Clinical Biomechanics 30 (2015) 28–32

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Trunk movements during gait in cerebral palsy

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ARTICLE INFO

Article history:
Received 7 August 2014
Accepted 18 November 2014

Keywords:
Cerebral palsy
Diplegia
Hemiplegia
Clinical gait analysis
Trunk movements

ABSTRACT

Background: Lower limb deficits have been widely studied during gait in cerebral palsy, deficits in upper body have received little attention. The purpose of this research was to describe the characteristics of trunk movement of cerebral palsy children in terms of type of deficits (diplegia/hemiplegia) and gross motor function classification system (1, 2 or 3).

Methods: Data from 92 cerebral palsy children, which corresponds to 141 clinical gait analysis, were retrospectively selected. Kinematic parameters of trunk were extracted from thorax and spine angles in the sagittal, transverse and coronal planes. The range of motion and the mean positions over the gait cycle were analysed. Intra-group differences between the children with diplegia or hemiplegia, gross motor function classification systems 1 to 3 and typically developing participants were analysed with Kruskal–Wallis tests and post hoc tests. Pearson correlation coefficients between the gait profile score normalised walking speed and kinematic parameters of the thorax were assessed.

Findings: The results revealed: 1) the range of motion of the thorax and spine exhibited more significant differences between groups than the mean positions; 2) greater levels of impairment were associated with higher thorax range of motion, and 3) the children with diplegia and gross motor function classification system 3 exhibited a greater range of motion for all planes with the exception of spine rotation.

Interpretation: This study confirmed that greater levels of impairment in cerebral palsy are associated with greater thorax range of motion during gait. The thorax plays an important role during gait in cerebral palsy.

1. Introduction

Cerebral palsy (CP) is a non-progressive neurological disorder that results from brain damage caused before birth or during the first two or three years of life (Bax et al., 2005). CP is the most common cause of motor impairment in children in Europe with an incidence of two per 1000 births (Johnson, 2002; Sellier et al., 2010).

The motor disorders of individuals with CP are complex and are related to primary and secondary deficits (Aisen et al., 2011; Dabney et al., 1997; Davids et al., 1999; Goodman et al., 2004; Stebbins et al., 2010). The primary deficits include the following: muscle tone abnormalities (spasticity), and loss of selective motor control. Secondary deficits can include muscle weakness, muscle contractures and bony deformities. Based on this, each person with CP develops different motor skills related to their specific deficits (Beckung et al., 2008; Johnson et al., 1997; Molenaers et al., 2010; Narayanan, 2007).

Walking is considered one of the most important motor skills in daily life. Due to the complexity of gait and, more specifically, pathological gait, clinical gait analysis (CGA) is generally used to understand the deficits specific to individual patients, this information is then used to inform and guide therapeutic decisions for that patient.

The literature surrounding gait deviations in CP is plentiful. However, most of these studies have focused on the lower extremities. Few studies have focused on the upper body during gait in CP (Heyrman et al., 2013; Heyrman et al., 2014; Romkes et al., 2007). During gait, the trunk, which is the heaviest segment of the body, provides the largest contribution to forward movement (Gillet et al., 2003) and is implicated in the control of locomotion (Cappozzo, 1983; Kavanagh et al., 2006). The trunk acts to decrease the effect of lower limb movements on the head and therefore serves to stabilise the head during walking (Kavanagh et al., 2006). This head stability is essential for the proper integration of vestibular and visual information needed in functions related to balance (Pozzo et al., 1991).

When the movement of the lower limbs is impaired, many activities of daily life can be performed using compensatory upper body movement strategies (Leardini et al., 2011). The repetition of these compensatory

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http://dx.doi.org/10.1016/j.clinbiomech.2014.11.009
0268-0033/

strategies over many years can lead to secondary musculoskeletal deficits (Jahnsen et al., 2004). Lower back pain is more common in adults with CP than in the general population and is often associated with gait disorders (Andersson and Mattsson, 2001; Jahnsen et al., 2004; Opheim et al., 2009). It seems evident that compensatory strategies and/or deficits that occur at the level of the trunk during pathological gait must be fully considered to understand gait alterations and to optimise treatment strategies (Goujon-Pillet et al., 2008; Romkes et al., 2007). The few studies that have examined trunk movements in CP children have reported larger movements of the trunk in CP compared to typically developing children (Heyrman et al., 2013; Heyrman et al., 2014; Romkes et al., 2007). However, these studies did not differentiate between types of CP (hemiplegia/diplegia) and were conducted using a small participant sample.

Therefore, to further understand the role of the trunk during gait in CP children, this study aimed to describe trunk movements in a large sample of CP children according to the type of CP (diplegia/hemiplegia) and the level of impairment (gross motor function classification system (GMFCS)).

2. Methods

2.1. Subjects

The database of the Willy Taillard Laboratory of Kinesiology was reviewed to retrospectively select CP children who had undergone CGA between 2005 and 2013. The inclusion criteria were as follows: (1) diplegia- or hemiplegia-type CP, (2) between five and 25 years of age, (3) able to walk 10 m without external aids (crutches, orthotics, walkers, etc.) and (4) had completed a full-body CGA. The exclusion criteria were as follows: (1) received surgery less than one year before the CGA and (2) received botulinum toxin injections less than six months before investigation.

