Impact of Passive Back-Support Exoskeletons on Manual Material Handling Postures in Construction

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Abstract –

Work-Related Musculoskeletal Disorders (WMSDs) are a leading contributor to workplace injuries in the construction industry, with the lower back being the most affected body part. To mitigate WMSDs, exoskeletons have been developed and recently introduced to industrial job sites to provide workers with assistance and support, reducing exposure to ergonomic risks. Due to the newness of industrial exoskeletons, successful application of this technology in the construction industry requires thorough evaluation of different aspects of its adoption to ensure a successful and effective uptake. As Manual Material Handling (MMH) tasks are the most common cause of lower back injuries, this study aims to evaluate the impact of using exoskeletons when adopting different postures during dynamic and static MMH tasks. An experiment is carried out and data reflecting Rate of Perceived Exertion (RPE), Level of Discomfort (LOD), overall fit and comfort, effectiveness, and limitation and interference levels is collected. Overall, the participants perceived the exoskeleton suit as effective with discomfort being reduced in the lower back and other body parts except the chest. However, the results indicate the importance of considering the specific task at hand (e.g., dynamic vs static MMH) and the posture adopted (e.g., squat vs bend) when evaluating and selecting an exoskeleton for construction tasks.

Keywords –

Exoskeleton; Exosuit; Wearable Robot; Manual Material Handling; Ergonomics; Posture; Construction

1 Introduction

Manual material handling (MMH) involving lifting, carrying, pushing, pulling, lowering, restraining, and holding is the most common cause of occupational fatigue, lower back pain and lower back injuries [1], leading to high rates of Work-Related Musculoskeletal Disorders (WMSDs) in the construction industry, including 30% of all lost workday cases among construction trades in the US [2]. Recently, exoskeletons, also known as exosuits or wearable robots, are adopted for different industrial applications to mitigate the ergonomic risks associated with physically demanding tasks, especially the ones involving MMH. The use of exoskeletons for such physically demanding tasks have shown to reduce fatigue and the frequency of injuries [3].

Several advancements have been recently made in the development and evaluation of exoskeletons for the construction industry. In a review article, Zhu et al. [4] investigated existing exoskeleton technologies and analyzed their potential for MMH tasks in construction. They generated a map to suggest the appropriate exoskeleton type for each trade while evaluating the benefits and challenges. In another study, Cho et al. [5] designed a wearable exoskeleton to habituate construction workers to safe postures and demonstrated that the developed exoskeleton can effectively assist workers when performing construction tasks. Ogunseiju et al. [6] evaluated a postural assist exoskeleton and its effectiveness for construction tasks involving MMH. They reported improvements in posture when using the exoskeleton over time, although higher perceived discomfort in the lower back was reported due to the pressure applied to the users' back. In another study, Capitani et al. [7] described the development of a passive exoskeleton to assist construction workers in dealing with shotcrete projection tasks. They indicated that the designed exoskeleton preserved adaptability to different lower-limb tasks without reducing its comfort during utilization. Furthermore, Chen et al. [8] presented a bilateral knee exoskeleton to provide kneeling assistance for construction workers. The results showed reductions in knee pressure, potentially leading to decreased WMSD risk for workers when performing kneeling activities on level and sloped surfaces.

While previous studies have provided valuable insight into the potential of adopting exoskeletons in the construction industry, more research is required to evaluate the different aspects of the adoption due to the recentness of using the exoskeleton technology for industrial applications. As one of the important aspects of effective adoption of exoskeletons is the impact of using an exoskeleton on user posture, this study intends to evaluate the effect of a back support exoskeleton on postures adopted when carrying out MMH tasks.

The goal of this study is to compare different postures adopted during dynamic and static MMH tasks, with and without exoskeletons. The experiments are designed to provide feedback on the impact of using exoskeletons on comfort, fatigue, and usability factors, for both male and female users.

