

Stumble recovery: Strategies, kinematics and kinetics as a function of foot perturbation timing during swing phase

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Summary

In order to better understand the biomechanics of stumbling and inform fall prevention strategies, seven individuals were tripped at a range of different times during leg swing. Kinematics and kinetics of their recoveries were analyzed. We identified the region in swing phase that elicited the most trunk deflection as well as highest recovery strategy variance.

Introduction

Falls and subsequent injury are commonly caused by tripping/stumbling over obstacles [1]. Studying how people recover from stumbling provides insight on fall prevention strategies and interventions. Previous research has identified three strategies that healthy individuals employ to recover from a stumble perturbation. Typically, the elevating strategy is used to recover from early-swing perturbations, the lowering strategy is used for late-swing perturbations, and the delayed lowering strategy is used for mid- to late-swing perturbations [2]. However, no obstacle perturbation study has investigated recovery strategy and associated kinematic/kinetic characteristics with higher resolution than three bins of swing phase (i.e., early-, mid-, and late-swing). Analyzing such responses as a function of swing phase with higher temporal resolution could provide insight into several unknowns regarding stumble recovery, such as (i) precisely when and why healthy individuals transition between strategies and (ii) when a perturbation causes the greatest disturbance to individuals (i.e., when people are most likely to fall). Other unknowns include questions such as (iii) how these recovery strategies and associated biomechanics are altered in people with physical disabilities (e.g., leg amputation), and (iv) how to design better interventions (e.g., prostheses) to prevent falls. The overarching goal of this project is to address these knowledge gaps. The specific objective of this Abstract is to summarize progress related to questions (i) and (ii), which we accomplish using a custom stumble perturbation system (Figure 1) that we have designed, built and validated [3] to systematically perturb swing phase.

Methods

Seven healthy subjects participated in the study, and each gave written informed consent. Subjects walked on a force-instrumented treadmill at 1.1 m/s. A steel block was introduced onto the treadmill belt via a custom ramp so that the obstacle contacted the subject's foot at a targeted percentage of swing phase (Figure 1). Each subject was perturbed 28 times, targeted from 10% to 75% of swing phase in 5% increments, in randomized order. Ground reaction forces and full-body kinematics were collected. Joint-level kinematics/kinetics were estimated using inverse dynamics. Peak trunk deflection angle after perturbation was computed as one metric related to the size of the disturbance, which may

provide insight on fall susceptibility. Recovery strategy and swing percentage of perturbation were identified for each trial.

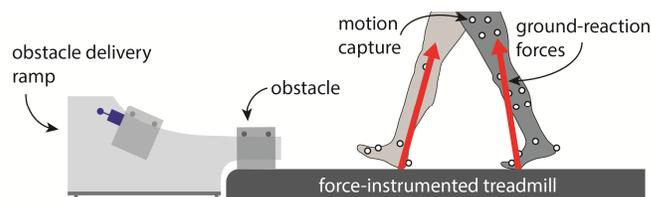


Figure 1: Schematic of custom stumble perturbation system.

Results and Discussion

The study yielded 188 successful perturbations (across all subjects), resulting in 127 elevating strategies, 34 lowering strategies, and 27 delayed lowering strategies (Figure 2). The largest trunk deflections after perturbation were observed when perturbations occurred between 50% and 69% swing phase, suggesting this may be the portion of swing phase when people are particularly susceptible to falling. Notably, this region was also marked by the most variance in recovery strategy chosen. Complementary biomechanical metrics and further analysis will also be presented at the conference.

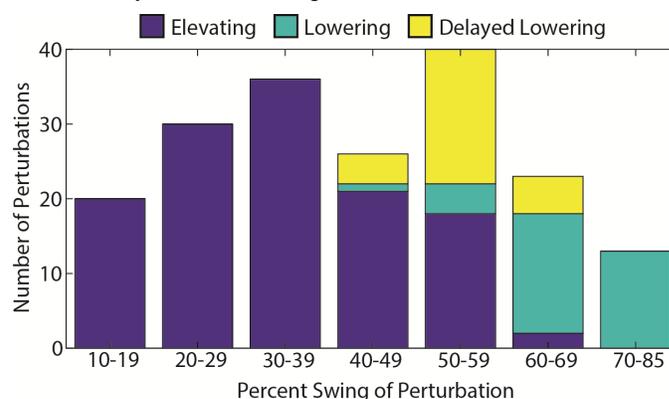


Figure 2. Stumble recovery strategy as a function of perturbation timing during swing phase (0% swing corresponds to toe lift off the ground, 100% to foot contact).

Conclusions

This work presents the first systematic analysis of obstacle perturbation stumble recovery as a function of percent swing. The region of 50-69% swing was identified as causing the greatest disturbance to subjects, in terms of trunk deflection angle. This region of interest warrants further study.

Acknowledgments

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References

- [1] Leamon TB et al. (1995). *Ergonomics*, **38**: 487-498.
- [2] Schillings AM et al. (1996) *J Neurosci Meth*, **67**: 11-17.
- [3] Eveld ME et al. (2019). *JNER*. In Review.