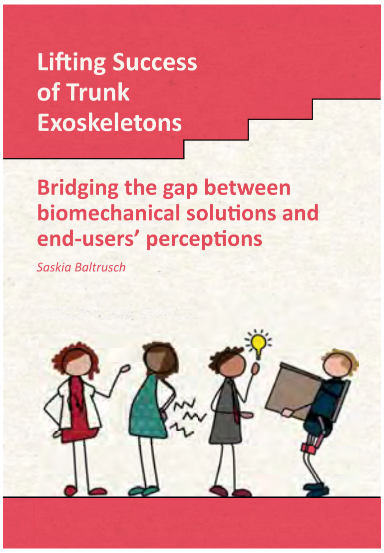
Lifting Success of Trunk Exoskeletons

Bridging the gap between biomechanical solutions and end-users' perceptions



Low-back pain is the number one cause of disability in the world [1]. The Netherlands spend more than 3 billion euros on low-back pain each year [2]. Low-back pain causes a considerable burden on industry, involving negative consequences for companies and the individual employee [3,4]. A variety of factors is believed to contribute to the onset of low-back pain [5], including biomechanical, psychosocial and personal factors [6,7]. Researchers have, for many years, tried to understand the underlying mechanisms of this multifaceted disorder. With no clear pathological cause established in almost 90 % of the cases [8], current treatment is not very successful.

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Physically demanding jobs that require heavy lifting, trunk rotations or working in awkward postures for a longer period of time have been shown to lead to high back loading. This might sooner or later result in low-back injury and pain [6, 9-11]. Being aware of the occupational risk factors and the increased need to prevent work-related low-back pain, companies strive to introduce preventive strategies in their work environment. Research has

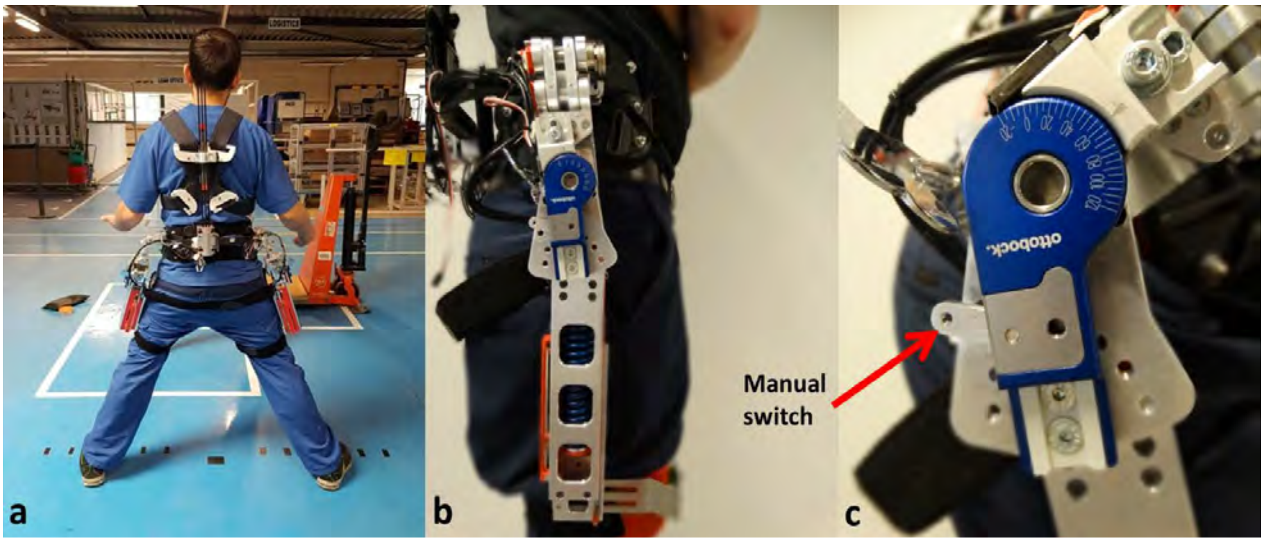

Figure 1. The SPEXOR exoskeleton. The exoskeleton unloads the back by applying a force at the torso, pelvis, an the thighs: (a) an elastic spinal module generates a torque through a set of carbon fibre ams and (b) a passive hip actuator. The implemented clutch allows disengagement of the passive hip actuators, by moving a manual switch (c). Note: electrical wires were used for measurements and are not part of the exoskeleton.

