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Title
Evaluation of usability of passive exoskeletons on the work floor: a step-by-step plan for mapping between exoskeleton, employee and performed task

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Summary
Our qualitative study on the effect of passive exoskeletons on work-related tasks indicates that a good mapping between the kinematics of the exoskeleton (working area and range of motion) and the movements of the employee, is a decisive factor in the functioning of the exoskeleton.

Introduction
Passive exoskeletons are fairly new, and are still very little used in dynamic work-related tasks. These exoskeletons contain no external power. The relief of the physical load on a particular muscle or body zone is achieved by redistributing the forces to other zones, force reduction by springs, dampers or weight absorption by rigid structures that divert forces to the ground.
Two main categories are relevant her: the upper body exoskeletons (arms and trunk) supporting back, shoulders and arms and the lower body exoskeletons (legs) supporting hip, knees, back and shoulders.
We aimed a qualitative assessment in the lab on the effect of different passive exoskeletons on different work-related movements/tasks in healthy individuals by means of objective parameters and subjective parameters.

Methods
The use of exoskeletons was evaluated during insulated movements, which occur on the work floor, some with weight, some without. Movements were split up according to the Isernhagen Work System for Functional Capacity Evaluations [1]. Three operators performed the movements without exoskeleton as a reference and with 5 different passive exoskeletons each [figure 1].

In each test interface pressure (via pressure mats on shoulder, chest, thigh, back and arm), balance (via contact pressure under the sole of the foot) and energy consumption (via heart rhythm) are measured.
In addition, the working area, freedom of movement in the wrist, forearm, elbow, shoulder, hip and back and the fitting possibilities (alignment of the exoskeleton with own joints, fitting of structures and pressure points, adaptability between users) per exoskeleton were evaluated and mapped by a multidisciplinary team of physiotherapists and engineers.

Results

The study showed, among others, that some movements are limited, impossible or painful in some exoskeletons. Possible affected movements that has to be taken into account when selecting an exoskeleton are: limited rotation in the trunk, limited abduction of the hip, limited flexion and extension of the hip, limited movement in the shoulders, limited abduction in the shoulder, limited flexion and extension in the elbow. Sometimes the movements are not restricted, but rather give a certain load, such as sanding paddings on the body, or a resistance that needs to be bridged, before the movement can be done.
In the non-working area of the exoskeleton, for example while walking, the weight of the exoskeleton directly affects your calorie consumption. Depending on where the forces of this extra weight are transferred, this gives an extra ballast and possibly pressure points on shoulders, back, andor hips. Typical for shoulder exoskeletons, the extra weight to carry also caused instability when bending forward.
An exoskeleton transfers power through your body, creating pressure points between the support surfaces and your body. The pressure can be limited by large support surfaces and anatomical fits. Here, too, fitting and adaptability play an important role.
A non-optimal fitting can lead to limited freedom of movement, reduction of the working area and additional pressure points.

Conclusion

Our study indicates that a good mapping between the kinematics of the exoskeleton (working area and range of motion) and the movements of the employee, is a decisive factor in the

functioning of the exoskeleton. Therefore, we propose a step-by-step plan to determine the optimal mapping between the employee, the exoskeleton and the tasks to be performed.
As first step, a kinematic analysis of the (sub)process must be carried out. This involves dividing the process and tasks into sub-movements up to the joint level and checking for each joint which postures (static) and/or which movements (dynamic) are assumed per phase. Each (partial) movement that an operator makes in the different processes can be divided into a combination of movements in joints in the wrist, forearm, elbow, shoulder, back and hip and these can be divided into partial movements per joint. As a second step, range of motions and working areas of possible exoskeletons are inventoried per joint.
As a last step, the decision-making process takes into account the following aspects: do certain logistic (sub)tasks remain sufficiently long in the supported zone (working area) of the exoskeleton? Does the exoskeleton need sufficient degrees of freedom for the logistic part (task)? What are the fitting possibilities of the exoskeleton?
In addition to analyzing the right match between task and exoskeleton, the user must also be supported with training, familiarization and guidance during the implementation process.

References

[1] Isernhagen S. Rehabilitation ergonomics. In: Marras WS, Karwowski W, eds. Fundamentals and Assessment Tools for Occupational Ergonomics. Boca Raton, Fla: Taylor and Francis/CRC Press; 2006:Chapter 22

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