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HUMAN FACTORS

Dossier: Exoskeletten op de werkvloer

Octrooien: Alles bij de hand

A concept car in the airport

Colofon

Human Factors streeft naar het zodanig ontwerpen van gebruiksvoorwerpen, technische systemen en taken, dat de veiligheid, de gezondheid, het comfort en het doeltreffend functioneren van mensen worden bevorderd.

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Voorwoord

Beste lezer,

Voor u ligt de eerste editie van het Tijdschrift voor Human Factors in 2019. Ons vakgebied richt zich op het raakvlak van, en de interactie tussen, mens en technologie. Een perfect voorbeeld hiervan is het exoskelet waarbij de mens fysiek ondersteund wordt door de techniek, of in dit geval een machine. De ontwikkeling van het exoskelet speelt al tientallen jaren, maar lijkt recentelijk in een stroomversnelling te komen. Tijd om in een Dossier eens goed aandacht te besteden aan de huidige stand van zaken bij (industriële) exoskeletten op de werkvloer en de groei van (wetenschappelijk) onderzoek ernaar.
Onze eigen redactrice Tessy Luger leidt het dossier in en schreef – net als Saskia Baltrush (Heliomare), Stefano Toxiri (Istituto Italiano di Tecnologia) en medeauteurs – een artikel. Het dossier behandelt onder andere passieve exoskeletten voor de rug, actieve exoskeletten bij manuele arbeid en passieve exoskeletten voor de onderste extremiteit.
Het dossier wordt gecomplementeerd met een bijdrage van Linda ten Katen en medeauteurs (Health2Work) over praktijkervaringen met exoskeletten. Een gevarieerd onderwerp waarin HF op vele manieren en domeinen terug te vinden is.

Tevens in dit nummer weer een boeiende octrooiaanvraag, beschreven door Alex Hogeweg (DeltaPatents), die chirurgen moet helpen het overzicht te bewaren bij het gebruik van hechtnaalden.

Ter aanvulling en verfrissing bevat het huidige nummer ook nog een bijdrage van Odeke Lenior (Vanderlande) hoe het idee van een ‘concept car’ gebruikt kan worden in de design fase van bagageafhandelingssoftware.

Ten slotte is het laatste nieuws uit de vereniging en een aantal nieuwe activiteiten te vinden op de laatste pagina van dit tijdschrift. Houd in de gaten wat de verenging aankomende tijd in petto heeft!

Namens de gehele redactie, zoals altijd veel leesplezier gewenst!

Ruben Post
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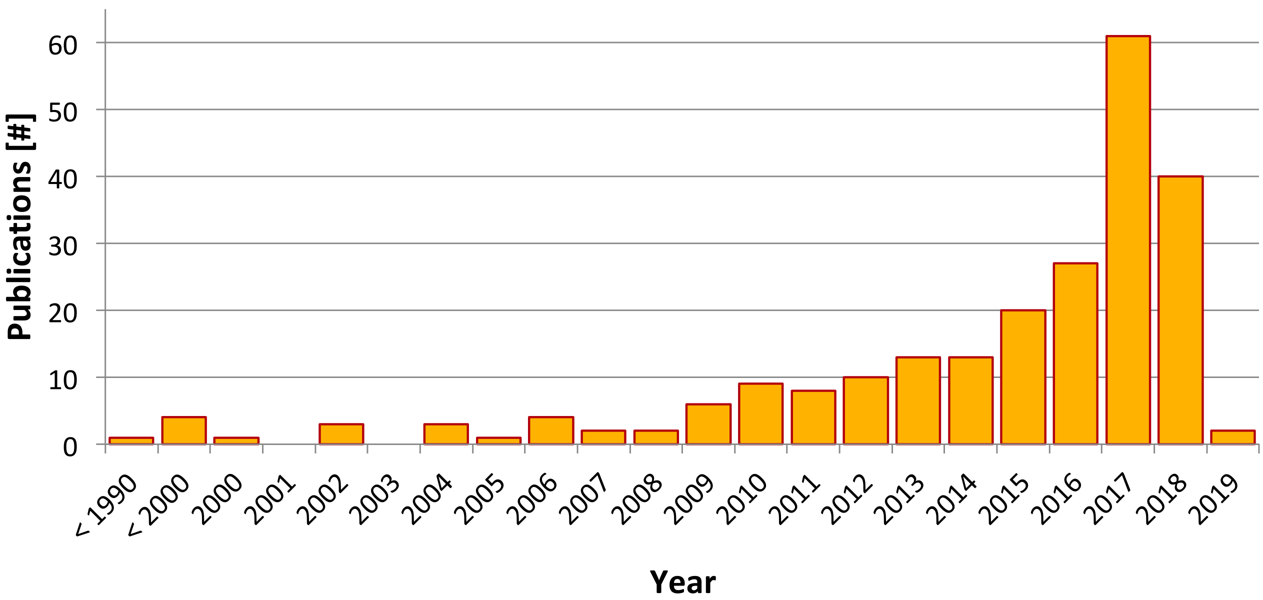
Inhoud

Het inzetten van exoskeletten op

In veel bedrijven waar werknemers fysieke arbeid uitvoeren, is de prevalentie van klachten of aandoeningen aan het spierskeletsysteem aanzienlijk. Dit is een belangrijke reden om te experimenteren met het inzetten van exoskeletten. Een exoskelet is een draagbaar, extern systeem dat op het lichaam gedragen wordt en dat de kracht van de drager versterkt (De Looze et al., 2015). Hierbij kan een onderscheid worden gemaakt in de techniek (passief, actief) en het lichaamsdeel dat wordt ondersteund (onderste extremiteit, bovenste extremiteit, hele lichaam).

