EFFECTS OF PROLONGED BACK-SUPPORT EXOSKELETON USE ON TRUNK KINEMATICS DURING REPETITIVE LIFTING AND LOWERING

Amir Mehdi Shayan[1], Duleepa Subasinghe[2], Jessica Aviles[2], Divya Srinivasan[1,2*]
[1]Department of Bioengineering, Clemson University, Clemson, SC, USA
[2]Department of Industrial Engineering, Clemson University, Clemson, SC, USA
*Corresponding author's email: sriniv5@clemson.edu

Introduction: This study investigated if wearing a back-support exoskeleton (EXO) affects trunk kinematics during repetitive lifting and lowering tasks after extended exposure to an EXO designed to mitigate the high physical demands experienced during dynamic lifting tasks. Prior research has shown that EXO use in the workplace can reduce muscle activity and strain during manual material handling (MMH) tasks. However, they may also cause changes in movement patterns [1] [2]. Small changes in trunk angles while bending could significantly affect muscle activity levels, and excessive trunk flexion by itself has been shown to be a risk factor for developing musculoskeletal disorders (MSD) [1]. While prior work has shown that wearing an EXO may alter natural trunk movements, whether such changes in trunk kinematics represent an initial reaction to the novelty of the device or reflect altered and stable kinematic strategies in response to the effects of an EXO is currently unclear. Furthermore, if users are trying to find an optimal strategy to compensate for the EXO's effect on their body, increased kinematic movement variability may be indicative of such cases. Therefore, our research investigated kinematic adaptations to understand how individuals with different anthropometric and strength characteristics (e.g., males and females) respond to using EXOs over prolonged exposures. To this end, a commercial soft passive EXO, the Apex (HeroWear, USA) (weighing 1.5 kg), was selected for this study. We hypothesized that trunk kinematics and trunk kinematic variability (mean and cycle-to-cycle standard deviation (SD) of sagittal plane range of motion (ROM) and peak angular velocity) would be impacted by using the Apex, but that over time, users would adapt to the device, as indicated by stable kinematics (lower variability). This study also aimed to explore whether such adapted kinematics would return to baseline (no EXO) patterns over time or show persistent differences from the baseline, indicating that users may have found a new 'optimal' way to work with the EXO.

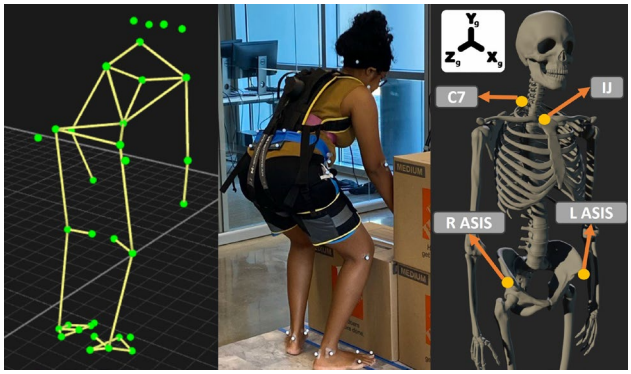

Figure 1: Shows an overview of the task, experiment setup, and the anatomical landmarks used to define the trunk segment.

Methods: A gender-balanced pool of participants (N=8), aged 18–31 years, with no prior EXO experience and no history of MSDs were recruited. A within-subjects repeated measures experiment was conducted in an A-B-A protocol: no exoskeleton (noExo), followed by EXO exposure, and then noExo. During the EXO exposure (lasting 90 minutes), assessments were recorded at the beginning, middle, and end of the exposure (exo1, exo2, exo3). During assessments, participants were tasked with performing repeated two-handed lifting of a box from ~30 cm above the floor to waist height in the sagittal plane (Fig. 1). The assistance level of the device was fixed at the medium level across all participants to reduce the confound effects of differing assistance levels. Kinematic data was recorded with 12 Arqus cameras at 100 Hz (Qualisys, Sweden). Outcome measures included the means and cycle-to-cycle SD of peak trunk flexion/extension angles ($Peak_{Flex}$, $Peak_{Ext}$), trunk ROM, peak trunk flexion/extension angular velocity (peakFlexVel, peakExtVel), and time to reach peak trunk flexion angle (normalized to task duration). A two-way repeated measures ANOVA was conducted for both lifting and lowering portions of the task with EXO exposure and gender as independent variables.

Results & Discussion: As hypothesized, for both lifting and lowering, there was a significant reduction in $Peak_{Flex}$, ROM, as well as peakFlexVel and peakExtVel with EXO use (i.e., exo1 compared to noExo, $p < 0.0001$ for $Peak_{Flex}$, ROM, and peakExtVel, $p = 0.0011$ for peakFlexVel). There was also a significant GEN × EXO interaction: females showed a greater reduction in trunk $Peak_{Flex}$ and ROM as well as peakFlexVel than males when using the EXO (e.g., females showed ~21% change in Peakflex from noExo to exo1, while males showed a ~2% change). These effects did not fade with time: changes of exo3 (last EXO exposure) with respect to control (noExo) continued to be significant for all the measures reported above. However, contrary to our hypothesis, the cycle-to-cycle SD did not vary significantly with EXO use. Although preliminary, these results suggest that the reduction in trunk flexion when using the passive EXO is not only an initial reaction but persists through a 90-minute exposure with an EXO. These changes observed in trunk movement during lifting/lowering (which were more pronounced among females) could be because of more squat-like postures adopted by users. Given gender differences in strength and the fact that we made the assistance level uniform across all users, the female participants may have perceived more resistance when bending (due to the elastic bands), which may have caused them to reduce trunk flexion angle and velocity. Nevertheless, this may be a positive effect of the EXO, as reduced trunk flexion during lifting/lowering loads can decrease the biomechanical loading on the lumbar spine.

Significance: Our research shed light on kinematic adjustments associated with prolonged exposure to a soft passive EXO during MMH. Further exploration is needed to understand and enhance EXO use within workplace health and safety protocols.

References: [1] Kermavnar et al. (2021), *Ergonomics* DOI: 10.1080/00140139.2020.1870162; [2] Schwartz et al. (2023), *Int. J. Environ. Res. Public Health* 20, 6468; [3] M. Gorsic et al. (2022), *J Biomech* 126 (110620).