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Abstract title	**Exploring the relative contributions to reduced metabolic energy expenditure with an ankle exoskeleton**
Biography	**Katherine Poggensee is a Ph.D. student at Stanford University in the Biomechatronics Lab. She is interested in co-adaptation in human-robot systems, with a specific focus on ankle exoskeletons.**

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Abstract text

Introduction

Exoskeleton assistance has rapidly improved in the last decade. Insights from biomechanical models and observations led to broad assistance strategies which reduced the energy cost of walking [1], [2]. While these devices showed modest improvement in energy economy, they did not exploit the inherent variability of the human-robot system.

Human-in-the-loop optimization (HILO) uses black-box optimization algorithms and a rapid estimate of metabolic energy expenditure to identify individualized assistance patterns, resulting in the largest reduction in energy expenditure to date [3], [4]. These participants also exhibited better performance on generalized assistance strategies, suggesting that HILO could also be an effective training regimen.

Customization, training or adaptation, and the discovery of a good general assistance profile were proposed in the original study as major contributors to the reduction in energy cost but were not rigorously tested. With this experiment, we sought to determine the relative contributions of these aspects.

Research Question

What are the relative contributions of customization, adaptation, and a good generic assistance pattern to the reduced energy cost of walking with an ankle exoskeleton? Do protocols of similar time and variety of assistance profiles provide the same level of training as human-in-the-loop optimization?

Methods

Naive participants (N=8, 1 ongoing) were sorted into three groups (continued optimization, static, and re-optimization). Participants wore bilateral ankle exoskeletons that assist in plantarflexion. On the first day, all groups completed six-minute validation tests of a static profile and baseline walking trials. For each subsequent day, participants experienced a 74-minute adaptation trial, followed by validation tests.

The static group experienced the static profile for the entire adaptation trial, followed by the same validation tests as the first day. The two optimization groups experienced HILO as described in [3]. The optimization seed was either reset on each day (re-optimization) or continued from the day before (continued optimization). In addition to the static group validation trials, these participants also walked with the optimized assistance profiles from that day. Metabolic cost, electromyography, motion capture, and ground reaction forces were collected for all trials.

Results

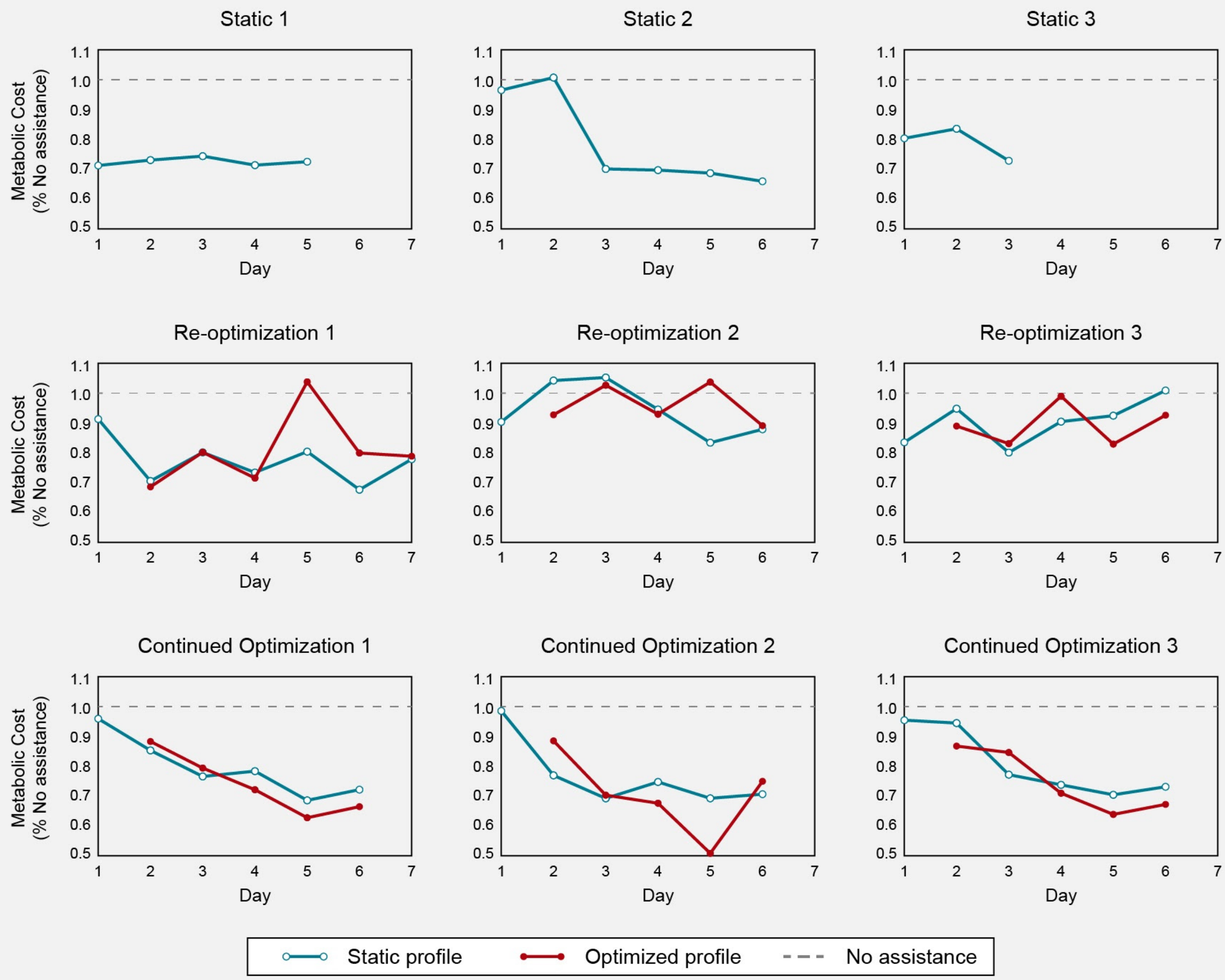

Figure 1. Metabolic cost of generalized assistance and optimal assistance validation trials for each participant on each day as a percentage of the no assistance trials. Participants were randomly assigned to one of three groups. The static group experienced a generalized assistance profile for 74 minutes on each day before experiencing validation tests of that same profile. Because they did not experience optimization, they do not have an optimized assistance profile. Participants in the re-optimization group experienced HILO with a constant seed at the beginning of each day. The optimized profiles were optimized over four generations. Participants in the continued optimization group experienced HILO with a seed determined by the prior day. Their optimized profiles are determined after four, eight, twelve, etc. generations. The generalized assistance trials are shown in blue, and the optimized assistance trials are in red. The dotted gray line indicates the cost of the no assistance trial.

Picture 1 - "Results"

Performance in the static assistance profile converged by the fifth day (26.2±6.5% metabolic reduction compared to the device applying no assistance). Reseeding the optimization may interfere with training and does not appear to identify optimal controllers, which can take several days to discover.

Discussion

Due to the complex nature of walking with bilateral ankle exoskeletons, we have found that prolonged training is necessary to see the greatest benefits in using the device. While time is a significant factor, optimization is also an effective training method, particularly as the sampled profiles converge over multiple days. Further analysis will be done to determine how to most efficiently train participants to fully benefit from exoskeleton assistance.

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