Scientific evaluation of the HAPO CS exoskeleton dedicated to trunk bending tasks

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SUMMARY

Low back pain commonly refers to pain in the lower back. It affects millions of workers worldwide (nurses, logisticians, craftsmen, etc.). This pain is often a symptom of underlying musculoskeletal conditions, typically caused by excessive strain on tissues and joints. One approach to reducing strain involves using non-motorized exoskeletons, particularly in situations that require trunk bending. In this study, 15 participants (8 women, 7 men) performed two tasks, with and without an exoskeleton. The first task involved holding the trunk in a 40° bend relative to the vertical, and the second involved lifting a load 10 times. The results showed a reduction up to 14% in back muscle activity and a decrease in perceived discomfort, especially in the lumbodorsal area. Kinematic analysis showed no change in trunk and knee flexion angles, suggesting that the observed benefits in muscle activity can be solely attributed to the use of the exoskeleton. Ultimately, the results support the potential of the HAPO CS exoskeleton in reducing the risk of developing low back pain at work.

Keywords: Low back pain, Exoskeleton, Back assistance, Adaptability to men and women

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are a group of conditions affecting the joints, muscles, and tendons, representing a major public health and workplace performance issue. A report from the European Agency for Health and Safety at Work highlighted that 3 out of 5 workers are affected by MSDs.[1] In France, these conditions are the leading cause of recognized occupational diseases, accounting for 88% of cases in 2019, or 44,492 cases. A study conducted on the French active population showed a high proportion of back MSDs, affecting both women (48%) and men (42%).[2] This study also emphasized the prevalence of this issue in two key sectors: manufacturing industry for men and the human health and social work sector for women. In the United States alone, 56,360 cases of MSDs were recorded in the health sector in 2018.[3]

The causes of MSDs are multiple, but manual handling of loads, especially patients, is a major factor. For example, a 2008 study showed that 79% of nursing assistants handle heavy patients (weighing over 100 kg) daily, with an average of 11 patients lifted per day.[4] This issue has significant repercussions for employees, who suffer from chronic pain and disabilities, and for healthcare institutions, which face increased absenteeism and decreased productivity. In response to this situation, preventive solutions are emerging, including the use of non-motorized exoskeletons, a technology that has already proven its effectiveness in various fields such as industry and healthcare.[5][6]

Non-motorized exoskeletons are biomechanical devices that work by redistributing effort using springs or elastic bands to relieve certain parts of the body. Scientific literature has shown that these devices help reduce muscle effort, decrease fatigue, and improve workers' endurance, thereby contributing to the prevention of MSDs.[7] Additionally, the French National Institute for Research and Safety (INRS) has demonstrated that the use and deployment of exoskeletons in the workplace depend on their acceptance by workers.[8] However, as Professor de Looze mentioned in the introduction to the WearRacon Europe 2021 conference, one of the main barriers to the implementation of exoskeletons is their limited acceptability.[9] However, the majority of exoskeletons available on the market are designed for male body types, making their use sometimes unsuitable or uncomfortable for women, particularly around the chest area. To address this issue, a new exoskeleton, the HAPO CS, was specifically developed in collaboration with healthcare professionals to better fit female body types.[10]

While the integration of an exoskeleton like the HAPO CS represents a promising advance in reducing the risk of MSDs and improving working conditions in the healthcare sector, it remains crucial to conduct in-depth studies to ensure its effectiveness and acceptance by users.

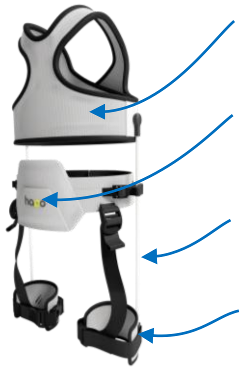

Figure 1 - Exoskeleton HAPO CS

2. EXPERIMENTAL PROTOCOL

a. Participants

Fifteen healthy adult participants took part in the study after signing an informed consent form. This panel consisted of 8 women (168 ± 4 cm, 72 ± 8 kg, 30 ± 9 years) and 7 men (179 ± 8 cm, 73 ± 13 kg, 31 ± 12 years).

b. Exoskeleton

The HAPO CS (ErgoSanté, Anduze, France) is a lightweight (0.850 kg), non-motorized exoskeleton designed to support the back, particularly the muscles of the lumbar region. This model is specifically suited for tasks involving partial or full trunk flexion, with or without load handling. The exoskeleton has been developed to specifically fit female body types (while still being suitable for men). A description of the various parts of the exoskeleton is provided in Figure 1.

c. Procedure

After a brief warm-up, participants were asked to perform two tasks involving trunk flexion: a static task and a dynamic task. Each task was performed under two conditions – Without and With exoskeleton – in a random order for each participant.

