The Trunk-Pelvis Perpendicularity Assumption in Mediolateral Balance Models is Invalid at Large Stance Widths

Caroline Aitken[1], Jesse Charlton[1], Calvin Qiao[2], Lyndia Wu[1], Jean-Sébastien Blouin[1]
[1]The University of British Columbia, Vancouver, Canada
[2]Simon Fraser University, Vancouver, Canada
Email: caroline.aitken@ubc.ca

Summary

Mediolateral (ML) balance control is implicated in falls in populations with neural injury and aging; understanding why requires a solid grasp of the biomechanics involved in maintaining upright posture. While many ML models assume the trunk remains perpendicular to the pelvis, our findings reveal that when stance width exceeds hip width, the angle between the trunk and pelvis deviates significantly from 90°. Incorporating an independent function for trunk movement in ML models could provide a more accurate framework for understanding ML control changes in vulnerable populations.

Introduction

Standing balance is a complex task essential for many daily activities. While mediolateral (ML) balance plays a key role in balance and fall issues among aging populations [1] and individuals with neural injuries [2], the simplicity of the inverted pendulum model—adequate for modeling anteroposterior motion—has led to a greater focus on anteroposterior balance than on ML balance. Typical frontal plane ML models use a four-bar linkage to represent the leg and pelvis interactions, while the trunk is assumed to be fixed perpendicularly to the pelvis. However, most might find this unnatural at stance widths much larger than their hip width. In this study, we tested whether the perpendicular trunk model accurately tracks in-vivo trunk-pelvis motion at different stance widths.

Methods

While standing upright, 20 participants smoothly and continuously shifted their weight from right to left within their base of support. A metronome helped maintain constant weight shift. Participants did this for 60 s at each stance width (inter-ankle joint distance) of 50%, 75%, 100%, 125%, 150%, 175% and 200% of the distance between hip joint centres (HJCs) [3].

Kinematic data were collected from participants using a 13-camera motion-capture system (Motion Analysis Inc.) while they balanced on two force plates (OR6-6 AMTI), one for each foot. We placed motion-capture markers on the manubrium, and the left and right anterior and posterior iliac spines to track trunk and pelvis motion. Pelvis motion was estimated by the vector pointing from the right to left HJC, and trunk motion by the vector pointing from the mid-HJC to the manubrium. The trunk-pelvis angle, θ_{tp}, was segmented and time-normalized into sway cycles based on timepoints when the centre of mass was over the centre of pressure [4].

To test the hypothesis that the pelvis-trunk angle, θ_{tp}, may not remain perpendicular in ML balance, we performed a one-sample two-tailed t-test using 1D statistical parametric mapping (α=0.05) for θ_{tp} in each stance width.

Results and Discussion

Participants significantly deviated θ_{tp} from 90° at stance widths greater than 100% hip width, corresponding to, on average, 80% of a sway cycle. Further analysis showed this is because at stance widths greater than 100% hip width, the 90° assumption predicts that the manubrium stays close to the centre of the base of support, while participants actually kept their trunk vertical or moved it towards the edges of their base of support.

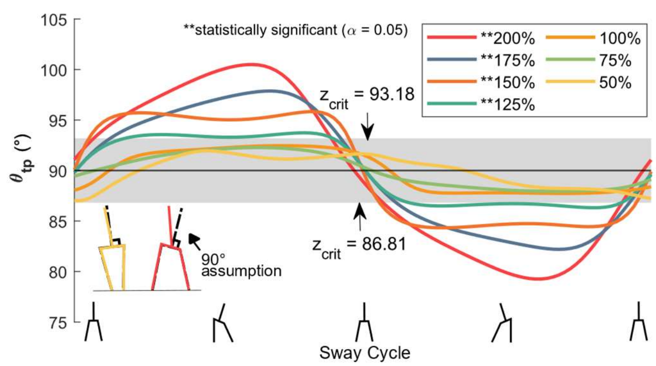

Figure 1: Statistical parametric mapping of θ_{tp}.

Conclusions

The perpendicularity assumption is not an appropriate assumption of human ML balance motion at stance widths larger than a person's hip width. A more physiologically accurate model that modifies θ_{tp} with an independent function would better assist our understanding of how ML balance control is affected in vulnerable populations.

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