Clinical Biomechanics 32 (2016) 142–149

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Coordination between pelvis and shoulder girdle during walking in bilateral cerebral palsy

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ARTICLE INFO

Article history:
Received 9 August 2015
Accepted 26 November 2015

Keywords:
Cerebral palsy
Gait analysis
Continuous relative phase
Pelvis
Shoulder girdle

ABSTRACT

Background: Studies revealed that pelvis and shoulder girdle kinematics is impaired in children with the diplegic form of bilateral cerebral palsy while walking. The features of 3D coordination between these segments, however, have never been evaluated.
Methods: The gait analyses of 27 children with bilateral cerebral palsy (18 males; mean age 124 months) have been retrospectively reviewed from the database of a Movement Analysis Laboratory. The spatial–temporal parameters and the range-of-motions of the pelvis and of the shoulder girdle on the three planes of motion have been calculated. Continuous relative phase has been calculated for the 3D pelvis–shoulder girdle couplings on the transverse, sagittal and frontal planes of motion to determine coordination between these segments. Data from 10 typically developed children have been used for comparison.
Findings: Children with bilateral cerebral palsy walk with lower velocity ($P = 0.01$), shorter steps ($P < 0.0001$), larger base of support ($P < 0.01$) and increased duration of the double support phase ($P = 0.005$) when compared to typically developed children. The mean continuous relative phase on the transverse plane has been found lower in the cerebral palsy group throughout the gait cycle ($P = 0.003$), as well as in terminal stance, pre-swing and mid-swing. The age, gait speed and pelvis range-of-motions on the transverse plane have been found correlated to continuous relative phase on the transverse plane.
Interpretation: Compared with typically developed children, children with bilateral cerebral palsy show a more in-phase coordination between the pelvis and the shoulder girdle on the transverse plane while walking.

1. Introduction

Children with cerebral palsy (CP) show impaired walking as a consequence of loss of selective motor control, muscle weakness, spasticity and compromised postural control, which cause primary, secondary and compensatory mechanisms (Aisen et al., 2011; Heyrman et al., 2014).

Specific walking impairments have been observed in children with the diplegic type of bilateral CP (D_CP) in the pelvis, whose kinematic feature is characterized by an increased range of motion (ROM) in the frontal, coronal and sagittal planes (Steinwender et al., 2000), as well as, in the thorax (Attias et al., 2015).

The altered kinematic of the pelvis has been considered to be multifactorial in origin and secondary to both static clinical measures (O'Sullivan et al., 2007), as well as dynamic muscular activations during gait (Krautwurst et al., 2013).

As for the thorax, if, on the one hand, compensatory upper body movement strategies are often implemented during the execution of many activities of daily life, including walking, when the movement of the lower limb is impaired (Leardini et al., 2011), on the other hand children with CP also show altered mechanisms of trunk control during gait (Saether et al., 2015). The latter have been also correlated with both gross motor function and mobility skills (Curtis et al., 2015).

This observation leads to the assumption that coordination between the pelvis and the upper trunk, i.e. the shoulder girdle, might be impaired, as well. Moreover, as all these alterations are observed in different anatomical planes, it is important to assess the coordinative feature of pelvis and shoulder girdle on all three planes of motion simultaneously.

The coordination between the shoulder girdle and the pelvis on the transverse plane while walking is pivotal in order to optimize the forward displacement, while maintaining the stability of the entire body (Lamoth et al., 2002). In fact, the pelvis rotates, determining an

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http://dx.doi.org/10.1016/j.clinbiomech.2015.11.020

angular momentum, which must be counterbalanced by the upper trunk, in terms of a proper coordination between these two segments. Likewise, an optimal coordination between these two segments should be required on the sagittal and frontal planes, too. In patients with low-back pain, for example, frontal plane coordination is more affected than transverse coordination, and some alterations could be observed on the sagittal plane as well (Seay et al., 2011). Also, results from a recent research have pointed out that three-plane alteration of coordination can be observed, during gait, in adolescent with idiopathic scoliosis (Park et al., 2015).

Continuous methods for gait analysis allow the computation of the continuous relative phase (CRP), which describes continuously, during a definite cycling movement, the in-phase or out-phase relative motion of two segments. The CRP has been used to describe the features of the coordination between the pelvis and the shoulder girdle in several medical conditions, including Parkinson's disease, ankylosing spondylitis and low back pain (Mangone et al., 2011; Seay et al., 2011; Van Emmerik et al., 1999).

To date, no research has been made to explore the CRP between pelvis and shoulder girdle in children with CP. Based on the evidence of the altered pelvis and upper thorax kinematics in CP, we speculate that the CRP between these two segments could be different when compared to the one of typically developed (TD) children.

Thus, we conducted a retrospective exploratory study to describe the coordination between the pelvis and the shoulder girdle on the transverse, frontal and sagittal planes in a population of children with D_CP in terms of CRP.

