A SELF-ALIGNING PASSIVE ANKLE EXOSKELETON TO REDUCE TRICEPS SURAE LOAD IN WALKING

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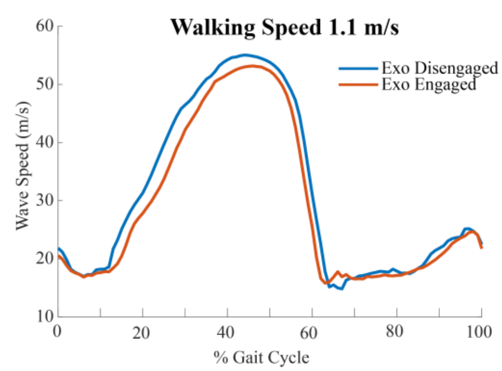
Introduction: The triceps surae generate significant force during the push-off phase of walking. Passive ankle exoskeletons and ankle-foot orthoses have been introduced that can offload the triceps surae by storing energy during mid-stance and releasing that energy during push-off. For example, Collins et al. showed that a clutched passive exoskeleton that utilizes a spring acting in parallel with the triceps surae can reduce the metabolic cost of human walking [1]. One challenge with a parallel spring approach is that it requires a calf interface for proximal spring attachment which must be secure enough to prevent slip during walking. This can be achieved using a carbon fiber shank frame [1] or a tightfitting calf wrap [2]. However, the rigid frame approach can require a customized fit to an individual, and a calf wrap can be uncomfortable given the high shear forces at the skin-interface that are needed to prevent slipping due to the longitudinal spring force. These challenges can be potentially mitigated by changing the direction that the force acts on the shank attachment and using a self-aligning mechanism. Sarkisian et al. [3] introduced such a self-aligning interface to improve performance and comfort in active hip exoskeletons. With a redesigned ankle exoskeleton that creates forces normal to the shank instead of axially, slipping of the calf interface can be prevented and discomfort can be reduced. As a result, the objective of this research was to design and test a self-aligning passive ankle exoskeleton that has capacity to offload the triceps surae during steady-state walking.

Methods: The passive exoskeleton uses a carbon fiber bar to store and release energy during gait (Fig. 1a). The bar pivots about a hinge point that rigidly extends from the shoe and is positioned posterior to the ankle. Translation of the distal end of the bar is constrained posteriorly by an adjustable backstop on a heel attachment to the shoe. The proximal end of the bar is constrained to flex posteriorly against a roller at the calf interface while being free to translate vertically along it. As a result, the bar undergoes flexural bending during dorsiflexion and thus generates a plantarflexion torque about the ankle. To evaluate how the exoskeleton altered triceps surae loading, a shear wave tensiometer [4] was secured over the right Achilles tendon of two subjects. Tendon wave speeds were recorded for 10 seconds when walking with and without the exoskeleton engaged at speeds ranging from 0.9 to 1.8 m/s on a treadmill.

(a)



(b)

Figure 1: a) Self-aligning passive ankle exoskeleton. b) Representative walking trial in which the Achilles tendon wave speed is diminished during stance when the exoskeleton is engaged, reflecting a reduction in tendon loading.

Results & Discussion: When compared to the no exoskeleton condition, Achilles tendon wave speeds were diminished during the mid- and early terminal stance phases of walking, particularly at the slower walking speeds (Fig. 1b). As a result, integrated squared wave speeds over the gait cycle were substantially lower (reduced by 11-23 %) in the engaged exoskeleton condition, when compared to the unengaged condition at slow (0.9-1.1 m/s) walking speeds. Exoskeleton effects on integrated wave speeds at higher walking speeds (1.3-1.8 m/s) were modest and less consistent (reduced by 0-14%). These results suggest it may be feasible to use a self-aligning ankle exoskeleton to offload the triceps surae during the stance phase of walking. To accomplish this, the device seems to generate a sufficient amount of force to aid in heel-off and provide some amount of propulsion during steady-state walking. Further study is needed to ascertain why the current exoskeleton was less effective at reducing triceps surae loading at higher walking speeds. The challenge may arise from the walking pattern used while wearing the device, and/or over-engagement of the triceps surae muscles by the user at high speeds. Future enhancements will incorporate a clutch in the shoe backstop to enable engagement in stance while allowing for unencumbered motion in swing.

Significance: This study introduces a simple, self-aligning passive exoskeleton that has the potential to reduce triceps surae loading during human walking and be more comfortable than other ankle exoskeletons that rely on transmitting assistive forces in parallel with the triceps surae.

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References: [1] Collins+, *Nature* vol. 522,7555, 2015; [2] Schmitz+, ASB 2023; [3] Sarkisian+, *IEEE* vol. 29, pp. 629-640, 2021; [4] Martin+, *Nat. Commun*. vol. 9, 1592, 2018.