INTRODUCTION

Children with cerebral palsy (CP) demonstrate a more variable stepping pattern than their typically developing peers [1]. Gait variations have been noted to arise from subtle corrections in the motor command to overcome perceived errors in the stepping pattern and mechanical perturbations. Alternative evidence suggests that these variations may stem from stochastic features that at contaminate the motor command at the sensor and neuronal processing level [2,3]. However, separation of these deterministic and stochastic sources that promote variability in the motor output has historically been a challenge, and has rarely been evaluated in children with CP [3]. Since CP is associated with damage along the thalamocortical and corticospinal tracts [4], it is possible that the accentuated variability seen in these children may be a result of an increased presence of stochastic features in motor output. However, it is alternatively plausible that the gait variations seen in these children are a result of inconsistencies in properly selecting and formulating a successful stepping pattern. To begin to address this knowledge gap, we used a Langevin approach to evaluate differences in the deterministic and stochastic features that may be contributing to the variability present in the stepping pattern of children with CP [5].

METHODS

Ten children with spastic diplegic CP (Age = 7.8 ± 2.8 yrs.) and nine typically developing (TD) children (Age = 8.0 ± 2.4 yrs.) participated in this investigation. The children walked on a treadmill for two minutes at 0.8 m/s, which is a speed that has been previously reported for children with CP while walking in the community. The position of reflective markers placed on the heel, toe, ankle and the sacrum were recorded with a three-dimensional motion capture system (120 Hz). The marker positions were filtered with a low-pass zero lag digital filter at 6 Hz. Since the position of the children on the treadmill may drift, the difference in the horizontal position of the sacrum and the right ankle marker at foot-contact was used to quantify the stepping kinematics. The stepping kinematic data was differenced to ensure that the data was stationary and that the mean of the stepping pattern was zero. The standard deviation of the differenced stepping kinematics was calculated to determine the amount of gait variability present in the respective groups.

We evaluated the change in the stepping kinematics as a Langevin process

\[ \dot{x}(t) = D^{(1)}(x) + \sqrt{2D^{(2)}(x)\Gamma(t)} \]

where \( D^{(1)}(x) \) was the drift coefficient, \( D^{(2)}(x) \) was the diffusion coefficient and \( \Gamma(t) \) was the Langevin force [5]. The drift coefficient represented the deterministic changes in the gait pattern from one step to the next, while the diffusion coefficient represented the stochastic features present in the stepping kinematics. Reconstruction of the amount of drift and diffusion present in the stepping kinematics was based on a conditional probability distribution that represented the probability of the system to be in state \( x' \) at time \( t+\tau \). The amount of drift and diffusion from the respective states was calculated as follows

\[ D^{(\omega)}(x) = \lim_{\tau \to 0} \frac{1}{\tau} \int \left[ \frac{x'-x}{n!} \right]^n P(x', t+\tau | x, t) dx' \]

where \( t \) represents time, \( \tau \) represent a change in time from the initial state, and \( P(x', t+\tau | x, t) \) is the conditional probability distribution established from the stepping kinematics [5]. The coefficients were evaluated by fitting a first and second order
polynomial to the reconstructed drift and diffusion processes present in the collected data (Figure 1).

RESULTS AND DISCUSSION

Concurrent with what has been previously reported [1], our results also show that children with CP have a greater amount of variability in the stepping kinematics compared to TD children (CP = 29.6 ± 3 mm; TD = 22.3 ± 2 mm; p=0.03). However, the slope and intercept of the line fitted to the reconstructed drift of the stepping kinematics (Figure 1A) was not significantly different between the children with CP and the TD children (p>0.05). This indicated that both groups were capable of adapting the stepping kinematics to perturbations in a similar fashion. In addition, this suggests that subtle adjustments in the stepping motor command were most likely not the reason that the children with CP had a greater amount of variability in their stepping kinematics. This notion was further confirmed by a lack of correlation between the amount of variability in the stepping kinematics and the drift coefficient (p>0.05).

For both groups, the reconstruction of the amount of diffusion present in stepping kinematics had an inverted parabolic shape with the mean of the differenced stepping kinematics located where the stochastic features were at a minimum (Figure 1B). Although divergence away from this preferred state resulted in an increased amount of stochastic features, the coefficient of the second order polynomial was not significantly different (p>0.05). However, the amount of diffusion evaluated at the local minimum of the polynomial was significantly higher for the children with CP (CP = 0.16 ± 0.03 mm; TD = 0.08 ± 0.01 mm; p=0.01). This indicated that children with CP had a greater amount of stochastic features in their stepping kinematics. Moreover, we found that the amount of diffusion at the local minimum had a strong positive correlation (r=0.89; p<0.0001) with the standard deviation of the stepping kinematics. Indicating that greater variability in the stepping pattern was associated with the presence of more stochastic features.

Together, these results imply that the differences in the variability present in the stepping kinematics of children with CP and TD children are most likely related to stochastic features. We suspect that these stochastic features partly arise from the damage present in the thalamocortical and cortical spinal tracts [4]. Alternatively, it is possible that the stochastic features may arise from muscular spasticity. To address this knowledge gap, our current investigations are directed at identifying the stochastic features in the gait are amplified in children with greater sensorimotor impairments.

REFERENCES


Figure 1. Exemplary reconstructed drift (A) and diffusion of the stepping kinematics (B) for a child with cerebral palsy. Zero represents the mean of the differenced data. This point coincides with where the stochastic features of the gait are minimized.