motion analysis was used to capture 34 retro-reflective markers secured at the bony landmarks of the participant in accordance with a strict protocol [24] enabling reconstruction of the segmental axes and their respective joint centers.

The participants walked, barefoot without walking aids and in underwear, at their preferred speed in a minimum of ten trials on a 10 m × 0.60 m gait track delimited by a dark color on the floor.

2.3. Data analysis and statistical methods

Data were 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 retro-reflective markers and permitting the calculation of the COM [9] for each participant (Fig. 1). The progress of the COP in the three spatial planes was then extracted using force platform data. The COP has been computed (Fig. 1) from the reaction forces and torque 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 COM (from VICON-Nexus®) – COP (from platform data) trajectory relative to the propulsive forces.

After establishing that each variable was normally distributed (according to a Shapiro–Wilk test), the following statistical analyses were conducted: (i) an intercorrelation between the COM–COP trajectory and the propulsive forces, around the anteroposterior (*Y*) and mediolateral (*X*) axes, using the Motion Inspector® software; (ii) a correlation coefficient between the COM–COP trajectory and the propulsive forces [10]. These intercorrelation and correlation coefficient show the quality of dynamic stability during walking. It is these trajectories that reveal how the subject produces the propulsive forces necessary for forward motion. They permit an analysis of a subject's capacity or strategy used in generating the necessary imbalance between the COM and the COP; (iii) an ANalysis Of VAriance (type III) using the R software [25] in order to observe significance between the correlation coefficient differences. In all cases, results were considered statistically significant where $p \leq 0.05$.

3. Results

3.1. Kinetic data

The kinetic analysis shows the mean correlation coefficient between the COM–COP trajectory and the propulsive forces around the anteroposterior (*Y*) and mediolateral (*X*) axes, in each group.

This analysis shows both significant differences between the two groups either around the anteroposterior axis (0.59 ± 0.26 for the CP group *vs* 0.87 ± 0.05 for the TD group) or around the mediolateral axis (0.68 ± 0.24 for the CP group *vs* 0.88 ± 0.05 for the TD group), but also significant differences in the time duration resulting of the imbalance between the COM–COP trajectory and the propulsive forces created around

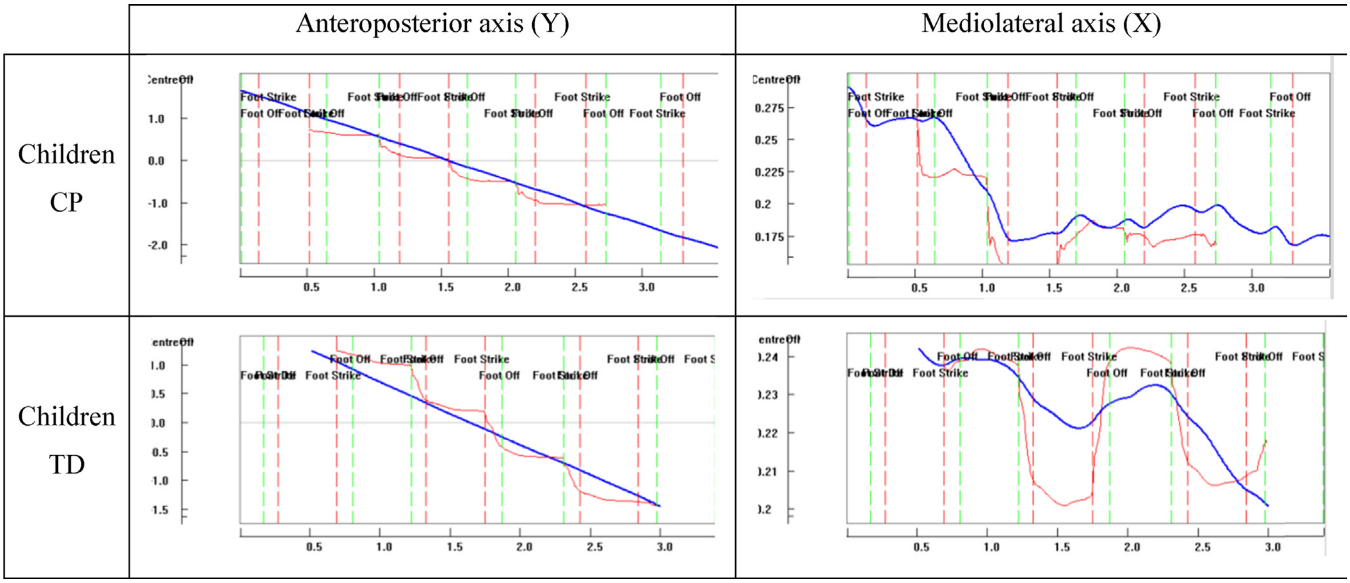

Fig. 1. Superimposition of the COP and the COM trajectories in the horizontal plane around the anteroposterior (*Y*) and mediolateral (*X*) axes, in each group (TD group and CP group). Blue curves correspond to COM trajectories and red curves correspond to COP trajectories. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)