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Do children with cerebral palsy change their gait when walking over uneven ground?

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ABSTRACT

Independently ambulant children with Cerebral Palsy (CP) often report balance difficulties when walking in challenging settings. The aim of this study was to compare gait in children with CP to typically developing (TD) children walking over level ground and uneven ground, as an evaluation of dynamic balance. Thirty-four children participated, 17 with CP (10 hemiplegia and 7 diplegia, mean age 10 years) and 17 TD (mean age 10 years 1 month). Three-dimensional kinematic and kinetic data of the lower limbs and trunk were captured during walking over level and uneven ground using Codamotion®. Statistical analysis was performed using a mixed-effects model two-factor Analysis of Variance (Group × Surface). Over both surfaces, children with CP showed increased trunk movement in the sagittal (Group effect, $p < 0.001$) and transverse planes ($p < 0.001$), and increased pelvic movement in the coronal plane ($p = 0.008$), indicating impaired trunk control. Peak separation between the centre of mass and centre of pressure was reduced in CP, indicating impaired dynamic balance ($p = 0.027$). TD children made a number of significant adaptations to uneven ground, including reduced hip extension (mean difference 3.4°, 95% CI [−5.3, −1.0] $p = 0.006$), and reduced ankle movement in the sagittal (5.2°, 95% CI [0.01, 10] $p = 0.049$) and coronal planes (2.4°, 95% CI [0.3, 4.5], $p = 0.029$), but these adaptations were not measured in CP. A significant Group × Surface interaction was detected for knee sagittal range ($p = 0.009$). The findings indicate that children with CP walk show impaired control of trunk movement and are less able to adapt their gait to uneven ground, particularly at the ankle.

1. Introduction

Deficits in postural control and balance pose a significant limitation to motor development and gait in children with cerebral palsy (CP) [1,2]. Children with CP encounter problems during static upright standing in altered sensory environments and when rapid weight shifts during standing are required, such as in gait initiation [3] or when reacting to external perturbations [1,4,5]. These limitations may have profound effects on a child's ability to participate in activities with their peers in outdoor settings.

The negotiation of uneven ground (UG) warrants investigation as it presents a significantly different challenge compared to level-ground (LG) walking. A study of children with CP who walked with stiff-knee gait over UG found an increase in peak knee flexion to improve clearance in swing compared to LG walking [6]. This suggests that people with CP have some ability to adapt to UG, but the cost of these adaptations to the preservation of stability has not been measured. Increased agonist–antagonist co-activation [5], reduced ability to modulate muscle activation [7] and muscle weakness [8] can contribute to impaired anticipatory adjustments and postural responses. In particular, the proximal-to-distal activation pattern often seen in children with CP indicates a reduced ability to use an ankle strategy for regaining balance [7]. This may be particularly important in adapting to UG when active ankle control may be required to maintain lateral stability [9].

The aim of this study was to compare gait in children with CP and typically developing (TD) children, walking over LG and UG. The research hypothesis was that children with CP would show greater differences to TD over UG in comparison to LG, indicating further impairment of gait kinematics in response to the additional balance challenge. This hypothesis was based clinically on the frequent reporting of balance problems over UG in the CP population.

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2. Methods

2.1. Participants

Ethical approval was granted by a local Research Ethics Committee. Children with CP, aged 5–18, were recruited from a cohort attending outpatient rehabilitation services at the clinic. Inclusion criteria were: (1) diagnosis of diplegia or hemiplegia, (2) Gross Motor Function Classification Score (GMFCS) I or II, (3) ambulant without aids, (4) physiotherapy goal to improve dynamic balance. Potential participants were identified by their treating physiotherapist between June 2013 and January 2014 and invited to participate. Participants were excluded if they had surgery within one year or Botox within three months prior to the assessment, or if they had co-existing neurological or orthopaedic conditions (other than CP) that might affect gait. TD children were recruited from the local community via parental invitation. A participant information leaflet was provided to parents and guardians, who then gave written informed consent.

