

Spatiotemporal recovery responses used to combat translational platform perturbations during walking

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Introduction

Robust bipedal locomotion is required to traverse the unpredictable and non-uniform environment that exists outside of the lab. However, we know much less about locomotion in these kinds of non-steady-state environments in comparison to steady-state ones. Previous studies have used perturbations to cause instability during gait, revealing information about recovery strategies, step responses, and muscle contributions used to maintain balance [1]. However, much of this work has not evaluated the interplay between many independent variables, which would improve our understanding of highly unpredictable reactions to gait perturbations that occur in real-world environments. In this study, we establish an experimental protocol to investigate how perturbation *magnitude* and *direction* affect locomotion stability. Specifically, we focus here on how perturbation magnitude and direction affect step response.

Methods

One subject walked at 1.25 m/s on a treadmill mounted on a Stewart platform and we applied translational perturbations in the mediolateral and anteroposterior directions. We applied 288 perturbations that varied in direction (8 directions, 45° increments) and magnitude (5, 10, 15 cm), creating 24 conditions. We collected lower body motion capture.

We lowpass filtered marker data at 6 Hz. We identified gait events using a kinematic coordinate method [2]. We identified the step length (SL) and step width (SW) at the heel contact at the beginning of each step using the distance between heel markers, shown in Figure 1. We examined the mean SL and SW for each of the 24 conditions for the perturbed step (S_0) and the five subsequent steps (S_1 - S_5), shown in Figure 1.

Results and Discussion

The steady-state SL and SW were 0.661 m and 0.096 m, respectively. SL was affected by perturbation direction, but only for a single step after the perturbation. In the S_1 step, platform

movement lateral or posterior to the stance foot resulted in a SL decrease. Similarly, platform movement medial or anterior to the stance foot resulted in a SL increase. These changes in SL also increased with the magnitude of the perturbation. Following the S_1 step, magnitude and direction do not appear to influence SL. SW was also affected by direction, with effects lasting for three steps following the perturbation. Platform movement medial to the stance foot caused a SW decrease in the S_1 step and a SW increase in the S_2 and S_3 steps. Similarly, platform movement lateral to the stance foot caused an SW increase in the S_1 step and a SW decrease in the S_2 and S_3 steps. Similar to SL, perturbation magnitude also scaled the severity of SW changes. The simultaneous influence of both perturbation magnitude and direction on SL and SW responses confirm the importance of considering both of these independent variables when analyzing locomotion stability. Future work will also evaluate the interplay between perturbation timing and the two independent variables tested here.

Significance

Understanding how balance during bipedal locomotion is resilient to unsteady environments is imperative for designing rehabilitation therapies, assistive devices, and bipedal robots. Our results provide a foundation to understand how a diverse set of perturbations affect locomotion dynamics. Additionally, these data provide a biomechanical reference for researchers and engineers who are designing advanced devices for use in non-steady-state environments.

Acknowledgments

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References

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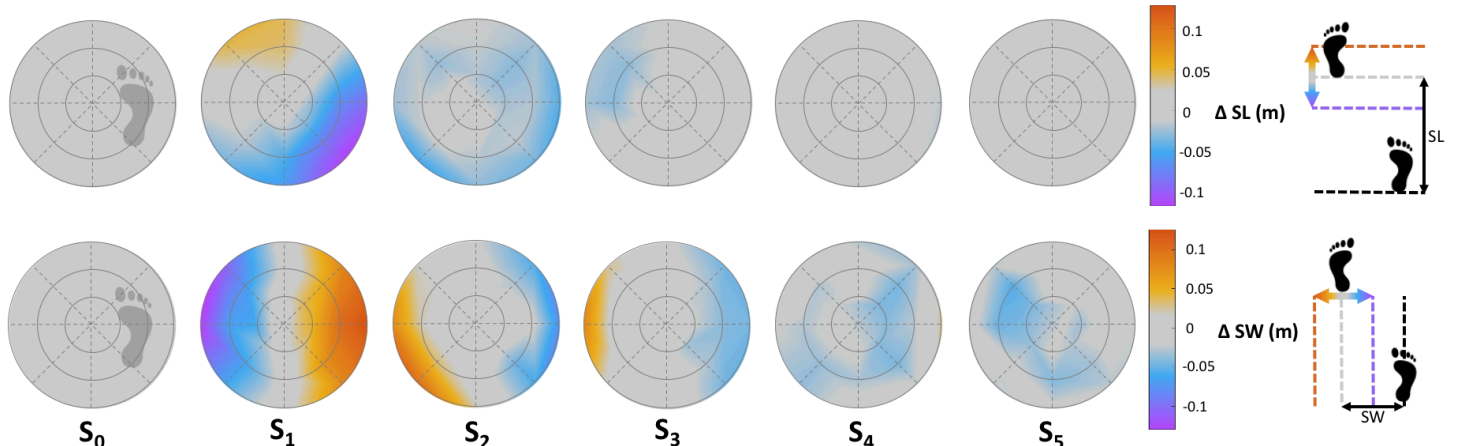


Figure 1: Circular axes represent perturbation magnitude (5, 10, 15 cm) and radial axes represent the direction of platform movement. Perturbations on the right or left foot are normalized and displayed as though the right foot was the perturbed step (S_0), shown by the footprint. The colors show the mean SL and SW deviations from steady-state for each step.