

## MECHANICAL PERFORMANCE OF ARTIFICIAL PNEUMATIC MUSCLES TO POWER AN ANKLE-FOOT ORTHOSIS

<sup>1</sup>Keith E. Gordon, <sup>1,3</sup>Gregory S. Sawicki and <sup>1,2</sup>Daniel P. Ferris  
<sup>1</sup>Departments of Movement Science, <sup>2</sup>Biomedical Engineering, <sup>3</sup>Mechanical Engineering  
University of Michigan, Ann Arbor, MI; email: [kegordon@umich.edu](mailto:kegordon@umich.edu)

### INTRODUCTION

A powered ankle-foot orthosis could be very useful for investigating neuromechanical control of human locomotion. Plantar flexor muscles are critical to the generation of forward velocity and support of the center of mass during human walking. The purpose of this study was to quantify the mechanical performance of a pneumatically powered ankle-foot orthosis that assists plantar flexion during the stance phase of walking.

### METHODS

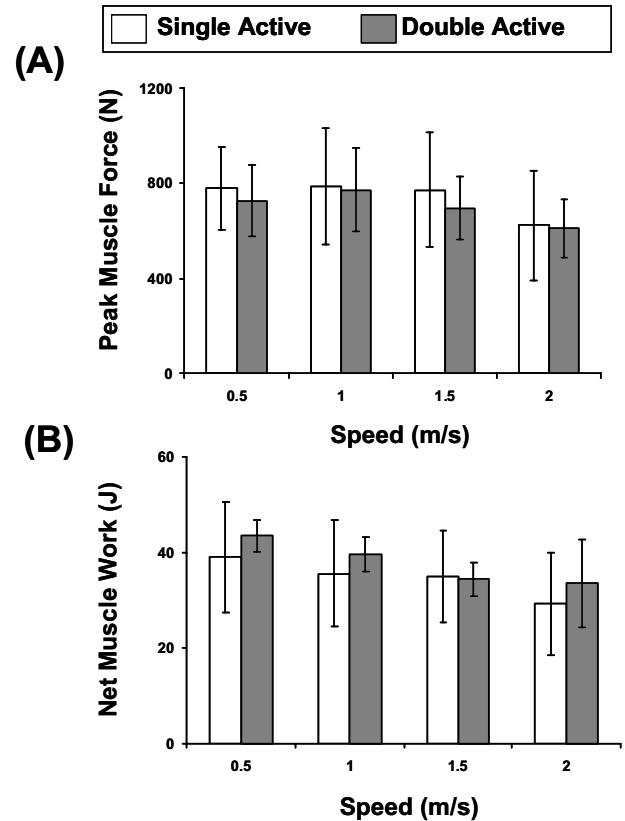
Three subjects walked at a range of speeds (0.5-2.0 m/s) wearing a unilateral ankle-foot orthosis (~1.5 kg) with either one or two artificial muscles working in parallel (Figure 1). Foot switches on the ball of the foot activated the artificial pneumatic muscles (6.2 bar) using on-off control. We hypothesized that two artificial muscles would provide greater torque and mechanical work than one artificial muscle.



**Figure 1: Powered Ankle-Foot Orthosis.** Left) Orthosis fit with a single artificial muscle. Right) Orthosis fit with two parallel artificial muscles to provide plantar flexor torque.

### RESULTS AND DISCUSSION

Contrary to our hypothesis, the orthosis produced similar total plantar flexor torque and net work independent of the number of artificial muscles (Figure 2). The orthosis generated 57% of the peak ankle plantar flexor torque during stance and performed ~80% of the positive plantar flexor work done during normal walking. The similarity in torque and work between single and double muscle conditions can be explained by the artificial muscle force-length properties. Peak artificial muscle force will decrease linearly as artificial muscle length decreases during contraction. Subjects altered their ankle kinematics between single and double muscle conditions. During the double muscle condition subjects increased plantar



**Figure 2:** A) Peak artificial muscle force (mean  $\pm$  s.d.). B) Net artificial muscle work (mean  $\pm$  s.d.). Double muscle data is the sum of both muscles.

flexion resulting in shorter artificial muscles lengths. At shorter artificial muscle lengths, the peak artificial muscle force was less.

Positive work performed by the orthosis on the ankle joint (torque-angle) was about 29% less than work performed by the artificial muscles (force-length). Compliance in the muscle attachment brackets and orthosis shell resulted in the artificial muscles shortening without concomitant changes in joint angle.

### CONCLUSIONS

These findings emphasize the importance of human testing in the design and development of robotic exoskeleton devices for assisting human movement. In this study, subjects modified their joint kinematics when walking with the powered orthosis, resulting in similar joint kinetics between conditions.

### ACKNOWLEDGEMENTS

Supported by NIH R01NS045486 and NSF BES-0347479.