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published in
Biosystems and Biorobotics: Challenges and Trends
2019

DOI (link to publisher)
10.1007/978-3-030-01887-0_44

citation for published version (APA)
Baltrusch, S. J., van Dieën, J. H., Bruijn, S. M., Koopman, A. S., van Bennekom, C. A. M., & Houdijk, H. (2019). The effect of a passive trunk exoskeleton on functional performance and metabolic costs. In M. C. Carrozza, S. Micera, & J. L. Pons (Eds.), *Biosystems and Biorobotics: Challenges and Trends: Proceedings of the 4th International Symposium on Wearable Robotics, WeRob2018, October 16-20, 2018, Pisa, Italy* (pp. 229-233). (Biosystems and Biorobotics; Vol. 22). Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-030-01887-0_44

The Effect of a Passive Trunk Exoskeleton on Functional Performance and Metabolic Costs

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Abstract. The objective of this study was to assess the effect of a passive trunk exoskeleton on functional performance and metabolic costs in healthy individuals.

Functional performance of 12 work-related tasks was assessed based on objective outcome measures and perceived task difficulty. In addition, we measured energy expenditure during 5 min of repetitive lifting and walking, with and without exoskeleton.

Wearing the exoskeleton tended to increase objective performance in static forward bending. Performance in tasks that involved hip flexion decreased and these were perceived as more difficult with the exoskeleton. Wearing the exoskeleton during lifting decreased metabolic costs by as much as 17%, and may reduce the development of fatigue and LBP risk. During walking, metabolic costs increased by 17%. These results indicate the potential efficacy of the exoskeleton to support trunk bending tasks, but also stress the need to allow disengagement of support depending on activities performed.

1 Introduction

Mechanical work-related risk factors for low-back pain are difficult to efface from the work environment [1]. Several studies have shown that body worn assistive devices that passively support the user's trunk, i.e. exoskeletons, can be used to decrease low-back load at work [2–5].

Next to the mechanical risk factors for low back pain (LBP), physiological strain needs to be considered when aiming to decrease workload. High physiological strain can result in systemic or local fatigue which might increase LBP risk [6, 7]. Using an

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The work presented in this paper was supported by the European Union's Horizon 2020 research and innovation program under grant agreement No 687662 – SPEXOR.
The authors would like to acknowledge the support of Laevo for unconditionally providing the exoskeleton for this research.

M. C. Carrozza et al. (Eds.): WeRob 2018, BIOSYSROB 22, pp. 229–233, 2019.
https://doi.org/10.1007/978-3-030-01887-0_44

exoskeleton may reduce moments around the low back and hence muscle activity. Therefore, it could be expected that it also reduces metabolic load and as such reduce the risk of fatigue-related injuries.

Intervention studies have mostly been aimed at analyzing the effect on low back load and metabolic costs in stereotypical lifting [8, 9]. However, many work environments are characterized by a variety of tasks and trunk movement patterns, and hence require a device that can be used across a range of different tasks, such as walking, stair climbing or forward bending. An exoskeleton may not only support, but also hamper performance of some of these tasks by increasing energy costs or affecting task execution.

2 Objective

We aimed to assess the effect of a passive trunk exoskeleton on functional performance and metabolic costs for a set of different work-related tasks including lifting and walking. By using a currently commercially available device we aimed to point out potential design problems and to create a benchmark for further developments.

3 Methods

3.1 Passive Trunk Exoskeleton

In this study, the passive trunk exoskeleton “Laevo” (Intespring, Delft, The Netherlands) was tested. It consists of four components: a pad at the anterior side of the chest, leg pads at the anterior side of the thighs, a pelvis belt to keep the device in a fixed position relative to the pelvis and a smart joint with spring-like characteristics. The chest and thigh components are connected through semi-rigid bars running over this joint, which generates a supporting extension moment at the level of the lower back when bending forward.

3.2 Functional Performance

18 healthy men participated in the functional performance testing. Participants performed a test battery of 12 functional tasks with and without the exoskeleton. The selection of tasks was based on tasks from the functional capacity evaluation (FCE, Isernhagen Work Systems) [10] and tasks derived from workplace observations.

Three different type of tasks were considered: (1) tasks in which the user potentially benefits from the exoskeleton, (2) functional tasks in which the user is potentially hindered by resistance against movement generated by the device and (3) basic tasks requiring participants to use a large range of motion (ROM). Functional performance was assessed both in objective outcomes (e.g. time to perform a task) and subjectively, in terms of perceived task difficulty.