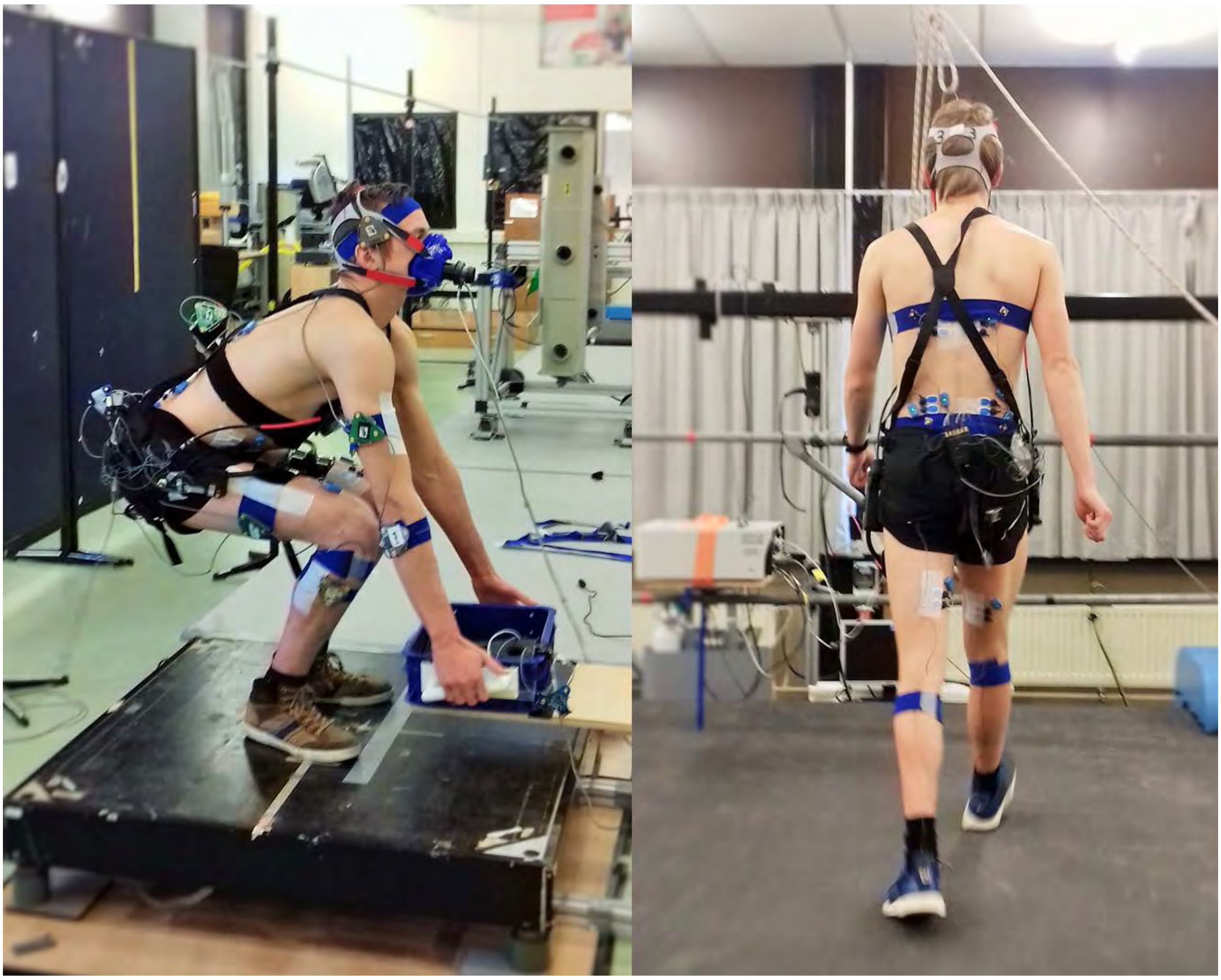

Figure 2. Benchmark testing. Oxygen consumption, muscle activity and kinematics were measured during repetitive lifting (left) and walking (right).

focused on different ways of adapting work environments to reduce mechanical risk factors. For example, increasing lifting height, reducing the lifted load, or introducing lifting robots have shown to be promising in terms of reducing the load on the lower back [11,12]. However, these preventive strategies often require an adaptation of the work environment. In practice, redesigning the workspace is not always feasible and such interventions often face implementation problems. Potential challenges include high costs of the intervention, time-consuming use and the end-user's lack of trust in an intervention [13].