Static task: Trunk flexion at 40°, performed twice for 1 minute each. This task was selected to represent professional situations, such as bedside hygiene care for nursing assistants (Figure 2 (a)).

Dynamic task: Repeated lifting of a 6 kg load 10 times. This task aims to represent physically demanding work situations encountered in healthcare, industry, agriculture, and other fields (Figure 2 (b).

(a) **(b)**

Figure 2 – Tasks illustration: (a) Static trunk bending task; (b) Dynamic load lifting task

d. Data acquisition

For each trial, electromyographic (EMG) activity of 8 muscles was recorded on the right side of the body (Figure 3), following SENIAM recommendations. [11]. EMG signals were sampled at 2,148 Hz. A band-pass Butterworth filter (20–450 Hz, 4th order) was applied, followed by signal rectification and centering. For the dynamic task, movements were automatically segmented based on the trunk angle velocity profile. For each participant, the maximum RMS value across the entire task was extracted and used as a reference value. The normalized RMS values were then averaged across all participants (n = 15) during the lifting phase with load, for each experimental condition.

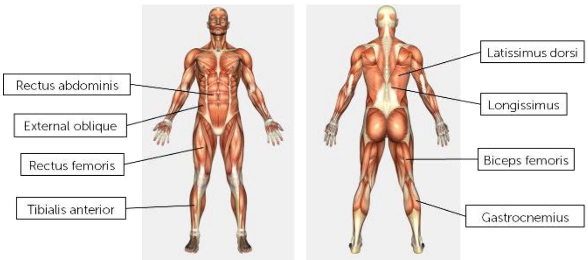

Figure 3 – EMG sensors placement

Kinematic analysis, obtained from 17 inertial measurement units placed on the whole body, was performed using a motion capture software (MVN, Movella, The Netherlands).

Perceived discomfort in the lower limbs, torso, and dorso-lumbar region was assessed using a Borg scale (Figure 4) for each participant, under both conditions (without/with exoskeleton).

0	None
0,5	Very, very light
1	Very light
2	Light
3	Moderate
4	
5	Intense
6	
7	Very intense
8	
9	Very, very intense
10	Maximum

Figure 4 - CR10 scale

3. RESULTS

a. Muscular activity

The EMG results from the static trunk flexion task, presented in Figure 5, show an effect of the exoskeleton on all muscles, with a particularly notable impact on the back muscles: a 14% reduction in the latissimus dorsi (p = 0.006) and a 8.0% reduction in the longissimus.

During the dynamic load-lifting task (Figure 6), a significant reduction of 13% in the latissimus dorsi (p = 0.02), of 14% in the biceps femoris (p = 0.01) and 9% in the gastrocnemius (p = 0.03) was observed during the lifting phase with load.

Since kinematic analysis revealed no differences in trunk and knee flexion angles between the two conditions, it can be concluded that the reduction in muscle activity is solely attributable to the use of the exoskeleton.

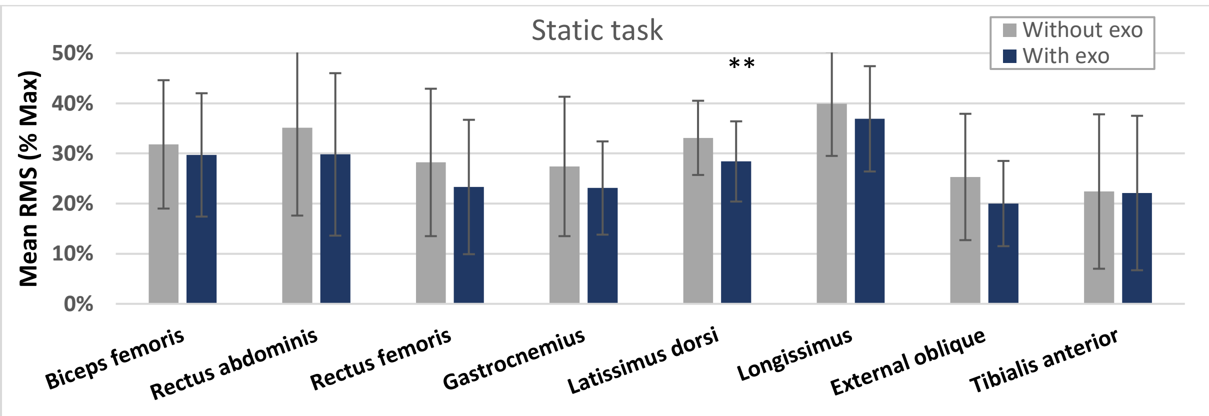

Figure 5 – Normalized mean EMG values, with and without exoskeleton for static trunk flexion

