How Training, Adaptation, and Customization Contribute to Exoskeleton Assistance

Katherine L. Poggensee[1] and Steven H. Collins[1]
[1]Department of Mechanical Engineering, Stanford University, Stanford, California, USA
Email: *ktpognc@stanford.edu

Introduction

Human-in-the-loop optimization (HILO) methods can be used to identify customized device parameters to best assist human walking [1]. One of the unique features of these methods is that while the algorithm is identifying the ideal parameters, the human is experiencing a range of possible candidate controllers. The long periods of exposure time as well as the variation in the experienced controllers have been suggested as possible reasons HILO can also be used as a training protocol.

We conducted an experiment to determine how training and customization affect exoskeleton performance. We hypothesize that the extended training will contribute the most to reductions in metabolic cost, while customization will provide additional benefit. We also expect a moderate amount of variation to result in better outcomes than static exposure to a fixed controller.

Methods

Naïve participants (N=15) were randomly sorted into three groups for a six-day protocol. The first day of testing served as a pre-test to determine performance with a generic assistance profile relative to baseline walking trials. On each subsequent day, participants experienced a group-specific adaptation trial for 74 minutes followed by short validation tests. One group (continued optimization) experienced HILO as in [1], where each day was a continuation from the previous day. Another group (static training) experienced the generic assistance for the duration of the adaptation block to decouple the effects of time on training. The final group (re-optimization) experienced HILO with a reset on each day to understand the effects of variation on learning. All groups experienced the generic assistance trial and baseline walking trials during the validation tests. The two optimization groups also experienced their optimized profiles from the end of the adaptation period.

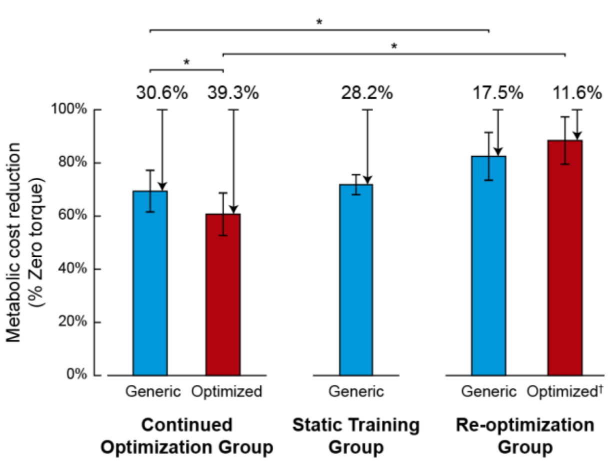

Figure 1: Metabolic costs of exoskeleton walking under different types of training, with respect to a zero torque condition. The optimized assistance for individuals in the continued optimization group resulted in the largest reduction in metabolic cost by any exoskeleton to date. The response to the generic condition was significantly worse for the re-optimization group compared to the continued optimization group, suggesting that too much variation can interfere with training.

Results and Discussion

Initially participants receive very little benefit from exoskeleton assistance, with 10.0±11.0% reduction in energy cost compared to walking in a zero torque condition. By the end of the experiment, the continued optimization group exhibits a 30.6±8.1% energy cost reduction in response to the generic profile and a reduction of 39.3±8.2% for the optimized profile, compared to the zero torque conditions. The latter result is the largest reduction in metabolic cost with an exoskeleton to date. In response to the generic profile, all participants learned to reduce their metabolic cost (Fig. 1).

Participants in the static training group reduced their energy cost by a statistically similar amount by the end of the experiment, though at a slower rate. This result indicates that some amount of variation may speed training. Participants in the re-optimization group were significantly worse at walking with the generic assistance by the end of the experiment than participants in the continued optimization group, indicating that there is a limit to the amount of beneficial variation training. Because this group was not properly trained, their customized profiles were less beneficial.

In addition to reducing the energy cost of walking, participants simultaneously reduced the mechanical power received from the ankle exoskeleton. This result is in contrast with the idea that increasing mechanical power should decrease the metabolic cost of walking with an assistive device.

These results illustrate the importance of training in exoskeleton studies. Customization can also increase the benefits of walking with an assistive device, provided that the user is properly trained. Previous exoskeleton failures may have actually been failures of training.

Significance

Exoskeletons can enhance human mobility, but we still know little about why they are effective. In this study, people learned how to use ankle exoskeletons through different training methods. Their performance was measured to understand the relative importance of training, human adaptation, and device customization. We found large benefits, reducing the energy cost of walking by 39%, of which about half was due to training and a quarter to customizing assistance. Training type had a strong effect on training time and expertise. Our results show that work to improve training could be more important than robot design for developing better gait aids.

Acknowledgments

This research is supported by the National Science Foundation Graduate Research Fellowship Program and National Science Foundation Award No. 1818749.

References

1. Zhang, et al. (2017) *Science* **356**(6344): 1280 – 1284.