THE UTILITY OF STABILITY: WHOLE BODY ANGULAR MOMENTUM INFORMS STEP PLACEMENT DURING PERTURBED WALKING

Jennifer K. Leestma[1,2*], Courtney R. Smith[3], Pawel R. Golyski[1,4], Aaron J. Young[1,2], and Gregory S. Sawicki[1,2,5]
[1]George W. Woodruff School of Mechanical Engineering, [2]Institute for Robotics and Intelligent Machines, [3] Wallace H. Coulter Department of Biomedical Engineering, [4]Parker H. Petit Institute for Bioengineering and Biosciences, and [5]School of Biological Sciences, Georgia Institute of Technology, Atlanta, GA, USA
email: *jleestma@gatech.edu

Introduction

Understanding stability recovery strategies during walking is crucial for better understanding and treating individuals with balance impairments. However, there is relatively little work in determining if stability measures correlate with biomechanical outcomes [1]. If such a relationship exists, it would support the utility of stability measures and suggest that humans use some proxy of stability for strategy planning. Though several strategies can be employed to recover stability (e.g. ankle strategy), larger perturbations typically demand the use of step placement to provide larger changes to the center of pressure [3]. We hypothesize that stability informs recovery strategies during perturbed walking. We investigated stability using whole-body angular momentum (WBAM) [2] and recovery strategy using step placement.

Methods

Data shown is for a single healthy subject walking at 1.25 m/s on a 6 degree-of-freedom moving platform. The platform was translated in eight directions (anteroposterior, mediolateral, and diagonals), three magnitudes (5, 10, 15 cm) (Fig 1A), and at four onset times (double stance; early, middle, late single stance) (Fig 1B). We collected full-body motion capture.

We identified gait events using a kinematic method [4]. We calculated step width (SW) and length (SL) using the difference between heel markers. We calculated WBAM using OpenSim and custom Matlab scripts. We calculated frontal and sagittal integrated WBAM (iWBAM) over the two steps following the perturbation, termed the perturbed step and next step. We evaluated the correlations between frontal iWBAM and SW as well as sagittal iWBAM and SL (Fig 1C).

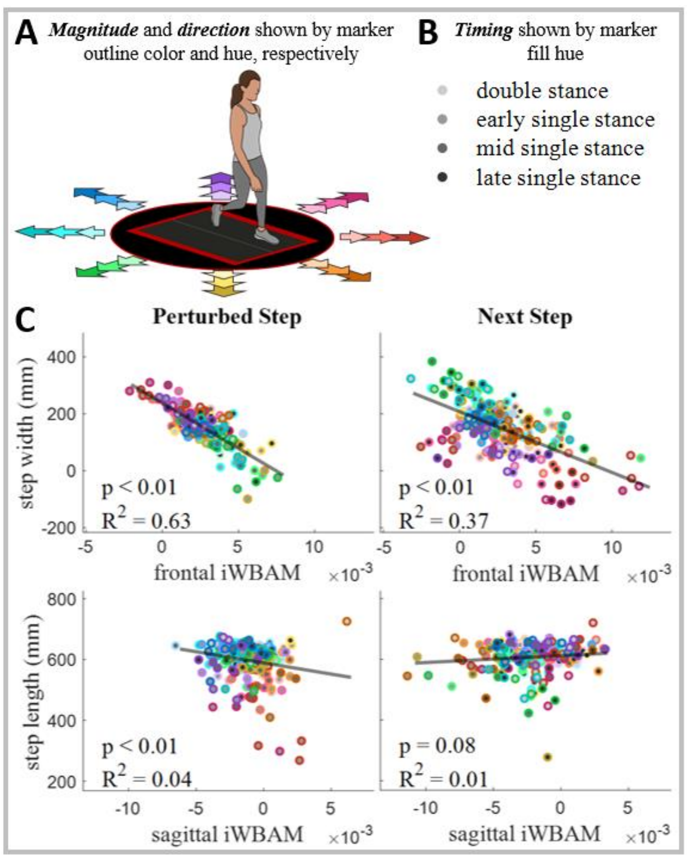

Figure 1: *(A)* Perturbations vary in magnitude and direction. *(B)* Perturbations onset at various times. *(C)* Correlation between iWBAM and step placement. Trend line and statistical values are shown.

Results and Discussion

All correlations, with the exception of sagittal iWBAM to SL in the next step, were significant ($p<0.01$). Frontal iWBAM strongly correlated with SW ($R^2 = 0.63$) in the perturbed step. However, the correlation was weaker ($R^2 = 0.37$) in the next step. Though significant, the correlation between sagittal iWBAM and SL was very weak ($R^2 = 0.04$) in the perturbed step. The correlation was also very weak ($R^2 = 0.01$) in the next step.

Frontal iWBAM and SW showed stronger correlations than sagittal iWBAM and SL, consistent with previous work [1]. This suggests that individuals execute a frontal plane strategy that scales linearly with stability during perturbed walking. This may also suggest that individuals possess some representation (e.g. proprioception, vestibular feedback, center of mass sensing, etc.) of whole-body mechanics that they use to assess their stability, supporting the validity of WBAM as a useful stability metric and as a possible measure to inform step placement control. However, individuals do not seem to alter their sagittal stepping strategy based on stability. This could be due to within-step balance responses (i.e., ankle moment modulation) predominantly mediating stability recovery in the sagittal plane.

Significance

If the correlation between stability and response is weaker or shifted in clinical populations, this approach could be used as a tool to understand stability deficits or evaluate interventions intended to improve stability. Here, all perturbed steps were included, despite some perturbations perhaps being addressed by passive dynamics; our ongoing work seeks to identify these steps to better address our hypothesis. We will also investigate if stability similarly informs joint and muscle-level responses. Long term, we aim to use WBAM as a control input for exoskeleton interventions that seek to augment recovery strategies.

Acknowledgments

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References

[1] Wang, Srinivasan (2014) *Biol. Lett.* [2] Herr, Popvic (2008) *J. Exp. Biol.* [3] Hof et al. (2010) *J. Exp. Biol.* [4] Zeni et al. (2008) *Gait Posture*