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Three-dimensional head and trunk movement characteristics during gait in children with spastic diplegia

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ABSTRACT

This study uses a recently developed trunk model to determine which head and trunk kinematic parameters differentiate children with spastic diplegia from typically developing (TD) children while walking. Differences in head and trunk parameters in relation to the severity of the motor involvement (GMFCS levels) were additionally examined. The trunk model consisted of five segments (pelvis, thorax, head, shoulder line, spine). Discrete kinematic parameters (ROM, mean position) and angular waveforms were compared between 20 children with spastic diplegia (age 9.8 years ± 2.9 years; GMFCS I: $n = 10$, GMFCS II: $n = 10$) and 20 individually age-matched TD children (9.7 years ± 3 years). A new measure for overall trunk pathology, the trunk profile score (TPS), was proposed and included in the comparative analysis. Compared to TD children, children with GMFCS II showed a significantly higher TPS and increased ROM for pelvis tilt, for thorax and head in nearly all planes, and the angle of kyphosis. In children with GMFCS I, only ROM of thorax lateral bending was significantly increased. Sagittal ROM differentiated best between GMFCS levels, with higher ROM found in children with GMFCS II. Current results provide new insights into head and trunk kinematics during gait in children with spastic diplegia.

1. Introduction

Children with spastic diplegia often show pathological gait patterns resulting in increased energy expenditure and impaired functional abilities in daily life [1,2]. Thorough understanding of these patterns is indispensable for adequate treatment planning. The impact of lower limb impairments on gait has been extensively studied and knowledge is used for gait classification and treatment planning [3,4]. Conversely, while the importance of trunk control to attain an upright posture during gait is generally well accepted [5,6], literature on head and trunk deviations during gait in children with CP, and in particular in children with spastic diplegia, is scarce. Nevertheless, reports based on visual observations indicate that these children often show decreased head and trunk stability, increased shoulder protraction and spinal curve deviations, such as increased kyphosis and lordosis [7–9]. The use of more objective methods, such as three-dimensional (3D) movement analysis, could contribute to gain further insights in trunk and head involvement during gait in children with spastic diplegia. This may ultimately lead to more specific clues for therapeutic interventions. Until now, only one study examined trunk kinematics during gait in children with spastic diplegia and reported increased trunk movements in all planes compared to typically developing (TD) children [10]. However, the different segments that comprise the trunk were not taken into account, head kinematics were not reported and information on reliability of the model was missing.

We recently developed a new trunk model to quantify head and trunk movements during gait, consisting of a head, thorax, pelvis, shoulder line and spine segment. Reliability of the model was established, however head kinematics should be considered with caution due to lower reliability, particularly in the sagittal and transverse planes [11]. Clinical implementation of this kinematic model necessitates the examination of its ability to discriminate between typical and pathological trunk and head kinematics. To further facilitate the interpretation of the kinematic data, this

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paper also introduces the trunk profile score (TPS). It is a single measure that summarizes the overall quality of a child's head and trunk movement patterns, similar to other indices used for gait and upper limb movement pathology [12,13].

The first aim of the study was to define which head and trunk kinematics differed between children with spastic diplegia and individually age-matched TD children during gait. Secondly, we assessed whether differences in severity of motor involvement, expressed by the levels of the gross motor function classification system (GMFCS) [14], were reflected into differences in head and trunk kinematics.

2. Methods

2.1. Participants

Children with CP were selected from the database of XXX, based on following criteria: (1) diagnosed as spastic diplegia; (2) aged 5–15 years; (3) independent gait without aids (GMFCS I–II); and (4) sufficiently cooperative to complete the test procedure. Children were excluded if they had received botulinum toxin-A injections or multilevel orthopedic surgery within the previous year, or had undergone implantation of an intrathecal baclofen pump or other spinal interventions. Children scheduled for routine clinical gait analysis who met these criteria were invited to participate. Twenty children with CP (16♂/4♀; mean age 9.8 years ± 2.9 years) participated. Ten children with CP were classified as GMFCS I, and 10 as GMFCS II. Also, 20 individually age-matched TD children (mean age 9.7 years ± 3 years) without history of musculoskeletal or neurological disorders were recruited to provide reference data. Written informed consent was obtained from all children's parents. The study was approved by the Hospital's Ethics Committee.

