EPiC Series in Built Environment

Volume 2, 2021, Pages 10–17

ASC 2021. 57th Annual Associated Schools
of Construction International Conference

Subjective Evaluation of Passive Back-Support Exoskeleton for Flooring Work

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Work-related musculoskeletal disorders are a major concern in the construction industry. The back is the most commonly affected body part, accounting for about 43% of construction cases. To reduce back loading, exoskeletons has been introduced in the workplace. Back-support exoskeletons are potential interventions to reduce physical demands on the back. Successful application of the exoskeleton will require an assessment of user acceptance and comfort with the device. The objectives of the study were to capture subjective evaluations of the impacts of exoskeleton use, including usability and discomfort. The participants perceived the exoskeleton as user-friendly, by providing moderate-to-high ratings of ease-of-use and ease-of-learning, and reduced time for donning and doffing. Using the exoskeleton reduced discomfort in the lower leg, lower back, and thigh by 28%, 21.74%, and 3.13% respectively, suggesting the potential of the exoskeleton for reducing low back injuries amongst floorers. However, an increase of discomfort in the chest region (111.11%) reveals the unintended consequence of the exoskeleton. Overall, the exoskeleton has the potential of being accepted as an intervention for flooring work. Future work is needed to better assess the exoskeleton among actual construction workers.

Key Words: Passive exoskeleton, Usability, Discomfort, Flooring

Introduction

The health and wellbeing of the workforce have implications on the growth of any industry sector. The Construction industry, being one of the industries with the largest labor force in the United States (8% of the total workforce (BLS, 2019a)), has long suffered from productivity loss, premature exits of workers from the workforce and safety issues. A significant number of construction workers continuously suffer from non-fatal injuries and illnesses associated with work-related musculoskeletal disorders (WMSDs). Exposures to overexertion, bodily reaction (e.g., bending and twisting), and repetitive motion from construction activities are the main triggers of WMSDs and are responsible for about 30% of all lost workday cases among construction trades (BLS, 2019c). There is evidence of

T. Leathem, A. Perrenoud and W. Collins (eds.), ASC 2021 (EPiC Series in Built Environment, vol. 2), pp. 10–17

these exposures resulting in back injury or disorder, which is the most prevalent WMSD, reported by construction workers. In 2019, the incidence rate of back injuries in construction was about two times the rate in all industries (BLS, 2019b).

There is growing interest in wearable robotic technologies like exoskeleton, as a promising intervention for preventing WMSDs. Exoskeleton is a "wearable device that augments, enables, assists, or enhances motion, posture, or physical activity" (Billotte, Lowe, & Peterson, 2019). Exoskeleton originated from the military (Zoss, Kazerooni, & Chu, 2006) and rehabilitation (Jarrassé et al., 2014) fields and is rapidly gaining recognition in industrial settings such as manufacturing and construction. These robotic wearables are classified as active (or powered) and passive. In contrast with active exoskeletons, passive exoskeletons are lighter, cheaper, do not require external power source. Exoskeletons include back, upper limb and full body supports, designed to reduce physical demands on the back, shoulder, and multiple body muscles respectively, while preventing overexertion.

While exoskeletons provide assistive power to reduce risks to the body parts, the device needs to have sufficient usability and be comfortable to use, so that users can accept and be willing to adopt the technology. According to Davis (1989), user acceptance is influenced by perceived usefulness and perceived ease of use. Moreover, as a wearable device, the acceptability will also be influenced by the amount of discomfort experienced by the user (De Looze, Bosch, Krause, Stadler, & O'Sullivan, 2016). Early studies in other industry settings have shown that exoskeletons can increase the loading or cause moderate discomfort on some body parts. For example, using back support exoskeleton can cause some discomfort in the chest, waist, knee, and ankle during manual material handling work (Hensel & Keil, 2019; Kim, Madinei, Alemi, Srinivasan, & Nussbaum, 2020). Given the potential of back-support exoskeletons to prevent back injuries in construction, understanding its usability and unintended consequences could help inform future designs suitable for physically demanding construction tasks such as carpentry and flooring.

