BIOMECHANICAL DETERMINANTS OF GAIT STABILITY ASSESSED WITH STABILIZING AND DESTABILIZING FORCES IN YOUNG AND OLDER HEALTHY ADULTS

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INTRODUCTION
Evaluating stability during functional tasks is important to understand balance control and balance deficits in elderly and pathological populations. We recently proposed a model [1] based on two theoretical forces:
- the stabilizing force represents the force applied at the centre of mass to cancel the body kinetic energy over the distance between the centre of pressure and the limit of the base of support, in the direction of centre of mass velocity;
- the destabilizing force represents the force applied at the centre of mass to move the centre of pressure to the limit of the base of support, in the direction of the centre of mass velocity

\[ F_{st} = \frac{-m_{global} \cdot \vec{v}_{CM} \cdot \vec{v}_{CM}}{2D_{CP}^2} \cdot \vec{D}_{CP} \]

\[ F_{d} = \frac{\vec{F}_{rr} \cdot \vec{n}}{h_{CM}} \cdot \vec{D}_{CP} \]

With \( m \): body mass, \( v_{CM} \): centre of mass velocity, \( D_{CP} \): distance from the CP to the limit of the base of support, \( h_{CM} \): centre of mass height, \( F_{rr} \): ground reaction forces, \( n \): unity vector normal to walking surface.

The two forces are computed at each instant of the task.

Higher stabilizing force indicates higher level of difficulty in maintaining the centre of mass within stable limits, i.e. lower dynamic stability. Higher destabilizing force indicates that more force is needed to put the body into an unstable position over the base of support, i.e. higher postural stability. An index of stability was defined as the ratio of the destabilizing to the stabilizing force; the closer to 0 the index, the lower the stability level.

To further validate the model, we compared the minimal value of the stability index between young and older healthy adults at natural and maximal gait speeds over 10 meters, Berg Balance Scale (maximal score 56) and Timed-Up-and-Go test were evaluated clinically.

An NDI Optotrak 3020 system, with 4 cameras sampling at 60 Hz, was used to record 3D whole-body kinematics from three to four non-collinear infrared markers placed over the feet, legs, thighs, pelvis, trunk and head segments; and from single markers on the dorsal surface of the wrists, lateral epicondyles and humeral heads for arm movements.

AMTI force platforms embedded in the floor were used at a 600 Hz sampling frequency to measure ground reaction forces. Data were filtered with a 4th-order Butterworth zero-lag filter with a cut-off frequency of 10 Hz and re-sampled at 60 Hz to match the kinematic data.

Centre of mass and centre of pressure displacements, as well as the limits of the potential base of support, using an Optotrak probe to determine the contours of the feet according to the feet markers, were obtained in 4 to 5 trials of two consecutive steps for each participant in each condition.

The following values were obtained at the lowest value of the index of stability time point at each step: destabilizing and stabilizing forces, index of stability, area of the base of support, distance of centre of mass and centre of pressure to the point at the limit of the base of support in the direction of centre of mass velocity, distance between the centre of mass and the centre of pressure, velocity and acceleration of the centre of mass, velocity of the centre of pressure.

Non-parametric Wilcoxon and Mann-Whitney tests were used to compare mean values between conditions and between groups respectively. Pearson r correlations were used to establish linear correlation between variables.

RESULTS AND DISCUSSION
The clinical balance of the participants was good, with natural and maximal Timed-Up-and-Go test within normal (6.8 ± 0.7 s and 4.7 ± 0.3 s for young, 8.5 ± 1.1 s and 6.7 ± 1.1 s for older participants, respectively), shorter for the young group (p<.05). Berg Balance scale scores (56 [56-56] vs. 56 [53-56]), natural (1.59 ± 0.16 vs. 1.37 ± 0.16 m.s⁻¹) and maximal (2.35
± 0.19 vs. 1.78 ± 0.33 m.s⁻¹) gait speed were higher in the younger group (p<.05).

The two groups differed in their destabilizing force (p<.05, higher for the older group) at natural speed, velocity (lower for older group) and acceleration (higher for older group) of their centre of mass at natural and maximal speed; but their index of stability did not differ at natural (p=.096) or maximal (p=.369) speed. In both groups, the index of stability and destabilizing force decreased (p<.05), the stabilizing force and centre of mass velocity increased (p<.05) and the distance between the centre of mass and the limit of the base of support decreased (p<.05). The velocity of the centre of pressure increased in the group of young participants (p<.05) but this did not reach the threshold for the older group (p=.059).

Using individual trials of the participants, correlation with the index of stability was found high (>0.5, p<.01) for the velocity and acceleration of the centre of mass, distance of the centre of pressure to the limit of the base of support at natural and maximal speed for the young group. Stabilizing and destabilizing forces were highly correlated to the stability index only at natural speed. For the older group, the destabilizing force at natural speed and the velocity of the centre of mass at maximal speed were highly correlated to the index of stability.

**CONCLUSIONS**

Our model did not show differences in the level of stability between young and older participants, event if the older group had lower, though within normal, clinical balance abilities. However, correlation of the stability index to different biomechanical variables in young and older adults suggested a more important role of postural than dynamic variables in gait stability in the older group.

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