2.2. Data collection

All assessments and data analyses were done by one trained physiotherapist. Nineteen retro-reflective markers were mounted on predefined anatomical landmarks of the head, thorax, pelvis, shoulder line and spine while standing upright. Further details on marker placement and definition of anatomical planes can be found elsewhere [11]. The standard lower body Plug-In-Gait marker-set was used whereby children walked barefoot over a 10 m walkway at self-selected speed. Marker trajectories were captured using a 15-camera VICON system (VICON Oxford Metrics, Oxford, UK) at a sampling rate of 100 Hz and filtered using spline interpolation [15].

2.3. Data analysis

Marker labeling and trajectory reconstructions were performed using Nexus software (VICON Oxford Metrics, UK). Gait cycle events were manually defined per trial. Three representative trials from left gait cycles were used for further data processing with custom-made Matlab routines (Mathworks, Inc.). For head and thorax, both absolute (vs. the global laboratory frame) and relative (head vs. thorax and thorax vs. pelvis) angles were calculated using Euler/Cardan decompositions (flexion/extension, lateral bending, rotation) [16]. For the pelvis, absolute angles were calculated in all three planes (tilt, obliquity, rotation). For the shoulder line, relative angles (shoulder line vs. thorax) were computed in the frontal and transverse plane. Spine movement was described as the angle of kyphosis (angle between T2–T6 and T10–L1) and the angle of lordosis (angle between L1–L3 and L3–L5) [17].

Spatiotemporal parameters included cadence (steps/min), step length (m), step width (m) and walking speed (m/s). Discrete kinematic parameters included range of motion (ROM) and mean position over the gait cycle.

The trunk profile score (TPS) reflects overall severity of trunk movement pathology during the gait trial. The trunk variable score (TVS) provides an index of deviation of each segmental angle. These indices have a similar mathematical construction as the gait profile score and the arm profile score [12,13]. Calculations were based on absolute angles of head, thorax and pelvis, relative angles of the shoulder line, and angles of kyphosis and lordosis. The TVSs were calculated per segmental angle as the root mean square error (RMSE) of the point-by-point comparison between that particular angle of the child with diplegia and the angle derived from the reference database of TD children. The RMSE average of all segmental angles resulted in the TPS.

Also, a descriptive analysis of the continuous kinematic waveforms of each segment in the different planes was performed.

2.4. Statistical analysis

The TVS and TPS were calculated per child based on three representative gait cycles. For each spatiotemporal and discrete kinematic parameter, the average of these three gait cycles was calculated and used for further analysis. Data distribution was verified with Kolmogorov–Smirnov tests. Differences between children with GMFCS I, II and TD children were determined using different statistical tests depending on data distribution. Spatiotemporal and discrete parameters were compared with a one-way analysis of variance (ANOVA), with Tukey–Kramer post hoc tests for comparison between GMFCS levels and Dunnett's tests for comparison of each GMFCS level with the control group. Differences in TVSs and TPS between the three groups were examined using a Kruskal–Wallis test and post hoc Wilcoxon rank sum tests. Statistical analyses were performed using SAS Enterprise guide 4.2 (SAS Institute, Inc., Cary, NC, USA). The level of significance was set at 0.05, with post hoc Bonferroni corrections ($p = 0.0167$).

3. Results

3.1. Spatiotemporal parameters

Spatiotemporal parameters for GMFCS I and II and TD children are shown in Table 1. Differences were found for step length and walking speed, with children with GMFCS II having a significantly smaller step length (0.42 m) and slower walking speed (0.9 m/s) than children with GMFCS I (0.55 m, 1.2 m/s) and TD children (0.6 m, 1.2 m/s). No differences were found for cadence and step width.

3.2. Comparison of discrete kinematic parameters

Most significant differences between groups were found for ROM (Table 1). Differences in mean position were found for pelvis and head in the sagittal plane (Table 2).

ROM differed significantly between groups only for **pelvis** anterior/posterior tilt, with children with GMFCS II showing significantly higher ROM than GMFCS I and TD children (difference ~3–5°). We also found a significantly higher mean anterior tilt position in GMFCS I (16.5° (SD 3.9°)) compared to TD children (11.7° (SD 4°)).

Absolute and relative **thorax** ROM differed significantly between groups in nearly all planes. Children with GMFCS I showed significantly higher absolute ROM for lateral bending compared to TD children (difference ~4°). In children with GMFCS II, absolute and relative ROM were significantly higher in all planes compared to TD children, except for relative rotation. Children