A Bio-Robotic Framework for Rapid Prototyping and Testing of Exoskeletons Assisting Compliant Muscle-Tendon Systems

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1 Motivation

Current methods of developing effective robotic exoskeletons are limited by time consuming prototype fabrication, minimal understanding of effects on underlying neuromuscular systems, and the role that variations in limb/muscle physiology between individuals may play in design optimization. There is a need for an experimental framework that facilitates rapid implementation of actuation strategies, direct measurement of variations in muscle-level mechanics, and flexibility in physiological/inertial constraints. This is especially important for assisting joints that are influenced by dynamic inertial loading and series elastic recoil in a muscle-tendon unit (e.g. ankle) as part of functional and efficient movement.

2 State of the Art

There is currently a framework for rapid prototyping of exoskeleton actuation strategies [1]. However, functional imaging methods that allow direct measures of neuromuscular mechanics have not yet been integrated into these approaches [2]. Simple musculoskeletal models provide some insight, but cannot fully encompass the complexity of biological actuators [3]. Previously developed bio-robotic systems allow for direct measurement of muscle level mechanics, but are limited by the inability to interact with a dynamic inertial load, and rely on imposed trajectories [4].

3 Our Approach

We have developed a bio-robotic system that allows for direct measurement of muscle level mechanics in a compliant muscle-tendon system while interacting with a dynamic inertial load [5]. We use the plantaris-Achilles tendon from the bullfrog *Rana Catesbeiana*, which scales well to the human triceps surae-Achilles tendon complex. The plantaris muscle is instrumented with sono-micrometry crystals to take direct measurements of muscle trajectories. Muscular contraction is governed via direct electrical interface with the intact sciatic nerve. A dynamic inertial environment is simulated via a feedback controlled servo motor directly coupled with the series Achilles tendon (**fig. 1a**). Motor controllers are designed to mimic dynamic inertial loads from [6], with mechanics scaled to illicit a passive frequency response similar to those predicted from human studies [6].

4 Current Results

We can vary both the inertial environment and nerve stimulation parameters to generate muscle tendon mechanics comparable to those observed in functional human movement (**fig. 1b**). With this emergent behavior established, we are poised to implement any number of actuation strategies along with our “virtual load” to examine the interplay of exoskeleton assistance and muscle level mechanics.

5 Best Possible Outcome

We anticipate that this experimental preparation will allow for implementation and optimization of robotic assistive strategies in a rapid and physiologically meaningful way. The ability to scale and manipulate our inertial environment allows us to investigate the role that these factors may play in further optimizing exoskeleton design. Finally, real time measurements of muscle force, length, and velocity, in conjunction with our ability to modulate neural signals in real time, allow for investigation of the role that neuromechanical reflexes plays in adaptation to a wearable robotic device.

7 Citations

[1] Eicholtz et al. 2012 *Proc. Am. Soc. Biomech.*
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[4] Josephson. 1999 *J. Exp. Biol.*
[5] Richards et. al. 2012 *Proc. Dynamic Walking*
[6] Robertson et. al. (In Review) *J. Theor. Biol.*