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# Gait characteristics in children and adolescents with cerebral palsy assessed with a trunk-worn accelerometer

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ABSTRACT

This study aimed to investigate gait characteristics reflecting balance and progression in children and adolescents with cerebral palsy (CP) compared with typically developing (TD) children. Gait characteristics variables representing aspects of *balance* were trunk acceleration, interstride regularity and asymmetry of accelerations while gait characteristics representing *progression* were gait speed, cadence, step time and step length. Children in the age range 5–18 years (mean age 11.1 years) with spastic CP ($n = 41$) and a gross motor function corresponding to GMFCS I–III and children with TD ($n = 29$) were included. The children walked back and forth along a 5 m pathway with a tri-axial accelerometer worn on the lower back to allow assessment of their gait characteristics. Data were recorded along the anterioposterior (AP), mediolateral (ML), and vertical (*V*) axes. To assess the magnitude of potential differences in gait characteristics, standard deviation scores were calculated, using TD children as reference. Gait parameters related to balance, such as AP, ML, and *V* accelerations, were higher in the children with CP (*z*-scores between 0.4 and 0.7) and increased with increasing GMFCS levels. The differences in accelerations in the AP and *V* directions increased between children with CP and TD children with increasing speed. Also asymmetry in trunk accelerations differed significantly between the two groups in all three directions (*z*-scores between 0.8 and 1.8 higher in the CP group), while interstride regularity differed only slightly between children with CP and TD children, and only in the AP direction. Gait characteristics also differed between children with the spastic subtypes unilateral and bilateral CP, for accelerations and asymmetry in the AP and ML directions. Our results showed significant differences in gait characteristics between children with CP and TD children. The differences may be more related to balance than progression, and these problems seem to rise with increasing gross motor impairment and speed.

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## 1. Introduction

In children and adolescents with cerebral palsy (CP), gait is usually assessed in the decision processes leading to orthopedic surgery, botulinum toxin injections, and/or prescription orthoses. The main focus of such assessments has been the movements of the lower limbs (Dobson, Morris, Baker, & Graham, 2007). Several, but not all studies have reported that children with CP walk slower and with shorter steps compared with children with typical development (TD) (Abel & Damiano, 1996; Bourgeois, Mariani, Aminian, Zambelli, & Newman, 2014; Iosa, Marro, Paolucci, & Morelli, 2012; Norlin & Odenrick, 1986). These components of gait may be described as *progression*. Another important component of gait is *balance*. Balance during gait is particularly challenging since the body's center of mass (COM) is located outside the base of support in 80% of the gait cycle (Winter, 1995). Despite the high prevalence of balance problems in children with CP (de Graaf-Peters et al., 2007), relatively few studies have focused on balance during gait in this population, and even fewer have addressed the relationship between progression and balance (Bruijn et al., 2013).

Recently, some authors have studied balance during gait using optoelectronic and force plate motion analysis. A variety of parameters, such as kinematics of the COM, the trunk, the upper limbs and head, kinetics of the center of pressure (COP), Floquet analysis, and a foot placement estimator have been used to quantify balance. Several authors have reported displacement, velocity, accelerations, and variability in the anterioposterior (AP), mediolateral (ML) and vertical (*V*) directions of COM and COP in children with CP compared to TD children. More specifically, in children with CP, COM (displacement, velocity, and accelerations) was found to have increased in the AP, ML, and *V* directions (Cherng, Chou, Su, Shaughnessy, & Kaufman, 2007; Hsue, Miller, & Su, 2009a; Hsue, Miller, & Su, 2009b; Massaad, Dierick, van den Hecke, & Detrembleur, 2004), and COP (displacement, velocity and accelerations) in the ML direction (Feng, Pierce, Do, & Aiona, 2014; Hsue, Miller, & Su, 2009a; Hsue, Miller, & Su, 2009b). Moreover, kinematic analysis of the trunk showed increased forward tilt and increased range of motion in children with CP (Heyrman, Feys et al., 2013; Romkes et al., 2007). The kinematic analysis of the upper limbs showed decreased arm swing on the least affected side and the opposite on the most affected side (Bruijn, Meyns, Jonkers, Kaat, & Duysens, 2011), and a "guard position" with increased shoulder abduction and elbow flexion in children with CP (Meyns et al., 2012; Romkes et al., 2007). Kinematic analysis of the head showed greater variability of the head angle in the ML direction in children with CP (Wallard, Bril, Dietrich, Kerlirzin, & Bredin, 2012). Floquet analysis revealed that children with CP appear to utilize a wider step width and to modulate their step length (Kurz, Arpin, & Corr, 2012). Moreover, an assessment using a foot placement estimator showed marked instability in the AP and ML directions (Bruijn et al., 2013).

Trunk-worn accelerometers may provide an alternative approach to assessing the gait characteristics of both progression and balance (Kavanagh & Menz, 2008). The method is less time-consuming, less expensive, and not restricted to assessments conducted in a laboratory environment. The method is well established in assessments of adults with CP (Kavanagh & Menz, 2008), whereas we have identified only two studies using a trunk-worn accelerometer to assess gait in young children with CP (Iosa et al., 2012; Iosa, Morelli, Marro, Paolucci, & Fusco, 2013). The two latter studies, which were conducted by the same research group, found that children with CP had higher accelerations of COM, indicating impaired balance during gait, compared with TD children (Iosa et al., 2012, 2013). The authors reported that the children with CP were able to walk at speeds comparable to those of the TD children, but had higher trunk instability. However, the results regarding progression are inconsistent across studies, and few gait studies include both children and adolescents with CP, and to date no study including different CP subtypes has addressed both progression and balance.

The aim of our study was therefore to investigate, with the use of a trunk-worn accelerometer, the gait characteristics of children and adolescents (hereafter referred to as children) with CP compared with those with TD.

## 2. Materials and methods

### *2.1. Study design and subjects*

In this cross-sectional study, gait was assessed with the use of a trunk-worn accelerometer. A consecutive sample of 70 children was included: 41 children with spastic CP (24 males) recruited from the neuro-orthopedic outpatient clinic at St. Olavs Hospital, Trondheim University Hospital (Trondheim, Norway), and 29 children (13 males) with no motor impairment were recruited from several public schools. To qualify for inclusion, participants had to be able to understand certain instructions and to walk at least 10 m without support, shoes, or orthoses. Exclusion criteria were treatment with botulinum toxin in the lower extremities during the preceding four months and/or surgery during the preceding 12 months. The characteristics of the included children are summarized in Table 1.

### *2.2. Instrumentation*

In order to measure linear acceleration, a six degrees-of-freedom inertial sensor (MTx. XSens, Enschede, NL) (weight: 15 g) was attached over the L3 region of the participant's lower back. The sensor contains tri-axial units of accelerometers, gyroscopes, and magnetometers and is connected to a battery-operated communication unit (weight: 300 g), also worn by the participant. Data were acquired at a sampling frequency of 100 Hz and transmitted in real time to a laptop by Bluetooth technology (Aaslund, Helbostad, & Moe-Nilssen, 2011). Gait time was registered by photoelectric cells synchronized with the

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