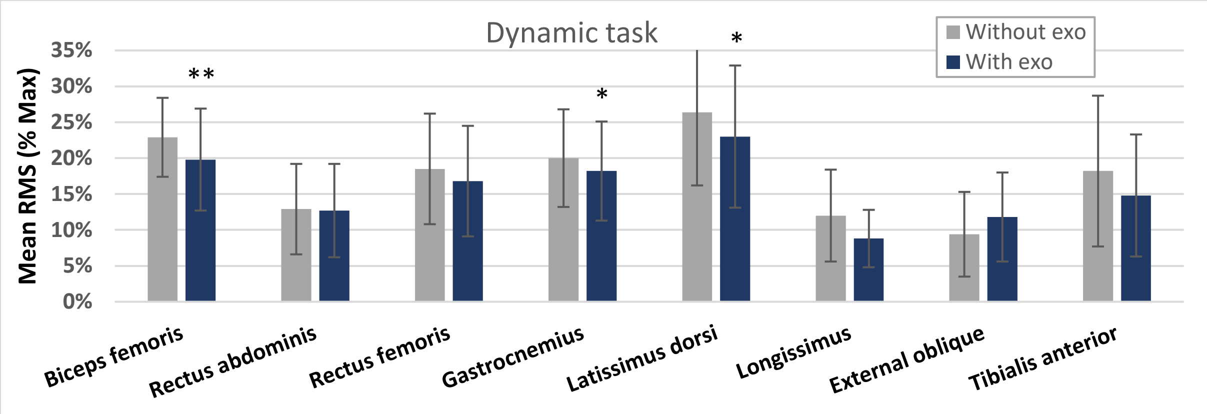

Figure 6 – Normalized mean EMG values, with and without exoskeleton for dynamic load lifting task

b. Subjective measurements

The subjective results during the static trunk bending task presented in Figure 7 show a reduction in perceived discomfort scores in the lower limbs (from 1.9 to 1.3/10) and in the dorso-lumbar area (from 3.2 to 0.7/10).

The perceived discomfort results for the dynamic load lifting task (Figure 8) show similar trends, particularly for the back (score from 3.0 to 0.9/10).

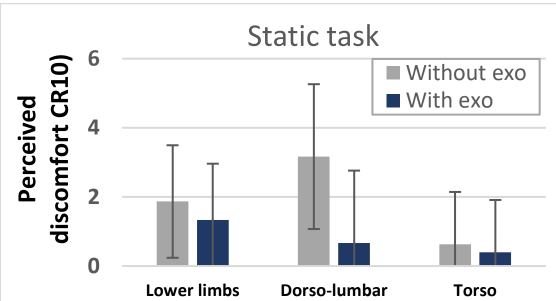

Figure 7 – Subjective results with and without exoskeleton for static trunk flexion

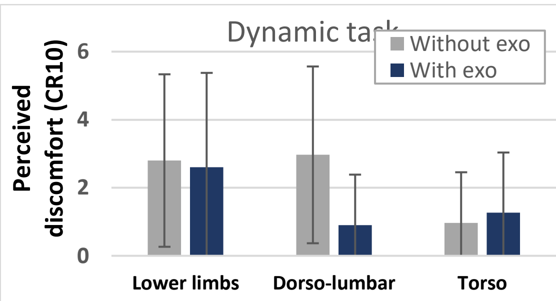

Figure 8 – Subjective results with and without exoskeleton for dynamic load lifting task

4. CONCLUSION

The reductions in EMG signal amplitude observed in the erector spinae muscles, as well as the reductions in perceived discomfort in the dorso-lumbar area, indicate that the HAPO CS reduces biomechanical strain. These results highlight the value of the exoskeleton as an effective strategy for reducing the risk of developing lower back pain during trunk bending work, both static and dynamic.

CONFLICTS OF INTEREST

The authors are affiliated with the company that manufactures and distributes the exoskeleton.

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