DYNAMIC STABILITY IN YOUNG CHILDREN: EXTRAPOLATED CENTER OF MASS IN TWO WALKING TASKS

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Abstract: The ability to maintain locomotor balance is more complex than that of standing, because stability is not continuous, but periodically discrete in each step. The development of dynamic stability in children is critical to promote definite changes in walking patterns and has been studied with functional scales. Since it is not known whether functional scales and quantitative descriptors of dynamic stability represent the same construct, the purpose of this study is to quantify the extrapolated center of mass and margin of stability in small children during walking and to compare these results to scores of a validated balance scale. Ten typical children between 3 to 6 years of age volunteered to this study. They performed walking in two situations: basic overground walking and walking over a foam obstacle. Outputs from an automated infrared retro-reflective camera system and three force platforms were used to calculate the extrapolated center of mass and the margin of stability for the walking tasks. A validated developmental balance scale was also applied. Differences in dynamic stability between the two walking tasks could be recognized. Discussion will emphasize the relations between the scores of the functional balance scale and the extrapolated center of mass parameters to describe the level of dynamic stability in small children.

Key-words: dynamic stability, children, extrapolated center of mass.

Introduction

Dynamic stability in human gait is the ability to respond to external (like ground irregularities) and internal perturbations (like neuromuscular noise) without falls [1]. This is the quality of motor systems to cope with destabilizing forces.

The ability to maintain locomotor balance is a more complex task than that of standing balance since it involves a compromise between forward propulsion, which requires highly destabilizing forces, and the need to maintain lateral stability of the body [2]. Additionally the stability during walking is not continuous like it is during standing, but periodically discrete in each step, which may require a different mechanism to integrate the sensorial information [3] to effector commands.

It has already been demonstrated that definite changes in the locomotion ability of children are not influenced by static postural instability, but by insufficient use of the inverted pendulum mechanism and by the dynamic instability of the step transitions [4], features that are closely related to walking experience.

Largely due to the lack of consensus regarding which parameters characterize dynamic stability in children, the development of this ability in typically developing children is not known. This knowledge is essential in rehabilitation contexts for providing a reference to identify dynamic balance deficits in children with disorders that affect gait.

Motor control researchers have recently provided different approaches to quantify dynamic stability in cerebral palsy children [5] and children with vestibular hypofunction [6], while clinicians have developed functional balance protocols to assess movement quality and identify developmental delays [7,8]. Thus, it is the purpose of this study to quantify dynamic stability in two different walking tasks performed by small children using the extrapolated center of mass (XCoM) concept and margin of stability (MoS) [9] and to verify whether these measurements are related to scores of a validated functional balance scale.

Materials and Methods

Study population – Ten typical children between 3 and 6 years of age volunteered to this study after their parents have agreed to the experimental procedures and signed the informed consent. The Ethics Committee of the University of Antwerp approved the research protocol.

Experimental protocol – The experimental protocol was developed in the Multidisciplinary Motor Center Antwerp (M^2OCEAN, Belgium). The protocol included anthropometric measurements (mass, height, leg length, knee width and ankle width); gait analysis in two situations: basic overground walking and walking over a foam obstacle. The children were motivated to walk over an instrumented walkway (11 x 3 m) and their movements were captured by an automated infrared retro-reflective camera system (Vicon Motion Systems, 8 cameras, T10, 100 Hz.). An adjusted version of the Helen-Hayes marker set-up [10] was used for measuring a 15-segment full body kinematics in 3D. Three force platforms (AMTI OR 6-7, at 1080 Hz) placed in series were used to record ground reaction forces, the respective moments and the coordinates of the center of pressure. Self-selected speed was used and the children walked barefoot.

Data analysis – Full body kinematics and kinetics were calculated using the Vicon Clinical Model. In order to calculate the MoS, the distance between the XCoM and the base of support (BoS), the full body center of mass (CoM) and BoS had to be calculated. The extrapolated center of mass (XCoM) was calculated as follow [9,11]:

$$XCoM = CoM + V_{CoM}/\omega_0 \quad (1)$$

where V_{CoM} is the CoM velocity and ω_0 is the natural frequency of the inverted pendulum given by

$$\omega_0 = \sqrt{\frac{g}{l}} \quad (2)$$

where g is the gravity acceleration and l is length of the pendulum: the average height of the full body CoM Then, the margin of stability (b) is defined as

$$b = BoS - XCoM \quad (3).$$

A custom made MatLab code was written to calculate the analyzed variables (CoM, CoP, XCoM and b). Only the mediolateral direction was analyzed.

These biomechanical variables for dynamic stability will be correlated to the scores of the Ghent Developmental Balance Test [7], already validated for small children.

Results and Discussion

A representative result of one 6 year-old child during basic walking and obstacle crossing can be observed in the figures 1, 2 and in the table.

In Figure 1 the intervals between 0.49 and 0.56 s, and 0.92 and 1.02 s correspond to the first and second double contacts, respectively. The center of pressure is taken as the approximated BoS.