Floor layers are very susceptible to low back disorders as they spend a significant amount of their working time in a back bending position. In 2019, floor layers had about two times more lost work days than the general construction trade workers due to back disorders (BLS, 2019b). Yet, there is little evidence on user perception of the potential of back-support exoskeletons for construction tasks. Therefore, the objective of this study is to assess the effect of a commercially available passive back support exoskeleton on discomfort to the body parts and subjective usability for simulated floor laying task.

Methodology

Exoskeleton

This study employed a passive back-support exoskeleton (BSE) named Laevo V2.56, (see figure 1) designed to reduce the load on the back muscles during forward bending and repetitive tasks. The exoskeleton comprises of multiple torso fittings for adjusting to user's body structure. Laevo adopts a mass spring mechanism that functions by transferring load from the back during forward bending or lifting, allowing users to return to a safe upright posture. This is achieved through the chest and leg pads.

Participants

10 volunteer participants who are students of Virginia Tech were involved in the study and signed the informed consent approved by the Virginia Tech Institutional Review Board (IRB). The participants' demographic statistics in mean and standard deviation: age = 23yrs ± 1.99, weight = 155.70 lbs. ± 22.51 and height = 173.40 cm ± 4.97). The participants reported no current or prior musculoskeletal disorder or illness.

Experimental tasks

This study required participants to perform simulated flooring tasks in a laboratory setting. The simulated flooring task involved participants placing 20 flooring tiles in the form of wooden blocks in wooden frames (see figure. 2). While performing the task the participants were allowed to assume any comfortable posture (i.e., they were not restricted to a particular posture). Completion of the tile placement within each wooden frame represented a cycle, and participants were asked to perform six cycles. All cycles were performed with and without the use of the exoskeleton.

Procedure

Participants were introduced to the flooring task and were allocated 15 to 30mins to perform multiple cycles to make them comfortable with the flooring task. Subsequently, they performed the flooring task without the exoskeleton and were video recorded. After completing the tasks, the participants were provided with the Level of Discomfort (LOD) questionnaire to record their experience when performing the tasks without the exoskeleton and allowed to rest for 15 minutes to avoid any fatigue. Subsequently, participants were introduced to the workings of the Laevo exoskeleton and allowed to don and doff until they were confident to execute this without any external assistance. When comfortable, the participants performed the flooring task with the use of the Laevo exoskeleton. After completion of both the tasks, the participants provided feedback on their experience performing the flooring task with the use of the exoskeleton by filling out the usability and LOD questionnaires.

Figure 1. Laevo Exoskeleton

Figure 2. Setup for Simulated flooring task

Data collection and analysis

Data on the LOD and usability of the Laevo exoskeleton were collected using a structured questionnaire. The usability questionnaire was based on a 5-point Likert scale which varied from 1- Strongly Disagree to 5- Strongly Agree. This included a series of 16 user questions that were structured into three main criteria: ease of learning, ease of use, and comfort while using the exoskeleton. A separate questionnaire designed using the Borg CR10 scale (Borg, 2004) was employed for collecting data on the level of perceived discomfort of the participants during the experimental tasks. Participants provided ratings on the perceived LOD for eight body parts potentially impacted by the exoskeleton while performing the tasks. Participants' ratings of the LOD questionnaire varied from 0- 'Nothing at all' to 10 – 'Maximal'.

Collected data on the usability of the exoskeleton was analyzed using descriptive statistics such as mean, and standard deviation. The perceived LOD was analyzed using two-way ANOVA. The independent variables were the different body parts and exoskeleton conditions, and the dependent variable was the participants' ratings of the perceived LOD. Results from both questionnaires were separately plotted on bar charts to reveal the trend in the usability of the exoskeleton, and LOD across the different body parts.

