Analysis of the relief of the lumbar spine by different back-support exoskeletons during lifting and holding

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Summary

The aim of this study was to determine the effect of one active (A1) and two passive (P1 and P2) back-support exoskeletons (BSEs) during lifting and holding of a 10 kg load. Kinematic data and erector spinae (ES) muscle activity (EMG) were recorded from 12 subjects with and without a BSE. During dynamic lifting, all BSEs reduced peak L5/S1 extension moments (12-26%), calculated by invers-dynamics. The peak EMG activity of ES was reduced accordingly (13-28%). In the static holding task, analogous reductions of mean L5/S1 moments (12-20%) and EMG activity (16-23%) were found for P1 and P2. However, A1 showed a greater reduction during static holding for extension moments (46%) and EMG activity (54%).

Introduction

In recent years, the number of commercially available industrial exoskeletons has increased substantially. Most previous studies gathered either only EMG data and were focused on passive BSEs [1].

The objective of the present study was therefore to include multiple exoskeletons (one active, A1, and two passives, P1 and P2) in the investigation and to assess their impact on L5/S1 joint moments and erector spinae (ES) activity during lifting and holding of 10 kg. It was hypothesized that a BSE-specific but activity-independent support effect could be observed for passive systems. Conversely, a more task-specific support effect was expected for the active system.

Methods

As part of a laboratory study 12 subjects (6 m, 6 f; height: 1.77 ± 0.08 m; weight: 70.0 ± 11.4 kg; age: 25 ± 2 years) performed dynamic lifting (5 repetitions of freestyle lifting in front of the body) and static holding (20 s in 45° torso forward bend with legs extended) of a 10 kg load weight. Activities were performed in a randomized fashion under NoExo, A1, P1 and P2 conditions.

Full body 3D-motion capture (12 Cam, Vicon Nexus) of the subjects and the BSE was conducted at 100 Hz and used to calculate L5/S1 extension moments via inverse dynamics in accordance with the Plug-in Gait Standard. A 4-channel sEMG of the ES was recorded at vertebrae levels T11/12 and L2/3 at 1000 Hz.

For lifting and holding the mean and peak values for the lumbar extension moments and muscle activity were analyzed with separate 2-way mixed analysis of variance (ANOVA) with the factors subject (random effects factor) and exoskeleton (fixed effects factor). The level of significance for all tests of $p < 0.05$ was used.

Results and Discussion

During the dynamic lifting task, the mean peak L5/S1 extension moments for NoExo were 1.76 ± 0.16 Nm/kg. The analysis of the EMG data revealed peaks in muscular activity of 39.9 ± 9.5 %MVC. The application of exoskeletons A1 and P1 resulted in an average reduction of the maximum L5/S1 extension moments of 15% ($p < 0.01$) and 11% ($p < 0.01$), respectively. A reduction of 22% ($p < 0.01$) was observed for P2. Maximum ES muscle activity during lifting was also significantly reduced with all systems (A1: 32%; P1: 13%; P2: 17%, $p < 0.01$).

During the holding task, average L5/S1 extension moments were 1.41 ± 0.15 BW, and the average ES activity was 20.9 ± 4.9 %MVC for NoExo. Comparable reductions in L5/S1 extension moments were observed for both passive systems, with a 12% reduction ($p < 0.01$) for P1 and a 20% reduction ($p < 0.01$) for P2. A greater reduction of 41% ($p < 0.01$) was observed for A1. The muscle activation data exhibited a comparable pattern, with a reduction in mean ES EMG amplitude for P1 of 23% ($p < 0.01$) and P2 of 16% ($p < 0.01$), and a greater reduction by A1 of 54% ($p < 0.01$).

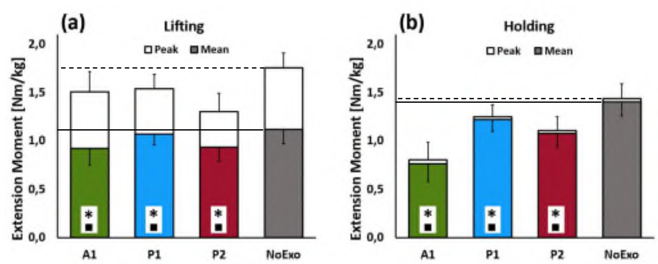

Figure 1: Comparison of peak and mean L5/S1 extension moments, during lifting (a) and holding tasks (b) between Exo and NoExo condition. Colored bar plots represent mean and stacked white bars peak values. T: 1 SD; peak(∗)/mean(■): p<0.05 (adapted from [2]).

Conclusions

The results confirm our hypothesis. The passive exoskeletons showed a support effect that was mostly unaffected by the activity. The active system in contrast showed a greater reduction for the static task. It can therefore be concluded that the task-specific fit of different exoskeleton types should be regarded in their analysis.

References

[1] Kermavnar, T et al. (2021). *Ergonomics*, **64**: 685-711.
[2] Johns, J et al. (2024). *J. Biomechanics*, **168:** ; 112125.