Exoskeletten bestaan al heel lang en vinden hun ontwikkelde, praktische toepassing met name op het gebied van de revalidatie en de militaire toepassingen (Vitechova et al., 2013). Als we kijken naar onderzoeken naar exoskeletten op het gebied van arbeid, dan is te zien dat de eerste studie al in 1977 plaatsvond en er vanaf 2010 een stijgende trend is waar te nemen (zie afbeelding 1). Zoals in een eerder beknopt literatuuroverzicht vermeld, zijn veel studies uitgevoerd onder een beperkt aantal proefpersonen (n ≤ 5; Steinhilber et al., 2018). Bovendien worden vaak slechts kortetermijneffecten van exoskeletten onderzocht (De Looze et al., 2015), wat betekent dat het nog niet mogelijk is om een uitspraak te doen over effecten van het inzetten van exoskeletten op gezondheidsrisico's. Dit betekent dat er nog veel te onderzoeken valt op het gebied van exoskeletten op de werkvloer, met name ook de effecten op de lange termijn.



Afbeelding 1. Verloop van het aantal studies naar exoskeletten met toepassing arbeid over de afgelopen decennia (zoekopdracht in PubMed uitgevoerd op 11 september 2018, met de volgende termen: ((exoskeleton OR exoskeletons OR exosuit OR exosuits) AND (work OR occupation OR occupations OR industry OR industries)) NOT ((animals[MeSH] OR animal*[TW]) NOT (humans[MeSH] OR human*[TW])).

de werkvloer

In dit dossier wordt een drietal industriële exoskeletten gepresenteerd met als doel meer te weten te komen over deze systemen en hun werking. In het eerste artikel stellen Saskia Baltrusch en collega's een passief exoskelet voor dat zij ontwikkelen binnen het SPEXOR EU-project. Het exoskelet zal specifiek gericht zijn op ondersteuning van de rug voor gezonde arbeiders en reïntegrerende arbeiders die lage-rugpijnklachten hebben.

In het tweede artikel bediscussiëren Stefano Toxiri en collega's de ontwikkeling van actieve exoskeletten, met de focus op het ondersteunen van de rug bij manuele arbeid (*manual material handling*). De auteurs bespreken verschillende strategieën die de effectiviteit bepalen van een actief rugondersteunend exoskelet.
In het derde artikel presenteren Tessy Luger en collega's bevindingen over een studie waar een passief exoskelet voor de onderste extremiteit is geëvalueerd, de Chairless Chair®. De auteurs bespreken subjectieve bevindingen gedurende en na het uitvoeren van gesimuleerde, manuele montagewerkzaamheden.

De komende maanden, jaren, misschien wel decennia zullen er veel meer bijdragen komen op het gebied van industriële exoskeletten. De drie projecten die hier worden voorgesteld, zijn uitgevoerd in Europa. Ook onderzoeksgroepen in Amerika en Canada zijn actief in het onderzoek naar industriële exoskeletten. Hopelijk kunnen we in de nabije toekomst onze krachten bundelen en gezamenlijk werken aan kennis, effectiviteit en praktische toepassing van exoskeletten in de industrie en hierbij zowel acute als ook langetermijneffecten inclusief de potentiele risico's in kaart brengen.

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A change of perspective

From adapting working environments towards wearing a passive trunk exoskeleton

Since there are many factors contributing to the onset of low back pain, 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 (Krismer et al., 2007), treatment is not very successful. Thus, the prevalence of low back pain keeps on rising. Therefore, the million-dollar question is: how can we support people who suffer from low back pain and how can we prevent low back pain in those who are still healthy?

