INVESTIGATING THE ROLE OF HIP JOINT MOMENTS IN MODULATING MEDIOLATERAL STEP PLACEMENT DURING PERTURBED WALKING

Vibha R. Iyer[1*], Jennifer K. Leestma[2,3], Aaron J. Young[2,3], Gregory S. Sawicki[2,3,4]
[1]Wallace H. Coulter Department of Biomedical Engineering, [2]George W. Woodruff School of Mechanical Engineering, [3]Institute for Robotics and Intelligent Machines, [4]School of Biological Sciences, Georgia Institute of Technology
*Corresponding author's email: viyer72@gatech.edu

Introduction: During normal walking, humans are excellent at maintaining biomechanical stability. However, environmental disturbances, or perturbations, can cause varying degrees of imbalance during gait. For larger magnitude perturbations, common balance recovery strategies include large changes in step placement, primarily driven by hip musculotendons [1]. Understanding the role of the swing and stance limb hip moments during step placement could provide insight into how humans achieve such robustness to external perturbations and how sensorimotor deficits in the hip joint may influence balance recovery. Moreover, investigating hip moments across a variety of perturbations could illuminate if and when humans alter stance and swing limb contributions to balance. In this work, we aimed to determine the relationship between stance and swing limb hip moments and step placement during perturbed walking.

Methods: This study was approved by the Georgia Institute of Technology Institutional Review Board. Using a 6 degree-of-freedom perturbation platform containing a treadmill, we had participants (N = 11) walk at 1.25 m/s while suddenly moving the walking platform with various magnitudes (5, 10, 15 cm) and directions (eight at 45-degree increments), with perturbation onset during double stance (Fig. 1A). We identified gait events using a kinematic method and collected data from full-body motion capture [2]. Analysis was limited to frontal-plane step placement, as imbalance in the mediolateral direction tends to induce greater step placement modulation [3]. We calculated hip joint moments using OpenSim and filtered moment data with a 6 Hz lowpass filter. We calculated integrated hip moment over the single stance following the perturbation onset and normalized by participant mass (Fig. 1B). We calculated step width (SW) using the mediolateral distance between heel markers at the end of the same single stance and normalized by participant height. We evaluated the correlation between integrated hip moment in the stance and swing limbs and step placement during the perturbed step.

Results & Discussion: We found a significant relationship ($p < 0.01$) between both swing and stance integrated hip moments and step width (Fig. 1C). However, there was a much stronger correlation between the swing hip moment and step width (R = 0.682) compared to the stance hip (R = 0.054). This indicates that the swing limb is the primary driver of step placement when perturbed. Conversely, there is very little correlation between the stance limb hip moments and step width. The stance limb's integrated moment during steady state walking was negative (widening-abduction); even during perturbations requiring a narrowing step (green) in which some hip adduction would be required. This suggests that any stance hip moment modulation during balance recovery may be constrained by the stance hip's typical role in supporting and directing the center of mass during walking. Indeed, the swing limb is more manoeuvrable because it can move in all degrees of freedom, subject only to inertial constraints.

Significance: Understanding the links between stance and swing limb hip moments and step placement could inform biomechanical stabilization strategies, and also help diagnose contributors to balance deficits in clinical populations. Future work will include investigating how different perturbation conditions cause varied hip moment contributions and analysing the role of the ankle joint in step placement to better understand balance recovery. We will also mine this data for balance augmenting exoskeleton assistance strategies - focusing on benefits of targeting swing leg step placement modulation versus stance leg stability assistance. Long term, we expect this data to inform studies on 'best-practices' in the effective control of dynamic balance using our 2DOF hip exoskeleton [4].

Acknowledgments: Supported by Georgia Tech President's Undergrad Research Award (PURA) and NSF GRFP Award #1324585.

References: [1] Hof et al. (2010) *J. Exp. Biol*. [2] Zeni et al. (2008) *Gait Posture.* [3] Leestma et al. (2023) *J Exp Biol*. [4] Leestma et al. (2024) *RAL*.

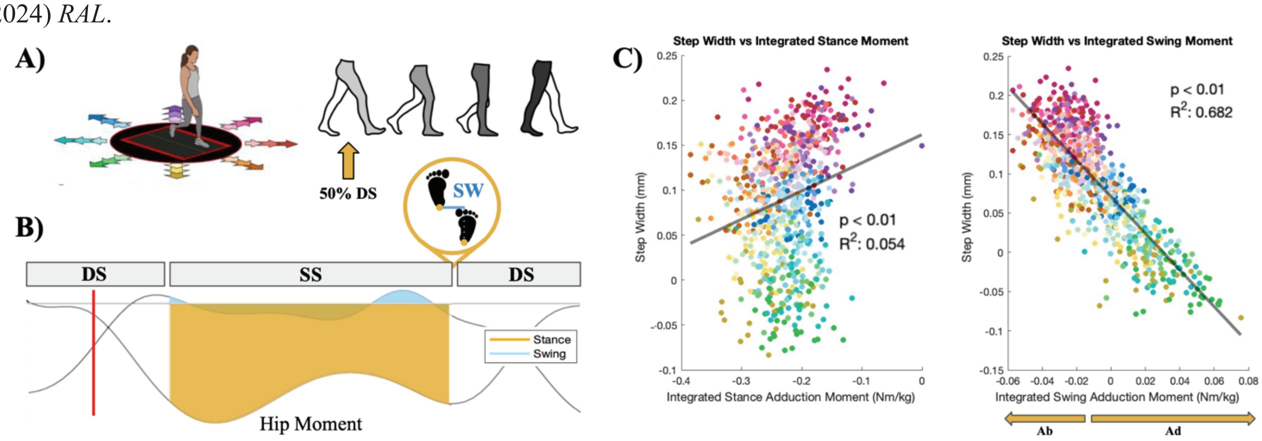

Figure 1: A) Perturbation conditions with varying magnitudes (hue) and direction (color) at 50% double stance. B) Integrated hip moment for stance and swing limbs calculated using the single stance (SS) following the double stance (DS) containing the perturbation onset (red line). Step Width (SW) calculated at the end of SS. C) Correlation between normalized SW vs. integrated hip moment. Trend lines and statistical values are displayed.