

USING ELASTIC ANKLE EXOSKELETONS TO COUNTERACT AGE-RELATED STRUCTURE-FUNCTION DEFICITS

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INTRODUCTION

Elastic exoskeletons have the potential to add structural stiffness about a joint during gait using external springs placed in parallel with biological muscle-tendon units (Fig. 1 A-D). Our previous work has shown that elastic exoskeleton assistance at the ankle leads to decreases in plantarflexor force and activation as well as a decrease in whole body metabolic demand [1]. This is despite evidence for unfavorable changes in fascicle dynamics (*e.g.* longer fascicle lengths) in young adults [2]. Aging on the other hand is associated with a myriad of performance declines. For example, with age comes slower walking speeds and increased metabolic costs [3]. Evidence suggests that the ankle plantarflexors are at the forefront of these performance declines, with age-associated decreases in Achilles tendon (AT) stiffness and muscle force-generating capacity contributing to shorter fascicles and reduced ankle push-off capability in older adults [3,4] (Fig. 1 E-F).

Our aim is to determine whether walking with elastic ankle exoskeletons can augment plantarflexor performance in older adults (Fig. 1). Unlike in young adults, longer fascicle lengths in older adults may lead to improved economy of muscle force production at normal walking speeds [4]. We hypothesized that parallel elastic assistance during walking in older adults would decrease the biological ankle moment, decrease muscle activation, and increase soleus muscle fascicle operating lengths (Fig. 1G).

METHODS

One elderly subject (female, age: 68) completed the IRB approved protocol. The subject walked for 5 minutes at 1.25 m/s while we applied three exoskeleton assistance levels (stiffness = 0, 100, 150 Nm/rad).

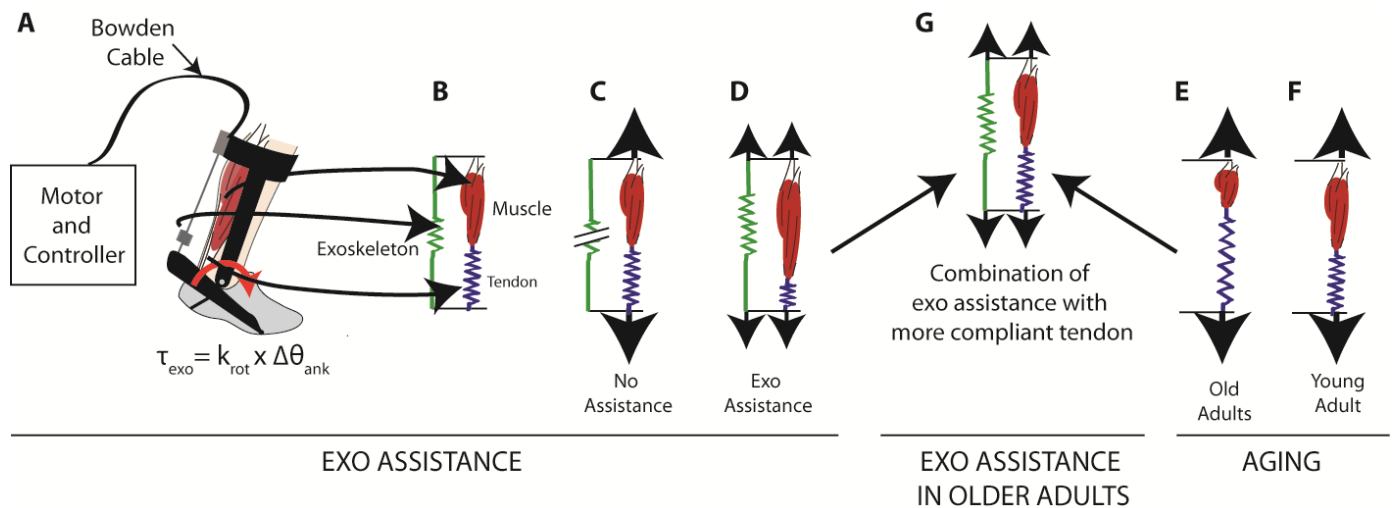


Figure 1: Cartoon representation of the expected effect of exoskeleton assistance and aging on the ankle plantarflexors muscle-tendon units (MTU). **A:** Diagram of exoskeleton testbed where plantarflexion assistive torque is applied to the ankle. **B:** Simplified representation of MTU and exoskeleton as parallel force-applying actuators. **C:** Without exoskeleton assistance, the MTU generates the required force for walking. **D:** With exoskeleton assistance, the force is distributed between the parallel elements and force in the MTU decreases leading to a decrease in tendon stretch. **E:** Decrease in tendon stiffness and muscle force-generating capacity associated with aging results in longer tendon length and shorter fascicles compared to **F:** MTU of young adult. **G:** Hypothesized effect of exoskeleton assistance in older individuals. Muscle fascicles return to longer lengths due to decreased tendon stretch as MTU force is offloaded using exoskeleton.

