OPTIMIZING EXOSKELETON ASSISTANCE TO IMPROVE WALKING SPEED AND ENERGY ECONOMY FOR OLDER ADULTS

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Introduction: Forty percent of Americans aged 65 and older report mobility challenges [1], marked by declines in gait speed and energy economy. Lower-limb exoskeletons have demonstrated potential to improve either measure, but primarily in studies with healthy younger adults [2-4]. Promising techniques like optimization of exoskeleton assistance may provide the greatest benefits in walking performance but have yet to be tested with older populations. Multi-objective exoskeleton optimization is another critical step: speed and energy consumption have yet to be simultaneously targeted for any population. The primary objectives of our study were to: (1) assess the extent to which trained older adults can garner speed and energy benefits from ankle exoskeleton assistance and (2) extend human-in-the-loop optimization [4] to target both self-selected walking speed and metabolic energy consumption in a multi-objective paradigm. We also aimed to characterize older adults' adaptation to exoskeleton use and gain initial insights into the effects of aging on response to exoskeleton assistance.

Methods: We investigated the effectiveness of human-in-the-loop optimization [4] of ankle exoskeletons in ten older adults, aged 65 and older (5 females; mean age: 72 ± 3 years). Participants walked on a self-paced treadmill [5] wearing an indirect calorimetry device and ankle exoskeleton emulators [6] that provided an assistive plantarflexion torque once per step. Participants were instructed to walk at a comfortable speed during testing. A human-in-the-loop optimizer varied torque profiles every two minutes in search of parameters that maximized the user's self-selected walking speed and minimized the user's metabolic rate according to a multi-objective cost function. After four hours of training and optimization, a validation session was conducted to compare self-selected speed, metabolic rate, metabolic cost of transport, optimized exoskeleton mechanics, and spatiotemporal gait parameters between unassisted and assisted walking conditions.

Results & Discussion: Optimized exoskeleton assistance improved walking performance for older adults. On average, participants experienced an 8% (0.10 m/s, p = 0.001) increase in self-selected walking speed, a 19% (0.68 W/kg, p = 0.007) decrease in metabolic rate, and a 25% (0.71 J/kg/m, $p = 7.5e{-4}$) decrease in metabolic cost of transport due to optimized ankle plantarflexion assistance (Fig. 1). These speed and energy benefits are clinically meaningful [7,8] and show that human-in-the-loop optimization can effectively target multiple aspects of walking performance.

Optimized exoskeleton parameters varied between participants (peak of 0.54 ± 0.10 Nm/kg at 52.3 ± 1.1% stride, rise time of 27.3 ± 7.0%, and fall time of 10.4 ± 2.6%), indicating the importance of personalizing assistance. Step frequency and peak plantarflexion angle increased with assistance, while other gait features were unchanged, suggesting that benefiting from exoskeleton assistance did not require many changes that could compromise older adults' comfort and stability. Older adults' optimal exoskeleton parameters and biomechanical responses to assistance appeared distinct from those previously established for younger adults [2,3]; smaller and lighter-weight exoskeletons may be more appropriate for older adults.

Participants adopted an improved motor control strategy with training but did not fully adapt to walking with exoskeletons within the study duration. Both age and self-paced treadmill use appeared to slow motor adaptation, motivating targeted familiarization and training protocols for older exoskeleton users.

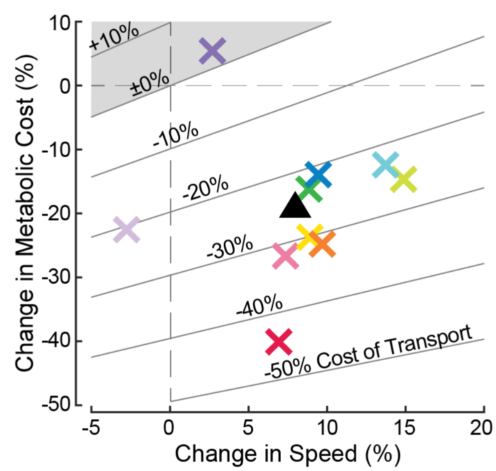

Figure 1. Changes in self-selected walking speed, metabolic cost, and metabolic cost of transport with exoskeleton assistance. Participants plotted in unique colors and mean plotted in black.

Significance: Our results demonstrate that (1) exoskeletons can provide clinically meaningful improvements in walking performance for older adults and (2) multiple objectives can be simultaneously addressed through human-in-the-loop optimization. Our findings point to the potential of portable, commercial exoskeletons that enable older adults to walk comfortably at faster speeds with reduced energy consumption, helping them navigate everyday environments with increased ease, independence, and satisfaction.

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