Spring stiffness affects energy cost during walking with a clutched ankle-foot orthosis

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1 Motivation

Wearable robots are a promising approach to augment healthy or restore impaired locomotion in humans [1]. However current devices drastically increase the user's energy cost to move, in some cases by as much as 40% [2]. The ankle plantar flexors provide the majority of the mechanical work for the step-to-step transition and much of this work is delivered via elastic recoil from the Achilles' tendon - making it highly efficient. Even though the plantar flexors play a central role in propulsion, body-weight support and swing initiation during walking, very few assistive devices have focused on aiding ankle plantarflexion. Our goal was to develop a portable, passive ankle exoskeleton taking inspiration from the passive elastic mechanisms at play in the human triceps surae-Achilles' tendon complex during walking.

2 State of the Art

The challenge was to use parallel springs to provide ankle joint mechanical assistance during stance phase but allow free ankle rotation during swing phase. To do this we developed a novel 'smart-clutch' that can engage and disengage a parallel spring based only on ankle kinematic state. The system is purely passive - containing no motors, electronics or external power supply. This 'energy-neutral' ankle exoskeleton could not only be used to restore symmetry and reduce metabolic energy expenditure of walking in populations with weak ankle plantar flexors (e.g. stroke, spinal cord injury, normal aging), but may benefit to healthy populations as well.

3 Own Approach

We aim to significantly reduce the metabolic cost of walking by reducing the forces on the triceps surae muscles during the stance phase. We conducted a study to determine the relationship between parallel spring stiffness and metabolic rate during walking with the passive elastic exoskeleton. We hypothesized that there would be an intermediate (i.e. optimal) exoskeletal spring stiffness yielding maximum metabolic benefit during assisted walking at 1.25 m/s.

4 Current Results

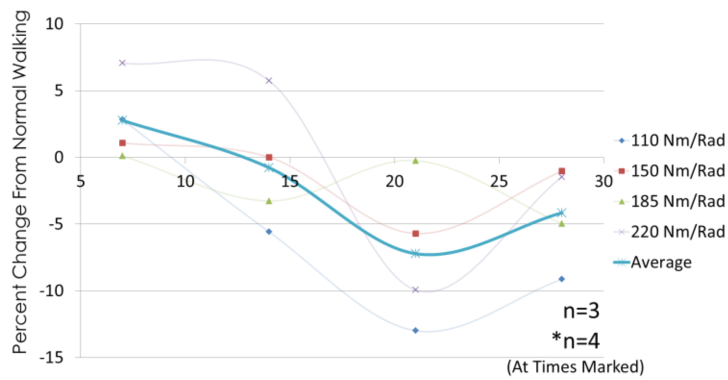

Fig. 1: Metabolic Adaptation: Stiffness vs. Time (min)

Study participants were asked to walk in the exoskeletons after a training period of 21 minutes with 5 different springs ranging from approximately 35-75% normal ankle joint stiffness at 1.25 m/s. The added mass cost of the ultra-light exoskeleton was ~2.7% and the metabolic cost was reduced on average by 6.7% below normal walking

5 Best Possible Results

We plan to determine the spring parameters necessary to extend these metabolic reductions to different gaits and locomotion contexts such as walking or running at different speeds and gradients. On the design side, we are developing and electromechanical clutch that can respond to the user's muscle activation to engage the clutch. Finally, we are using ultrasound imaging to understand the mechanism behind metabolic reductions (i.e. is it primarily muscle force or work?)

Acknowledgments

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References:

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