Biomechanical evaluation of upper limb exoskeletons in automotive assembly using EMG

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Introduction

Injuries in the workplace are common among assembly workers in the automotive industry due to ergonomics of the worksite and performance of repetitive tasks. Especially problematic are overhead postures, where the worker performs most of the tasks with arms above the shoulders, increasing the risk of shoulder injury[1]. Indeed, shoulder injuries are the ones that result in the longest recovery time, resulting in a median of 23 days missed per injury[2]. All these facts show the necessity to adopt measures to reduce injuries and increase workers comfort. One solution could be to apply modifications on the worksite, but may be costly and not feasible. In such cases, passive exoskeletons can be useful to reduce shoulder loads.
Although there are several exoskeletons for the industry sector available on the market, few independent studies have been performed to objectively evaluate their benefits. Gillette et al.[1] reported significant reductions in deltoids, biceps and erector spinae over a study with Toyota workers. They also concluded that exoskeleton benefits were highly influenced by the workplace, task to performance, weight to move and repetitions.
The main purpose of this work is to study the application of industrial passive exoskeletons in companies of the automotive sector, specifically under-floor (UF) workers from Nissan Motor Iberica SA (NMISA) plant at Zona Franca in Barcelona. Biomechanical functional evaluation tests have been performed to document the real benefit that the use of these exoskeletons would bring in the reduction of efforts registered in certain muscle groups, which are related to the risk of musculoskeletal injury. EMG signals have been used to test three different exoskeletons in the assembly line.

Materials and methods

Eight workers, six men and two women, of UF workstations at NMISA factory participated in the study. Workers were excluded if presented a musculoskeletal pathology in the last year. Approved informed consent was obtained from all participants. Results from worker 4, due to workspace limitation, and worker 5, because of the tasks performed, were omitted.
Six different stations have been analyzed respecting the working shifts between programmed line stops. Trials with and without exoskeleton took 50 minutes, which is the time that takes the shortest shift. In all selected workplaces, it was needed to work with the arms raised over the shoulder level (50-60% of the task cycle) adopting a non-ergonomic position. The tasks performed ranged from putting plugs or connecting cables, bearing no load; to assembling plates and other pieces on the vehicle floor, bearing both the weight from the piece and from the assembling tool.
Three different passive upper limb exoskeletons were tested: Levitate AIRFRAME®, Skelex 360® and SuitX ShoulderX®. In order to prevent factors such as fatigue or the time of day from influencing the results, the order in which the trials with and without the exoskeletons were performed was randomized.
Two portable surface electromyography (EMG) devices (Biometrics Ltd. 8 channels Datalog MWX8) with 16 superficial bipolar silver/silver chloride electrodes (Biometrics Ltd. SX230) were used to measure muscle activity. EMG was recorded in the following muscle groups: Pectoralis major, abdominal internal oblique, abdominal external oblique, rectus abdominis, deltoids, biceps, triceps, upper trapezius, cervical erector spinae, latissimus dorsi, erector spinae longissimus (lumbar) and biceps femoris. The electrodes were placed following the SENIAM criteria[3]. Maximum voluntary contraction (MVC) was recorded for all the muscles. From raw EMG signal, spikes were removed, through deleting anomalous peaks. Then, DC offset was eliminated by centering the signal at its average value. Then, signal was filtered using a band pass filter (5Hz-400Hz) and rectified. Finally, signal was smoothed through a low-pass filter at a cut-off frequency of 3Hz. Once the signal was processed, MVC value of each muscle was calculated. Subsequently, the signal of the different tests was normalized by means of the previously calculated MVC values.
The highest 50% of EMG amplitudes, average of 50 percent of the highest values, were determined per each duty cycle. These variables allow to get an indicator of how much activated the muscles are during the periods of maximum contraction within the task[1].
Given the non-normality nature of the data, Wilcoxon signed rank test, was used to find statistically significant differences between wearing and not wearing an exoskeleton. Each of the three exoskeletons, for each muscle, are compared to the case without exoskeleton.

*Table 1: Maximum 50% EMG amplitude (** p<0.05, * p<0.1)*

(%MVC)	Maximum 50% EMG Amplitude			
	Deltoid	Biceps	Trapeizus	Erector Spinae
Without	11.26 ± 4.9	7.8 ± 2.4	18.1 ± 7.5	9.09 ± 1.2
Levitate	**8.1 ± 3.3****	7.5 ± 2.4	**13.7 ± 7.0****	9.12 ± 1.8
Skelex	6.5 ± 2.8*	7.8 ± 2.6	**13.9 ± 6.1****	10.03 ± 1.5
SuitX	**8.2 ± 3.4****	7.4 ± 2.4	**12.3 ± 7.0****	8.48 ± 1.5