Ankle exoskeleton assistance was delivered to the user through an exoskeleton emulator consisting of bilateral ankle exoskeletons, a benchtop motor and transmission, and a control system (Fig. 1A). A torque-angle relationship was imposed to emulate elastic assistance. We collected a comprehensive kinematic, kinetic, EMG, ultrasound, and metabolic dataset while the subject walked on an instrumented treadmill. Specifically, we recorded kinematics using reflective markers (Vicon), muscle activity in the medial and lateral gastrocnemii and soleus using surface EMG (Biometrics), soleus fascicle lengths using B-mode ultrasound (Telemed), and whole body metabolic power using indirect calorimetry (OxyCon Mobile).

RESULTS AND DISCUSSION

Compared to the no assistance condition (0 Nm/rad), the stiffest exoskeleton condition (150 Nm/rad) reduced the peak biological plantarflexion moment by 4.8% and the soleus integrated EMG by 12% (Fig. 2A). During stance, average soleus fascicle length increased by 8.5% when high exoskeleton stiffness was applied (Fig. 2C). Assistance also increased the ankle quasi-stiffness (Fig. 2B) and decreased metabolic demand by more than 5%. In this pilot study, the subject obtained the greatest metabolic benefit from the stiffest condition prescribed (150 Nm/rad). Interestingly, this is about twice as stiff as the optimal stiffness in young adults (80 Nm/rad). Due to the structural MTU changes associated with

aging (e.g., reduced AT stiffness), it is unclear whether making the exoskeletons even stiffer could further improve metabolic outcomes.

CONCLUSIONS

The optimal prescription of elastic ankle exoskeletons has the potential to preserve or restore mobility in our aging population. Ultimately, by personalizing the structural properties of the device to the morphology of an individual user, we may offset unfavorable reductions in tendon stiffness and their metabolic consequences, thereby maximizing independence and quality of life.

REFERENCES

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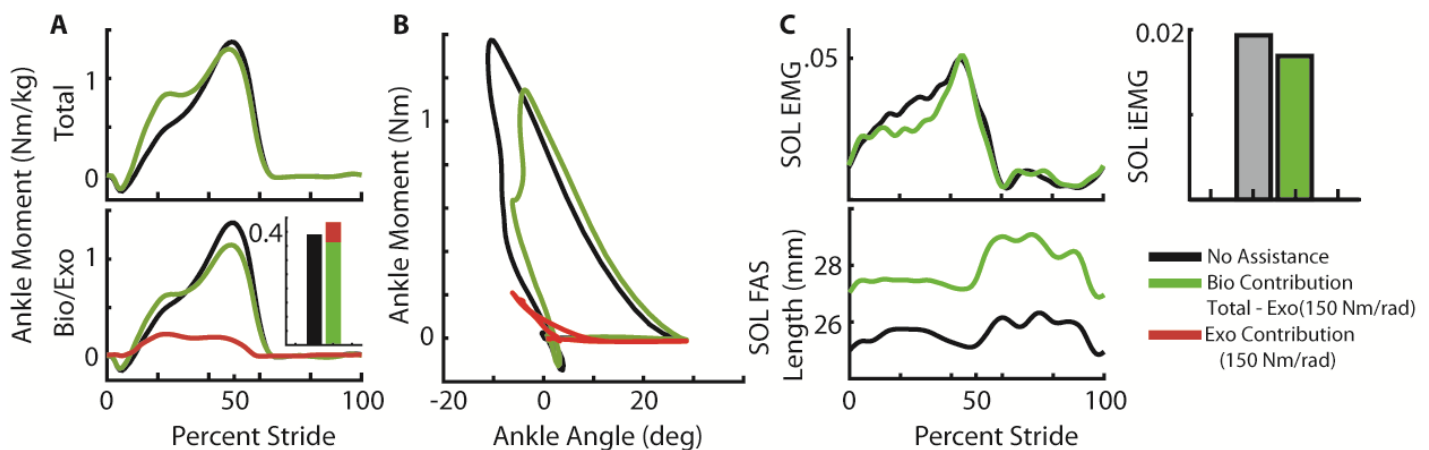


Figure 2: Joint and muscle mechanical changes as result of applying exoskeleton assistance. At the ankle joint, exoskeleton assistance results in decrease in biological moment. Soleus activation decreases and length increases with application of rotational stiffness.