Human-in-the-loop optimization of ankle exoskeleton assistance for one individual with chronic stroke

Thu Nguyen[1*] and Steven Collins[1]

I. SUMMARY

The purpose of this study was to use human-in-the-loop optimization to find an optimal ankle exoskeleton assistance profile that decreased the metabolic cost of walking in an individual with chronic stroke with the exoskeleton assisting the paretic limb. The participant with chronic stroke selected for this study had gait impairments but was nonspastic and could walk unassisted. The participant walked in three generations of optimization followed by validation. The participant had a 5% energy reduction with the optimal controller compared to walking with the device applying no assistance. However, the participant did not effectively use the device and had reduced knee flexion. Future work will involve biofeedback to help with training. We are also currently building a knee ankle exoskeleton emulator to assist knee flexion and extension, plantarflexion, and dorsiflexion.

II. INTRODUCTION

Human-in-the-loop optimization using an ankle exoskeleton emulator has been shown to decrease metabolic energy consumption by about 24% compared to wearing the device without assistance [1]. A similar optimization strategy could also be beneficial for individuals with chronic stroke. The goal of this study was to adapt the existing exoskeleton emulator hardware and optimization algorithm to assist one individual post-stroke. We hypothesized that human-in-the-loop optimization using covariance matrix adaptation evolution strategy would be able to find an individualized exoskeleton controller that would significantly decrease the energy cost of walking for an individual with chronic stroke.

III. METHODS

One individual with chronic stroke and hemiparesis walked on a treadmill at a self-selected speed wearing an ankle exoskeleton emulator on the paretic leg while the optimizer worked to find an optimal assistance profile. The participant was nonspastic and was able to walk unassisted but had a slow and asymmetric gait.

A. Hardware and software modifications

Passive dorsiflexion assistance was added to the existing device by adding springs in parallel between the foot and shank such that the participant's foot was approximately parallel to the ground when relaxed.

New software bounds on torque timing and amplitude were found for the participant to ensure safety during optimization. To find the bounds, torque amplitude and timing parameters were swept for the upper and lower bounds until the participant felt unstable.

B. Experimental protocol

On the first day, the participant experienced treadmill and exoskeleton familiarization at his maximum sustainable walking speed. After acclimation, the software bounds were found. The participant's heart rate and respiratory exchange ratio were measured throughout all trials to ensure safety.

Human-in-the-loop optimization was conducted to find the optimal torque control law. The participant walked in the optimizer for four days total. For the first two days, the participant completed four generations of optimization. Additional training and forced exploration occurred on the third day to improve the participant's ability to effectively use the exoskeleton, and optimization was restarted. The participant completed three generations of optimization and a validation test over the last two days.

IV. RESULTS

The participant had a 5% energy reduction walking with the optimal controller compared to walking with the device applying no assistance. Because of the noise in metabolic data, energy reductions were not statistically evaluated.

V. DISCUSSION

The participant did not appear to have voluntary control over knee flexion which is normally coupled with plantarflexion during ankle push-off. Because the participant had reduced knee flexion, applying greater plantarflexion torque did not increase his plantarflexion angle, so push-off power remained low. The participant also prematurely shifted his center of mass to over his nonparetic leg during push-off of his paretic leg. His center of mass, therefore, was not optimally propelled forward with ankle push-off, so energy reductions were minimal. To achieve greater energy cost reductions, we believe we need to train the participant to more efficiently use the device and to assist knee flexion.

VI. FUTURE WORK

We will implement various biofeedback scenarios to better train participants. We are also currently building a knee ankle exoskeleton emulator to assist in knee flexion and extension, plantarflexion, and dorsiflexion.

VII. REFERENCES

[1] Zhang J et al. (2017). *Science*, **356(6344)**: 12801284

[1] Department of Mechanical Engineering, Stanford University
* Corresponding author: tmn33@stanford.edu