3.3 Metabolic Costs

We measured energy expenditure in 11 healthy men during 5 min of repetitive lifting and 5 min of walking, with and without an exoskeleton. Participants had to lift and lower a 10 kg box from two heights at an auditory imposed pace (6 lifts/min) in three different conditions: (1) Control (without the exoskeleton), (2) Low-cam Exoskeleton (supports at bending angles >20°) and (3) High-cam Exoskeleton (supports at bending angles 0–20°). In the walking protocol, participants walked with the Low-cam Exoskeleton and without the exoskeleton at two different walking speeds: (a) preferred walking speed determined without the exoskeleton and (b) preferred walking speed determined with the exoskeleton.

4 Results

4.1 Functional Performance

Wearing the exoskeleton tended to increase objective performance in static forward bending, but decreased performance in tasks, such as walking, carrying and ladder climbing.

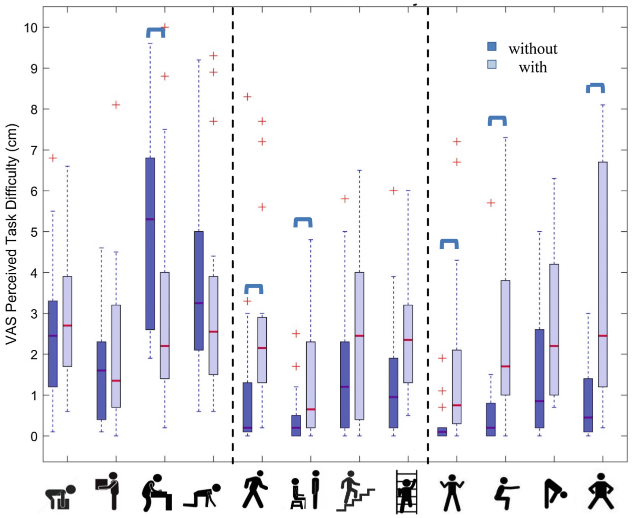

Fig. 1. Boxplots of perceived task difficulty. (The red line represents the sample median. The distances between the tops and bottoms are the interquartile ranges. Whiskers show the min and max values; outliers are represented as a +). The dotted lines represent the division between the groups of tasks, in which the user is potentially assisted (left side), tasks, in which the user is potentially hindered by resistance against movement generated by the device (middle) and tasks requiring participants to use a large range of motion (right side). Brackets indicate significant differences between the exoskeleton (with) and control condition (without). 0 = very easy, 10 = very difficult.

Subjectively, we found a significant decrease in perceived task difficulty and local discomfort in the back during static forward bending, but a significant increase of perceived difficulty in several other tasks, like walking, squatting and wide standing. Especially non-load handling tasks that involved substantial trunk and hip flexion without trunk inclination were perceived as more difficult with the exoskeleton (Fig. 1).

4.2 Metabolic Costs

Metabolic costs decreased by 17% and 16% when lifting with the low-cam exoskeleton from knee and ankle height, respectively.

For walking, metabolic costs increased by 12% and 17% when wearing the exoskeleton in the two different speed conditions (Fig. 2). Participants preferred to walk faster without the exoskeleton.

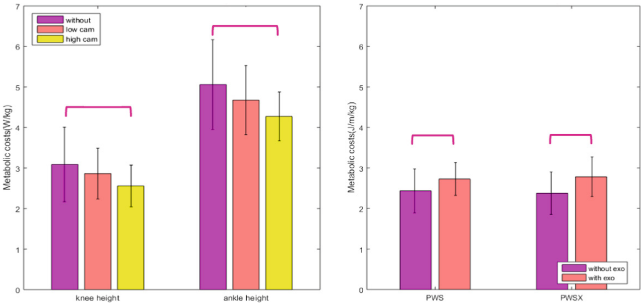

Fig. 2. Left: Metabolic costs of lifting from knee and ankle height. Values are normalized for bodyweight. Right: Metabolic costs of walking in preferred walking speed without exoskeleton (PWS) and preferred walking speed with exoskeleton (PWSX). Values are normalized for bodyweight and walking speed. Error bars indicate standard deviations. Brackets indicate significant change in metabolic costs between control condition (without) and exoskeleton condition (with exo/high cam).

5 Conclusion

Wearing an exoskeleton seems to effectively unload the back in static holding tasks and decreases metabolic costs during lifting. It may hence reduce the development of fatigue and LBP risk for these specific tasks.

However, it limits functional performance in several non-load-handling tasks. Especially tasks that require hip flexion get hampered by the exoskeleton, such as walking, which also showed increased metabolic costs when wearing an exoskeleton.

This stresses the need for a support system that can be disengaged depending on activities performed. Design improvements should include provisions to allow full range of motion of hips and trunk to increase versatility and user acceptance.

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