

Treadmill Belt Acceleration Timing Affects Stability During Walking

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Introduction

Balance is a major health problem in the United States, with around 30% of adults over 65 years old falling each year – often caused by trips or slips [1]. In a laboratory setting, treadmill belt accelerations are a reproducible way of emulating slips [2]. Previous research using treadmill belt accelerations looked at the effect of acceleration magnitude on walking stability but overlooked the effect of *when* in the gait cycle the perturbation is delivered [3].

During 15-20% of the gait cycle is when a single foot is flat on the ground during initial support and the body's center of mass is posterior to the foot. This leads us to hypothesize that between 15 and 20% of the gait cycle is when individuals are most vulnerable to losing balance during walking due to a rapid treadmill belt acceleration.

Methods

We had 10 subjects walk on a split-belt treadmill at 1.25 m/s while rapid (15 m/s²), brief (0.2 sec) accelerations were applied to a single treadmill belt in a randomized order. While the subjects walked, we “slipped” each leg 10 times at 10, 15, 20, 30, 40, and 50% of the gait cycle. We used three metrics to quantify stability of the step before, during, and for four steps after the perturbation. The three metrics we used to quantify balance were mediolateral dynamic stability margin [4], step width, and step length. Increased dynamic stability and step width, as well as decreased step lengths indicated a participant was destabilized. A linear mixed model was used to evaluate the influence of slip timing for each step. Bonferroni-corrected pairwise comparisons were used for post-hoc tests. An $\alpha \leq 0.05$ indicated significance. All slips that resulted in balance metrics $>3x$ the interquartile range were excluded from analysis (12.7% of the data were excluded).

Results and Discussion

Dynamic stability margins were largest (i.e. subjects were most destabilized) for slips that occurred at 20 and 30% of the gait cycle during the step after the perturbation (Figure 1a). Step widths were larger for 20% slips during the second and third steps after the perturbation (Figure 1b). Step lengths were smaller after

slips delivered at 20 and 30% during the second step after the perturbation (Figure 1c). Our results partially support our hypothesis of 15-20% of the gait cycle being sensitive to slips, but slips delivered at 30% of the gait cycle were also destabilizing as measured by dynamic stability margin, step width, and step length. The reason for this discrepancy could be that our hypothesis was based off of static postures throughout the gait cycle, but velocity is also a major contributor to dynamic stability. Additionally, there was a strong mediolateral response to a posterior belt slip. For example, during slips delivered at 20% of the gait cycle, we found a 43% increase in step width, which is substantially larger than responses due to sinusoidal mediolateral translations of the floor (5% increase) or visual field motion (22%) with 5 cm amplitudes [5].

Significance

Despite the wide variety of perturbations used to study stability during walking, the extent to which stability varies as a function of the gait cycle is not understood. We found differences in subject stability responses across 6 treadmill belt acceleration timings, with the largest responses occurring during perturbations applied closer to midstance. This finding suggests that to most effectively quantify a person's limit of stability with a belt acceleration, slips should not be applied during heel strike, as is common in literature, but closer to midstance. Furthermore, wearable robots and training regimens designed to prevent slips/trips during walking may also need to prioritize assisting muscles active during midstance.

Acknowledgments

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References

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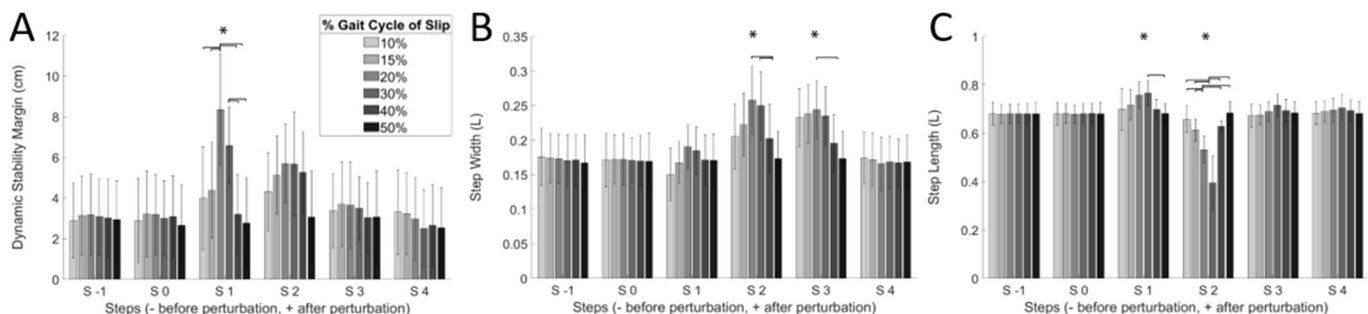


Figure 1: Stability metrics for the step before (S -1), step of (S 0), and 4 steps after belt acceleration. Left and right legs were combined. “L” = normalized to subject leg length. “*” = significant effect of slip timing. Bars = significant pairwise comparisons. Error bars = SD.