Effacing risk factors for occupational low-back pain in the work environment, therefore, remains a challenge. Given the fact that external assistive devices have their limitations in terms of flexibility and applicability, a wearable device or so-called exoskeleton, might be promising for low back pain prevention and rehabilitation. Therefore, the European consortium SPEXOR aimed to design a spinal exoskeleton for low-back pain prevention and vocational re-integration and rehabilitation. This thesis dealt with the development and evaluation of the SPEXOR trunk exoskeleton and applied a user-centred approach by combining quantitative and qualitative research methods. In the thesis, we studied the potential effectiveness of using a passive trunk exoskeleton for low-back pain prevention, vocational reintegration and rehabilitation and provided insight into factors that influence usability and acceptability of the exoskeleton. How to bridge the gap between biomechanical solutions and end-users' perceptions to raise chances of success of a trunk exoskeleton?

The development and evaluation of a new trunk exoskeleton

The first part of my thesis aimed attention at identifying criteria that should be considered when developing an exoskeleton. End-users' perspectives on a passive exoskeleton were assessed using a qualitative approach. Conducting focus group discussions with low-back pain patients with different levels of pain severity and healthcare professionals of various backgrounds, I aimed to collect a broad view of factors that need to be considered when developing an exoskeleton [14].

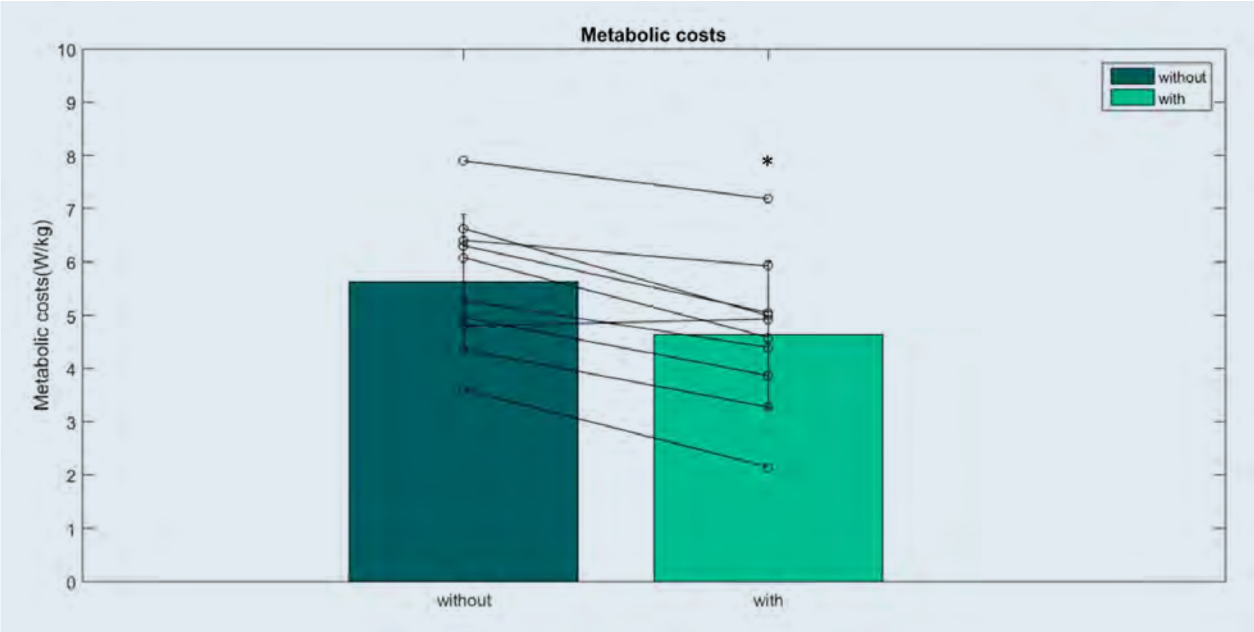

Figure 3. Metabolic cost of lifting with and without exoskeleton. Values are normalised for bodyweight. N=10. Error bars indicate standard deviations. Black lines indicate individual responses. *Significant change in metabolic cost between control condition (without) and exoskeleton condition (with).

