

Stumble recovery strategies for healthy individuals and transfemoral prosthesis users

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Introduction

Transfemoral prosthesis users (TFPUs) fall 200x more often than healthy individuals [1]. In order to develop interventions (e.g., prostheses) to decrease their fall likelihood, it is important to understand (1) reflexive mechanisms that help prevent falls in healthy populations, and (2) deficiencies in recoveries of the TFPUs.

Concerning (1), it has been established that healthy individuals employ one of three *primary strategies* to recover from a stumble: elevating, lowering, or delayed lowering. However, we have observed that participants used one of two *sub-strategies*: with or without an aerial phase (i.e., jump). Only two prior studies have mentioned an aerial phase [2]; thus the frequency, causes, effects, and implications of these sub-strategies are unknown. This knowledge gap limits how prosthetic interventions are designed/controlled.

Concerning (2), TFPU stumble recovery has been rarely studied. In one study all TFPU participants recovered from perturbations [3], but the perturbation was simulated without a physical obstacle to clear. In the second all TFPUs fell, but stumbles were only elicited at 50% swing. Recovery strategies used/attempted were not consistent between studies, leaving a gap in understanding. A comprehensive characterization of TFPU stumble recovery strategies is needed to identify functional deficiencies of current prostheses, and inform design of next-generation prostheses to help prevent falls.

The overarching goal is to provide a better understanding of both healthy and TFPU stumble recovery by addressing the aforementioned knowledge gaps. Specifically, we aimed to: (1) Characterize the incidence of the aerial phase for each primary recovery strategy in healthy participants, across swing phase, and across speeds, and (2) characterize the recovery strategies of TFPUs for each limb across swing phase.

Methods

For (1), seven healthy participants were stumbled 28 times each at 1.1 m/s using our custom obstacle perturbation system [4]. One participant was tested at two additional speeds, 0.8 and 1.4 m/s. For (2), one TFPU participant was stumbled six times, three times per limb. Testing on additional TFPUs is ongoing and will be presented at the conference. The perturbations were targeted to occur at a range of points in swing phase. Ground-reaction forces and kinematics were collected and joint-level kinematics/kinetics were estimated. For each stumble, the swing percentage of perturbation was calculated and the strategy used/attempted was recorded.

Results and Discussion

Regarding (1), aerial phase occurred in 40% of recoveries for 1.1 m/s trials. It was used in 92% of delayed lowering strategies, 30% of lowering strategies, and 26% of elevating strategies (Figure 1). For perturbations during 40-70% swing phase, 90% of these resulted in aerial phases. For the single participant tested at multiple speeds, the aerial phase was employed in 92% of 1.4 m/s trials, 32% of 1.1 m/s trials, and

7% of 0.8 m/s trials. Thus the aerial phase was more likely to be used to recover from mid to late swing-phase perturbations and at higher walking speeds. In order to accomplish this aerial recovery with a prosthetic device, an active ankle joint may be required, and device loading capabilities may need to be considered in order to land safely.

Regarding (2), the TFPU participant recovered from all stumbles on his prosthetic side. For the early/mid-swing perturbations, the participant lowered behind the obstacle with the prosthetic limb, followed by a short contralateral step and a hop to clear the obstacle. For the late-swing perturbation, the participant used ipsilateral circumduction to clear the obstacle instead of a hop. On the sound side, the participant attempted an elevating strategy for the early-swing perturbation, and attempted a lowering strategy for mid/late-swing perturbations, but ultimately fell. Thus, sound side stumbles were more dangerous for this TFPU. We are evaluating if this observation holds true in other TFPUs. For stumbling on the prosthesis side, a lack of active knee flexion may contribute to the prolonged recovery (i.e., more recovery steps compared to healthy controls). For stumbling on the sound side, a lack of active plantarflexion and knee flexion may contribute to falls.

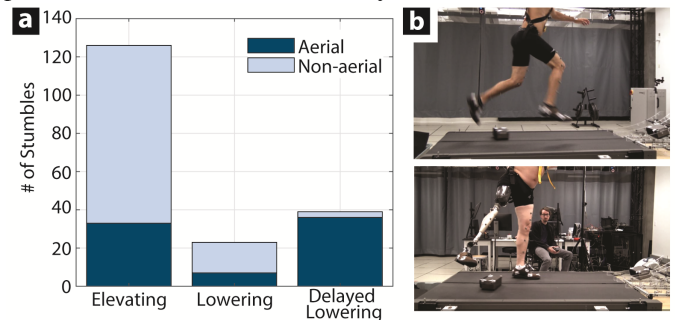


Figure 1: (a) Breakdown of strategies used in healthy stumble study. (b) Aerial phase during recovery for healthy participant (top), and circumduction during recovery for TFPU participant (bottom).

Significance

This is the first study to quantify the prevalence of the aerial phase during healthy stumble recovery, and also the first study to analyze the recovery/falls of a TFPU across a range of swing phase perturbations with a physical obstacle to clear. The insights gained from both healthy and TFPU stumble recovery provide a roadmap for how to successfully design reflexes into a robotic lower-limb prosthesis in order to reduce fall incidence and subsequent injury for this TFPU population (300,000 in U.S. alone).

Acknowledgments

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References

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