2 Methods

2.1 Experimental Design

As passive exoskeletons have shown to be more suitable for industrial applications compared to active exoskeletons due to lighter weight, lower price and simpler maintenance [2], a passive exoskeleton was used for the experiment. Furthermore, since the back is the primary body part affected by WMSDs in construction [9], a back-support exoskeleton was selected. Back support exoskeletons are designed to reduce the load on the low back muscles during bending tasks by redistributing the weight to the legs [10]. The backX exoskeleton was used which weighs 7.2 lbs and can reduce the strain on the user's lower back by an average of 60%.

The experiment was designed to simulate dynamic and static MMH tasks. Participants were asked to carry out the tasks in different scenarios to cover different task types (i.e., dynamic and static), postures (i.e., freestyle, bending, squatting), and the impact of the exoskeleton (i.e., with and without wearing the exoskeleton).

2.2 Participants

For this study, 12 healthy individuals, including 6 male and 6 female, were asked to participate in the experiment. The mean and standard deviation for the age, weight, and height of the participants were 28 ± 6.28 years old, 143 ± 33.87 lb., and 5' 6.8" ± 4", respectively. None of the participants reported any current or previous musculoskeletal disorder or illness. The detailed process including the objectives, instructions and possible risks were explained to each participant through written and verbal instructions and on-site discussions. Ethics approval was received for the study from the University of Alberta Research Ethics Board (Study ID: Pro00109264).

2.3 Testing Procedure

The variables of the experiment included freestyle, bending, and squatting lifting postures, existence of the exoskeleton, and the static and dynamic nature of the task. Dynamic MMH involved lifting, carrying, and placing a 20 lb. box multiple times, while each time lifting and placing on a surface with a different height (i.e., on floor and on a table). Static MMH involved moving items from a box and placing them on a table through a static posture.

Prior to the experiment, participants were introduced to the procedure and equipment. Participants were given enough time between each experiment to recover from any fatigue associated with the previous experiment. After completing each experiment, the participants were asked a series of questions including the Rate of Perceived Exertion (RPE), Level of Discomfort (LOD), overall fit and comfort of using the exoskeleton, the extent to which the exoskeleton limits movements and interferes with movements, effectiveness of the exoskeleton, and other general feedback. In total, seven scenarios reflecting different postures and the use of the exoskeleton were tested, as shown in Table 1. Figure 1 shows the experiment setup for some of the scenarios as a sample.

Table 1 Experiment scenarios

Category	Scenario	Trial Type
Dynamic MMH	D1	No Exo + Freestyle
	D2	Exo + Freestyle
	D3	Exo + Bending
	D4	Exo + Squatting
Static MMH	S1	No Exo + Freestyle
	S2	Exo + Bending
	S3	Exo + Squatting

(a) (b)

Figure 1. Experiment setup: (a) dynamic MMH,

bending with exoskeleton (scenario D3), (b) static MMH, squatting with exoskeleton (scenario S3)

2.3.1 Participant Response

The participants were asked to rate the level of their perceived discomfort (i.e., LOD) on a Borg CR 10 scale, where 0 indicates no discomfort and 10 shows maximum discomfort [11]. The intensity of perceived discomfort was measured and quantified after conducting each experiment. Furthermore, the participants provided the discomfort ratings separately for each body part including shoulder, chest, lower back, thighs, feet, etc. on a scale of 0 to 10. Also, RPE was rated from 1 (very light activity) to 10 (maximum effort), fit/comfort of the exoskeleton suit was rated from 1 (not satisfactory) to 10 (very satisfactory), limitation/interference was rated from 1 (limits a lot) to 10 (does not limit at all), and effectives was rated from 1 (not effective at all) to 10 (very effective). Collected data was explored through descriptive statistical analysis.

3 Results

3.1 Dynamic MMH

The reported RPEs for the dynamic task are shown in Figure 2. As shown in the figure, the average RPE for the different scenarios of the dynamic MMH is fairly close. Overall, it can be concluded that the existence of the exoskeleton and the posture used does not impact the average RPE. It is also worth noting that in cases where the exoskeleton was used, a maximum RPE of 6 was reported by users.