2. Methods

2.1. Subjects

We analyzed the database of our Movement Analysis Laboratory to select retrospectively CP children who had undergone clinical gait analysis between 2011 and 2014. We considered eligible those patients who had completed a full-body clinical gait analysis and who fulfilled the following inclusion criteria: (i) D_CP patients, (ii) ages 6 to 14, and (iii) levels I or II of the Gross Motor Function Classification System (GMFCS) (Palisano et al., 1997). Potential participants were excluded if they underwent orthopedic or neurosurgical treatment, over a six month period, or if they have been administered 'botulinum toxin A' over a three month period, before the assessment.

All the procedures followed were in accordance with the Ethical standards of our Institutions.

Age, height, weight and GMFCS at the time of gait analysis have been collected from the clinical charts.

2.2. Gait analysis

Three-dimensional kinematics have been collected using an 8-camera stereophotogrammetric system (ELITE, BTS, Milan, Italy) sampling at 100 Hz. All kinematic data have been filtered using a fourth-order, zero-lag, low-pass Butterworth filter with a cut-off frequency of 6 Hz. Anthropometric data have been collected for each subject and 20 retro-reflective markers have been placed on specific landmarks (Fig. 1) (Davis et al., 1991).

Three-dimensional marker trajectories during walking have been gathered through a frame-by-frame tracking system (Tracklab, BTS, Milan, Italy). Three-dimensional angular motion has been calculated using the Cardan sequence, defined as the orientation of the coordinate system of one segment in relation to the orientation of the coordinate system of the adjacent segment. The hip, knee and ankle angles have been all considered relative angles, hence depicting the rotations of the distal segment, relative to the proximal segment, while the shoulder girdle, pelvis and foot rotation angles, were absolute angles, i.e. referenced to the inertially fixed laboratory coordinate system

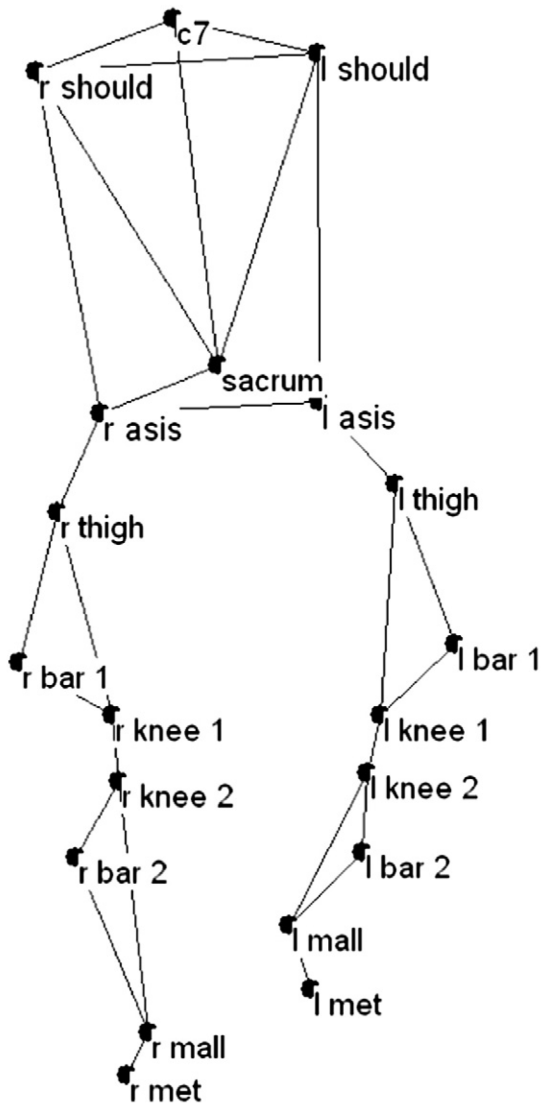

Fig. 1. Setup of the kinematic model. (C7): the seventh cervical vertebrae; (should): acromion clavicular joint; (asis): anterior superior iliac spine; (sacrum): the middle point on a line connecting the right and left posterior superior iliac spine; (thigh): the lateral aspect of the great trochanter; (knee 1): lateral epicondyle; (bar 1): a marker mounted on a bar placed in the middle point of the lateral aspect of the femur; (knee 2): the head of the fibula; (mall): the lateral malleolus; (bar 2): a marker mounted on a bar placed in the middle point of the lateral aspect of the shank; (met): the head of the fifth metatarsal bone; (r): right side; (l): left side. The shoulder girdle has been defined using markers (c7)-(r should)-(l should). The pelvis has been defined using markers (sacrum)-(r asis)-(l asis).

(Davis et al., 1991). A stride has been considered as the time between two consecutive heel-floor contacts of the same limb and has been subdivided into the following sub-phases: loading response (LR) (0–10% of gait cycle [GC]); mid-stance (MS) (11–30% of GC); terminal stance (TS) (31–50% of GC); pre-swing (PSw) (51–60% of GC); initial swing (InSw) (61–73% of GC); mid-swing (MSw) (74–86% of GC); and terminal swing (TSw) (87–100% of GC) (Don et al., 2007; Perry and Burnfield, 2010).

2.3. Outcome measures

The mean walking speed (m/s), cadence (step/min), normalized step length (% of height), duration of the double support phase (% of gait cycle) and width of the base of support (normalized to subject's height) have been calculated as spatial–temporal outcome measures.