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

Lindsey Trejo[1,2], Jordyn Schroeder[2], Gregory S. Sawicki[2,3]
[1]Parker H. Petit Institute of Bioengineering and Biosciences, [2]George W. Woodruff School of Mechanical Engineering,
[3]School 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 (k_{exo}) values greater than 10% of young adult Achilles tendon stiffness (k_{ten}*) 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 (k_{ten}), 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 (k_{ten}* = 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 (+P_{mech}) of 2.25 W/kg [3] with the lowest metabolic power (P_{met}) (Table 1, rows 1 and 2). Next, we added an elastic exoskeleton to the simulation to examine how k_{exo} affects older adult P_{met}. We excluded results from simulations with muscle strain >30% (injury risk) and hop height <1 mm (bouncing, not hopping).

Table 1: The optimal P_{met} point for young & older adults, and older adults with an exoskeleton at 20% k_{exo}. L_0 is muscle slack length. HH = hop height. Hop frequencies at optima were 2.9-3 Hz.

k_{ten} (kN/m)	Act	P_{met} (W/kg)	HH (cm)	+P_{mech} (W/kg)	L_m/L_0
180-Y	73%	1.33	0.15	2.33	100%
140-O	76%	1.39	0.12	2.25	96%
140-O+Exo	45%	0.90	0.21	2.20	99%

Results and Discussion

In the reference condition, lower k_{ten} of older adults increased P_{met} by 4.5% compared to young adults (Table 1, row 1 vs 2). With an exoskeleton, older adults *decreased* P_{met} by 35% relative to no exoskeleton (Table 1, row 2 vs 3).

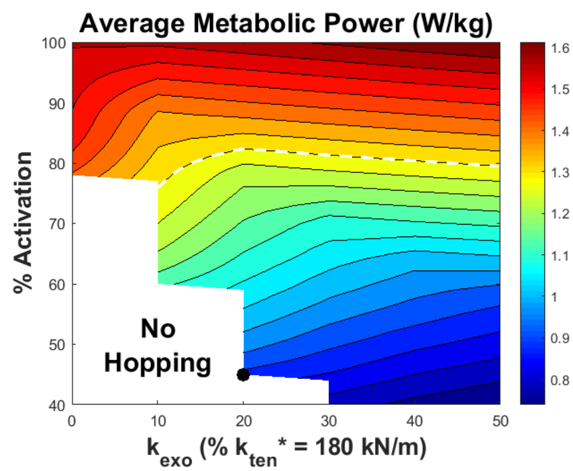

Figure 1: The average P_{met} for an older adult across exoskeleton stiffness values. The star represents the reference condition and the cases below the dashed line have a smaller P_{met} than young adults.

Older adults could not hop at 3 Hz with a P_{met} of a young adult while performing the same +P_{mech} (Figure 1, k_{exo}=0). A k_{exo} of 10% k_{ten}* or greater allowed older adults to attain P_{met} values lower than that of young adults. For hopping with +P_{mech} set to the reference output, an exoskeleton with stiffness set to 20% k_{ten}* reduced P_{met} by 32% from young adults (Figure 1, solid dot). Consistent with our hypothesis, there was a range of k_{exo} values that allowed older adults to achieve metabolic performance equivalent to or better than young adults. Notably, exoskeletons that reduced P_{met} 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

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