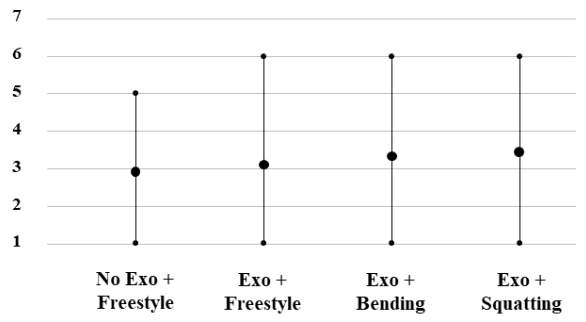


Figure 2. Reported RPE for dynamic MMH

For each scenario, the participants were also asked about the comfort and useability of the exoskeleton. In particular, they were asked to rate the overall fit and comfort level, the extent to which it limits movements and interferes with activities, and the overall effectiveness. The results are shown in Figure 3. The results indicate that the participants feel similar effectiveness in all postures, while they experienced more comfort during bending. Overall, the participants felt that the exoskeleton moderately limits their movements and can interfere with other tasks.

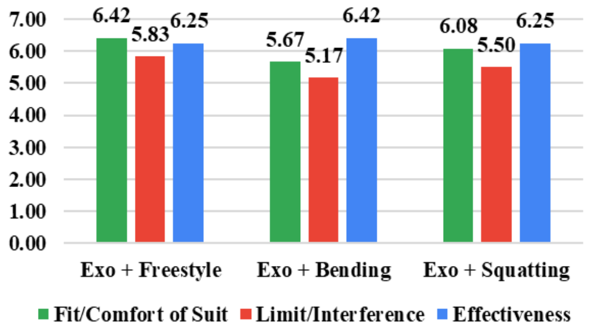


Figure 3. Reported usability for dynamic MMH

The reported body discomforts for the dynamic scenarios are presented in Figure 4. As shown, most of the perceived discomfort is detected in the lower back and legs. While using the exoskeleton substantially reduced the discomfort in the lower back during bending and squatting, using the exoskeleton with a freestyle posture did not have considerable impact in improving the discomfort. It is also observed that the perceived discomfort in legs is much higher when squatting compared to bending.

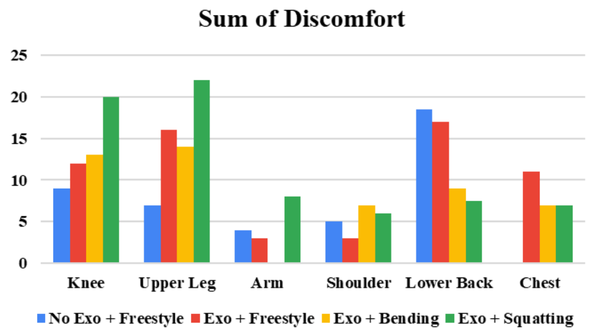


Figure 4. Perceived discomfort of body parts for dynamic MMH

3.2 Static MMH

The reported RPEs for the static task are shown in Figure 5. While minimum and maximum reported RPEs are similar for all scenarios, the average RPE is reported as slightly higher for squatting, which indicates the difficulty of performing the static task in a squatting posture due to the pressure applied to the legs and the need to maintain balance.

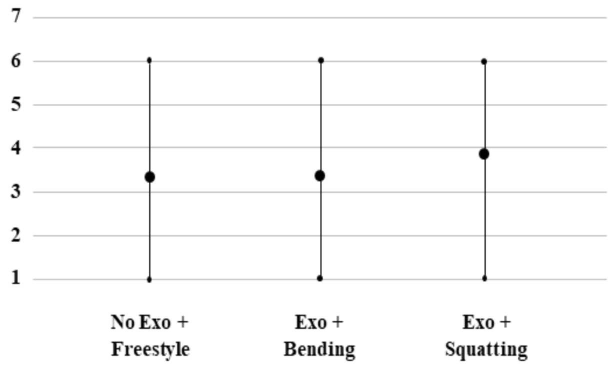


Figure 5. Reported RPE for static MMH

As shown in Figure 6, the overall effectiveness and comfort level is higher in bending compared to squatting. However, higher levels of limitation and interfering with other activities is also reported for bending.

