METABOLIC DIFFERENCES IN GAIT ADAPTATION TO AN ANKLE VS. HIP EXOSKELETON

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Introduction: Transient dynamics of adaptation to a powered exoskeleton reflect motor learning occurring over many minutes to hours, and the mechanism of this adaptation may be joint-specific [1, 2, 3]. While net metabolic cost reduction is similar when an assistive exoskeleton torque is provided at the ankle or hip with the same control paradigm [3], the mechanism of adaptation at a distal vs. proximal joint may differ, based both on musculotendon anatomy and individual user differences. For example, signaling from the sensory organs that drive motor learning (e.g., spindles) can be attenuated when there is significant tendon compliance in series with muscles [4]. Additionally, prior work has shown reduced metabolic cost and ongoing kinematic changes as participants become expert exoskeleton users over multiple training sessions [1, 2]. Understanding adaptation over a single walking bout may reveal additional insights about underlying structural and functional differences between the ankle and hip joints. Here, we preliminarily investigated within-participant metabolic differences between adaptation to an exoskeleton acting at the ankle compared to the hip. We predicted that adaptation would be observed in both conditions, where metabolic cost will peak and then decay following the onset and offset of exoskeleton assistance, in line with exoskeleton adaptation literature [1, 2]. We further hypothesized that this effect would be smaller at the ankle, where increased tendon compliance would attenuate sensory input from exoskeleton torque, slowing motor adaptation.

Methods: One able-bodied young adult walked on a treadmill at 1.25m/s with either an ankle or hip exoskeleton. Metabolic cost was collected using indirect calorimetry. One continuous trial consisted of 6 minutes of quiet standing, 6 minutes walking without assistance, 30 minutes walking with a torque applied at the hip or ankle, 6 minutes walking without assistance, and 6 minutes quiet standing (Fig. 1A). The ankle exoskeleton (Dephy EB60 Exoboots) delivered 15 Nm of peak plantarflexion torque using a spline-based optimized torque assistance profile controller [5], which we estimated to be similar to or greater than 10% of the participant's biological torque. A custom hip exoskeleton delivered 10% of biological hip flexion torque during swing phase using a deep learning real-time estimate of biological torque [6]. Metabolic power from each walking block was fit with a first-order exponential. We normalized metabolic cost to participant weight and reported the percent change in metabolic cost from steady-state walking. We defined steady-state as minutes 3-5 of the initial unassisted walking block. Early and late adaptation phases are the first and last 2 minutes of walking with the exoskeleton on, and post-adaptation is the first 2 minutes of the second unassisted walking block.

Results & Discussion: Metabolic power data showed a greater adaptation effect in the hip exoskeleton condition compared to the ankle, as shown by the larger spike in metabolic cost and smaller time constant at the onset and offset of exoskeleton assistance (Fig. 1B). The ankle condition did not show the expected increase in metabolic cost compared to baseline walking during early and post adaptation (Fig. 1C), suggesting less adaptation occurred. Less pronounced adaptation effects at the ankle compared to the hip may reflect underlying structural differences in the muscle-tendon unit. Sensory organs in ankle muscles may not as directly reflect changes to the joint due to the more compliant Achilles tendon, attenuating sensory signals driving motor adaptation. Limitations of this protocol include that the control algorithm and percentage of biological torque delivered differed between devices. Future work will use the same torque estimation controller on both joints and investigate whether the magnitude of exoskeleton torque influences adaptation rate and extent.

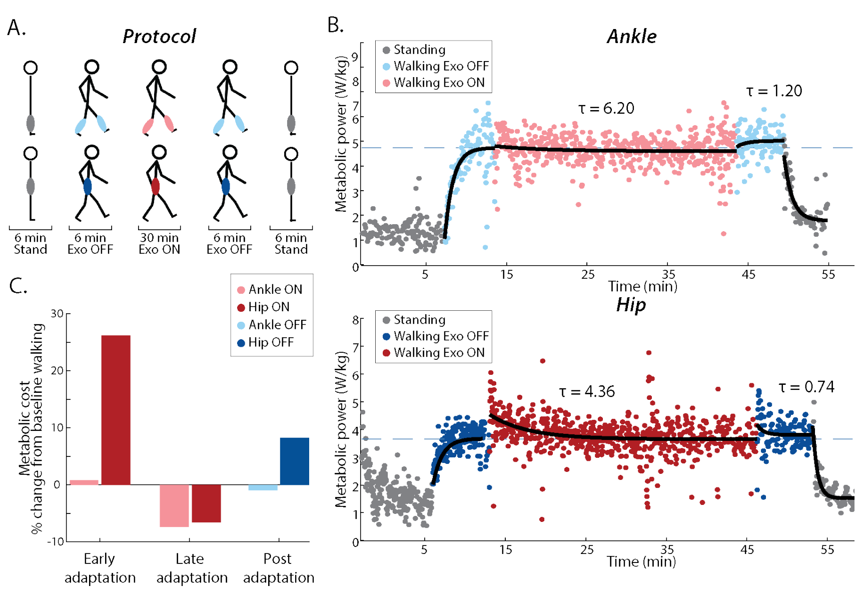

Figure 1: (A) Trial structure for an ankle (top) and hip (bottom) exoskeleton. (B) Breath by breath metabolic power during each adaptation trial. τ (in minutes) is the time constant of the adaptation and de-adaptation exponential fit. (C) Percent change of mean metabolic cost from steady state walking during early adaptation, late adaptation, and post-adaptation.

Significance: User adaptation to assistive exoskeletons can be a long process. Understanding mechanisms of adaptation at different joints and on shorter time scales may allow for more personalized and efficient exoskeleton selection.

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