OFFSETTING THE LOAD: CAN EXOSKELETONS MITIGATE INJURY RISK DURING INDUSTRIAL LIFTING TASKS?

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Introduction: Exoskeletons have been shown to reduce user joint loading [1] and metabolic cost [2] during manual labor tasks. These findings have influenced the slow adoption of such devices in workplaces where manual labor tasks that involve twisting and lifting high loads are associated with high worker injury rates [3]. Both active and passive commercial exoskeletons are designed to offset joint loading by providing assistive torque either in parallel or perpendicular to the body. Such assistance reduces user muscle forces and activations [4]. Previous research has proposed that joint kinematics, joint kinetics, and muscle activity can indicate injury predisposition; however, few studies have investigated how exoskeletons affect joint and muscle loading in manual labor tasks. Further, the impact of exoskeletons on internal joint contact forces is largely unknown due to the inability to measure *in vivo* and the complex computations required for estimation. Our experimental protocol addressed this gap by recreating industry-relevant lifting conditions in-lab to understand joint and muscle-level demands. We hypothesized that an active knee exoskeleton and a passive back exoskeleton will reduce user back and knee extensor muscle activity while performing assisted lifts versus unassisted.

Methods: Ten participants lifted a 11.3 kg. weight during a symmetrical (0°- no turn) and asymmetrical (90° - rotational turn) task which varied in starting and ending lift height (Fig 1A). The weight was lifted from knee-to-waist (KW) height (ascension) and waist-to-knee (WK) height (descension). Participants performed each task 10 times. Participants wore an active knee exoskeleton, a passive back exoskeleton (HeroWear), and a no-exoskeleton case. We collected ground reaction forces, a full-body marker set, 16 inertial measurement units (IMUs) for segment orientation, and surface electrodes to record muscle activity via electromyography (EMG). We analyzed our data using OpenSim 4.0 and custom MATLAB scripts.

Results & Discussion: Contrary to our hypothesis, we found that assistance from the passive back exoskeleton, HeroWear, reduced back flexor (rather than extensor) peak muscle activity (rectus abdominis) by ~5% during symmetric lifting (Fig 1B). Compared to unassisted lifting, HeroWear's passive assistance reduced peak net back flexion moments (~10% symmetric and asymmetric), lateral bending (~20% symmetric), and axial rotation (~40% symmetric, ~10% asymmetric) (Fig 1C). In support of our hypothesis, we found that the active knee device reduced the peak muscle activity in the knee extensor (rectus femoris) [5] by ~20% and ~10% in symmetrical and asymmetrical lifting, respectively (Fig 1B). The peak net knee flexor moment only showed a ~5% decrease in asymmetric lifting (Fig 1C). Changes in the net joint moments imply that participants used different overall kinematic strategies to perform the given tasks. The elastic band design of the HeroWear and rigid interface of the knee exo may have constrained users' movement to operate in the sagittal plane, thus altering their lifting strategies. In lifting with fixed foot placements, asymmetric lifting could induce rotation and shear about the joints. Constrained motion with devices may add out of plane stability to help mitigate risks in asymmetric motions.

Significance: Our research suggests that both passive back and active knee exoskeletons may be able to mitigate injuries during lifting tasks. However, internal loading within joints (i.e., contact forces) cannot be captured from these data alone. Ultimately, we intend to use information about the external joint loads, muscle activity, and kinematic patterns to compute knee and back joint contact forces and study whether they are influenced by exoskeleton design. Until then, the observed reduced muscle activity with exoskeletons indicates that muscle forces may also be reduced [6], potentially lowering internal joint loads during lifting tasks and further reducing injury risk.

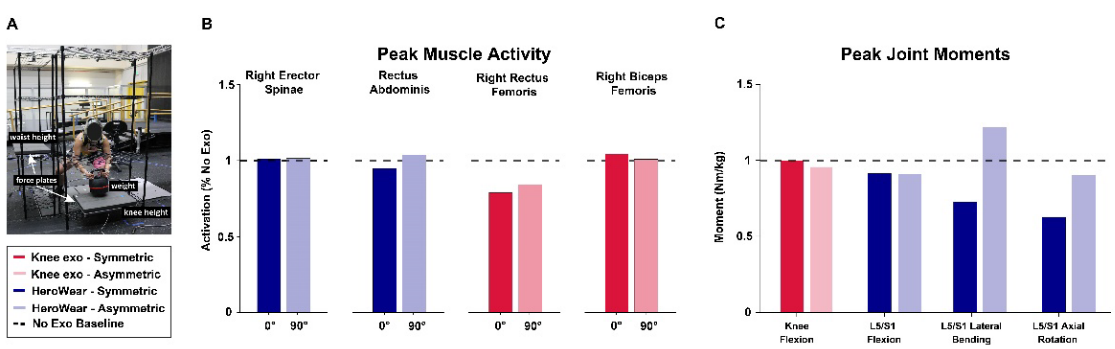

Figure 1: (A) Participant performing a lifting task. **(B)** Peak muscle activity normalized to the peak no exo muscle activity in symmetric (0°) and asymmetric (90°) lifting. **(C)** Peak net joint moments (exoskeleton + biological moments) in symmetric (0°) and asymmetric (90°) lifting. All values are normalized to the no-exo peak net joint moment. Each bar represents averaged ascension and descension conditions.

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References: [1] Kermavnar et al. (2020), *Ergonomics*; [2] Baltrusch et al. (2020), *Ergonomics*; [3] Matijevich et al. (2021), *Sensors*; [4] Medrano et al. (2021), *IEEE*; [5] Ranaweera et al. (2018). *JRNAL*; [6] Uhlrich et al. (2022), *Sci Rep*.