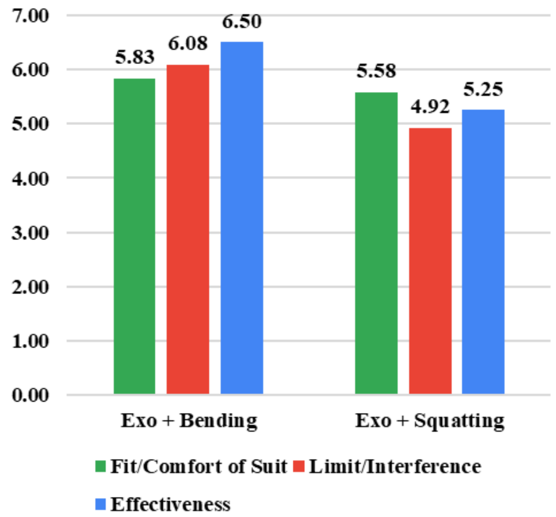


Figure 6. Reported usability for static MMH

Figure 7 demonstrates the reported discomfort for the static scenarios. Since the body is positioned in an awkward position for a prolonged period in the static task, the discomfort levels are generally high without the exoskeleton. Similar to the dynamic tasks, most of the reported discomforts are in the lower back and legs. The use of the exoskeleton has caused higher discomfort levels on the chest during bending, which is due to the existence of the chest pad. While the use of the exoskeleton has reduced the discomfort on the legs in bending compared to squatting, the discomfort in the lower back is much less in squatting.

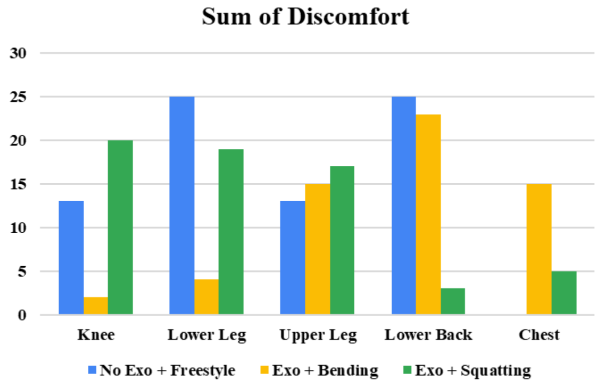


Figure 7. Perceived discomfort of body parts for static MMH

3.3 Dynamic vs. Static MMH

Figure 8 shows a comparison between the results for all scenarios of the dynamic and static bending tasks. While other factors remain the same, higher level of limitation is reported during static tasks. Overall, it can be concluded that the performance of the exoskeleton for bending is similar for both static and dynamic tasks.

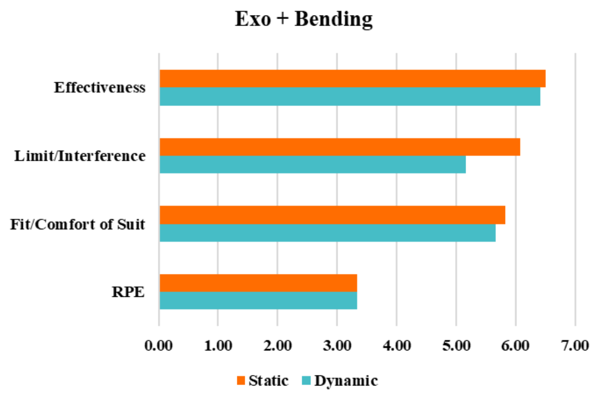


Figure 8. Comparison between static and dynamic scenarios for bending

Similarly, Figure 9 shows the comparison between the results for all scenarios of the dynamic and static squatting tasks. While the overall effectiveness and comfort is higher for dynamic tasks, the limitation level is reported slightly higher.

