DEVELOPMENT AND EVALUATION OF A PASSIVE LOWER BODY EXOSKELETON FOR AGRICULTURE

Veronika Hofmann[1], Nico Bölke[1], Urs Schneider[1,2], Peter Pott[3]

[1]Fraunhofer Institute for Manufacturing Engineering and Automation, Nobelstrasse 12, 70569, Stuttgart
[2]Institute of Industrial Manufacturing and Management, University of Stuttgart, Pfaffenwaldring 9, 70569, Stuttgart
[3]Institute of Medical Device Technology, University of Stuttgart, Pfaffenwaldring 9, 70569, Stuttgart

ABSTRACT

The risk of musculoskeletal disorders is particularly high in physically demanding work. The agricultural sector is depicted as a critical field for such straining activities. In order to prevent these health complaints, exoskeletons can assist the users and relieve the strain on workers. The objective of this project is the development of a new exoskeleton for the agricultural work environment. The developed prototype encompasses three different support concepts. These are tested separately to conclude the best possible solution. The evaluation of the final exoskeleton is carried out using a specially developed test course, which was implemented in accordance with the EXOWORKATHLON® concept. Results show that users feel less exertion, especially in the lower back area. Usability as well as wearing comfort, customization options and the freedom of movement were rated positively.

Keywords: exoskeleton, support systems, musculoskeletal disorder, agriculture

1. INTRODUCTION

Physically demanding activities, such as those found in agriculture, are a significant health risk for employees in this sector. A project by the German Federal Institute for Occupational Safety and Health (BAuA) demonstrates the correlation between the occurrence of back complaints and heavy physical stress [1]. Especially *lifting and carrying loads* and *bending forward* are frequent movements in this industry [2]. Prior studies investigate the influence of exoskeletons for these heavy-duty movements in the agricultural sector and present positive effects while using passive exoskeletons [3].
In order to provide evidence on these findings a passive lower back exoskeleton for the application was developed. Special requirements for this sector were considered. These were, most importantly, durability for operation in all weather conditions, no risk of injury for the user and the environment and a great freedom of movement for the varying activities in the sector. Therefore, the question whether a robust and efficient passive lower-back exoskeleton can be developed and provide enough support for movements in the agricultural sector was investigated.

2. MATERIALS AND METHODS

Following the methodical development process according to VDI 2221 sheet 1 (2019) a prototype was designed and constructed. Subsequently, this prototype was tested with an abstracted test course. After providing informed consent eight test subjects (equal gender distribution, age 21-27 years, height 158 – 196 cm) recruited among the research group completed this course by replicating picking and carrying tasks from agriculture.

3. SYSTEM DESIGN

The main concept of the exoskeleton is based on the conduction of force via bending structures. When deforming these structures store passive energy, which helps the users perform tasks such as lifting, carrying or bending forward.

Figure 1: Complete exoskeleton with bending concept "rod modules" in front view [a], side view [b] and rear view [c].

The underlying principle of the developed exoskeleton is a distribution in a base structure and interchangeable bending modules at the back (see figure 1).
The base structure consists of leg straps, a hip belt with an offset module and the upper torso connection with linear compensation unit. This structure establishes the interface to the user and allows several adjustments regarding the personal fit, but also the magnitude or offset of support power. The offset module was designed in order to adjust the angle of inclination at which the support effects the user. Rotating a handle of the module causes a threaded rod to move and therefore adjust the range of unhindered movement of the bending modules. Three separate bending modules were developed to test their characteristic behavior in use. These were: rod modules with varying diameters, a rotatable rectangular rod (different length as width) and a bending spring. Preliminary tests showed the advantages of the rod modules, as they are easy to use and the most robust. This is due to the minimalism and sturdiness in the implementation of the connecting parts.

4. Evaluation study

In order to test the exoskeleton in a realistic but yet feasible setting the test course "*agriculture"* was created. It was designed based on the principles of the EXOWORKATHLON® [4] and can be seen in figure 2. The test subjects had to complete several cycles of picking "*field crops*" and carry the 5 kg boxes over a distance of 2.5 m to the storage area. One repetition was performed while using the exoskeleton, one without. The order was randomized. Each sequence consisted of 30 min of continuous working. Following the EXOWORKATHLON® principle this was paused every 10 min to complete a questionnaire about the current perspective of exertion [4].

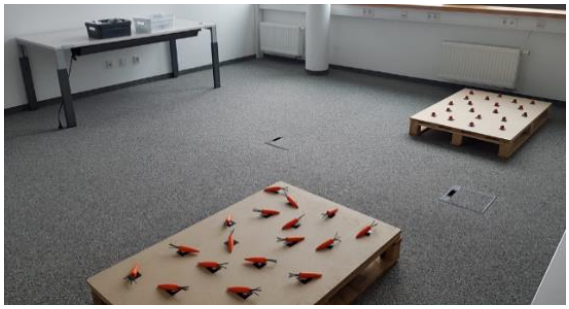

Figure 2: Test setup with storage area "*trailer*" (upper left corner) and two "*fields*" (front and right).

5. RESULTS AND DISCUSSION

Eight test subjects completed the test. Figure 3 displays the result of the questionnaires. The reduction in subjective perception of exertion is visible due to the BORG-scale varying from 0 (= no effort) to 10 (= maximum) [4]. A more detailed perspective on the different body regions shows that users feel less exertion especially the lower back area.

Moreover, comfort, usability, adjustment options and the physiological freedom of movement and the support power was ranked positive when using the exoskeleton.

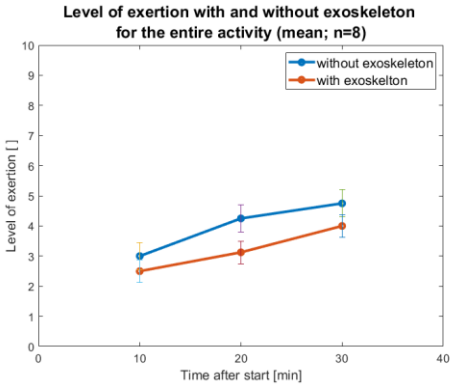

Figure 3: Subjective perception of exertion with and without exoskeleton after 10 min, 20 min and 30 min.

6. CONCLUSION

In the course of this project a functional and robust exoskeleton has been developed. The evaluation study showed the positive effect on the users and clearly demonstrates the potential of exoskeletons in the agricultural sector.

ACKNOWLEDGEMENTS

The authors would like to thank all participants for their time.

REFERENCES

[1] F. Liebers, C. Brendler, U. Latza, "Berufsspezifisches Risiko für das Auftreten von Arbeitsunfähigkeit durch Muskel-Skelett-Erkrankungen und Krankheiten des Herz-Kreislauf-Systems." Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Dortmund, (2016).
[2] S. Upasani, F. Roberto, K. Niewolny, D. Srinivasan "The Potential for Exoskeletons to Improve Health and Safety in Agriculture - Perspectives from Service Providers" IISE Transactions on Occupational Ergonomics and Human Factors (3-4), pp. 222–229. (2019).
[3] O. Thamsuwan, S. Milosavljevic, D. Srinivasan, C. Trask, "Potential exoskeleton uses for reducing low back muscular activity during farm tasks" In: American journal of industrial medicine (11), pp. 1017–1028. (2020):
[4] V. Kopp, M. Holl, M. Schalk, U. Daub, E. Bances, B. García, I. Schalk, J. Siegert, U. Schneider, "Exoworkathlon: A prospective study approach for the evaluation of industrial exoskeletons" Wearable Technologies, 3, E22. (2022).