Saskia Baltrusch, Axel Koopman, Han Houdijk and Jaap van Dieën

Did you ever experience low back pain? You are not alone! About 80% of all adults experience low back pain at some point in their life. It is the second most common reason for disability, with over a 100 million lost work days a year, reported in the UK (Croft, 1993). Also, it is tremendously expensive. The Netherlands

Figure 1. Working conditions as a luggage handler.

spends more than 3 billion euros on low back pain each year, with a ratio of 12% to 88% between direct costs, such as medical care, and indirect costs, such as production loss and disability costs (Lambeek et al., 2011).
Physically demanding jobs that require heavy lifting, trunk rotations or working in awkward postures for a longer period of time lead to high back loading and might sooner or later result in low back injury and pain (Coenen et al., 2014a; Coenen et al., 2014b; Griffith et al., 2012, Faber et al., 2009). Therefore, researchers have focused on adapting working 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 (Faber et al., 2009; Marras et al., 1999). Nevertheless, these adaptations are often difficult to implement.
Let us illustrate the challenges of reducing physical workload with a practical example of an airline company. An employee working at the luggage handling service has to handle about 300 suitcases per flight for up to 9 flights a day. These suitcases can weigh up to 45 kg. Considering the promising adaptations of the working environment mentioned earlier, there are different challenges to face. Reducing the mass that needs to be lifted may not be feasible in our example. When checking in luggage, there is no strict weight limit. By paying some extra fee, travellers can check in luggage of any weight. The lifting height is another challenge in the working environment of a luggage handler. Their main task consists of lifting suitcases from conveyer belts onto carts or the other way around (figure 1). These conveyer belts used to be built at ankle height, forcing the luggage handlers to bend down even further and increasing the load on their back. Companies therefore started to increase lifting height to reduce back loading by adjusting old conveyer belts from ankle height to hip height. Nevertheless, old conveyor belts are still in use. Another way airline companies try to reduce physical workload and specifically the load on the back, is the implementation of lifting devices. However, luggage handlers perceive the use of lifting devices as too slow and feel interfered with their normal working behaviour. As soon as work must be done fast, they prefer manual handling. So, how can we effectively assist those people when it comes to reducing the load on their lower back? Perhaps we need to change our perspective: what if we do not adapt the working environment, but instead enhance the ability of the worker through wearable, assistive devices?

This challenge was the starting point of the SPEXOR project (www.spexor.eu), a collaboration between institutions from 5 different countries, including the Netherlands represented by the Vrije Universiteit Amsterdam and the Rehabilitation Center Heliomare. The aim of this project is to develop a spinal exoskeleton that assists the user's movements and reduces the load on the lower back. To arrive at a first prototype, VU Amsterdam took the responsibility to define the biomechanical requirements for such a device, whereas Heliomare assessed the design requirements from the potential end-user's point of view. The established requirements and initial benchmark testing of an existing commercial device will be described briefly in the following paragraphs.

Defining design requirements

In daily live, peak compression forces on the low back can easily reach 5000 N (Kingma et al., 2016), for example when lifting a box of 20 kg. This value of 6000 N is within the range in which damage of vertebrae can occur. Therefore, the National Institute for Occupational Safety and Health (NIOSH) developed a guideline to ensure safe lifting in working environments (Waters et al., 1993). The recommended weight limit according to this guideline is widely accepted as a tool for answering the question: 'Is this weight too heavy for this task?'. As mentioned before, in practice it appears difficult working within these limits at all times. The main aim of the SPEXOR project is to reduce peak spinal compression forces during load handling tasks. By supporting the upper body during trunk flexion and lifting, and thereby reducing the required activity of the back muscles, peak compression forces will decrease, leading to a smaller risk of tissue damage and consequently lower risk of getting low back pain. Our ambition is to generate a supporting extension moment during trunk flexion and lifting between 50-100 Nm, resulting in a reduction of peak compression force by 1000-2000 N. Additionally, literature has shown strong evidence that working in a bent posture is a major risk factor for developing low back pain (Hoogendoorn et al., 2000). Therefore, in SPEXOR, a warning signal or a hard stop of the system will be generated whenever subjects are bending beyond a subject specific limit (80% of maximum lumbar flexion) to reduce the risk of developing low back pain.

The end-users' point of view

To understand the complex demands on people suffering from low back pain and to be able to develop a device that truly meets the end-user's demands, communication with these people is essential. Therefore, we conducted focus group studies with low back pain patients, health care professionals and luggage handlers. We discussed the main problems they face due to low back pain and their wishes and doubts about such an exoskeleton. One of the main findings in these focus groups was that patients want such a device to help them function independently and consequently using the device should not require any

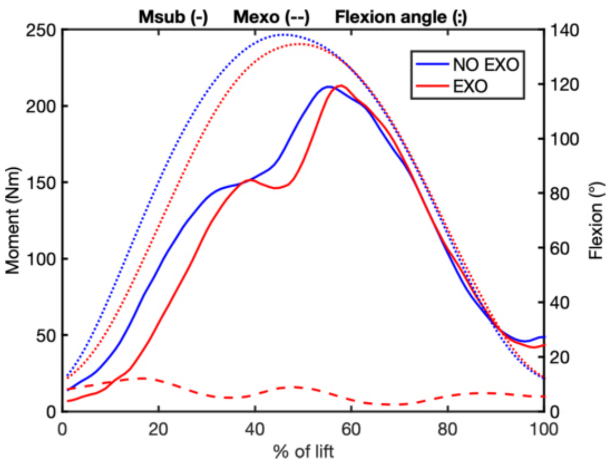

Figure 2. Time series of the moment generated by the subjects (MSUB, solid), the exoskeleton (MEXO, striped), and the flexion angle (dotted), over the whole lifting cycle averaged over subjects.

help for example for donning and doffing or for making adjustments. Another important point was, having a versatile device that can provide different modes of support, depending on the task performed. In certain tasks one might not want to have as much support as in others. Main doubts were the fear of getting dependent on the exoskeleton and getting weaker physically when using it too often.