Results

Usability

The usability of the exoskeleton was assessed based on ease-of-use (see figure 3), ease-of-learning (see figure 4), and comfort (see figure 5). Participants rated each of these factors based on the user questions provided in the usability questionnaire. To further assess the usability of the exoskeleton, participants were timed during the donning and doffing of the exoskeleton.

Ease-of-Use

Participants (N =10) used the Laevo Exoskeleton for performing the flooring task. The average rating (including the standard deviation) of ease-of-use was 3.4 (±0.4), which implies that participants moderately agree that the Laevo exoskeleton was easy to use. Results show that the participants could easily don and doff, and use the exoskeleton without assistance, 4 (± 0.8) and 3.9 (± 0.9) respectively (see figure 3). The average time to don and doff the exoskeleton was less than one minute (see figure 7). In addition, the rated effectiveness of the Laevo exoskeleton to 'make the task easier to accomplish', were rated below average, 2.9 (± 1.37). The participants moderately agreed that they prefer completing the tasks with the use of the exoskeleton 3.1 (± 1.2).

Ease-of-Learning

Similar to the ease-of-use, the average ratings (including the standard deviation) of ease-of-learning how to use the exoskeleton was 3.4 (± 0.8). Participants agreed that they could easily learn how to assemble and adjust the fittings of the exoskeleton and use the exoskeleton without assistance (see figure 4). When asked 'if a lot of prior knowledge was required before the effective use of the exoskeleton', participants disagreed 1.9 (± 1.3). Hence prior knowledge is not needed to use of the Laevo exoskeleton.

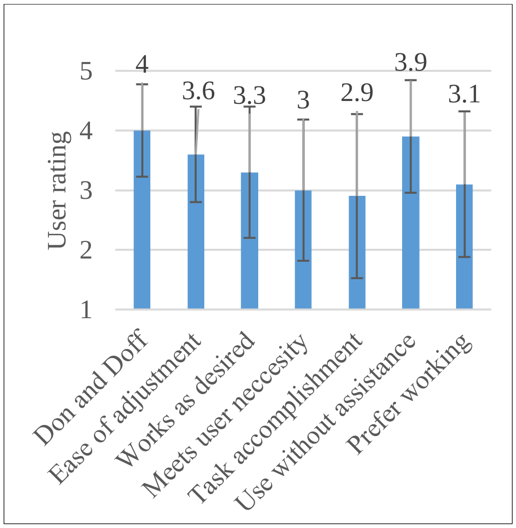

Figure 3. Ease of Use

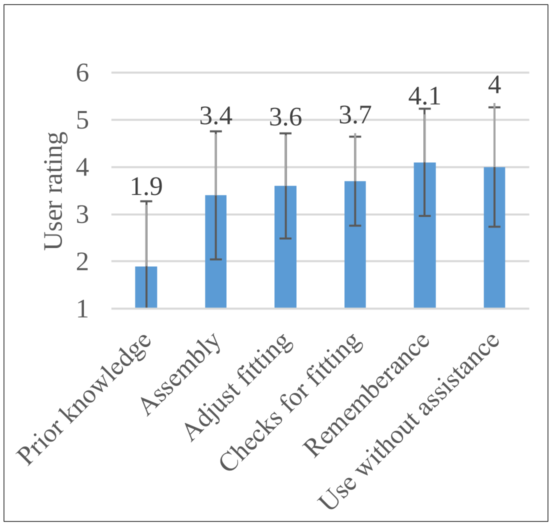

Figure 4. Ease of Learning

Comfort

The participants were asked if the exoskeleton restricted their movements and interfered with their work environment while performing the flooring tasks. They were also asked about their satisfaction with the use of the exoskeleton. The participants moderately agreed to these questions (average ratings of 3 (± 0.1)). When asked 'if the exoskeleton interfered with their work', the participants moderately disagreed 2.8 (±1.3). It can be inferred that Laevo exoskeleton posed minimal interference with the flooring task (see figure 5). However, results show that the Laevo exoskeleton restricted the participants' movements while performing the tasks (3 (±1.3)). Participants moderately agreed that they were satisfied with using the exoskeleton for flooring tasks.

