Three-dimensional dynamic criterion to quantify gait instability during slip-like perturbations

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Summary

Despite numerous attempts at finding the best parameter to quantify gait instability, there is still no consensus. This study introduces a dynamic criterion by measuring the vector between the body center of mass and the minimal moment axis of the external mechanical action ($\mathbf{d}_{\text{BCoM-MMA}}$), which is linked to the whole-body angular momentum (**WBAM**). This study aimed at determining its three-dimensional orthogonal projection onto the MMA during treadmill walking under external perturbations. So far, eight asymptomatic participants walked on a dual-belt instrumented treadmill under controlled slip and trip perturbations. 3D $\mathbf{d}_{\text{BCoM-MMA}}$ was increased along the mediolateral axis on the perturbed cycle. Further research is needed to establish thresholds for fall prediction.

Introduction

Understanding how people control instability is crucial for developing fall prevention strategies [1]. Split-belt treadmills offer controlled perturbations with a safe environment. Laboratory-based dynamic instability measurements resulted in various parameters, without reaching consensus [2]. In this study, we propose to use a dynamic criterion by measuring the vector between the body center of mass and the minimal moment axis of the external mechanical action applied to the body ($\mathbf{d}_{\text{BCoM-MMA}}$). This can easily be linked to the variation of the whole-body angular momentum (**WBAM**) [3]. The greater the distance, the greater the instability. The goal was to determine how the 3D $\mathbf{d}_{\text{BCoM-MMA}}$ evolves under external perturbations while walking on a treadmill. We hypothesized that perturbations would increase the $\mathbf{d}_{\text{BCoM-MMA}}$, and induce rapid changes in its value.

Methods

This protocol was ethically approved (RCB 2020-A01357-32). So far, eight asymptomatic volunteers (3 F/5 M, 25.6 ± 1.3 years, 73 ± 5 kg) walked on a dual-belt treadmill equipped with two force platforms (1000 Hz, Treadmetrix©) and a motion capture system (100 Hz, Vicon©). Following a stabilized walking phase at 1.2 m/s, participants experienced acceleration and deceleration phases (3 and 10 m/s²) with eight slips and trips induced, reaching 2.04 and 0.36 m/s. While aware of disruptions, they were not told their timing or type. A safety harness was used, and participants wore their own flat-soled sneakers. We analyzed 64 Slip-like perturbations trials that were normalized by gait cycles. We compared pre-perturbation to post-perturbation cycles.

Results and Discussion

We found significant differences in the mean and maximum 3D $\mathbf{d}_{\text{BCoM-MMA}}$ between pre-perturbation cycles and the perturbed cycle along the mediolateral axis for both acceleration levels ($p<0.001$). Few significant differences were also found between pre-perturbed cycles and the perturbed cycle (Figure 1). Most differences were found along the anteroposterior axis, while we clearly identify an increased distance along the mediolateral axis at around 50% GC. While the Euclidian norm of this criterion was already described in several papers [3–7], 3D $\mathbf{d}_{\text{BCoM-MMA}}$ was only provided along the anteroposterior axis by [5]. However, it seems like the mediolateral component is the most impacted by perturbations.

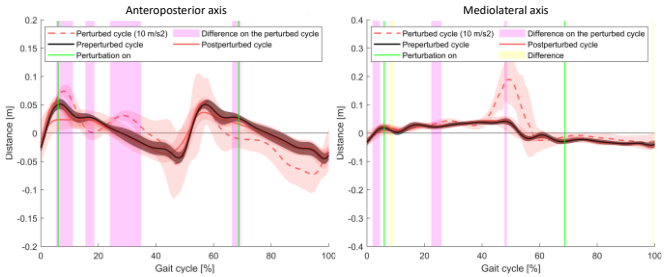

Figure 1: $\mathbf{d}_{\text{BCoM-MMA}}$ along the anteroposterior and mediolateral axes for slip-like perturbations. Statistical non-parametric mapping results between the pre-perturbation cycles (black line) and the perturbed cycle, and post-perturbed cycles are respectively highlighted in magenta and yellow.

Conclusions

The 3D $\mathbf{d}_{\text{BCoM-MMA}}$ showed a sensitivity in detecting external disturbances during treadmill walking. In this ongoing project, we aim at creating a bigger data basis to determine thresholds above which the fall would be inevitable.

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