Benchmarking: Testing the state of the art

Testing an exoskeleton that is already on the market was an important first step to define the requirements for the SPEXOR device, but also to understand the challenges of current designs. How can we improve the current state of the art? The test procedure consisted of three parts: (1) biomechanical testing: how does the device affect the loading on the lower back? (2) physiological testing: does the exoskeleton change the metabolic demand and potential fatigue of the user? And (3) functional testing: does the exoskeleton support or hinder the user in daily activities? For this test procedure we used a passive exoskeleton (Laevo, Intespring, Delft, The Netherlands) that generates a support at the lower back when the user is bending forward by transferring the load from the lower back to the chest and upper legs.

Biomechanical testing

To calculate the loading on the low back we measured movements, forces and muscle activity in participants performing different load handling tasks with and without the exoskeleton (Koopman et al., online). During static bending tasks, the moment generated by the subjects around the low back was reduced by 15-20% when wearing the exoskeleton. The exoskeleton generated around 20 Nm support. However, the back-muscle activity when wearing the exoskeleton was not always significantly lower compared to not wearing it. This could be explained by the large lumbar flexion angle that occurred in some participants. These participants showed the so-called flexion-relaxation phenomenon, in which the extension moment around the lower back is not generated by active muscle force but by passive tissues in the low back. Thus in these postures, the flexion moment due to gravity is balanced by an extension moment produced by passive tissues and when the exoskeleton then also produces an extension moment the subject would have to counteract this moment, by abdominal activity, to maintain the same posture. This will increase low back loading. These results indicate that flexion-relaxation and its inter-individual variation should be considered in future exoskeleton designs.

During dynamical lifting from ankle height, we found that the exoskeleton did not affect lifting strategy in terms of movement speed or lifting style. The support of the exoskeleton was similar as in the static bending tasks (20 Nm). However, during lifting, the moment that needs to be generated is twice as high (210 Nm) compared to static bending (100 Nm). Therefore, the relative effect of the exoskeleton was only around 10% (figure 2). In addition, we found a substantial reduction in support (of almost 10 Nm) during upward movement compared to downward movement. Due to friction in the system, energy is lost in the device, leading to less support at peak loading, just after picking up the load. Although effects were small, peak moments generated by the participants were significantly reduced while using the exoskeleton. This finding was supported by reduced back muscle activity by around 10%. These results indicate that while a reduction in low back load can be reached with an exoskeleton, we have to aim at more support and less hysteresis of future exoskeletons, to achieve more substantial reductions in loading on the lower back during dynamical lifting tasks.

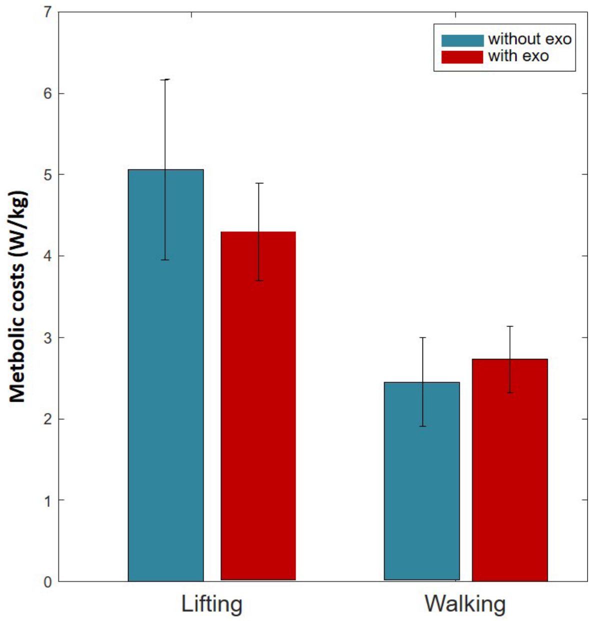

Figure 3. Metabolic costs during lifting and walking with and without the exoskeleton.

Physiological testing

According to the guidelines of the National Institute for Occupational Safety and Health (NIOSH), besides the mechanical load, physiological strain needs to be taken into account, to guarantee safe manual material handling. High physiological strain can result in systemic or local fatigue (Waters et al., 1993), leading to an increased risk of lifting-related low back pain. For physiological testing, we measured the aerobic strain of the participants, by assessing the oxygen consumption during lifting and walking (Baltrusch et al., under review). Participants had to lift and lower a box of 10 kg for 5 min at a frequency of 8 lifts per minute. In addition, we assessed the aerobic load while walking on a treadmill, to test the potential hindrance of the device during this task. We found that oxygen consumption decreased when wearing the device during lifting (figure 3). This indicates that this passive exoskeleton supports the user during lifting, probably by reducing muscular effort in the low back, which might reduce fatigue during working tasks, but also observed changes in lifting technique, from squat to stoop lifting, may have contributed to this effect. On the other hand, during walking the oxygen consumption increased (figure 3), which indicates that the device could hinder the user in other functional tasks that occur at a worksite that might offset the positive effect on fatigue.

