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EVALUATION OF AN ELASTOMER-BASED UPPER-LIMB EXOSKELETON DURING A SIMULATED DYNAMIC WORK TASK OVER A LARGE SHOULDER WORKSPACE

Leon Lauret[1], Brent J. Raiteri[1,2], Paolo Tecchio[1] and Daniel Hahn[1,2]

[1] Human Movement Science, Faculty of Sport Science, Ruhr University Bochum, Bochum, Germany
[2] School of Human Movement & Nutrition Sciences, The University of Queensland, Brisbane, Australia
Email: leon.lauret@ruhr-uni-bochum.de

ABSTRACT

Industrial upper limb exoskeletons are implemented to prevent musculoskeletal disorders to the shoulder caused by overhead working postures. While numerous studies showed benefits of upper limb exoskeletons for overhead work, it remains unclear whether an elastomer-based exoskeleton design impedes non-overhead working postures. This study therefore tested the Ottobock Paexo Shoulder over a large shoulder workspace from overhead to hip height with shoulder abduction and adduction. EMG and upper body kinematics were compared between not wearing an exoskeleton and three support settings, and muscle activity level heatmaps were used to visualize support differences in nine working postures. Upper limb muscle activity was significantly reduced with exoskeleton support in a 6-minute dynamic work task in positions away from the core, but there were minimal effects in adducted arm positions. Upper body kinematics remained unchanged with exoskeleton support. The results indicate that an elastomer-based exoskeleton is effective at reducing upper limb muscle activity over a large shoulder workspace. However, exoskeleton support is not useful in non-overhead working postures with a less abducted shoulder. Consequently, an elastomer-based exoskeleton could be recommended to potentially reduce shoulder work-related musculoskeletal disorders, given that an equal amount of time is spent with an abducted as an adducted shoulder.

Keywords: Industrial exoskeleton, shoulder workspace, EMG, upper body kinematics

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are a leading cause of work-related injuries in the industrial field and greatly affect worker well-being. Assistive devices, so-called exoskeletons, pose a promising solution for companies to reduce potential risk factors that lead to MSDs [1]. However, most upper limb exoskeleton studies [2,3] only examined exoskeleton support in overhead working postures, which do not represent a realistic shoulder workspace [4]. Therefore, the aims of this study were to evaluate a passive elastomer-based exoskeleton over a large shoulder workspace, and to construct a posture-specific support profile to help inform how exoskeleton support should be adapted for different work tasks [4]. We hypothesized that the elastomer-based exoskeleton design would have adverse effects when working below overhead.

2. MATERIALS AND METHODS

Bipolar surface EMG recordings (1000 Hz) of the upper trapezius, anterior and middle deltoid, and biceps and triceps brachii were recorded from eighteen participants (7 women) and their upper body kinematics were captured using an eight-camera Vicon motion capture system. Data were recorded during four conditions: 1) No support (NoEXO) when the exoskeleton (Ottobock Paexo Shoulder) was not worn; 2) no support when the exoskeleton was worn (EXO_{dis}); 3) moderate support (EXO_{mod}) when the exoskeleton supported 50% of the participant's calculated arm weight, and; 4) high support (EXO_{high}) when the exoskeleton supported 100% of the participant's calculated arm weight. During these conditions, participants completed two tasks with their dominant hand (2 left-handed participants) using a 1.5 kg cordless drill while their acromion was aligned with the second left column of screws. The first pattern task (PAT) required participants to drive each screw of a 6x6 matrix for 10 s in a predefined pattern without a break in between screws and ended with the first screw being driven again (Fig. 1, black line). The second mapping task (MAP) required participants to drive each screw of a 3x3 matrix for 10 s with a 30 s break in between screws (Fig. 1, purple circles).