Overall, the participants moderately agreed to the overall usability of the Laevo exoskeleton for flooring task. Although the comfort provided by the exoskeleton was rated lesser than the ease-of-use, and ease-of-learning of the exoskeleton (see figure 6).

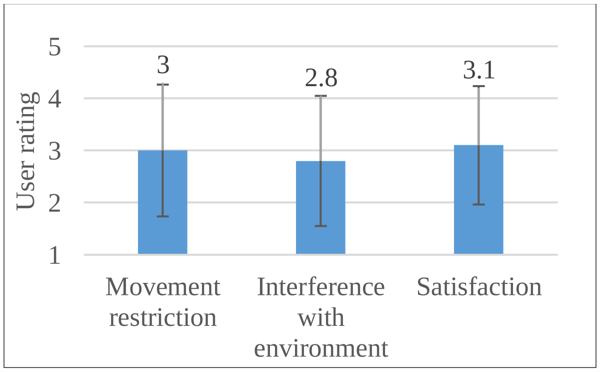

Figure 5. Comfort

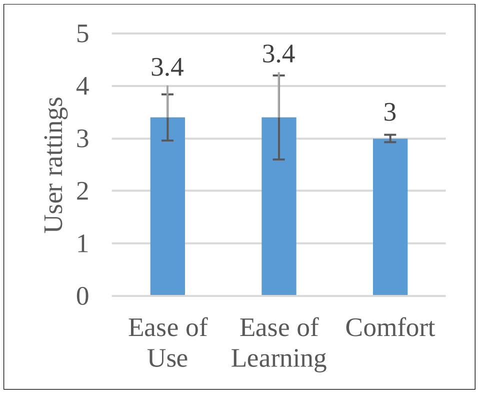

Figure 6. Overall usability rating

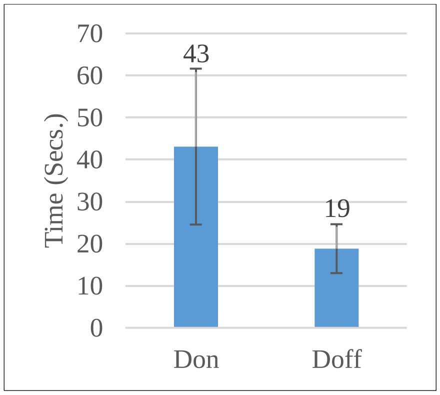

Figure 7. Donning and doffing time

Perceived muscle discomfort

Table 1 presents the Summary of the ANOVA ((Mean, F-Value, P-Value, and effect sizes (η^2)) performed across the different body parts and exoskeleton condition (see table 1). P-values with '*' have a confidence level < 0.05. Note that E = Exo Condition, and B = Body parts, while H= Hand/wrist, UA = Upper arm, S = Shoulder, LB = Lower Back, T = Thigh, N = Neck, LL = Lower leg, and C= Chest.

Table 1

Perceived discomfort of participants with and without Laevo Exoskeleton during flooring task

Outcome Measure		Body parts	Exo Condition	B X E
LOD	Mean	4.83	0.909	0.800
	F-value	12.51	0.222	0.451
	P-Value	6.30E-10*	0.649	0.866
	η^2	0.336	0.002	0.009

The perceived LOD was significantly different across the different body parts (see Table 1). More discomfort was perceived at the lower back and lower right leg, with the highest discomfort felt in the thigh. Results also reveal that the use of the exoskeleton reduced the discomfort in these body parts. Although a converse result was discovered in the chest region, as there was reportedly an increase in discomfort when the exoskeleton was used.

