Exploring Effects of Artificial Gastrocnemius on Persons with Transtibial Amputation Using a Powered Ankle Prosthesis

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Summary

The objective of this study is to restore a gastrocnemius-like ankle-knee coupling to individuals with lower limb amputation (ILLA), then 1) characterize how different gastrocnemius dynamics (e.g., stiffnesses) affect whole-body gait biomechanics and 2) explore which gastrocnemius behaviors are most beneficial. We have developed a custom-modified robotic emulator system and validated that our system is capable of simulating a broad range of artificial gastrocnemius and powered ankle prosthesis behaviors. Our first set of experiments is getting underway. We will test unilateral, transtibial ILLA while we sweep across a range of stiffness values for a passive artificial gastrocnemius, and also sweep across different ankle prosthesis behaviors (e.g., magnitudes of net work during push-off). At the conference we will summarize robotic hardware development and validation to date, as well as the latest human subject results.

Introduction

Powered prosthetic ankles have been developed that can restore the monoarticular function of the soleus muscle, one of the main contributors to ankle plantarflexion push-off during walking. However, the benefits observed from powered ankles (e.g., magnitude of metabolic cost reduction) have often been less than those theorized/expected [1], [2].

One potential explanation is that powered ankles do not restore the biarticular function of the gastrocnemius, which provides a mechanical coupling across the ankle and knee, and also contributes to plantarflexion push-off. Simulation [3] and experimental [4] studies find that restoring the gastrocnemius may improve walking performance above and beyond restoring soleus function alone. For instance, preliminary experiments found that some ILLA on powered ankles demonstrated large metabolic reductions when gastrocnemius function was restored [4]. However, systematically varying gastrocnemius stiffness has not yet been tested experimentally.

The objective of our study is to fill this knowledge gap by using a robotic emulator to systematically vary the stiffness of an artificial gastrocnemius worn by ILLA and quantify how this affects gait biomechanics, particularly push-off dynamics when a burst of power is transferred from the device to user.

Methods

To study the role of the gastrocnemius we are using a robotic emulation system (HuMoTech) that we customized to include: a soleus actuator (to emulate the powered ankle prosthesis), a separate gastrocnemius actuator (to vary behaviour of the ankle-knee coupling), a soft conformal leg interface (which attaches to the user's thigh to provide an anchor point for the gastrocnemius), and a foot prosthesis (a modified version of HuMoTech's standard prosthesis hardware). We have developed a controller that can command the artificial soleus and gastrocnemius in a repeatable, accurate, and precise manner. As subjects walk, we can independently control the dynamics of the soleus and gastrocnemius, in order to systematically analyze how different parameters affect gait.

The experimental setup also consists of the following measurement systems: a force-instrumented treadmill (Bertec) to measure ground reaction forces, a motion capture system (Vicon) to measure kinematics, and an electromyography system (Delsys), to measure muscle activity. Multi-subject testing on ILLA is now getting underway, in which we will systematically test a range of gastrocnemius stiffnesses. The latest human subject results will be presented at ISB/ASB.

Results and Discussion

We have verified the controller's ability to emulate different gastrocnemius spring stiffness profiles during walking. Fig 1. shows average pilot data that yields an RMS error of 2.4 N between the measured and target forces during stance phase of walking, with minimal resistance/interference during swing.

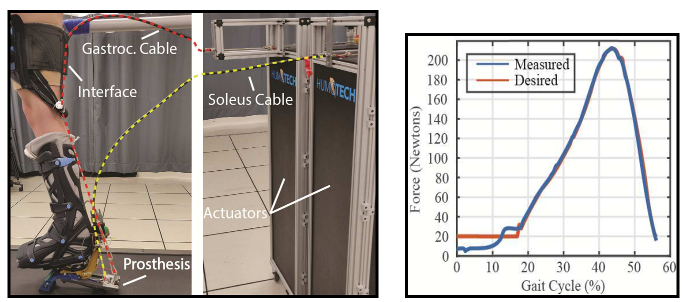

Figure 1: Experimental Set-up (left), Stiffness Emulation (right).

Conclusions

We have developed hardware and control software to emulate both the monoarticular and biarticular actions of the ankle plantarflexors. This system will enable us to sweep across a broad set of stiffness and work parameters to gain new insight into how the gastrocnemius ankle-knee coupling dynamics affect the gait of ILLA walking on powered ankle prostheses.

Acknowledgments

We would like to thank Dr. Michael Goldfarb and Dr. Steve Collins for their insight and advice during this project. This research was supported by funds from NSF grant 1705714.

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