Functional testing

To further assess the effect of the passive exoskeleton on functional performance, we developed a test battery of 12 different tasks that can be found in many work environments (Baltrusch et al., 2018). This test battery consists of range of motion tasks, such as forward bending, rotation or squatting, and tasks that are performed commonly in work settings, such as carrying, lifting, walking and stair climbing. Our aim was to test both tasks that are expected to be supported as well as tasks that might be hindered. Performance of all tasks was measured in terms of objective performance, i.e. time to perform the task, and in terms of subjective performance, i.e. perceived task difficulty. The results showed that the passive exoskeleton only increased performance in static forward bending, but decreased performance in several other tasks (figure 4). Especially tasks that required hip flexion were hindered by the device. The subjective estimation of perceived task difficulty showed a similar picture, with only one task being perceived as easier when wearing the exoskeleton and a number of other tasks being perceived as more difficult. These findings indicate the importance of the possibility to disengage the hip spring in the device when the type of task that is performed requires unrestricted hip movement.

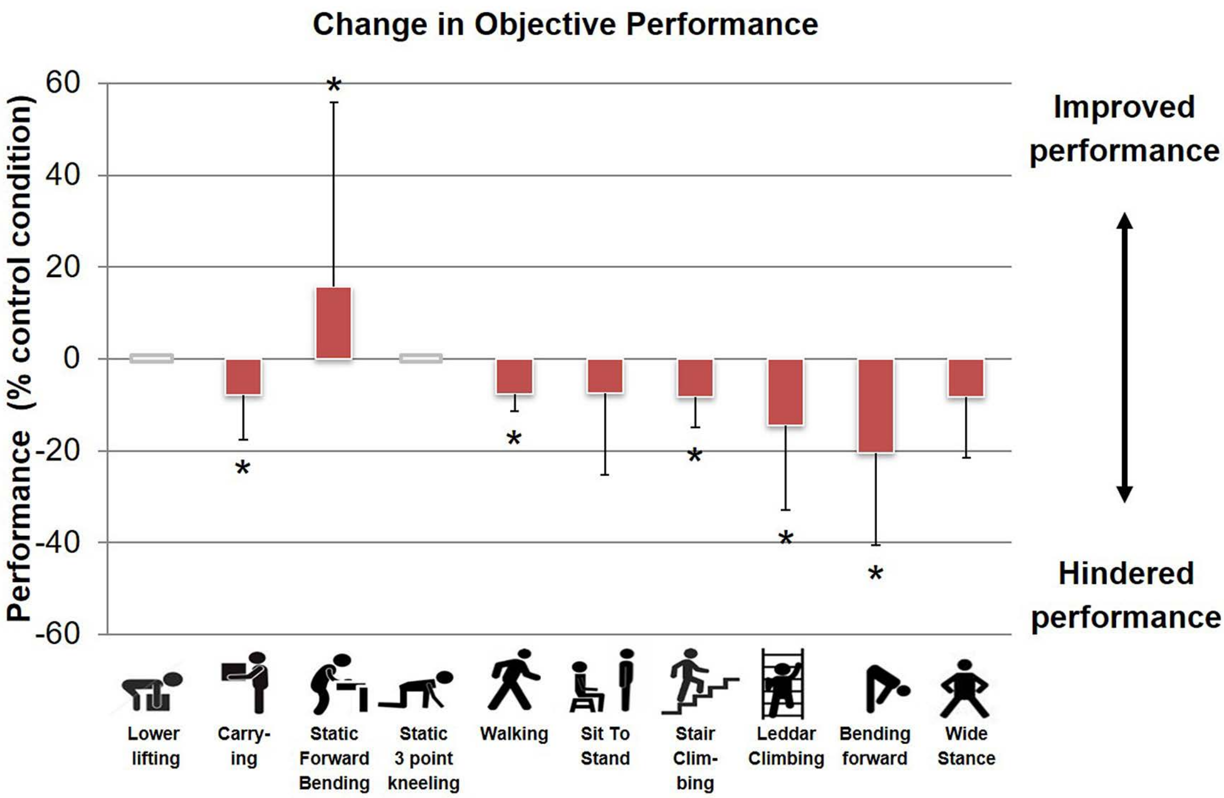

Figure 4. Change in objective performance when wearing the exoskeleton, compared to not wearing the exoskeleton. Note that only one task (static forward bending) increased in performance, whereas several other tasks decreased in performance when wearing the exoskeleton.