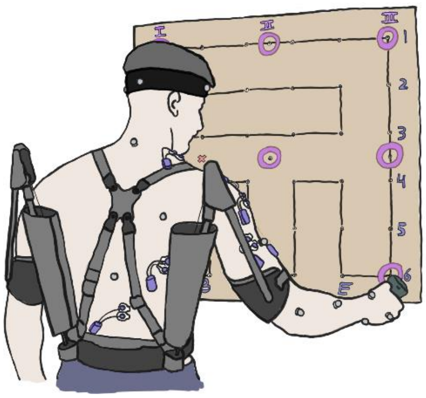

Figure 1: Experimental setup. A wooden board with a 6x6 matrix of screws was used for two tasks, during which upper limb EMG and kinematics were recorded. The pattern task (black line) took ~6 minutes to complete.

The mean EMG amplitude across all muscles (calculated as a 1000 ms root-mean-square amplitude) and shoulder and elbow angles were calculated post-testing. These outcome variables in EXO_{dis}, EXO_{mod}, and EXO_{high} were then compared with NoEXO over the first and last 10 s of PAT to investigate (1) immediate and (2) fatigue-dependent and/or learning-dependent effects with exoskeleton support, respectively. The EMG recordings during MAP were used to construct a heatmap to visualize differences in the exoskeleton's muscle support for different screw locations and arm positions. Differences were calculated as symmetrized percent differences relative to NoEXO. From the upper body kinematics, the pathlength of the most distal marker (finger marker) during the first and last 50 seconds of PAT was calculated and compared across conditions to determine whether exoskeleton support changed how people moved.

3. RESULTS AND DISCUSSION

A reduction in mean (±SD) summed activity of the upper limb muscles occurred during the first 10 s of PAT in EXO_{high} (-11.1±16.1%, p=0.011), but there were no significant differences relative to NoEXO in EXO_{dis} and EXO_{mod} (+1.9±7.6%, -0.5±13.0%, respectively, $p \geq 0.842$). Over the last 10 seconds of PAT, these effects persisted in EXO_{high} (-10.2±19.4%, p=0.002) and EXO_{dis} (3.0±12.3, p=0.984), but the reduction in EXO_{mod} relative to NoEXO became significant (-5.8±9.3%, p=0.036). The heatmaps generated from MAP (Fig. 2) indicate that the reductions in mean summed muscle activity occurred in arm positions with an abducted shoulder, whereas positions with an extended elbow showed smaller effects. Conversely, exoskeleton support had a limited effect on upper limb muscle activity in working postures close to the core.

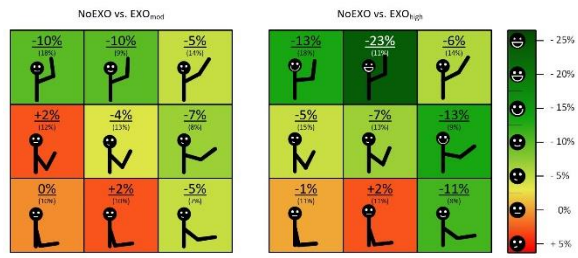

Figure 2: Heatmaps (N=18) for EXO_{mod} and EXO_{high} showing the mean (SD) differences in summed upper limb muscle activity relative to NoEXO at different screw locations during MAP (purple circles, Fig. 1).

The mean (±SD) pathlength was not significantly different between conditions (NoEXO 2831±353 mm; EXO_{dis} 2565±511 mm; EXO_{mod} 2724±383 mm; EXO_{high} 2643±353 mm; $p \geq 0.085$), which is consistent with previous studies [2,3] that showed no significant change in how people moved with exoskeleton support.

4. CONCLUSION

The passive elastomer-based exoskeleton reduced overall upper limb muscle activity in EXO_{high} throughout the dynamic work task, whereas this effect was only observed at the end of the task in EXO_{mod}. However, the mean reduction in muscle activity was not as large as compared with previous studies that assessed a smaller shoulder workspace [2,3]. The heatmaps indicate that this elastomer-based exoskeleton is only likely to be effective when working overhead and/or with an abducted shoulder. Exoskeleton support did not noticeably change how people moved during the dynamic work task.

REFERENCES

[1] De Looze et al. Ergonomics 59: 671-681, 2016
[2] Maurice et al. IEEE Transac 28: 152-164, 2019
[3] Schmalz et al. Int. J. Environ. Res. 16: 4792, 2019
[4] De Vries et al. IISE Transac 7: 311-321, 2019