2.2. Protocol

Three-dimensional kinematic and kinetic data were captured using a Codamotion cx1 system (Charnwood Dynamics, Leicestershire, UK) with four Coda monitors, sampling rate 200 Hz, and two Kistler force plates. Light-emitting diodes were placed on each participant's lower limbs in keeping with a previously described protocol for lower limb kinematics [10]. Trunk data were captured using a recently validated single cluster [11]. Fig. 1 shows the full marker set.

Fig. 1. The Codamotion lower limb marker set and Central Remedial Clinic (CRC) Trunk Model.

Gait was analysed barefoot along the laboratory's 10 m walkway, firstly over LG and then over UG. The uneven surface was customised by placing 16 bags of 0.5 cm pebbles, each measuring 16 cm $\times$ 10 cm and maximum 2.5 cm thick, on the walkway spread over an area measuring 150 cm in length and 40 cm in width, covering the two adjacent force plates. The pebble bags were not aligned directly in the line of progression, but scattered at varying angles, no more than 5 cm apart in the anterior–posterior direction and 2 cm in the medio-lateral direction. This arrangement ensured each foot would have to strike the uneven surface at least once over the force plates. The bags were covered with a mat of thickness 0.2 cm, fixed to the floor by tape at its margins. The mat was speckled grey in colour to obscure the exact positions of peaks and troughs. This set-up is similar to previously reported protocols for UG [6].

A warm-up trial was conducted over LG to allow participants to adapt to marker placement and ensure clean kinematic data. Participants were instructed to walk at comfortable self-selected speed. No feedback was given. LG data were captured first. Participants were aware of the change in surface prior to the UG trials, but were not given a practice trial to ensure that their natural reactive balance strategies could be captured. One or two experimental trials were obtained for each condition. The first trial was analysed if complete contact was made with the force plate during single limb support. If not, the start point was adjusted to ensure complete contact on the second trial.

Gait cycle events (heel strike and toe-off) were identified in Codamotion® software, based on the movement of heel- and toe-marker trajectories and force plate data. Data were imported into MATLAB® version 8.1.0.604 (Mathworks, Mass., USA). Custom-written software extracted kinematic and kinetic variables. Whole body centre of mass (CoM) was calculated as the weighted average of each segment's CoM, based on published body-segment parameters [12,13]. The position of the centre of pressure (CoP) was determined from force plate data. The relationship between CoM and CoP was defined using three variables: (1) the sagittal inclination and (2) medio-lateral inclination angles [14] (degrees), (3) peak separation (millimetres). Key temporal–spatial and kinematic variables for the trunk and lower limb were analysed (Table 2). The Gait Profile Score (GPS) was calculated as a summary of lower limb kinematics [15]. To avoid erroneously doubling the sample size, data were analysed for one limb only, namely the involved limb of children with hemiplegia, and the left lower limb (selected randomly by coin toss) for TD and children with diplegia.

2.3. Statistical analysis

Calculation of sample size was based on step length as the primary variable. Based on an average of 50 cm from the laboratory database, and considering a difference of over 10% to be clinically important, the minimum clinically important difference (MCID) between groups and surfaces was determined to be 6 cm. With a standard deviation of 5 cm, significance of 0.05 and power of 0.9, a sample size of 15 was calculated.

Data were checked for normal distribution, graphically using box-and-whisker plots and quantitatively using tests of skewness and kurtosis and the Shapiro–Wilk test. Differences between CP and TD over LG and UG were examined using a mixed-effects model two-factor Analysis of Variance (ANOVA) (Group $\times$ Surface), with Surface designated a repeated-measures (within-subject) factor and Group a between-subject factor. Where significant Surface effects were found, post hoc paired t-tests (two-tailed) compared within-group differences over LG and UG to further evaluate the adaptations to the uneven surface. 95% confidence intervals (CI) are reported. Significance was set at $p < 0.05$. Analysis was performed in Stata 13 (StataCorp, Texas, USA).