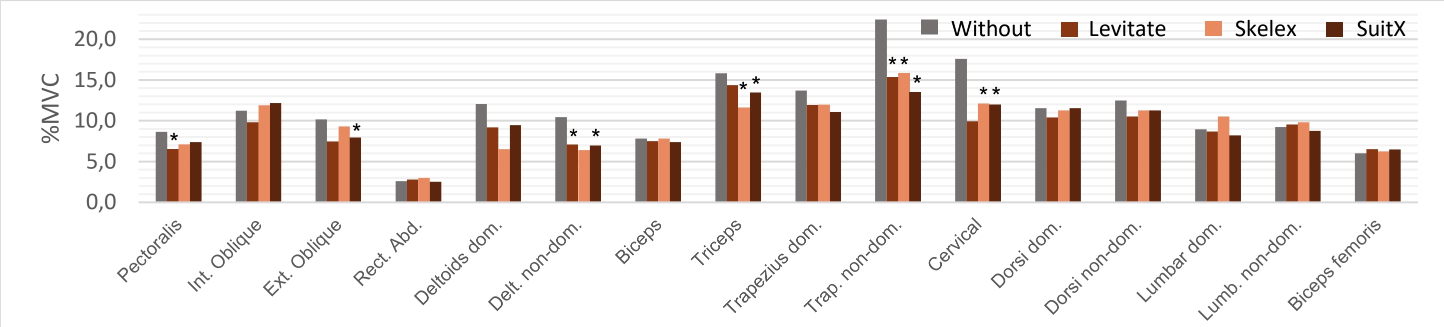

Figure 1: Bar chart with the overall results. Statistically significant differences(p-value<0.05) are starred with an asterisk.

Results

The mean activation of the muscles for all participants included in the study, is presented in Figure 1. Significant differences (using p-value<0.05) have been highlighted with an asterisk. Significant reductions of activation were found for non-dominant deltoid, using Levitate and SuitX, although Skelex showed a larger mean reduction. It was also observed that non-dominant upper-trapezius was the muscle that exerted a higher effort (above 20% of the MVC when not wearing exoskeleton) and that significant reductions were achieved with all three exoskeletons (reducing up to the 15% of the MVC). Important reductions in cervical muscles were also observed, with significant results for Skelex and SuitX. Finally, significant reductions in triceps were found through the use of SuitX and Skelex. Additionally, despite their lack of statistical significance, reductions in pectoralis major (except for Levitate), non-dominant longuissimus dorsis, dominant deltoids and dominant upper-trapezius were observed. Concerning the lumbar muscles and biceps femoris, a slight increase (non-statistically significant) was seen for Levitate and Skelex, while is minor for SuitX.

Maximum 50% of the four most relevant muscles, regarding the use of shoulder exoskeletons: deltoids, biceps, erector spinae and trapezius, has been reported in table 1. In this case, dominant and non-dominant muscles have been averaged, except for the biceps where only the dominant side was recorded. Significant differences with a p-value<0.1 have been starred with an asterisk and, for a p-value<0.05, with two asterisks and bold numbers. It can be concluded that deltoids and trapezius reduce significantly their activity when using any of the three studied exoskeletons.

Discussion

Significant reductions in deltoids activation were found while wearing any of the three studied exoskeletons. These results, which are in accordance with Gillette et al.[1], make possible to ensure that passive upper limb exoskeletons assist deltoid muscles and, hence, can be useful to prevent injuries in the shoulder area.

However, discrepancies were found in some muscles when comparing with Gillette et al.[1]. For instance, in the present work activations showed a reduction in upper-trapezius and an increase in lumbar muscles when wearing exoskeleton, whereas Gillette et al. obtained the opposite result. Regarding biceps, no differences were observed in our work, but Gillette et al. stated significant small differences (1% of MVC) for this muscle. These discrepancies can be due to the heterogeneity in the tests. In Gillette et al., the exercises were standardized and subjects performed the same vehicle assembly tasks, while in our study workers performed their habitual workplace tasks (including non-aerial tasks). Given the high intrinsic variability of the tests, it was more difficult to obtain statistical significance in our results. Nevertheless, it allowed to study a wider range of situations and draw conclusions beyond aerial tasks.

This variability on the workers and workstations was even more prominent when sorting the exoskeletons for each worker according to their reflected overall results in muscle activation reduction, adding special emphasis on deltoids, upper-trapezius and lumbar muscles. It was noticed that for each subject the order varies, so it can be stated that each mix of worker and workstation was better adapted to a different exoskeleton. Moreover, the use of exoskeletons was assessed and found recommendable for most of the subjects.

Although significant results consistent with the literature were found, it is important to bear in mind the study limitations: a small sample size that reduced the statistical power, and heterogeneity on the tasks that increased the variability of the study.

Conclusions

Upper limb exoskeleton assistance while performing aerial assembly tasks was assessed through analysing EMG data. The results, which show great reductions in muscle activity at the shoulder area, up to 40% in deltoids in average, illustrate that the studied exoskeletons may be useful for preventing injuries in UF tasks, such as the ones analysed in this work. Indeed, workstations with more aerial tasks (which imply higher shoulder flexion angles) obtained even better results, achieving reductions in the deltoids activation above 65%. Finally, regarding the three exoskeletons tested, it was found that each of them adapts better to a specific worker and workstation.

Acknowledgments

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References

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