The relationship between assistance torque and muscle activity during lifting with Back-Support Exoskeletons

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Introduction: Active back-support exoskeletons offer varying levels of support to users, yet there are no standard guidelines for optimizing assistance to individual needs or task demands. Improper assistance can lead to over-reliance or inadequate support, potentially compromising user performance, comfort, and long-term musculoskeletal health [1]. Prior work exploring optimal assistance patterns in ankle exoskeletons has shown that the relationship between metabolic rate and peak assistance torque exhibited an asymptotic exponential function, with decreasing returns at higher levels of torque assistance [2]. It is unclear whether this relationship would also hold for back-support exoskeletons, and how higher torque support from an exoskeleton translates to muscle relief (instead of metabolic rate). This study examines whether muscle activity of the trunk extensor muscles changes systematically with increasing support levels from a powered back-exoskeleton during repetitive lifting tasks, and whether this trend is influenced by the load level. We used an active rigid exoskeleton called the Apogee (German Bionic Systems GmbH, Augsburg, Germany), with two electric torque generators aligned with the hip joints, for this study. We systematically adjusted the support settings of the device (EXO) in increments of 10%, from 20 to 80%, as users performed repetitive lifting tasks with loads adjusted to 10% and 20% of their respective body masses.

Method: Sixteen healthy participants (10 males aged 27.7 ± 8 years and 6 females aged 29.5 ± 8) lifted and lowered a box at 10% (low-load) and 20% (high-load) of their body mass @ 4 lifts per minute for 90 seconds, under 9 conditions: without EXO (control), while wearing the EXO but without any assistive support from the device, and while using the EXO at seven different levels of assistance ranging from 20 to 80%. The order of exposure of each participant to the different conditions was randomized. Inertial Measurement Unit (IMU) sensors (MTw Awinda, Xsens, B.V., Netherlands) were used to capture trunk kinematics, while surface electromyography (EMG) sensors (Ultium EMG system, Noraxon, AZ, USA) were placed bilaterally on trunk extensors (thoracic and lumbar erector spinae). EMG data were normalized to individual maximum voluntary contractions (MVC), as per standard guidelines for sensor placement, MVC tests, and data processing [3,4]. Peak thoracic (TES) and lumbar (LES) erector spinae muscle activities, and peak trunk flexion angle (pelvis-T8 segment) in the sagittal plane were extracted for the control condition, and at 20% (low), 40% (medium), and 80% (high) support levels of the EXO. Separate repeated measures ANOVAs were performed to assess the effects of support level on EMG and postural measures in low-load and high-load conditions, with significance at $p < 0.05$.

Results and Discussion: EXO had a significant main effect on the peak muscle activities of TES ($p = 0.046$ and 0.003 in low and high loads respectively) and LES ($p = 0.012$ and <0.0001 in low and high loads respectively). In the low load condition (left panel of Fig. 1), Tukey HSD post-hoc comparisons revealed that TES activity was significantly lower than control at the 40% support level (reduction of ~15%), and LES was significantly lower at 40% and 80% support levels (reduction of ~20%). In the high load condition (right panel of Fig. 1), TES activity was significantly lower than control at the 80% support level (reduction of ~25%), and LES was significantly lower at all support levels (reduction of ~25% at 20% and 40% support, and reduction of ~45% at 80% support). In all EXO conditions and all load levels, trunk flexion angle was significantly lower than in the control condition (p=0.002). Overall, while increasing torque assistance offered smaller returns in the low-load condition when going from medium to high level of assistance, when the load level was increased to 20% of body mass, there was substantially greater impact on muscle activity at the 80% assistance level. Trunk flexion angles were significantly lower across all support levels, indicating that using the powered exoskeleton promotes a more upright posture, potentially due to the weight of the device loading the back of the users. Future work is needed to examine whether inter-individual differences in muscle activity benefits can be explained by subject-specific modeling; and, whether subjective changes in perceived exertion and fatigue align with the objective EMG changes across varying assistance levels from the EXO.

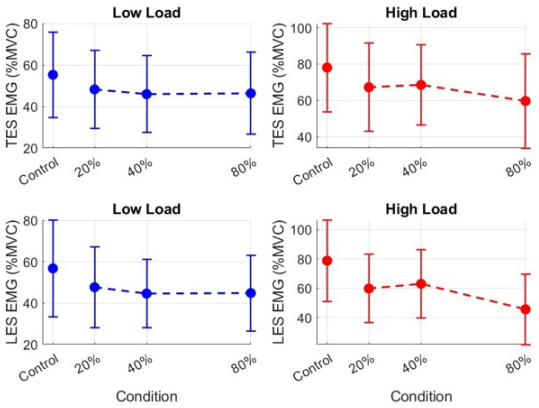

Figure 1. Peak thoracic (TES) and lumbar erector spinae (LES) EMG in control and EXO conditions of 20%, 40% and 80% torque assistance.

Significance: This study highlights that the relationship between exoskeleton assistance levels and objective biomechanical benefits is not linear and that it is modulated based on task demands. The findings emphasize the need for further understanding of whether individualized exoskeleton tuning to balance muscle relief may enhance long-term safety and usability of back-support exoskeletons.

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References: [1] Hu et al. *Ergonomics*, 2025 1-13; [2] Miller et al. *JNER*, 2022 19(1)-46; [3] Wu et al. *JBiomech,* 2002 35(4):543-8; [4] Boettcher et al. *J Orth Res*, 2008 26(12).