Exoskeletons need to react faster than reflexes to improve standing balance

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Introduction

It is important for people to maintain balance as they perform activities of daily life. Failure to do so may cause harmful falls and lead to declining independence and quality of life. To improve human balance and mitigate fall-risk, researchers often propose interventions that enhance human biomechanics. A feasible way to improve user biomechanics is through the use of wearable assistive devices, such as exoskeletons. Exoskeletons typically act in parallel to user leg joints and can deliver balance-correcting torque following postural perturbations.

While exoskeletons have the potential to improve user balance in many situations, it remains unknown *how* these devices should deliver restoring torque following a perturbation. As people begin losing balance, the body's sensory receptors detect perturbations and spur corrective motor commands. Due to delays in the nervous system, reflexive responses take ~150 ms until restoring leg muscle forces of the balance correcting response are measurable (1). Exoskeletons can detect a perturbation and produce torque faster than the nervous system, but artificially fast torque production may disrupt important sensory information and impair the body's reactive response.

Accordingly, the goal of our study was to determine whether it is more effective for balance-improving exoskeletons to deliver assistive torque 1) faster than, or 2) coinciding with physiological time delays. Based on the notion that artificially fast exoskeleton torque would impair user reactive feedback response, we hypothesized that user standing balance capacity would be best when ankle exoskeletons produced plantar flexor torque at the same latency as the body's reactive postural response, versus artificially fast or no assistive torque conditions.

Methods

To test our hypothesis, we evaluated the standing balance capacity of ten participants across three different ankle exoskeleton conditions (Fast, Slow, Off). Specifically, participants tried to maintain standing balance without taking balance-correcting steps during backward support surface translations (Fig. 1). During these translations, we commanded the exoskeletons to detect perturbation onset using accelerometers and randomly perform one of the following actions: (Fast condition) produce a 30 Nm peak plantar flexor torque following a ~20 ms delay over a 50 ms rise-time followed by a decline in torque in 150 ms, (Slow condition) produce the same torque profile following an additional 100 ms delay after detecting perturbation onset, or (Off condition) maintain 1 Nm throughout the duration of the trial (Fig. 1). The magnitude of each support surface translation was updated for each trial using an adaptive Parameter Estimation algorithm (2). This algorithm continuously estimated the perturbation magnitude for each exoskeleton condition that elicited a 50% chance of the participant taking a step, which we termed 'Step Threshold' and used as our measure of balance capacity (3). We determined each participant and exoskeleton condition step threshold by fitting psychometric curves to the experimental data via maximum likelihood. We performed a repeated-measures ANOVA to test the influence of exoskeleton condition on step threshold.

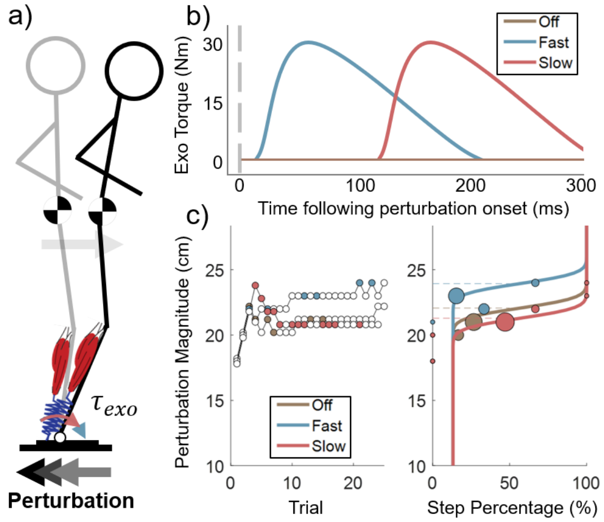

Figure 1. a) Depiction of a person experiencing a support-surface translation. b) Ankle exoskeleton torque (τ_{exo}) conditions. c) (left) Representative perturbation trials for a participant at each exoskeleton condition. Open and closed symbols indicate successful standing balance and stepping response per perturbation, respectively. (right) Psychometric curve fit for each exoskeleton condition, with symbol size proportional to number of trials at the indicated perturbation magnitude.

Results, Discussion, and Significance

The Fast exoskeleton condition improved step threshold 9% and 12% compared to the Off and Slow conditions, respectively (p=0.032. Average ± SD step threshold: Fast 25.4 ± 2.3 cm; Off 23.3 ± 2.4 cm; Slow 22.8 ± 2.4 cm) (Fig. 1). These data suggest that balance improving exoskeletons may be most effective if they can detect and correct postural disturbances faster than physiologically possible. Surprisingly, delivering plantar flexor torque at the same latency as postural reflexes did not improve participant step threshold compared to the Off condition, suggesting that exoskeletons controlled via physiological signals (*e.g.,* myoelectric control) may not improve user balance compared to the absence of an assistive device. Based on these data, we rejected our hypothesis stating that the Slow condition would yield the best user step threshold.

Moving forward we will assess neuromechanical data to propose mechanism(s) underlying our balance results. Perhaps the Fast condition is ideal because it quickly restores the person's center of pressure under their center of mass. Further, we are interested in the interplay of how artificially fast movements affect underlying muscle sensory receptors, and in turn the accompanying postural response.

Acknowledgments

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References

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