EXEREXO: EXPLORING THE EFFECTS OF ASSISTIVE AND RESISTIVE ANKLE EXOSKELETON TORQUE ON WALKING MECHANICS AND ENERGETICS

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Introduction: Lower-limb exoskeletons have been historically applied to the improvement of human movement, particularly walking, with the goal of reducing metabolic cost [1]. Assistive torque, through powered or unpowered means, complements biological moments to replicate or augment natural human motions in elderly, impaired, or clinical populations. The opposite application of exoskeletons has shown promise in the same populations, seeking to provide resistance to functional tasks with the intention of muscle strengthening, neuromuscular function improvement, and targeted rehabilitation resulting in measurable improvements in walking mechanics and muscle activation [2, 3]. The same robotic devices designed to restore and rehabilitate can be refocused on exercise training, increased metabolic effort, and targeted muscle activation in healthy individuals seeking to capitalize on exercise volume. This study aims to explore the benefits to exercise training with the use of an ankle exoskeleton capable of providing both assistive and resistive ankle torques. Analogous to standard workout practices, equal exercise effort can be achieved through low weight, high repetition conditions (exoskeleton assistance, fast walking speeds) and high weight, low repetition conditions (exoskeleton resistance, slow speeds). We hypothesize that measures of effort and exercise volume increase across walking speeds and resistive exoskeleton intervention can provide improved training benefits at lower speeds, creating instances of equal exercise volume across a landscape of training conditions.

Methods: A powered, cable-driven ankle exoskeleton (Biomotum) is used to provide 3 torque conditions (zero-torque, 15 Nm plantarflexion assistance, 15 Nm plantarflexion resistance) at 3 walking speeds (1.00, 1.25, 1.50 m/s) during walking bouts of 5 minutes (with 5 minutes intermittent rest between trials). This study produces heart rate, metabolic energy expenditure [4], unilateral EMG, lower body inverse kinematics and kinetics, ground reaction forces, and self-reported perceived exertion (per the Borg scale [5]) data. The average propulsive ground reaction forces observed in each of the three zero-torque conditions are presented as live biofeedback targets during the speed-matched assist and resist conditions, serving as a proxy for real-time ankle power and encouraging the participant to preserve constant ankle dynamics across all exoskeleton conditions (Figure 1B). Two additional trials are conducted without biofeedback (assist and resist at 1.25 m/s) in a condition-randomized order before the remaining six trials are conducted in a speed and condition-randomized order. Heart rate, gross metabolic power, and perceived exertion are the main metrics of exercise intensity while the applied exoskeleton torque (positive for assistance, negative for resistance), is subtracted from the net ankle moment to isolate the biological contribution to ankle moment and power. The preliminary study was collected with an n=1 population.

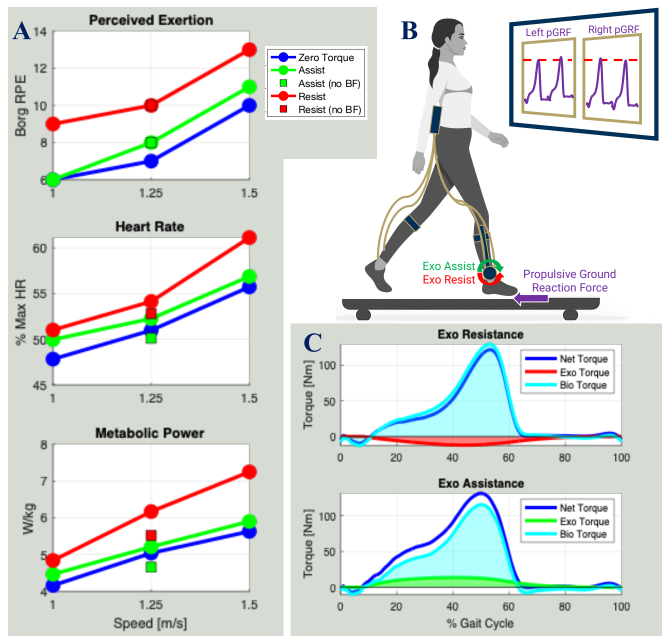

Figure 1A: Measures of exercise effort across exo conditions and speeds, including no-biofeedback conditions. **Figure 1B:** Propulsive ground reaction force real-time biofeedback targets during speed-matched trials. **Figure 1C:** Biological and exo contributions to net torque in assist and resist conditions.

Results & Discussion: All measures of exercise effort, including self-reported perceived exertion (RPE), heart rate, and gross metabolic power increased across walking speeds with similar patterns represented across all exo conditions (Figure 1A). In each metric, walking at slow speed with resistive intervention equated to assist or zero-torque conditions at higher speeds, showcasing the potential for equal exercise volume at lower physical speeds. Additionally, there is a larger biological contribution to net ankle moment in the resistance condition to overcome negative exo torque compared to the assistance condition, which supplements a reduced biological moment (Figure 1B). Gross metabolic power increased by 12% in both assistance and resistance biofeedback conditions when compared to no-biofeedback conditions. This demonstrates the need for real-time cues to guarantee participants experience the full effects of exoskeleton assisted exercise training.

Significance: This preliminary study demonstrates the viability of exoskeletons to be used as exercise training devices, exceeding the historically established use cases of mobility restoration and rehabilitation. This study also demonstrates the need for biofeedback cues to encourage users to engage standard levels of ankle power when exposed to exoskeleton intervention. Increased amounts of exercise volume can be achieved at lower repetitions with higher loads, translating knowledge of exercise training from the gym to the world of wearable robotics.

References: [1] Sawicki et al. (2020), *J Neuroeng Rehabil*; [2] Bulea et al. (2022), *Proc IEEE RAS EMBS*; [3] Swaminathan et al. (2023), *J Neuroeng Rehabil;* [4] Brockway (1987), *Hum Nutr Clin Nutr*; [5] Borg (1982), *Med Sci Sports Exer.*