Exploring the relative contributions to reduced metabolic cost with an ankle exoskeleton

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Summary

Human-in-the-loop optimization is an effective method for identifying parameters to decrease the energy cost of walking with an assistive device. Current methods use an estimate of the metabolic energy expenditure for each set of parameters and a black-box optimization algorithm to determine optimal parameters. Participants show improved performance in both their customized assistance profiles and a static profile. We are conducting an experiment to characterize potential contributors to the success of the algorithms, including the emergence of a universally beneficial assistance strategy, co-adaptation of the user during the optimization, and the customization of the device parameters. Preliminary tests suggested that co-adaptation is the most important factor for naive participants, so we have included experiments to decouple aspects of training, such as time, random sampling, and convergence of the parameters. Participants who have continually optimized parameters for six days yielded the largest reductions in metabolic energy expenditure for all groups tested.

Introduction

Human-in-the-loop optimization (HILO) algorithms have resulted in large reduction in metabolic energy expenditure in exoskeleton users [1]. This study, in particular, posed three hypotheses suggesting the success of HILO may come from the emergence of a good generic assistance profile, facilitating learning, and customization of the parameters.

We are performing an experiment to determine the relative contributions of these factors. We have further refined the questions to characterize different aspects of HILO as a training regimen, including exposure time, randomness in the sampling of controllers, and convergence of the parameters.

Methods

The experimental protocol was expanded from our previous HILO study [1] and is illustrated in the **Figure**. Naive participants were recruited for a six-day experiment. The first day serves as a pre-validation test and for the remaining days, participants are exposed to an adaptation block followed by validation trials.

The content of the adaptation block is determined by random assignment to one of three groups: static assistance, continued optimization, or re-optimization. The static assistance group experiences a static profile for the entirety of the adaptation block. Because their optimized assistance is not calculated, they experience three validation conditions: no exoskeleton, exoskeleton without assistance, and a static assistance profile. This profile was determined through pilot testing. Both the continued optimization and re-optimization groups experience HILO during the adaptation block. For the re-optimization group, the HILO seed is the same on each testing day, while for the continued optimization group, the seed on each day continues optimization from the previous day. Both groups experience the same validation as the static assistance group with added optimization trials: the optimized profile from the first adaptation day, i.e., after four generations, and the optimized profile from that day.

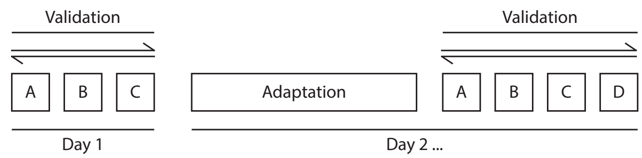

Figure: Experimental protocol. Each validation trial is six minutes in length, and the adaptation block is a 74-minute trial with beeps every two minutes indicating a possible change in assistance. Participants experience either a static assistance profile or HILO during the adaptation block.

By comparing the validation trials across the experiment, we can determine the relative contributions of HILO to reduced energy cost. Performance in the static assistance profiles indicates the emergence of a generally good assistance strategy. Comparison between these trials across days shows the progression of training. The optimal parameter trials demonstrate the importance of customization and, in the re-optimization group, how those parameters change over time.

Results and Discussion

Six participants have completed the protocol. We have found that training is an important factor in effectively using an assistive device. Time appears to be a significant factor in learning a static profile, but larger benefits can be achieved with optimized parameters. Continuing optimization over multiple days yields greater reductions than starting with the same initial seed. This may be due to the convergent nature of the randomly sampled parameters or may result from a more precise estimate of the customized profile. We hope to finish experiments this spring.

Acknowledgments

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References

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