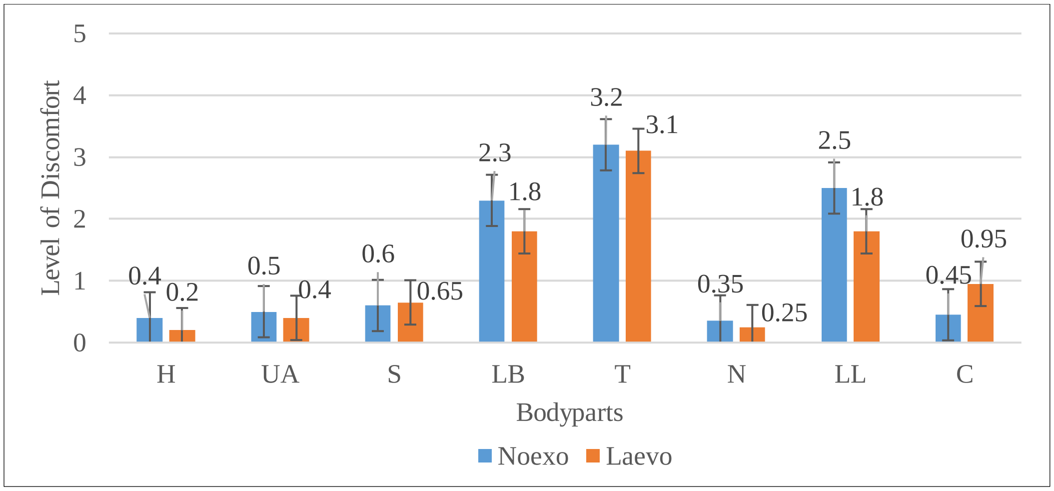

Figure 6. Perceived level of discomfort

Discussion

Owning to the high rate of musculoskeletal disorders in the industry, it is important to assess the usability of readily available exoskeletons for construction work. This study focused on understanding the perceived LOD and usability of using Laevo back support exoskeleton for flooring task. From the results of this study, it can be inferred that Laevo exoskeleton is user-friendly for executing flooring task. The high ratings of ease-of-use and ease-of-learning, and less time needed for donning and doffing further strengthens the assumption that Laevo can be easily used by the construction industry workforce.

However, participants were not convinced of Laevo's suitability for accomplishing flooring tasks, and averagely agreed that they prefer working with the exoskeleton. This may be related to the interference posed by the exoskeleton to the working environment, and the discomfort posed by the use of the exoskeleton. From the perceived LOD, the lower back, thigh, lower leg, and chest are the most affected body parts by the exoskeleton. It is however important to note that the use of the exoskeleton reduced discomfort in these body parts except the chest. The study revealed a 28% reduced discomfort in the lower back, and over 100% increased discomfort in the chest region. This implies that though the exoskeleton supports the lower back, but the mechanism of the exoskeleton poses a potential threat to the chest region. Although the Laevo exoskeleton is easy to use, and reduces discomfort in the lower back, lower legs, and thigh, the potential discomfort in the chest region may contribute to its unsuitability for the construction industry.

There were some limitations in this study that could affect the generalization of the results and findings. The participants were students who were unfamiliar with flooring tasks. Experienced floorers could have provided different ratings on the usability of the exoskeleton. In addition, this was a laboratory study conducted for a short duration and there is a possibility that the use of the exoskeleton for longer durations might affect the perceived LOD at the different body parts.

Conclusion

This study was aimed at understanding the potential acceptance of the passive back support exoskeleton for construction work. The results suggest that in terms of understanding the functioning and using the back-support exoskeleton, the Laevo exoskeleton was quite acceptable by the sample population. The reduced discomfort at the lower back further suggests that Laevo exoskeleton can assist in reducing back injuries amongst floorers. However, the exoskeleton posed movement restriction and interference with the work environment and this could affect the productivity of floorers. It can further be concluded that the use of the exoskeleton results in a high discomfort in the chest region. Although prolonged use of the exoskeleton may result in an overall reduced discomfort across all body parts. This study sets precedence for a long-term study to further understand the acceptance of passive exoskeleton amongst construction workers.

Acknowledgement

This material is based upon work partly supported by Construction and Infrastructure Research Affiliates Program (CIRAP).

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