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The use of turning tasks in clinical gait analysis for children with cerebral palsy

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ABSTRACT

Background: Turning while walking is a crucial component of locomotion that is performed using an outside (step) or inside (spin) limb strategy. The aims of this paper were to determine how children with cerebral palsy perform turning maneuvers and if specific kinematic and kinetic adaptations occur compared to their typically developing peers.

Methods: Motion capture data from twenty-two children with cerebral palsy and fifty-four typically developing children were collected during straight and 90° turning gait trials. Experimental data were used to compute spatio-temporal parameters, margin of stability, ground reaction force impulse, as well as joint kinematics and kinetics.

Findings: Both child groups preferred turning using the spin strategy. The group of children with cerebral palsy exhibited the following adaptations during turning gait compared to the typically developing group: stride length was decreased across all phases of the turn with largest effect size for the depart phase (2.02), stride width was reduced during the turn phase, but with a smaller effect size (0.71), and the average margin of stability during the approach phase of turning was reduced (effect size of 0.98). Few overall group differences were found for joint kinematic and kinetic measures; however, in many cases, the intra-subject differences between straight walking and turning gait were larger for the majority of children with cerebral palsy than for the typically developing children.

Interpretation: In children with cerebral palsy, turning gait may be a better discriminant of pathology than straight walking and could be used to improve the management of gait abnormalities.

1. Introduction

Turning while walking is crucial to activities of daily living (Glaister et al., 2007; Sedgman et al., 1994) and is performed using an outside (step) or inside (spin) leg strategy (Hase and Stein, 1999). Although it is unclear which technique is favored by adults, spin turns are preferred in typically developing (TD) children (Dixon et al., 2013). Turns can be separated into approach, turn, and depart phases (Glaister et al., 2008). Investigations have focused on the 90° turn (Glaister et al., 2008; Romkes, 2012; Strike and Taylor, 2009; Taylor et al., 2005), presumably due to the ubiquity of this change in direction in the built environment. Research revealed that 90° turning gait induces biomechanical adaptations compared to straight walking in unimpaired populations such as young adults (Glaister et al., 2008; Hasan et al., 1991; Strike and Taylor, 2009; Taylor et al., 2005; Xu et al., 2006) and TD children (Dixon et al., 2013, 2014c).

Turning gait may help identify and manage walking deviations in populations with restricted gait ability, such as children with cerebral palsy (CP) (Desloovere et al., 2010). To date, little is known about how children with CP biomechanically adapt to the requirements of this task (Brégou-Bourgeois et al., 2014; Romkes, 2012).

Brégou-Bourgeois et al. (2014) suggested that children with CP modify spatio-temporal parameters (STPs) during turning to increase stability. In fact, children with CP take a longer path and time to turn 90° (Romkes, 2012) and an increased stance time to turn 180° (Brégou-Bourgeois et al., 2014), compared to TD children; however, in these studies, stability was not assessed directly. Bruijn et al. (2013b) showed that children with CP walk with reduced dynamic stability as measured by the Foot Placement Estimator. This method was validated, but requires a full body marker set. A review of stability measures suggested that the extrapolated center of mass (xCOM) concept of Hof (2008), which takes into account the velocity of the center of mass (COM) to determine a margin of stability (MOS), represents a worthy alternative (Bruijn et al., 2013a). This approach is popular in stability studies (Beltran et al., 2014; Caderby et al., 2014; Hak et al., 2013; Mersmann et al., 2013).

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Lower-limb joint kinematics and kinetics also show differences during turning gait, compared to straight walking in adults (Taylor et al., 2005; Xu et al., 2006) and in TD children (Dixon et al., 2013, 2014c). As these metrics are often clinically assessed in straight walking for children with CP, analysis of these quantities during real-world turning tasks may also be warranted. Reporting of these measures over the gait cycle via composite scores such as the Gait Variable Scores and Gait Profile Score of Baker et al. (2009) is popular and provides clinicians with a single number from which to assess gait. Analogous scores for turning have not yet been proposed.

Ground reaction force (GRF) may also quantify turning. In particular, the analysis of GRF impulse estimates the overall effect of the GRF in accelerating the COM. In healthy adults, medio-lateral GRF impulse (J_{ML}) was found to increase during 90° step turns compared to straight walking (Glaister et al., 2008; Strike and Taylor, 2009). In transtibial amputees, J_{ML} directed radially inward was decreased compared to controls for the inside limb during circle walking (Segal et al., 2011; Ventura et al., 2011). Segal et al. (2011) suggest that this adaptation minimizes the COM acceleration in the direction of the turn.

