USE OF MULTI-SEGMENT FOOT KINEMATICS TO DISTINGUISH IDIOPATHIC TOE-WALKERS, CHILDREN WITH CEREBRAL PALSY, AND TYPICALLY DEVELOPING CHILDREN

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SUMMARY
Multi-segment foot kinematics were compared between idiopathic toe walkers (ITW) and typically developing children (TD) during toe walking and also compared to children with mild diplegic cerebral palsy (CP) who toe walked. Where possible, heel-toe walking was also compared between ITW and TD children. Significant differences were found between the ITW and TD groups during both toe walking and heel-toe walking, primarily evident at the hindfoot. Differences between the CP and ITW groups were evident in the forefoot and hallux angles. These results indicate that foot motion differs according to diagnosis, and may be used to aid differentiation between ITW and mild CP.

INTRODUCTION
ITW is a condition in which children persistently walk on their toes but where no distinct neurological abnormality is detectable. Clinical differentiation between ITW and mild CP can be challenging, but is important for appropriate treatment planning. Previous studies assessing differences in gait patterns between these two groups have focused on the lower limbs, but without considering motion within the foot [1-2]. These studies have identified differences in knee flexion, particularly at initial contact, between ITW and CP children. However, no differences were found between ITW and TD children during toe-walking [1]. The aim of the current study was to assess multi-segment foot kinematics in ITW, to determine if there are differences in foot motion between ITW and children with mild CP. In addition, it was hypothesised that analysis of heel-toe walking would further aid the characterisation of foot motion in ITW.

METHODS
Three groups of children were included in this study. 24 idiopathic toe walkers (ITW) (mean age 9.8 years) and 13 children with cerebral palsy (CP) (mean age 10.5 years) were identified from the gait laboratory database. In addition, 22 typically developing children (TD) (mean age 10.5 years) were recruited. In order to have a comparable CP group to the ITW group, only children who toe-walked (no heel contact), with relatively mild involvement (GMFCS 1 or 2), and with no significant asymmetry or rotational component to their gait were included. The ITW group was defined as children with tight plantarflexors causing reduced passive ankle dorsiflexion, who typically walked on their toes, but had no underlying neurological or musculo-skeletal diagnosis.

A 12 camera Vicon MX system (Vicon, Oxford, UK) was used to collect the data, sampling at 100Hz. Markers were attached to both feet and lower limbs, according to the PlugInGait (Vicon, Oxford, UK) protocol, along with the Oxford Foot Model (OFM) [3]. TD children were requested to walk on their toes, at a self-selected speed, for a minimum of four trials. Children in the CP and ITW groups were asked to walk in their normal manner, at self-selected speed, until a minimum of six trials were collected. All children in the CP group walked on their toes. Children in the ITW group either toe-walked or walked heel-toe. Where they were able to do both, data from both conditions was collected, so that 12 sets of data were collected heel-toe walking and 16 data sets toe-walking.

Discrete variables obtained from OFM kinematics were identified and compared between the groups (including peak values, time to peak and ranges). Heel-toe walking was compared between the ITW and TD group using students t-test. Toe-walking data were compared between all three groups using ANOVA analysis with Tukey post hoc testing. Correction for multiple comparisons was applied, and statistical significance was determined to be p<0.02.

RESULTS AND DISCUSSION
Analysis of toe walking data revealed significant differences between all three groups. Knee flexion at initial contact was increased in the CP group only (Figure 1), consistent with previously reported findings [1], presumably related to over-activity of the hamstrings and/or gastrocnemius. Hindfoot dorsiflexion in both stance and swing was reduced compared to the TD group in both the CP and ITW group, although they were not different from each other (Figure 2). This was evident even when children were able to walk heel-toe in the ITW group, and is probably related to plantarflexor tightness in these groups. Both the ITW and CP groups achieved peak dorsiflexion significantly earlier in stance than the TD group (Figure 2), which may be due to tibial arrest, and may explain the reduced peak. Range of hindfoot inversion was significantly reduced in both pathological groups compared to the TD group (Figure 3). These results suggest general stiffness of the ankle complex in both the CP and ITW groups during toe walking. In addition, there was greater inter-subject variability in hindfoot dorsiflexion in the ITW group compared to the TD group, indicating a range of strategies adopted across different subjects (Figures 2 and 3).
There was no difference in the peak or range of forefoot dorsiflexion between the groups, however the peak was achieved significantly earlier in stance in the CP group compared to the other two groups (Figure 4). Hallux varus was significantly increased in stance in the CP group compared to the TD group, while the timing of the peak was earlier only in the ITW group (Figure 5). These results suggest that forefoot and hallux motion may provide the best distinction between ITW and CP toe-walkers.

Comparison between the ITW and TD groups when heel-toe walking revealed further differences. Peak dorsiflexion of the hindfoot in both stance and swing was reduced in the ITW group, and the peak occurred significantly earlier in stance. Peak eversion of the hindfoot also occurred significantly earlier in the ITW group. This indicates that analysing both toe-walking, and heel-toe walking, where possible, in the ITW group may provide beneficial information for deciding on management.

**Figure 1:** Comparison of sagittal plane knee motion. Grey = TD mean, Red = ITW mean, Blue = CP mean. Dashed lines are +/- one standard deviation.

**Figure 2:** Comparison of sagittal plane hindfoot motion. Grey = TD mean, Red = ITW mean, Blue = CP mean. Dashed lines are +/- one standard deviation.

**Figure 3:** Comparison of coronal plane hindfoot motion. Grey = TD mean, Red = ITW mean, Blue = CP mean. Dashed lines are +/- one standard deviation.

**CONCLUSIONS**

Idiopathic toe walkers show different patterns of movement in their feet when walking on their toes compared to typically developing children. This is mostly evident when assessing hindfoot motion with respect to the tibia. They also demonstrate differences compared to equivalent children with cerebral palsy. These differences are evident when considering foot motion with respect to the hindfoot, and at the hallux. Differences at the hindfoot between ITW and TD children observed during toe-walking were also evident during heel-toe walking. In addition, the pattern of hindfoot eversion differed between these two groups during heel-toe walking. This information may be used to aid distinction between ITW and CP where the diagnosis is unclear. It appears that foot kinematics may be more helpful than conventional lower limb kinematics in distinguishing between these three groups. Previous research demonstrates inconclusive results based on lower limb kinematics alone. This study also provides information about the behaviour of the foot in ITW, and suggests that analysing both toe-walking and heel-toe walking may be beneficial where this is possible.

**REFERENCES**