Design improvements and further developments

Based on the results from biomechanical, physiological and functional testing, we could define three important design improvements with respect to the benchmark Laevo exoskeleton, to be considered when developing the Spexor device. First, prevention of the flexion-relaxation phenomenon or prevention of providing support when this phenomenon occurs is needed. To do so, the exoskeleton design could prevent deep flexion angles in the low back, but make the person use hip flexion when bending forward. Second, the data showed that a new design should provide more support with less hysteresis. Finally, disengaging the device whenever the support is not needed becomes essential when aiming for higher versatility and freedom of movement.

Going back to the example of the luggage handler, an exoskeleton will only be used during a working day if the exoskeleton provides sufficient support and when this support can be switched on when needed and switched off when a task does not require support. Based on these design requirements, we have developed a first SPEXOR protoype that is being tested with employees from load handling professions. First results showed that we are making progress to provide the end-user of our Spexor exoskeleton with more support, less hysteresis, improved versatility and unrestricted hip flexion (Näf et al., 2018). This prototype will be expanded with active components that should further increase support of the lower back and enhance control of this support in various work related tasks. Follow our progress at the project website.[1]

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[1] www.spexor.eu.

FYSIEK

Active back-support exoskeletons: how assistive strategies determine effectiveness

The potential versatility of active exoskeletons is achieved by appropriately modulating their actuation forces. This is done by assistive strategies that interpret user's movements and assistance needs during operation. This article shows how different strategies determine the effectiveness of an active back-support exoskeleton designed to assist manual material handling.

Stefano Toxiri, Axel S. Koopman, Maria Lazzaroni, Jesús Ortiz, Valeria Power, Michiel P. de Looze, Leonard O'Sullivan, Darwin G. Caldwell

Exoskeletons are wearable devices that assist physical activities by generating assistive forces to the user's body. There has been increasing interest in using exoskeletons in industrial environments to improve ergonomic conditions. Manual material handling is a common activity in different industrial sectors consisting of repeatedly lifting and moving objects, e.g. baggage handling in airports. It is typically associated with large compressive forces on the lumbar spine, leading to high risk of physical injury (Norman, et al., 1998), (OHSA (European Agency for Safety and Health at Work), 2000). To mitigate this challenge, a few exoskeletons have been developed internationally (within research studies and as commercial products) to support and assist the lower back.

Figure 1. Side view of the back-support exoskeleton prototype (DoF stands for Degree of Freedom).

An important distinction should be made between passive and active devices, based on whether the forces are generated by mechanical elements (e.g. springs) or by powered actuators (e.g. electric motors). While the forces in a passive device are determined at the design stage, the assistive function of an active exoskeleton is automatically adjusted during use by a computer, which controls the actuators based on data from sensors as input and according to what is known as the *assistive strategy*. Although sensors, computers and actuators certainly make the design of active exoskeletons more challenging compared to passive ones, it is generally considered that active devices hold the potential for superior versatility, within which assistive strategies are the key to exploiting it (Young & Ferris, 2017).

This study describes an experiment that assessed and compared two alternative assistive strategies for an active back-support exoskeleton prototype. A more detailed description of the methods and results can be found in (Toxiri, et al., 2018).

Methods

Platform: exoskeleton prototype

An active back-support exoskeleton was developed in the context of the Robo-Mate EU project (Stadler, et al., 2017) and developed further via national Italian funding by an INAIL project (the Italian Workers' Compensation Authority). The prototype (Figure 1) spans the torso and upper legs. Two actuators are located lateral to both hips and aligned approximately with its centre of rotation when putting on the exoskeleton. The rigid structures transmit actuator torques between the torso and the thigh frames. The assistive torques are approximately restricted to the sagittal plane, while passive degrees of freedom allow unhindered movements outside of that plane.

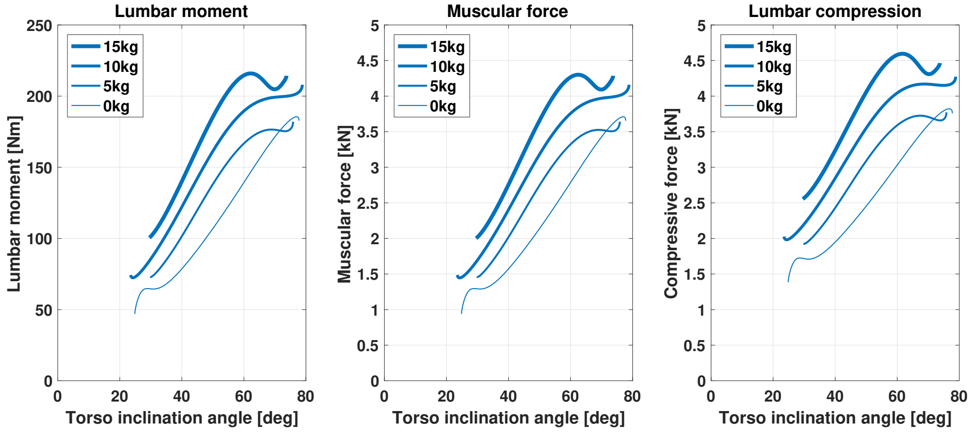

Figure 2. Computed lumbar moment, muscular force and lumbar compression as depending on (a) torso inclination angle, and (b) mass of the object lifted.

