Gait stability in children with cerebral palsy.

[1,2]Sjoerd M. Bruijn, [3]Matthew Millard, [1]Wouter Hoogkamer, [4]Pieter Meyns, [5]Ilse Jonkers

[1] Research Center for Movement Control and Neuroplasticity, Dept. of Kinesiology, KU Leuven, Belgium
[2]Department of Orthopedics, First Affiliated Hospital of Fujian Medical University, Fuzhou, Fujian, P.R. China
[3]Bioengineering, Stanford University, Stanford, CA 94305, USA
[4] Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation Sciences, KU Leuven, Belgium
[5]Research group in human movement biomechanics, KU Leuven, Belgium

SUMMARY

We tested whether a newly developed stability measure (the foot placement estimator, FPE) can be used to assess gait stability in typically developing (TD) children as well as children with Cerebral Palsy (CP). In doing so, we tested the FPE's sensitivity to the assumptions needed to calculate this measure, as well as the ability of the FPE to detect differences in stability between children with CP and TD children, and stability differences due to changes in walking speed.

The results showed that children with CP walked with marked instabilities in anterior-posterior (AP) and medio-lateral (ML) directions. Furthermore, the error caused by violations of the FPE's assumptions were small (~1.5 cm on average), while effects of walking speed (~20 cm per m/s increase in walking speed) and group (~5cm) were much larger. These results suggest that the FPE may be used to quantify gait stability in TD children and children with CP.

INTRODUCTION

Children with unilateral CP have impaired gait stability. We tested whether a newly developed stability measure (the foot placement estimator, FPE) can be used to asses gait stability in TD children as well as children with CP. The FPE is of clinical interest because it does not require long data recordings unlike other measures.

The FPE uses an inverted pendulum representation of the participant to calculate where the center-of-pressure (CoP) should be placed with respect to the center of mass (CoM), such that the participant passively transitions to a statically stable standing pose.

In order to use a simplified representation of the participant's dynamics, the FPE assumes that (1) leg length (in this context defined as the distance between the CoM and CoP), (2) total body moment-of-inertia, and (3) total body energy (kinetic + potential), remains constant after foot contact. In addition, it assumes that (4) the total body angular momentum about the new CoP location is conserved during contact. Although these assumptions might seem restrictive, sensitivity analyses completed in prior studies [2, 3] suggest that these assumptions introduce little error when analyzing healthy adult human walking. It is unknown whether these assumptions are also true for TD children, and more

specifically for children with CP. Thus, we tested the FPE's sensitivity to its assumptions, as well as the ability of the FPE to detect differences in stability between children with CP and TD children, and differences in stability caused by changes in walking speed.

METHODS

A total of 11 children with spastic unilateral CP (age 7.83 ± 2.98 years, weight 23.9 ± 7.6 kg and height 1.22 ± 0.15 m) and 24 TD children (age 9.40 ± 2.16 years, weight 31.7 ± 8.6 kg and height 1.38 ± 0.14 m) participated in the experiment. Participants walked at two different speeds (preferred and fast) while 3D gait kinematics were recorded. From these data, the distance from the FPE to the toe marker ($D_{FPE}AP$), and from the FPE to the most lateral point of the foot ($D_{FPE}ML$) at initial contact were calculated. If the swing foot covers the FPE, the FPE's theory [2] predicts that it is possible to come to a standstill without taking another step. If the FPE is outside of the feet (and not between them), at least one more stride is required to come to a standstill. $D_{FPE}AP$ and $D_{FPE}ML$ thus give an indication of how stable the gait pattern is in the AP and ML planes.

Moreover, the error caused by the FPE's assumptions were calculated using partial derivatives and maximum observed differences in relevant variables [2, 3].

For statistical analyses, we used Generalized Estimation Equations (GEE [4]), which allowed us to test the effects of group, leg, and speed (and their interactions) using actual measured walking speed (in both the preferred and fast conditions) as a continuous rather than categorical variable. Whenever an interaction effect did not reach significance, it was removed from the model.