Observe how the BoS is transferred from the right to the left foot (0.56 to 0.91 s – right contact, 1.03 to 1.40 s – left contact). In the middle of the double contact phase, when the CoP is transferred from the right to the left foot, the CoM is approximately at its average value, and it reaches its maximal value at the single contact phase.

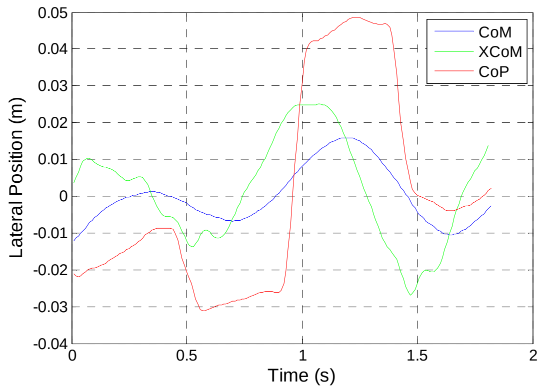

Figure 1: Lateral position of the center of mass, the center of pressure and the extrapolated center of mass during a walking cycle for a 6 year-old child.

On the other hand, the XcoM reaches its maximal value at the end of the double contact phase (toe-off of the contralateral foot), beginning of the single support phase, when the CoM is moving towards the support foot.

Figure 2 presents the CoM, XcoM and CoP curves when the same child is walking over a small foam obstacle.

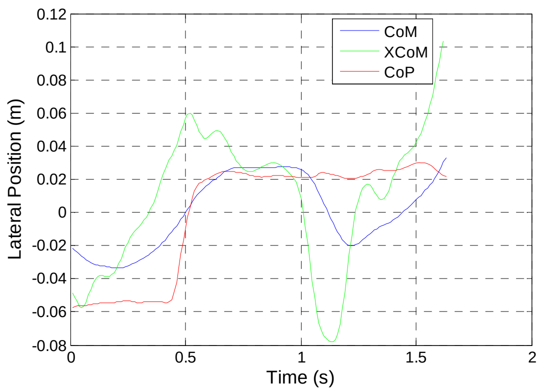

Figure 2: Lateral position of the center of mass, the center of pressure and the extrapolated center of mass during walking over an obstacle. The same child as presented in figure 1.

In Figure 2, observe as CoM, XCoM and CoP curves tend to approximate around the support foot during the transposition of the obstacle (after 0.7 s). However, larger peaks in the XCoM curve are observed in the toe-off of the contralateral foot (0.5 s) and during the transposition of the obstacle (~1.2 s). The values are 2 to 3 fold larger than the values observed during basic walking, revealing larger displacements and velocities of the CoM during weight transfer between the feet in the obstacle condition.

In both figures, the XCoM crosses the CoM when the velocity of the CoM is zero, as expected.

Figure 3 presents the MoS for the two walking tasks.

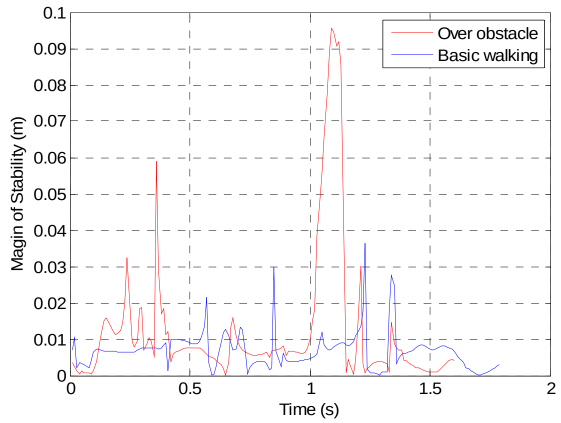

Figure 3: Changes in the Margin of Stability (MoS) for one cycle of basic walking and walking over an obstacle for a 6 year-old child.

Increased values for MoS denote more unstable situation as can be observed in the figure 3 and table 1. Obstacle crossing is associated to higher dynamic instabilities than basic walking across.

During basic walking, the smallest values of MoS are during the toe-off of the contralateral foot, whereas during walking over an obstacle the smallest values of MoS are during obstacle transposition. In fact, during the transposition of the obstacle, the small values of MoS reveals a condition of increased dynamic stability, since CoM and CoP are close to each other.

Table 1: Margin of stability (MoS) for basic walking across and obstacle crossing for a 6 year-old child.

	Basic walking across	**Obstacle crossing**
Mean (m)	0.0067	0.0122
Max (m)	0.0365	0.0955
Min (m)	0.00004	0.0002
Range (m)	0.0364	0.0953

Obstacle crossing is associated to higher dynamic instabilities than basic walking across.

Spatial-temporal paremeters of both walking tasks as well as the scores of the Ghent Developmental Balance Test will be processed and correlated to the results for margin of stability. The discussion will focus on the quality of the correlations found among biomechanical variables and the functional scores, and the probability of both stability measures being complementary.

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