Effects of Back-support Exoskeletons on Task Performance and Usability During Simulated Construction-relevant Tasks

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Work-related musculoskeletal disorders (WMSDs) continue to be a major health problem in the construction industry (Bureau of Labor and Statistics, 2018). The back was the most affected body part, with a rate of 21.5 per 10,000 full-time workers (Bureau of Labor and Statistics, 2018). Epidemiological studies attributed the high rate of back WMSDs among construction workers to high physical demands, involving forceful exertions, repetitive motions, and non-neutral and/or static body postures (Entzel et al., 2007; Hess et al., 2010).

Back-support exoskeletons (BSEs) are designed to support or augment the low back region, and can be categorized as rigid or soft BSEs; BSEs have clear efficacy in reducing back muscle activity and metabolic demands during laboratory simulated tasks such as static holding (Bosch et al., 2016; Koopman et al., 2019), assembly (Madinei et al., 2020), and repetitive lifting (Abdoli-E et al., 2006; Alemi et al., 2019). However, BSE use can reduce task performance and increase perceived task difficulty in some cases (Baltrusch et al., 2018; Madinei et al., 2020). The aim of this study was to provide specific evidence on the effects of different BSEs during several basic construction-relevant tasks.

A convenience sample of 17 (10 males, and 7 females) novice participants completed the study in a laboratory environment. A variety of tasks relevant to the construction industry were simulated in a laboratory environment to represent likely tasks that a worker would perform while wearing a BSE at a construction site, and in which wearing a BSE could have adverse effects.

The *Task* conditions simulated were both quasi-static and dynamic. Quasi-static tasks included: squatting; three-point kneeling, manual assembly at two heights above the ground, and shoveling. Dynamic tasks included: stair climbing, ladder climbing, material handling (box stacking), workspace maneuvering (through a stud wall, climbing on a scaffold, traversing through a window opening, figure-8 walking, walking on a pitched surface (15 and 30º slopes), and walking on a narrow beam.

Tasks were completed with four levels of *Intervention* – no BSE (ND), and three BSEs with distinct designs: backX^{TM} model S (BX), Paexo Back (PB), and HeroWear Apex (HW). The BSEs were tested in two *Support Settings*, both "on" and "off". A randomized incomplete block design with block size = 3 was employed, in which participants performed the 18 *Task* conditions with ND and two of the BSEs.

For each task, a digital stopwatch was used to record completion time as a measure of task performance. Upon completing each task, participants were asked to rate the usability of a given BSE using 10-point scales. Specifically, participants were asked to indicate: perceived ease of donning and doffing a BSE; how much physical effort was required to complete a task; discomfort; movement restrictions; feelings of safety; interference with performing a task; and sense of imbalance. In all cases, ratings of 10 corresponded to "worse" responses (e.g., extremely difficult, extreme discomfort, extreme effort).

Separate analyses of covariance (ANCOVAs) were performed to test the effects of *Intervention* and *Task Condition* on the outcome measures. For each measure, the baseline (ND) result was included as the covariate. Significant effects were followed by Tukey's HSD pairwise comparisons and simple effects testing where relevant. Parametric model assumptions were verified, and statistical significance was determined when $p < 0.05$.

Task completion time was significantly affected by the *Intervention* x *Task* interaction (p=0.0007). Compared to the baseline, using the BX, PB and HW led to significantly longer completion times during "box stacking low" task, by 18%, 22% and 18%, respectively. Using the three BSEs also led to increases in completion time in the low ceiling crawl, by 17%, 23%, and 9% respectively, compared to the ND. Similarly, completion time for scaffold climbing increased by ~31% with BX use, ~34% with PB use, and ~13% with HW use. Lastly, BX and HW significantly increased completion time by ~13% during shoveling.

Intervention x *Task* interaction effects were significant on perceived physical effort (p<0.0001), discomfort (p=0.015), and task interference (p=0.0018). During scaffold climbing, PB use increased perceived physical effort by ~36%. During shoveling, perceived effort decreased by ~18% with BX use, yet increased by ~15%-18% with PB and HW. Further, HW use decreased perceived effort by ~29% in the window walk task, while PB use increased by ~19%. Discomfort increased by ~56% with PB use during scaffold climbing.

PB use caused significantly higher perceived task interference during box stacking low, scaffold climb, and stud wall, compared to BX and HW use. In general, participants reported significantly lower interference ratings when using HW vs. the other BSEs during scaffold climbing, window walk, and stud wall tasks.

In summary, we investigated the effects of three different BSEs (two rigid devices and one soft) on task performance and usability during simulated construction tasks. Our results indicate that the use of BSEs increased task completion times in some of the simulated task conditions. These increases were typically <5sec, or 10-25% of the total completion time for a given task. Since most of the simulated tasks would be completed only infrequently in practice, it is unclear if these increases are practically important. Also, each BSE had distinct and task-specific effects on subjective outcomes. Future research is needed to better understand the generalizability of different BSE designs as they pertain to construction tasks and to better predict both the beneficial and adverse effects of different BSEs for diverse construction tasks.

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