Each actuator consists of a commercial brushless DC motor, a reduction gear and a joint torque sensor. The electronics to drive the actuators implements a closed-loop torque control scheme that tracks, on both sides, the reference signal generated by the assistive strategy.

Rationale for strategies: biomechanics of lifting

Based on the simplified two-dimensional musculoskeletal model of the spine introduced previously (Toxiri, et al., 2015), two key factors appear to affect the lumbar moment, the muscular force of the *erector spinae* and the resulting compression force (Figure 2) are: (a) the *orientation of the upper body* and (b) the *mass of the object* being handled. Lower back biomechanical loading increases with increased flexion in the sagittal plane, reflecting a corresponding increase in muscular activity. Indeed, greater forces at the back-flexion musculature (*notably the erector spinae muscle*) are necessary to counteract the moment generated by gravity acting on the user's upper body and external mass. Consequently, increased lower back biomechanical loading is directly associated with increased object mass. In order to appropriately time and assist modulated physical assistance in the exoskeleton, these two factors were considered for the design of the assistive strategies, as described below.

Proposed assistive strategies

Three strategies are proposed. The first (*imu*) and second (*myo*) strategies each reflect the two factors described above (i.e. torso inclination angle and external mass). The third strategy (*hyb*) is a combination of the first two strategies, accounting for both factors at the same time. Figure 3 illustrates their working principle in terms of the reference torque signal that each strategy generates during the task.

The *imu* strategy uses a measurement of the inclination of the torso to assist the user. This is based on the estimated weight of the upper body itself. Rather than using a precise estimate, the sine of the inclination angle is multiplied by a scaling factor . Increasing this scaling factor increases the physical assistance generated, which can be thus adjusted to user preference. The angle is measured via an integrated onboard Inertial Measurement Unit (IMU).

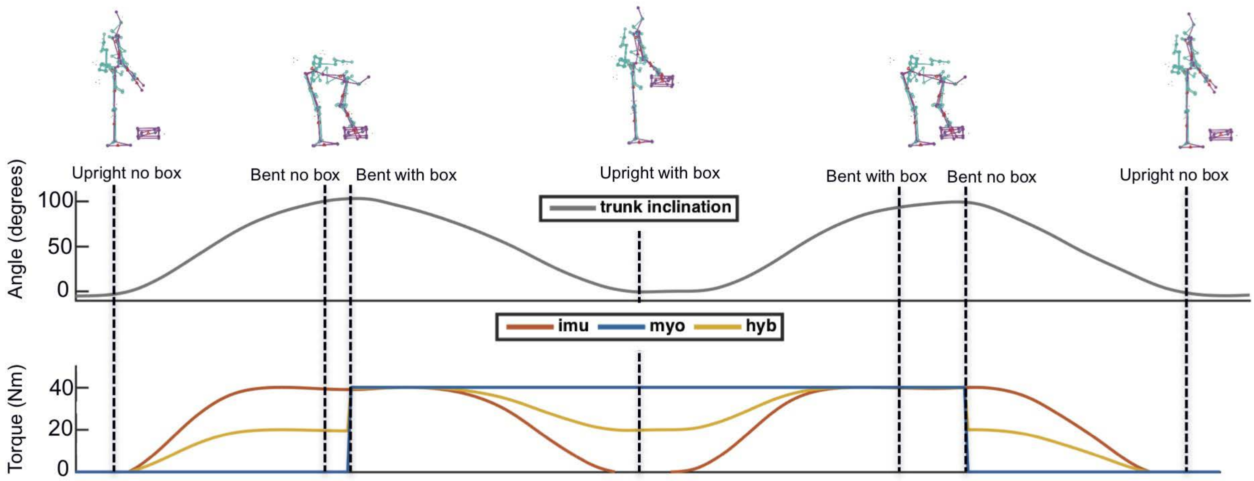

Figure 3. This simplified illustration describes the idea behind the implemented control strategies. The top plot displays the inclination angle of the torso over time. The bottom plot displays the torque reference signals generated by three different strategies., i.e. "imu" (orange), "myo" (blue), and "hyb" (yellow).

The *myo* strategy is based on the concept that the overall muscular activity at the forearm carries information about the weight of the object lifted. A commercial armband (Myo – www.myo.com) records forearm muscle activity by means of eight pairs of dry sEMG electrodes and sends the data to an integrated computer via Low-Energy Bluetooth. The sum of the eight values is normalized (using a maximum value recorded during a preliminary calibration procedure) and multiplied by a scaling factor that may also be adjusted to user preference. As with the previous strategy, increasing the scaling factor results in stronger physical assistance.

The *hyb* strategy generates a torque assistance based on the sum of the two previous strategies. This represents a more general case, and it is possible to adjust the two scaling factors independently based on user preference and task conditions.

