# Understanding the Mechanisms behind Human-in-the-Loop Optimization Strategies

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## 1 Introduction

While exoskeleton assistance strategies have been explored for decades, devices that can reduce the metabolic cost of walking are relatively new [1]. Many of the current strategies use autonomous hardware and controllers specific to the hardware rather than the subject. Our lab uses an emulator system with lightweight end-effectors [2] and off-board motors and control hardware [3]. With this hardware, we can test a wide variety of control strategies over the course of a single experiment and can customize the assistance to the user.

Customization can be achieved through different protocols. Hand-tuning or parameter sweeps [4] will give an idea of helpful assistance strategies, subject to the step size of the parameters. Body-in-the-loop strategies [5] measure human output and adjust device parameters in response.

## 2 Human-in-the-Loop Optimization Strategy: CMA-ES

We have shown success of a human-in-the-loop optimization strategy that determines customized assistance torque profiles which decrease the metabolic cost of walking [6]. Subjects walked with a unilateral ankle exoskeleton and experienced different control strategies which were optimized using an evolutionary algorithm called Covariance Matrix Adaptation Evolution Strategy (CMA-ES). For a predetermined parameterization of the space of possible controllers, several controllers are sampled in a single "generation" and are applied to the user. Metabolic measurements are estimated after two minutes [7] and are used to determine a rank ordering of the different controllers. This order is then used to define a new distribution of the control space, from which the next generation is sampled. After an hour of walking, subjects undergo validation trials to determine the metabolic cost of walking with the optimized assistance relative to a zero torque mode and a static controller [4]. The metabolic reductions in this study are the largest to date.

## 3 Understanding the Success of CMA-ES

We hypothesize that there are three main contributors to the success of our human-in-the-loop optimization scheme. The participant is first subjected to a wide range of control trajectories, which may be far from the optimized trajectory. The optimization algorithm then converges on an optimized trajectory. The optimized trajectories varied between subjects, suggesting a benefit from customization of the controller. The torque profiles for all of the subjects in this experiment converged to large peak torques, which indicates that there is a general benefit from large assistive torques. Thus, there are contributions from generalized assistance from the device, the customization of the optimized trajectory, and the initial generation which exposes the subject to a wide range of control strategies.

We propose an experiment to understand the roles of learning and customization in the optimization procedure. Subjects with no exposure to walking with an exoskeleton will first walk in the validation conditions of the original study: walking with normal shoes, walking with the exoskeleton on the user but with zero torque, and walking with the average assistance. Each subject will then undergo the optimization as in the prior experiment and will repeat the validation with the customized assistance as another condition.

The comparison between the average assistance before and after the optimization protocol will allow us to understand the effect of the optimization on the adaptation of the user. The comparison between the average control and the customized control will then lend insight into the role of customization of the assistance strategy. We are beginning tests soon and hope to have interesting results to discuss at the conference this summer.

## References

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