Can Ankle Exoskeletons Reduce the Metabolic Cost of Older Adult Locomotion?

Lindsey Trejo1,2, Jordyn Schroeder2, Gregory S. Sawicki2,3
1Parker H. Petit Institute of Bioengineering and Biosciences, 2George W. Woodruff School of Mechanical Engineering, 3School of Biological Sciences, Georgia Institute of Technology, Atlanta, GA, USA
Email: ltrejo@gatech.edu

Summary
We used a simple musculoskeletal model to determine the ability of an elastic ankle exoskeleton to restore older adult locomotion performance to that of young adults. We found that exoskeleton stiffness (kexo) values greater than 10% of young adult Achilles tendon stiffness (kten*) can reduce the metabolic demand of older adults to levels below that of young adults during simulated hopping.

Introduction
As we age walking gets slower and more energy intensive, limiting independence [1]. We believe the root cause stems from a reduction in Achilles tendon stiffness (kten), which causes plantarflexor muscles to operate at shorter lengths and higher activations. In young adults, passive ankle exoskeletons reduced metabolic cost of walking by 7% - potentially by enabling longer muscle lengths and lower activations [2]. We hypothesized there would be a range of elastic ankle exoskeleton stiffness values that could mitigate the metabolic penalty associated with the more compliant Achilles tendons of older adults.

Methods
We used a neuromuscular hopping model to investigate the effects of a passive elastic ankle exoskeleton on locomotion in aging [3]. The age difference was simulated by reducing the tendon stiffness of young adults (kten* = 180 kN/m) by ~20% to 140 kN/m for older adults [4]. First, we established a reference condition with maximal efficiency for both young and older adults. We defined the reference condition by finding the hopping frequency (2-3 Hz) and activation (40-100%) with positive mechanical power (+Pmech) of 2.25 W/kg [3] with the lowest metabolic power (Pmet) (Table 1, rows 1 and 2). Next, we added an elastic ankle exoskeleton to the simulation to examine how kexo affects older adult Pmet. We excluded results from simulations with muscle strain > 30% (injury risk) and hop height <1 mm (bouncing, not hopping).

Table 1: The optimal Pmet point for young & older adults, and older adults with an exoskeleton at 20% kexo. L0 is muscle slack length. HH = hop height. Hop frequencies at optima were 2.9-3 Hz.

<table>
<thead>
<tr>
<th>kexo (kN/m)</th>
<th>Act</th>
<th>Pmet (W/kg)</th>
<th>HH (cm)</th>
<th>+Pmech (W/kg)</th>
<th>Lm/L0</th>
</tr>
</thead>
<tbody>
<tr>
<td>180-Y</td>
<td>73%</td>
<td>1.33</td>
<td>0.15</td>
<td>2.33</td>
<td>100%</td>
</tr>
<tr>
<td>140-O</td>
<td>76%</td>
<td>1.39</td>
<td>0.12</td>
<td>2.25</td>
<td>96%</td>
</tr>
<tr>
<td>140-O+Exo</td>
<td>45%</td>
<td>0.90</td>
<td>0.21</td>
<td>2.20</td>
<td>99%</td>
</tr>
</tbody>
</table>

Results and Discussion
In the reference condition, lower kten of older adults increased Pmet by 4.5% compared to young adults (Table 1, row 1 vs 2). With an exoskeleton, older adults decreased Pmet by 35% relative to no exoskeleton (Table 1, row 2 vs 3).

Figure 1: The average Pmet for an older adult across exoskeleton stiffness values. The star represents the reference condition and the cases below the dashed line have a smaller Pmet than young adults. Older adults could not hop at 3 Hz with a Pmet of a young adult while performing the same +Pmech (Figure 1, kexo=0). A kexo of 10% kten* or greater allowed older adults to attain Pmet values lower than that of young adults. For hopping with +Pmech set to the reference output, an exoskeleton with stiffness set to 20% kten* reduced Pmet by 32% from young adults (Figure 1, solid dot). Consistent with our hypothesis, there was a range of kexo values that allowed older adults to achieve metabolic performance equivalent to or better than young adults. Notably, exoskeletons that reduced Pmet in older adults did so by reducing muscle activation and increasing muscle length.

Conclusions
Passive exoskeletons may counteract age-related consequences of reduced tendon stiffness by steering muscle dynamics to elicit more economical muscle contractions.

Acknowledgments
This work is funded by grant number R01AG058615 from the National Institutes of Health National Institute on Aging.

References