The aforementioned metrics can identify pathology in children with CP during straight walking. Therefore, changes to these measures in children with CP, compared to TD children, need to be different or disproportionately larger during turning gait, compared to straight walking, to warrant clinical implementation. Consequently, the aim of this study was to determine if these parameters could better identify gait deviations in children with CP during turning gait compared to straight walking. It was hypothesized that the following adaptations from normative data occur in an amplified manner during 90° turning for children with CP, compared to straight walking based on the perceived reduction in stability and typical CP-related gait deviations: (1) for STPs, decreased stride velocity and stride length, as well as increased stance time and stride width; (2) increased MOS; (3) decreased J_{ML}; and (4) worsened joint kinematics, moments, and power as measured by summary scores. Knowledge of turning gait adaptations provide further insight into gait control mechanisms and may lead to improved management of walking disorders in children with CP.

2. Methods

2.1. Subjects

Twenty-two children with CP (CP group) and fifty-four TD children (TD group) were recruited into this study. For the CP group, inclusion criteria were confirmed diagnosis of spastic diplegic CP and a Gross Motor Classification System (Palisano et al., 1997) score of 1 or 2. The exclusion criteria for the TD group were any history of gait or musculo-skeletal abnormalities. The local ethics committee approved this study and all children provided written assent/consent before participation. Data related to kinematic and kinetic quantities are based on a subset of children (Table 1) due to marker occlusions or missing GRF data. For the TD group, younger subjects were removed to ensure well-matched groups (all anthropometrics similar with $P \geq 0.056$). Anthropometrics, surgical history, and gait pattern, as determined by the algorithm of Sangeux et al. (2014), are provided for each child in the CP group (Supplementary Table 1).

2.2. Data collection

Subjects were fit with the Oxford Foot Model (Stebbins et al., 2006) and either the lower-limb (CP group) or full-body (TD group) Plug-in Gait (PiG) (Kadaba et al., 1990) markers and completed straight walking trials before performing 90° turning gait trials (left and right) (Supplementary Fig. 1). Based on the clinical gait analysis recommendations for the children in the CP group, the upper body PiG markers were not used. Positions of markers were recorded at 100 Hz via a 12–16 camera motion capture system (Vicon Motion Systems Ltd., Oxford, UK), which also synchronized GRF data (1000 Hz) from three force plates (OR-6, Advanced Mechanical Technology Inc., Watertown, USA) embedded in a 10.0 m walkway. All subjects freely chose their walking speed, starting foot, foot placement strategy, and turning radius, but start position was varied to capture GRF data.

2.3. Identification of turning strategies

Turn style was identified based on pelvic rotation (Dixon et al., 2013). In the complete TD group ($n = 54$), 43% of subjects only performed spin turns, 56% performed both step and spin turns, and a single subject solely performed step turns. For the CP group, no child chose to solely perform step turns. The CP group performed 142 spin and 30 step turns with 55% of subjects choosing both strategies and 45% only performing spin turns. As spin turns were the main strategy used by both groups, step turns were not analysed further.

2.4. Initial data processing

Initial data processing (marker gap filling, trajectory filtering, knee flexion/extension axis optimization (Baker et al., 1999)) and computation of hip and knee kinematics and kinetics as well as hindfoot with respect to tibia (HF/TB) and forefoot with respect to hindfoot (FF/HF) kinematics were conducted using Vicon Nexus (v1.8.4, Vicon Motion Systems Ltd., Oxford, UK). Then, the *c3d* files were imported into Matlab (v2012b, The Mathworks Inc., Natick, USA) using the open-source Zoosystem Toolbox (Dixon et al., 2014b) where GRF data were processed as in Dixon et al. (2014c) and foot strike (FS) and foot-off (FO) events were identified (Zeni et al., 2008). Events were used to partition the data and identify turning phases with steps 2, 3, and 4 representing the approach, turn, and depart steps, respectively (Fig. 1). A minimum of 4 trials were collected for each condition. A single representative trial was retained for analysis as in our previous work using these datasets (Dixon et al., 2013, 2014c).

2.5. Derivation of gait metrics

STPs were estimated using the approach of Huxham et al. (2006) for non-linear gait. Stride length and stride width were leg-length normalized (Hof, 1996), but stride velocity and stance time were not normalized (Dixon et al., 2014a). Dynamic stability was measured by

Table 1
Anthropometrics for children with cerebral palsy and their typically developing peers.

Group	n	Age (years)	Weight (kg)	Height (cm)	Leg-length (cm)	Sex
CP-kinematic	22	12.4 (2.8)	41.9 (13.7)	149.7 (17.7)	79.0 (9.9)	8 F, 14 M
CP-kinetic	18	12.7 [11.4–14.1]	42.9 (13.8)	151.4 (16.8)	80.1 (9.3)	6 F, 12 M
TD-kinematic	44	11.0 [10.2–11.8]	40.7 (13.9)	149.1 (15.5)	78.8 (8.8)	21 F, 23 M
TD-kinetic	41	11.3 [10.5–2.1]	42.5 (13.4)	151.3 (15.0)	80.4 (8.3)	18 F, 23 M

Mean (standard deviation) or median [95% confidence interval] for normally or non-normally distributed data, respectively. Anthropometrics presented for kinematic and kinetic analysis subgroups in children with cerebral palsy (CP) and their typically developing (TD) peers. Sample size (n) and sex (female (F) and male (M)) are also shown.