RESULTS AND DISCUSSION

Children with CP had a higher $D_{FPE}AP$ (effect of group, $P<0.01$) than TD children in general, more so for higher speeds (group x speed interaction, $P<0.01$), and more so for the affected leg (leg and group x leg effects, both $P<0.01$). These results indicate that in the AP plane, the children with CP were more unstable than TD children. At preferred speeds, both groups covered the FPE with their contacting foot (i.e., $0<D_{FPE}AP$, see figure 1), implying they could have stopped without taking another step. When walking speed

increased, all participants had a positive $D_{FPE}AP$ implying that they were "falling" forward at each step (effect of Speed, $P<0.01$).

In the ML plane, all participants placed their feet a few centimeters wider than the FPE position (i.e., positive $D_{FPE}ML$, see figure 1B). Moreover, statistical analysis showed a significant interaction between group and speed ($P<0.01$), indicating that $D_{FPE}ML$ decreased with increasing speed for the children with CP , thus indicating the children with CP children had a narrower step width during walking. A narrower step width leaves the CP children more vulnerable to falling towards their stance limb.

Furthermore, errors caused by violations of assumptions in calculation of FPE were small (~1.5 cm), while effects of walking speed (~20 cm per m/s increase in walking speed) and group (~5cm) were much larger. These results suggest that the FPE may be used to quantify gait stability in TD children and children with CP.

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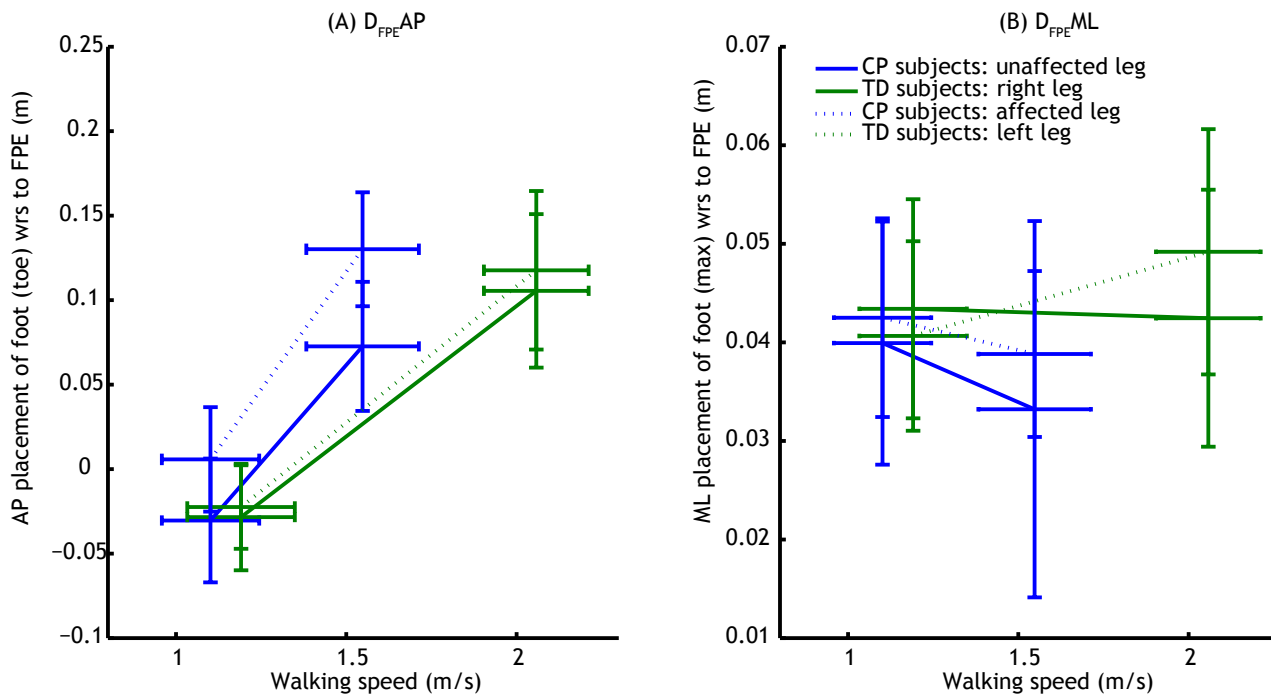
Figure 1: Differences in FPE between TD children (green) and children with CP (blue) in AP (A) and ML (B) planes, and the effects of walking speed.