The second part dealt with the evaluation of the exoskeleton (Figure 1). A test battery was developed to assess the effect of the exoskeleton on functional performance and user satisfaction [15] and aerobic loading [16]. First, this test battery was used to perform benchmark testing of already existing exoskeletons. This benchmark test allowed to assess drawbacks and benefits of current lifting devices and formulated design improvements to be considered in the SPEXOR exoskeleton. Subsequently, the benchmarking tests were repeated with the prototype SPEXOR exoskeleton to assess potentially achieved improvements with this novel device and to formulate aims for further design adaptations (Figure 2) [17,18].
The last part of my thesis focused on the challenge to implement the SPEXOR exoskeleton in the work environment. A focus group with potential end-users and an interview with decision makers added insight into design improvements and recommendations for implementation strategies [19].

The potential of exoskeletons in industry

The results showed that exoskeletons are of benefit for lifting and static postures involving mechanical back loading. The SPEXOR exoskeleton took over 25% of mechanical joint work, reduced muscular effort and hence decreased metabolic cost by as much as 18% on average (Figure 3) [17]. This suggested that the SPEXOR exoskeleton is beneficial for lifting by decreasing physiological strain. Work-related low-back pain might, therefore, be preventable when wearing an exoskeleton, due to lower mechanical loading and a lower risk of getting fatigued. Furthermore, design features that were identified in the conversations with potential end-users [14] were successfully implemented in the SPEXOR exoskeleton, which resulted in improved functional performance [18] and aerobic loading [17] when using the SPEXOR exoskeleton, compared to the Laevo exoskeleton used in the benchmarking tests. Employees felt supported in the selected working tasks and did not feel hindered in their range of motion, with relatively low levels of discomfort (between 0 and 3 on a scale from 0=no discomfort to 10 =maximal discomfort) and high levels of user satisfaction (average score 6 on a scale from 0= really bad to 10=perfect [18].
Major points that still need to be improved are wearer comfort by reducing the weight and the dimension of the device and the (perceived) support level. Thus, implementing the exoskeleton in the working environment is still a challenge and further improvements of the design are needed to make it ready to be used in real practice. The industry might be the most promising field of application at this time, supporting employees with a history of low-back pain. Furthermore, it was shown that an adequate implementation strategy is essential to deal with end-users' concerns over introducing a passive exoskeleton [19].

The added value of a user-centred approach

Maybe even more important, this thesis showed that applying a user-centred approach is essential to reveal design requirements that are tailored to the end-users' needs. By involving end-users before the development phase and listening to their thoughts on using a passive trunk exoskeleton, I was able to identify design requirements in an early stage of the developmental process. In that way, these results could be matched with requirements from theoretical biomechanical and engineering considerations to determine exoskeleton design. One important feature that was mentioned by healthcare professionals and patients was the wish to have 'different modes for different movements' [14]. This request implied a device that is versatile, thus a device that can be used for different movements without hindering the user. To be able to switch between tasks in which support is needed and tasks in which maximal movement capacity is desired, without donning and doffing the device, it was chosen to implement a manual switch (see Figure 1c). This clutch can be switched on and off, depending on the task and whether support is needed. Its implementation increased versatility of the exoskeleton [18].

Another important implication from this thesis was that the optimal design of an exoskeleton is context-dependent. When implementing it in the working environment, an exoskeleton needs to be adapted to the job and the end-users' needs. A first step of doing that is talking to potential end-users, as done in my thesis. A step that is still missing and is essential when it comes to designing a context-dependent exoskeleton, is actual field testing. Giving the employees the possibility to try out the exoskeleton during a whole working day might yield new insights into design requirements for the device and adaptations that still have to be done to make the exoskeleton suitable for their specific job.

In sum, user-centered research starts with users and ends with the answers that are tailored to their individual needs. Understanding the people one is trying to reach, and designing from their perspective, will yield answers that help to design an exoskeleton that truly meets their requirements. I show that the combination of listening to the end-users and measuring numerical data is essential to bridge the gap between biomechanical solutions and end-users' perceptions.

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Uit het juryrapport
Het moge duidelijk zijn dat het onderzoek een grote maatschappelijk relevantie heeft.