2.2. Gait assessment

All children had undergone a complete CGA with a twelve-camera motion analysis system (Vicon Peak, Oxford, UK) along a 10-metre walkway. Some children had performed several CGAs and each CGA was considered independently. A minimum of three trials by CGA (corresponding to a minimum of five gait cycles) were averaged to produce a single angular displacement of the thorax, pelvis segments and hip, knee, and ankle joints. The children were equipped with 34 reflective markers that were aligned to anatomical landmarks on the head, trunk and pelvis and bilaterally on the arms, thighs, shanks and feet according to the full-body Plug-in-Gait model (Davis et al., 1991). The model of Gutierrez et al. (2003) was used to compute trunk kinematics.

2.3. Data analysis and statistics

2.3.1. Selection and extraction of gait data

The kinematic parameters of the trunk were extracted from the thorax (trunk relative to the laboratory) and spine (trunk relative to the pelvis) angles in the sagittal (tilt), coronal (obliquity) and transverse (rotation) planes with MATLAB R2012b (MathWorks, Natick, Massachusetts, USA) and the open-source Biomechanical ToolKit package for MATLAB (Barre and Armand, 2014). The selected kinematic parameters for the thorax and the spine were the range of motions (RoMs) and mean positions over the gait cycle in the three planes. The absolute values of the mean positions were calculated for the transverse and coronal planes to account for differences in dependent sides. General gait characteristics were assessed in relation to normalised walking speed (based on the lengths of the legs of the children) (Bonnefoy-Mazure et al., 2013; Elsworth et al., 2006) and gait profile score (GPS) (Baker et al., 2009), which provided an indication of the kinematics data for the overall lower limb gait deviations as a single value. To analyse the data, several CP groups were defined according to the type of CP (diplegia/hemiplegia) and the level of impairment (GMFCS): diplegia with GMFCS 1 (D1), diplegia with GMFCS 2 (D2), diplegia with GMFCS 3 (D3), hemiplegia with GMFCS 1 (H1), and hemiplegia with GMFCS 2 (H2). In addition, these groups were compared with a group of children typically developed (TD). The data distribution was verified with a Shapiro–Wilk test. As the distribution was not normal, statistical analysis to compare the groups was performed using Kruskal–Wallis tests and post hoc tests. As non-parametric tests were used, the median and inter-quartile range (IQR) were reported. Pearson correlation coefficients were calculated between the GPS, normalised walking speed and kinematic parameters of the thorax to estimate the associations between the overall lower limb and upper body impairments during gait. Statistical analyses were performed using Statistica version 11 (StatSoft, Inc., USA). In order to control Type I error, the level of significance was set at 0.0045 (i.e., 0.05 divided by the number (11) of group's comparisons) according to the Bonferroni correction, however to reduce the risk of Type II error the results are presented with the corrected ($P = 0.0045$) and uncorrected ($P = 0.05$) significance levels.

3. Results

3.1. Population

The inclusion and exclusion criteria resulted in the inclusion of 92 CP children which corresponds to 141 CGA examinations in this study (CP children have performed between one and three CGA examinations). Each CGA examination was considered as an independent participant. This group was composed of 79 examinations of CP children with diplegia (median: 12.0 years (IQR 8.0)) and 62 examinations of CP children with hemiplegia (median: 10.0 years (IQR 5.8)). In terms of GMFCS, there were 101 examinations of CP children with a GMFCS 1, 32 with a GMFCS 2 and eight with a GMFCS 3. The age, height, weight and BMI of each subgroup are reported in Table 1, and no significant between-group differences were found in these parameters.

Twenty-two TD individuals (median: 11.0 years (IQR 3.0)) without problems or histories of neuro-musculo-skeletal disorders were recruited as a control group.

3.2. Overall gait parameters

Normalised walking speed (Table 2) was not significantly different between the hemiplegia and diplegia groups with the same impairment level (GMFCS) (e.g., D1/H1 and D2/H2). Some differences related to GMFCS were found. Lower GMFCS was associated with higher normalised walking speeds. The normalised walking speeds of the groups, listed from fastest to slowest, were as follows: H1 (1.6 m/s (IQR 0.4)); D1 (1.4 m/s (IQR 0.5)); D2 (1.3 m/s (IQR 0.4)); H2 (1.1 m/s (IQR 0.3)); and D3 (1.0 m/s (IQR 0.3)). TD (1.5 m/s (IQR 0.2)) was only significantly different (at the Bonferroni corrected significance level of $P < 0.0045$) compared to D3 (1.0 m/s (IQR 0.3)).

Similar to the normalised walking speeds, the GPS (Table 2) was not significantly different between children with hemiplegia and diplegia with the same impairment levels (GMFCS). Some differences were found across the different GMFCS levels; higher GMFCS was associated with higher GPS. The GPSs for each group, listed from lowest to highest, were as follows: H1 (6.1° (IQR 2.3)); D1 (6.9° (IQR 1.7)); H2 (8.8° (IQR 1.4)); D2 (9.4° (IQR 3.7)); and D3 (9.8° (IQR 1.5)). TD (4.9° (IQR 1.3)) was significantly different between all groups.

3.3. Trunk movements

The thorax and spine kinematic data for the sagittal, coronal and transverse planes are described in Table 2. Most of the significant