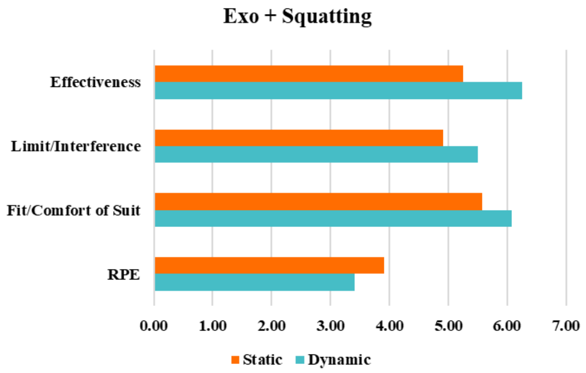


Figure 9. Comparison between static and dynamic scenarios for squatting

3.4 Male vs. Female

Figure 10 shows a comparison between the average RPEs for male and female participants for the dynamic scenarios. As shown, male participants reported a higher RPE in the dynamic scenarios compared to female participants. Also, the perceived exertion is similar for bending and squatting postures among both groups.

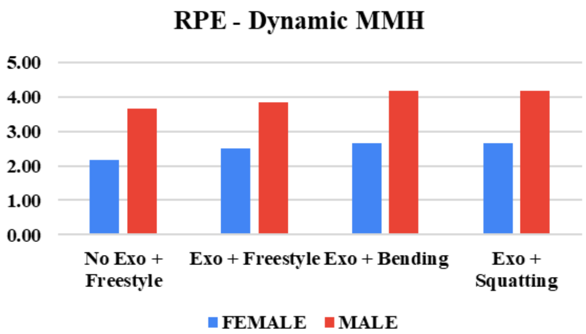


Figure 10. RPE comparison between male and female participants for dynamic scenarios

Similarly, Figure 11 shows a comparison between the average RPEs for male and female participants for the static scenarios. While both groups reported a slightly higher RPE in squatting compared to bending, male participants reported higher RPEs for all scenarios of static MMH. Using the exoskeleton did not improve the exertion levels when using the bending posture.

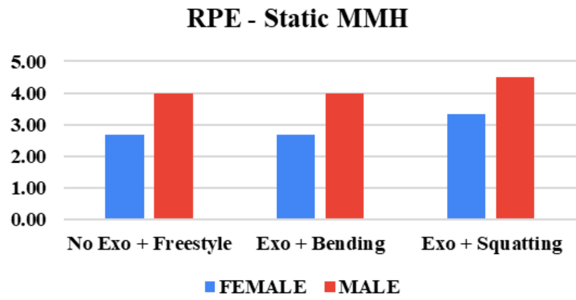


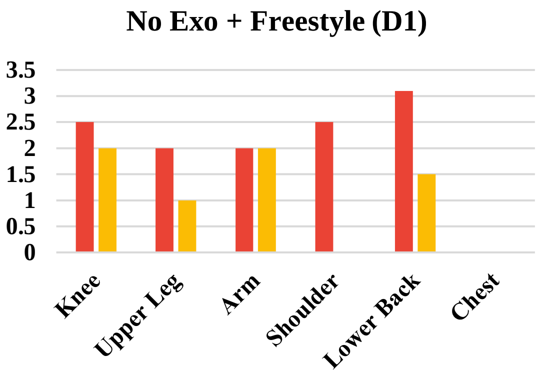
Figure 11. RPE comparison between male and female participants for static scenarios

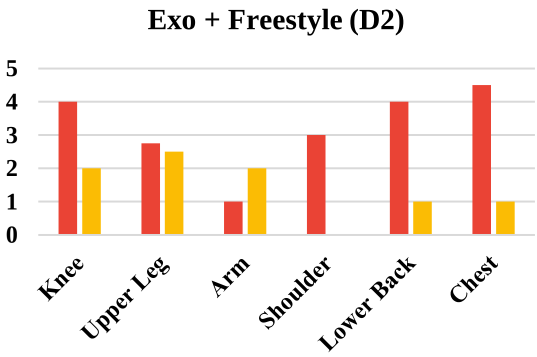
Table 2 shows a comparison of the average responses for the usability factors for male and female participants. As shown in the table, female participants found the exoskeleton more effective in all MMH scenarios, while both groups rated the fit and comfort level fairly similar. On the other hand, female participants rated the limitation factor of the exoskeleton higher than male participants.

