Reducing Positive Muscle Fiber Work in Simulated Walking: When to Start?

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Summary

Providing plantar flexion assistance during walking can alter Achilles tendon stretch and positive muscle fiber work, which may negatively impact the potential reduction in metabolic cost during walking. Using musculoskeletal modeling, we showed that only providing assistance during muscle fiber shortening led to less Achilles tendon stretch and greater reduction in positive muscle fiber work than also providing assistance when muscle fibers are isometric or lengthening.

Introduction

Exoskeletons providing a plantar flexion moment around the ankle joint have been shown to reduce metabolic energy cost of gait [1], but not when actuation starts early during stance [2]. This might be because providing assistance during early and mid-stance causes greater muscle fiber excursion and less stretch in the Achilles tendon [3,4]. This leads to less Achilles tendon recoil during push-off. As a result, muscle fibers must provide more positive work, which is metabolically costly [3].

Our aim was to use musculoskeletal modelling to investigate the effect of different plantar flexion assistance profiles on muscle fiber positive power. To understand changes in power, we also investigated the effect on muscle fiber and Achilles tendon lengths. We hypothesized that only assisting during muscle fiber shortening leads to less changes in muscle fiber and tendon lengths and, with that, to greater reduction in positive muscle fiber power than also assisting when muscle fibers are isometric or lengthening.

Methods

We computed muscle tendon lengths and moment arms of the soleus and tibialis anterior from kinematics of one participant of [5] using the Gait2392 model in OpenSim. Furthermore, we computed the ankle moment using inverse dynamics. We developed a model containing a Hill-type soleus and tibialis anterior muscle according to [6], and an exoskeleton providing a plantar flexion moment. We aimed to find excitations for which muscle activation was minimal under the constraint that soleus moment + tibialis anterior moment + exoskeleton moment was equal to the inverse dynamics ankle moment, for the following three exoskeleton conditions:

- *NoExo*: no exoskeleton moment;
- *PercID*: exoskeleton moment as percentage (47%) of inverse dynamics moment;
- *ShortPercID*: exoskeleton moment as percentage (47%) of inverse dynamics moment, but only active when soleus fibers are shortening.

We compared soleus fiber and Achilles tendon lengths and positive soleus fiber power and work for the three conditions.

Results and Discussion

As expected, *PercID* decreased Achilles tendon stretch and increased muscle fiber excursion compared to *NoExo*. For *ShortPercID*, Achilles tendon stretch and muscle fiber excursion were similar to *NoExo*, indicating less impact of the assistance on muscle fiber dynamics (Fig. 1).

Both assistance profiles decreased positive soleus fiber power (Fig. 1). Consequently, soleus positive mechanical work over one stance decreased from 23.7 J (*NoExo*) to 14.3 J (*PercID*) and 13.3 J (*ShortPercID*). Exoskeleton positive mechanical work over one stance was higher for *PercID* (11.4 J) than for *ShortPercID* (9.2 J). This suggests a lower exoskeleton efficiency for *PercID* (0.83) than for *ShortPercID* (1.13).

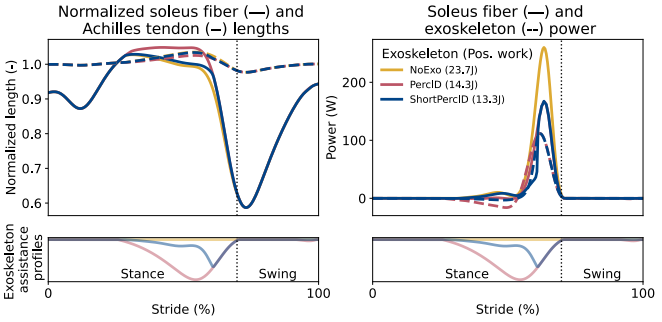

Figure 1: Normalized soleus fiber and Achilles tendon lengths (top left) and soleus fiber and exoskeleton power (top right) over a full stride, together with the exoskeleton assistance profiles (bottom). Positive mechanical work delivered by soleus fiber for each condition is shown between brackets in the top right panel.

Conclusions

Both exoskeleton plantar flexion assistance profiles based on the inverse dynamics moment led to a reduction in positive soleus fiber work. When only providing assistance during soleus fiber shortening, there was less decrease in Achilles tendon stretch and less muscle fiber excursion, and with that greater reduction in soleus fiber positive power and work, even though less mechanical work was delivered by the exoskeleton.

References

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