JOINT-LEVEL BIOMECHANICS OF HIGH-INTENSITY INDUSTRIAL TASKS TO INFORM EXOSKELETON MITIGATION STRATEGIES

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Introduction

Manual materials handling (MMH) tasks, such as asymmetrical lifting [1] in industrial jobs, pose a high risk for injuries and lower back pain development. Assistive devices (e.g., back and knee exoskeletons) are designed to mitigate joint and muscle loading during high-intensity loading tasks [2] and repetitive movements. Currently, there is no comprehensive framework to identify critical features associated with joint and muscle overload in MMH tasks, which could be useful to inform assistive technology. Our protocol addressed this gap by recreating industry-relevant lifting conditions in-lab to understand joint and muscle-level demands. We hypothesized that (1) asymmetrical (i.e., 90º and 180º knee-to-waist/waist-to-knee) versus symmetrical (i.e., 0º) lifts would lead to heightened biomechanical demand and (2) the knee and L5-S1 joints would be linearly related to each other across tasks.

Methods

Six participants performed a series of symmetrical and asymmetrical lifting tasks (Fig 1A), which included knee-to-waist (KW), waist-to-knee (WK), shoulder-to-waist (SW), waist-to-shoulder (WS), and waist-to-waist (WW) conditions across 0, 90, and 180 degree turns. The participants lifted a 25 lb. weight for each condition within 6-second intervals. Participants wore a full-body reflective marker set and 16 six-axis inertial measurement units (IMUs) sensors to collect motion capture, muscle activity, and body segment positioning. Force plates were used to collect ground reaction forces. Inverse dynamics and kinematics were performed using OpenSim 4.0 to calculate moments about the L5-S1 and knee joints. Integrated moments and correlation coefficients between the L5-S1 and knee joint efforts were evaluated with MATLAB scripts and the fitlm linear regression model function.

Results and Discussion

Contrary to our hypothesis, we found no evidence that biomechanical loading at the knee or L5-S1 joint was higher in asymmetric (90º, 180º) versus symmetric lifts (0). KW and WK conditions led to the highest combined load on the knee and L5-S1 joints (Fig 1B), revealing a "hot spot" to consider for targeted intervention. In partial support of our second hypothesis, two out of six participants exhibited a significant correlation between knee and L5-S1 joint loading independent of lifting task: Participant 3 ($p = 0.02$, $R^2 = 0.37$) and participant 6 ($p = 0.05$, $R^2 = 0.28$) (Fig 1B). The remaining four participants showed positive but weak correlations. Underlying intrinsic motor control strategies could be adapting to redistribute discrete and continuous loading across lower extremities to prevent injury.

Finally, across all lifts, the L5-S1 joint required more effort than the knee joint, consistent with previous studies [3]. These results suggest that intervention from wearable technology could be best focused on the L5-S1 joint versus the knee joint.

Significance

Our results will help establish the cost-benefit of industrial exoskeletons focused on back versus knee support. For example, our results indicate that back assistance during WK and KW lifts would be the most effective near-term strategy to prevent injury.

Acknowledgments

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References

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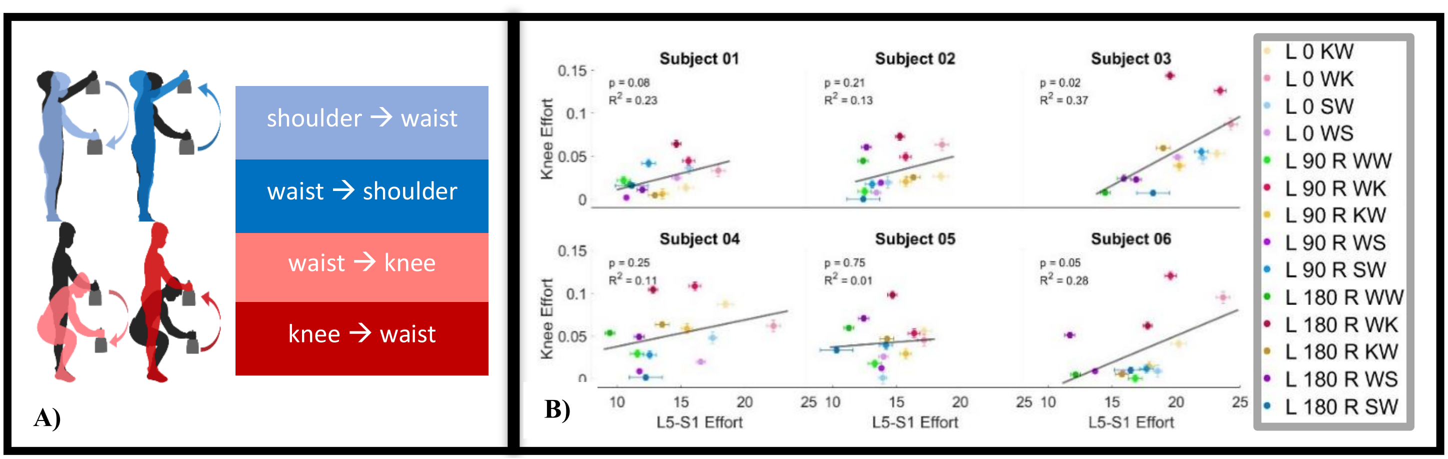

Figure 1: *(A)* Lifting conditions performed by participants across 0,90,180 degree turns. *(B)* Linear regression across six individual subjects for L5-S1 and knee joint efforts. Subject average integrated moments normalized to their weight are shown with standard deviations and correlation coefficients.