ADAPTIVE GAIN FOR PROPORTIONAL MYOELECTRIC CONTROL OF A ROBOTIC ANKLE EXOSKELETON DURING HUMAN WALKING

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INTRODUCTION

There exists a large disconnect between the natural fluid motion of unconstrained human walking and the unnatural, rigid motion of human walking with a robotic exoskeleton. This unnatural movement of walking in a robotic exoskeleton is largely due to poor controller design and can make the motion energetically inefficient for the user [1]. Our research group has been developing techniques to use neural signals from the wearer to directly control exoskeleton actuation timing and amplitude. By using neural signals to control the device we are attempting to alleviate the issues that come with relying on intrinsic mechanical measurements for exoskeleton control.

In our work, we use electromyography (EMG) to directly control walking robotic exoskeletons. In the past, these controllers created a control signal for actuation by using a *constant* mapping gain to map the EMG linear envelope to an actuation voltage. This constant mapping gain was hand tuned by the researcher. The researcher would tune the gain such that it mapped the peak EMG linear envelope during walking to the saturation voltage of the actuators. We call this max-to-max mapping the calibration mapping gain. The researcher would then scale the calibration mapping gain by 2.0 to encourage a reduction in the user's own muscle recruitment [2]. Because of this scaling, subjects were forced to adapt to walking with a peak muscle recruitment 50% lower than their normal walking muscle recruitment in order to achieve an unsaturated control signal. This technique has resulted in large reductions in metabolic cost; however, the constant mapping gain could be a limiting factor of the controller.

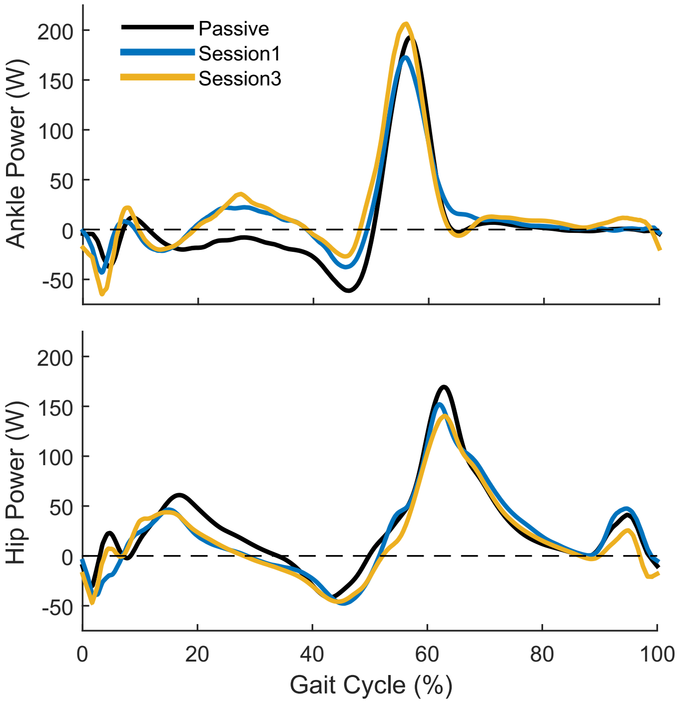

Figure 1: Subjects chose to use more ankle power at the ankle in order to reduce their effort at the hip. Data representing Session 1 and Session 3 were collections that occurred at the end of the powered walking portion of the corresponding testing days.

The constant gain constrained the way the user walked in previous ankle exoskeleton studies from our lab. The 2.0 scaling of the calibration gain led to a muscle recruitment of the user that may not reflect their preferred manner to walk with the exoskeleton. To overcome this limitation, we developed an EMG based control scheme that frees this mapping gain to *dynamically* adapt to the user as the user adapts to the device. This allows the wearer to use whatever muscle recruitment level they see fit while still receiving maximum unsaturated actuation from the device. By doing so, our adaptive controller refrains from constraining the user to specific dynamics at the ankle. This controller allows us to study what amount of ankle power is preferred by subjects during walking with a robotic exoskeleton. We hypothesized that subjects would learn to co-adapt with the device in order to achieve a metabolic reduction.

METHODS

For this study, we designed and built a simple one degree of freedom robotic ankle exoskeleton (2.09 kg). The exoskeleton used artificial pneumatic muscles to assist with plantar flexion and was controlled by an off board real-time processor. We used EMG from the user's soleus to control actuation.

Our controller processed the raw EMG to get the signal's linear envelope and then conducted a real-time max search of the linear envelope on a stride by stride basis. The detected maximum of each stride was added to a moving average of the previous fifty strides. Our controller then calculated the mapping gain necessary for this moving average to map to a desired maximum actuator voltage. The controller then updated the mapping gain after every stride. In other words, the exoskeleton always operated at its maximal power output while subjects were able to alter the amount of their own soleus recruitment; thereby adjusting the amount of total ankle power.

We tested three subjects (male, 19.3 ± .7 years, 70.8 ± 3.7 kg, 182.0 ± 6.6 cm; means ± s.e.m.) during treadmill walking at 1.2 m s^{-1}. All subjects walked in the device continuously for 50 minutes on three separate training days. Each training day was identical and consisted of 10 minutes of unpowered (passive) walking, 30 minutes of powered (active) walking, followed by 10 minutes of unpowered walking. We collected electromyography, metabolic, kinematic, and kinetic data across all sessions. All joint kinematics and dynamics were processed in OpenSim.

RESULTS AND DISCUSSION

We found that by the end of the third session, our adaptive controller had choosen gains that were a 1.76 ± 0.24 (mean ± s.e.m.) scaling of the would be calibration mapping gain. Previous studies used a constant scaling factor of 2.0. The scaling results show that subjects opted to use higher peak soleus activity than what was enforced in previous studies with a static mapping gain.

Table 1: Results percent change relative to passive conditions (mean ± s.e.m.)

Measurement	Session 1	Session 3
Peak Ankle Power	-15.8±8.0%	4.9±8.9%
Peak Hip Power	-8.5±9.3%	-12.2±1.0%
Metabolic Cost	-19.0±6.7%	-24.6±1.8%

Additionally, subjects chose to increase their peak ankle power across training days when using the adaptive controller. This increase in ankle power was coupled with a decrease in hip power (Figure 1 & Table 1). Because our adaptive controller did not constrain subjects to walk in any specified manner, this trade off between ankle and hip dynamics was discovered by subjects voluntarily. This trade off seen between ankle and hip dynamics is supported by the work of Lewis et al. [3]. We believe subjects adapted to these joint dynamics for their energetic benefits due to the metabolic reduction seen across training days. The energetic benefits from actuating the ankle as opposed to the hip has been shown in simulation by Kuo [4] and supports our findings.

Our results suggest that subjects voluntarily increased effort at the ankle in order to reduce effort at the hip. This finding opens an interesting discussion as to what is the best way of providing assistance to the human gait. Should we be employing similar strategies to intrinsically controlled exoskeletons or prosthesis as opposed to replicating 'normal' joint dynamics?

REFERENCES

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