Responses to locomotion commotion caused by translation perturbations

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I. Background

Human locomotion has been studied for centuries, with motivations spanning the creation of clinical outcome measures to the development of bipedal robots. Though previous research has extensively evaluated steady-state locomotion, there has been far less research on how bipeds navigate non-steady-state environments. However, understanding locomotion in these environments is imperative in aiding fall-prone populations [1], creating assistive devices [2], and controlling robots that are able to traverse the world outside of the lab. Here, we tested how magnitude, direction, and timing of perturbations during locomotion affect step responses used for balance recovery.

II. Methods

One subject participated in this study approved by the Georgia Institute of Technology Institutional Review Board. We applied ground perturbations during walking at 1.25 m/s by translating a treadmill mounted on a Stewart platform (CAREN System, Motek, Netherlands). We applied perturbations at three magnitudes (5, 10, 15 cm translations), eight directions (45-degree increments), and at four times during the gait cycle (5, 15, 30, 45% of the gait cycle). We collected motion capture data (Vicon Motion Systems, UK) for the lower limb segments, ground reaction forces, and electromyography (Delsys Inc., MA, USA) from eight lower limb muscles on each leg. We analyzed data using custom Matlab scripts (MathWorks, Natick, MA, USA).

III. Results & Discussion

We calculated the mean step widths and lengths for the perturbed step (S_0) and five subsequent steps (S_1-S_5) for all combinations of direction and magnitude (Fig. 1). In comparison to steady-state walking, perturbations that cause a center of mass (CoM) acceleration towards the inside of the stance foot resulted in wider step widths in the S_1 step, with the widest step of 0.24 m being more than double that of steady-state walking. Similarly, perturbations causing CoM acceleration towards the outside of the stance foot caused narrower step widths, often resulting in crossover steps, with the most severe crossover step being -0.07 m. However, the width of the second step following a perturbation (S_2) tends to oppose the S_1 step, with a wide S_1 step being followed by a narrow S_2 step. Though step width was affected for multiple steps, no perturbation condition appears to affect step length after the S_1 step. The two largest perturbation magnitudes resulted in the most prominent S_1 step length changes, with step lengths shortening by over 0.1 m. These data suggest different settling times for step width and length following a perturbation. These results provide insight on balance recovery from perturbations that vary in magnitude and direction. Future work will also evaluate the effect of perturbation timing on recovery responses and balance, as well as test more subjects.

IV. Conclusion

This work can inform the development of control systems that are robust to non-steady-state environments, whether it be for prostheses or bipedal robots. By detecting the effect of a perturbation on the CoM, these data may inform a spatiotemporal control strategy for balance recovery. In the future, we hope that this will enable the response time of machine systems to exceed that of human capabilities.

References

[1] S. M. Bruijn, O. G. Meijer, P. J. Beek, and J. H. Van Dieën, "Assessing the stability of human locomotion: a review of current measures," *J. R. Soc. Interface*, vol. 10, no. 83, June 2013.

[2] D. Tokur, M. Grimmer, and A. Seyfarth, "Review of balance recovery in response to external perturbation during daily activities," *Hum. Movement Sci.*, vol. 69, February 2020.

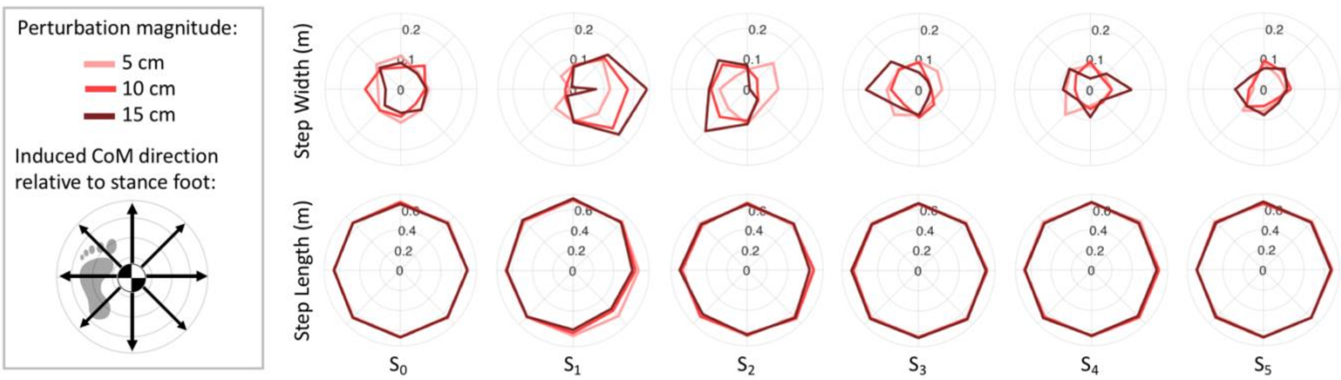

Fig. 1. This figure illustrates the step width (top) and length (bottom) responses following a perturbation. Perturbation magnitudes are represented by line color, direction is represented by the polar plot angle, and step width and length are represnted by the polar plot radius.