Effects of exoskeleton assistance in individuals with unilateral transtibial amputation

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Introduction

Unilateral transtibial amputation often leads to increased energy expenditure during gait, as well as larger ground reaction forces on the contralateral side [1, 2]. In turn, this causes a higher prevalence of joint pain and early onset osteoarthritis [3], negatively affecting mobility and reducing overall quality of life of individuals with impairment. Powered prostheses may help mitigate some of these issues (e.g. [4]), but the benefits of increased prosthesis work are uncertain [5]. Past research has largely focused on improving active prosthesis control and design, but it is possible that the potential benefits of active devices are limited by changes in motor learning post impairment [6]. The aim of this study was to identify if people with lower-limb amputation adapt to powered ankle exoskeleton assistance applied to their sound leg similarly to people without impairment. Specifically, we assessed changes in energy expenditure in users with impairment when walking with individualized assistance and no assistance at the ankle.

Methods

We evaluated the benefits of optimized exoskeleton assistance on energy expenditure in individuals with lower-limb amputation by implementing a controller optimization protocol previously shown to lead to an average 24% reduction in metabolic cost in users without impairment [7]. We used an experimental, tethered exoskeleton emulator device to provide plantarflexion assistance during stance (Figure 1A, [8]). To optimize exoskeleton assistance to each user, we used an optimization strategy that continually adapts to changes in user dynamics [7]. This human-in-the-loop approach relies on a standard optimization algorithm to reduce user energy expenditure by systematically updating four parameters that define the exoskeleton torque profile.

Five individuals with unilateral transtibial amputation participated in the study. Each participant walked with their prescribed prosthesis and with the exoskeleton worn on their sound limb. All participants completed 20 optimization bouts, performed over multiple days of testing, with each bout consisting of 8 optimizer-selected control profiles experienced by the user for 2 minutes each. This protocol was longer than in previous studies with unimpaired individuals in order to ensure the optimizer converged and users were fully acclimated to assistance. We performed separate validation trials after 4-6 optimization bouts and at the end of the experiment, measuring user energy expenditure during walking without the device, wearing the unpowered device (zero torque), and with the device providing optimized assistance (optimized).

Results and Discussion

The first evaluation of user energy expenditure in response to assistance occurred after 4-6 optimization bouts, or 1-1.5hrs of walking, and as dictated by participant fitness level. At this time, participants showed only a 3.6% reduction in net metabolic cost when walking with optimized assistance compared to walking with zero torque (2.63 and 2.73 W/kg, respectively; Figure 1B). In contrast, unimpaired users reduced energy cost on average by

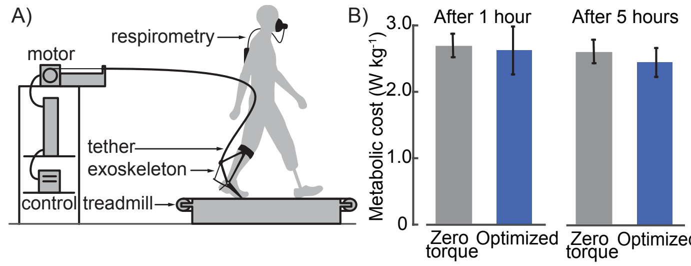

Figure 1: A) Exoskeleton emulator system, with the device worn on the sound limb of people with unilateral amputation. B) Average metabolic cost of users after approximately 1 and 5 hours of optimization, during the zero torque and optimized assistance conditions.

24% compared to walking with zero torque, and after only one hour of optimization [7]. Four participants with amputation completed 20 optimization bouts, or more than 5 hours of walking, and showed just a 5.8% reduction between conditions (2.43 and 2.58 W/kg, respectively). Energetic cost during the zero torque and normal walking conditions differed by less than 2%.

Such differences in metabolic cost reduction in response to assistance between impaired and unimpaired individuals imply that lower-limb amputation presents different motor learning challenges in the context of robotic assistance. In addition, these results further suggest that the benefits of powered prostheses could be significantly limited by learning and biomechanical restrictions caused by impairment. New user training and device assistance approaches are likely needed to significantly assist people with amputation.

Significance

The results of this study show that individuals with amputation adapt to assistive robotics differently from people without impairment. This is likely also true for individuals with other locomotor deficits, such as those following stroke, and advocates for further research into balance, coordination, and learning limitations caused by impairment. In addition, gait rehabilitation protocols post injury likely need to be reevaluated with the introduction of robotic assistive devices.

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References

[1] Gailey, R. *et al.* (1994). *Prosth. and Orth. Int.* **18**, 84-91.
[2] Powers, C.M. *et al.* (1994). *Arch. of Phys. Med. and Rehab.* **75**, 825–829.
[3] Hurwitz, D.E. *et al.* (2001). *Cells Tiss. Organs* **169**, 201–209.
[4] Grabowski, A.M. and D'Andrea, S. (2013). *J. of Neuro. and Rehab.* **10**, 49.
[5] Quesada R.E. *et al.* (2016). *J. of Biomech.* **49(14)**, 3452-3459.
[6] Sawers A. *et al.* (2012). *J. of Rehab. Res. and Dev.* **49(10)**. 1431-1442.
[7] Zhang, J. *et al.* (2017). *Science*. **356**, 1280-1284.
[8] Witte, K.A. *et al.* (2015). *IEEE ICRA*. 1223–1228.