HUMAN JOINT LEVEL FORCE RESPONSIVENESS AND CONTROL WITH EXOSKELETON ASSISTANCE

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Introduction: With significant advancements in wearable technologies for assisting locomotion and augmenting balance, there is a growing need to understand how such devices affect sensorimotor control of movement. Exoskeletons act mechanically in parallel to a joint, influencing the existing sensorimotor control loops that govern human movement [1]. As a result, although exoskeletons may be optimized for certain outcome metrics, the way they interact with our governing sensorimotor control system may have unintended impacts on overall agility and stability [2]. Recent work has begun to quantify human force responsiveness [3] and effects of neuromotor regulation on joint impedance [4]. Here we measure human joint level force responsiveness with and without exoskeletal assistance in a dynamometer, allowing for controlled isometric contractions to achieve set torque targets and measure joint-level force responsiveness and control. We hypothesize that the no torque assistance condition will have greater accuracy of force control than the myoelectric controller due to the human's inherent forward model of its sensorimotor control system (which does not include an exoskeleton).

Methods: Two young adults wearing an ankle exoskeleton (Dephy EB60 Exoboots) were placed in a dynamometer (Biodex) to measure ankle torque output during isometric contractions. Participants were given an auditory metronome at 15 bpm indicating the start and end of each 4 second step cycle, a visual target line on a screen of the torque target to reach, and visual feedback of their real-time torque. A randomly selected two out of ten cycles per condition were blinded by removing the visual target and torque feedback from the participant's view. Eight randomized trial conditions were conducted, with 4 torque targets at 20%, 40%, 60%, and 80% of maximum voluntary contraction across 2 exoskeleton conditions (No Torque Assistance (NT) and Proportional Myoelectric Control (PMC) with a maximum assistance level of 10 Nm) and 10 step cycles within each trial. There was a 20 second break between every trial, and all 8 trials were repeated after a 60 second break to investigate the effects of motor adaptation. The step responses were quantified using classical controls metrics including rise time, bandwidth, overshoot, steady-state error, steady-state variability, and fall time [3]. Higher bandwidth indicates higher responsiveness, and a lower steady-state error and steady-state variability indicates greater accuracy.

Results & Discussion: Increased torque targets correlated with lower responsiveness and lower accuracy for the system. In the first repetition, both the NT condition and the PMC conditions had a similar bandwidth, however in the second repetition the bandwidth of the PMC condition increased for the 20, 40, and 80% conditions, indicating potential adaptation to the exoskeleton assistance and improved responsiveness as opposed to the NT condition (Fig. 1B). Steady-state variability increased for the NT condition in the 20, 40 and 60% conditions between the first and second repetition, while remaining consistent in the PMC condition across both repetitions (Fig. 1B). Furthermore, in the second repetition the participants couldn't reach the 80% MVC target due to fatigue in the NT condition but were able to reach and maintain 80% MVC with PMC assistance (Fig. 1A). Although both exoskeleton conditions performed similarly in the first repetition, the improved performance of PMC in the second repetition suggests a potential benefit of exoskeleton assistance to the inherent sensorimotor control system's accuracy and responsiveness after adaptation and sensory reweighting.

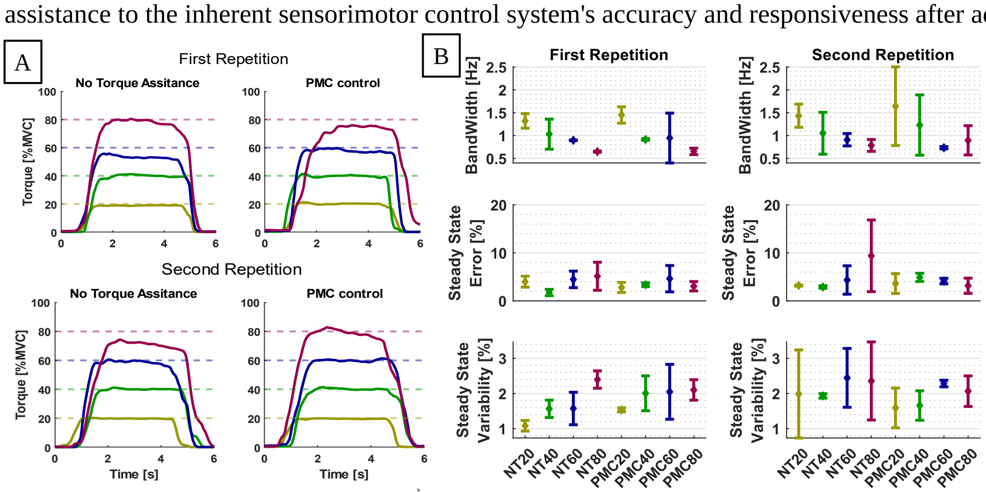

Figure 1: A) the average step response for n=2 participants across the four target torque conditions, 2 exoskeleton assistance types (left and right), and two repetitions of the trials (top and bottom). B) The bandwidth (top), steady state error (middle), and steady state variability (bottom) of the system across all conditions in the first (left) and second (right) conditions.

Significance: Investigating the effects of exoskeleton assistance on human force responsiveness will provide insights into the human sensorimotor control loop during physiologically relevant excursions. Modeling the human neuromuscular system as a feedback control system and incorporating external exoskeletal influences can offer crucial insights into the effects of exoskeletons the sensorimotor feedback. These insights can help illuminate the sensory weighting that occurs within humans, and further the potential of exoskeleton to counteract the effects of age and disease, such as altered tendon stiffness and increased instability.

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References: [1] Abram et al. (2022), *Curr Biol* 32; [2] Antonellis et al. (2018), *Plos One* 13; [3] Kudzia et al. (2022), *Sci Rep* 12; [4] Wind et al. (2020) *Sci Rep* 10.