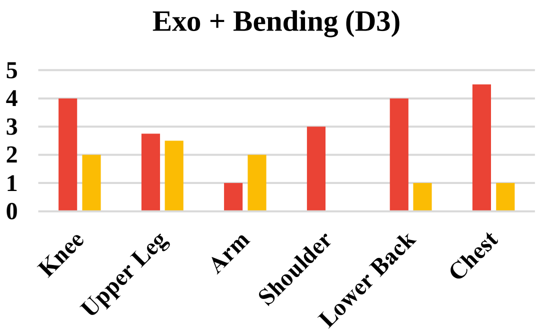
Table 2 Comparison of usability responses for male and female participants

Factor	Scenario	Female	Male
	D2	6	6.83
	D3	5.5	5.83
Fit/Comfort	D4	6.17	6
	S2	5.83	5.83
	S3	5.5	5.67
	D2	6.33	5.33
	D3	5.17	5.17
Limit/Interference	D4	6	5
	S2	6.83	5.83
	S3	4.83	5
	D2	6.83	5.67
	D3	6.67	6.17
Effectiveness	D4	7.17	5.33
	S2	7.17	5.83
	S3	5.83	4.67

Figure 12 shows a comparison of the LOD for male and female participants during different dynamic MMH scenarios. Male participants reported higher discomfort when carrying out the dynamic task without the exoskeleton (D1), with the highest discomfort on the lower back. When using the exoskeleton with a freestyle posture (D2), both groups reported discomfort in the chest area, with male participants reporting substantially higher LOD. During dynamic bending (D3), male participants reported most discomfort on the chest, lower back, and knees, while female participants reported the highest LOD on the upper leg and knees. The highest reported LOD during dynamic squatting (D4) belongs to the chest, lower back, and knees for male participants and upper leg, knees, and arms for female participants. While male participants reported discomfort on the shoulder in all dynamic scenarios, there were no reported LOD for shoulders by female participants. Overall, male participants reported higher LOD for all body parts except arms.







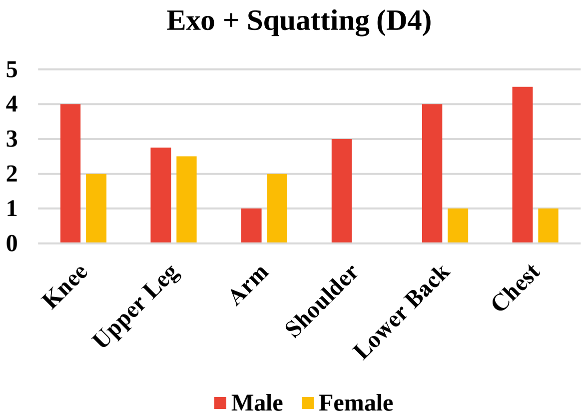
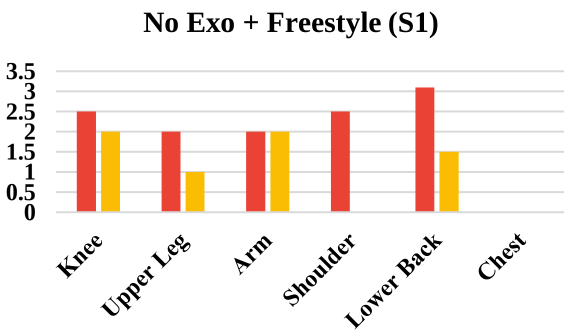


Figure 12. Comparison of LODs between male and female participants in dynamic MMH scenarios

Figure 13 shows a comparison of the LOD for male and female participants during different static MMH scenarios. When carrying out the static task without the exoskeleton (S1), male participants reported most discomfort on lower back, shoulder, and knees, while female participants reported the highest LOD on the arms and knees. The use of exoskeleton for the static bending task (S2) has resulted in higher discomfort in both groups, with male participants reporting highest LOD on the chest, lower back, and knees, and female participants reporting highest LOD on upper leg, knees, and arms. For static squatting (S3), male participants reported higher LOD in all body parts compared to female participants. Chest, lower back, and knees have the highest LOD among male participants, while upper leg, knees, and arms are the highest rated body parts for female participants. Both groups reported similar levels of discomfort in upper legs. Overall, similar to the dynamic MMH scenarios, male participants reported higher LOD for all body parts except arms for all static MMH scenarios.



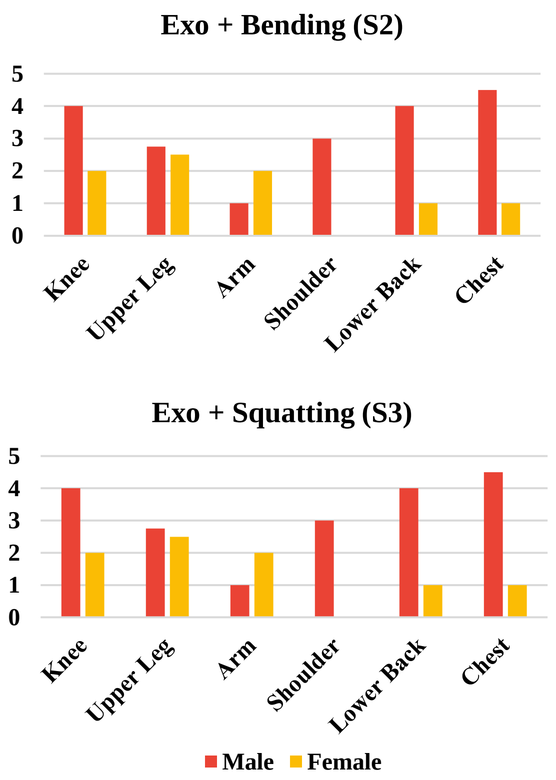


Figure 13. Comparison of LODs between male and female participants in static MMH scenarios

4 Conclusion

Emerging technologies such as exoskeletons have the potential to reduce the high rate of WMSDs in the construction industry. However, their adoption has to be evaluated from different aspects before introducing them to job sites, to ensure a successful and effective uptake. As MMH tasks are among the top contributors to WMSDs in construction, this study aimed to evaluate the impact of a passive back-support exoskeleton on different MMH postures. The results indicate that: (1) the impact of using the exoskeleton is similar for dynamic and static MMH tasks, while it is slightly less effective for squatting during static tasks; (2) using the exoskeleton impacts the level of perceived discomfort on different body parts especially the chest; (3) male participants experience higher discomfort on almost all body parts when wearing the exoskeleton compared to female participants; and (4) majority of the participants rated the exoskeleton suit as providing acceptable usability, while female participants found the suit more effective. According to the reported LOD, the lower back, knees, upper legs, and chest are the most affected body parts by the exoskeleton suit. Meanwhile, it should be noted that the use of exoskeleton reduced discomfort in the mentioned body parts except the chest.

Based on the results, it can be concluded that passive exoskeleton suits have the potential to be adopted to reduce the rate of WMSDs in construction. However, proper training and supervision is required on the postures adopted by the workers, based on the specific characteristics of the task that is carried out. It is important that exoskeletons are properly selected for the task at hand and is solely used for the identified task.

This study was limited in that the experiments were carried out for a short amount of time. Long-term trials are required to reflect on the impact of using exoskeletons on different factors more accurately. Furthermore, while subjective metrics can be useful for evaluation of exoskeletons from a usability perspective, the lack of objective measures limits the generalization of the analysis. Future studies should also include objective evaluation features [12] for a more comprehensive analysis. Furthermore, the findings of studies such as this one can be used in future studies to assist with improving the design of exoskeletons.

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