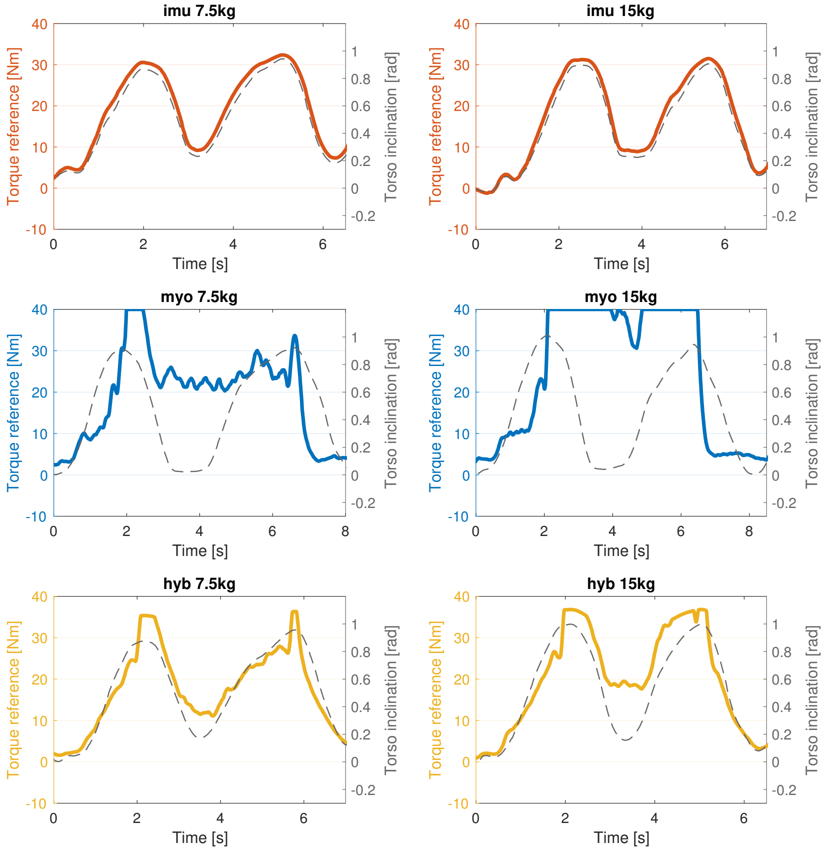

Figure 4. The solid lines represent the torque reference profiles (sum of the two actuators) generated by the different strategies, while the dashed lines show the corresponding torso inclination angle. The imu is invariant to the external object, while the myo increases the assistance for the heavier object. The hyb results in an intermediate behavior.

Evaluation

The effectiveness of the three strategies is evaluated by considering the resulting muscular activity at the lower back (de Looze, Bosch, Krause, Stadler, & O'Sullivan, 2016) during an experimental campaign aimed at recreating the key biomechanical conditions of a lifting task. A significant reduction in muscular activity is, in most cases, associated with a reduction in the corresponding compressive loads.

Protocol

The lifting and lowering task consisted of the sequence in Figure 3, i.e. bending over to reach a box placed at mid-shin height, taking it to an upright position, and taking it back down. This sequence was repeated three times and executed with a 7.5-kg and then with a 15-kg box. The task was performed in four different conditions:

- *no exo*: no exoskeleton is worn;
- *imu*: the exoskeleton is commanded via the *imu* strategy;
- *myo*: the exoskeleton is commanded via the *myo* strategy;
- *hyb*: the exoskeleton is commanded via the *hyb* strategy;

with the *no exo* condition being first in all cases, and the other three in a randomized order. The torque reference signals generated by the *imu*, *myo* and *hyb* conditions are shown in Figure 4, as averaged across all executions and subjects. No instructions on a specific lifting technique (i.e. stoop or squat) or speed were given. Eleven healthy, young males (average age 25.0 [SD 6.9] years, weight 70.9 [SD 8.8] kg, height 1.77 [SD 0.06] m) participated in the experiment, of which none had any history of low-back pain.

Muscular activity

Standard laboratory equipment for surface electromyography (sEMG; Porti-17TM, TMS, Enschede, The Netherlands) was fitted to measure the activity of left and right spinal muscles (*iliocostalis*) following SENIAM guidelines (Hermens, et al., 1999).

The recorded activity is shown in Figure 5. With respect to the *no exo* condition (green), reduced activation of the spinal muscles is observed in all three strategies. In more detail, the *imu* strategy (orange) led to the lowest activation during both the initial descending phase (before 2.0s) before the box is reached, and the final ascent after the box is released. In contrast, the *myo* strategy (blue) reduced activation the most during the central phase, corresponding to when the box was held by the subject. In line with the average muscular activation profiles, peak muscular activation is also reduced in all three strategies for both the 7.5- and 15-kg loads. With respect to the *no exo* condition, significant relative reductions ($p < 0.05$) in the peaks ranging from 28% to 35% were observed.

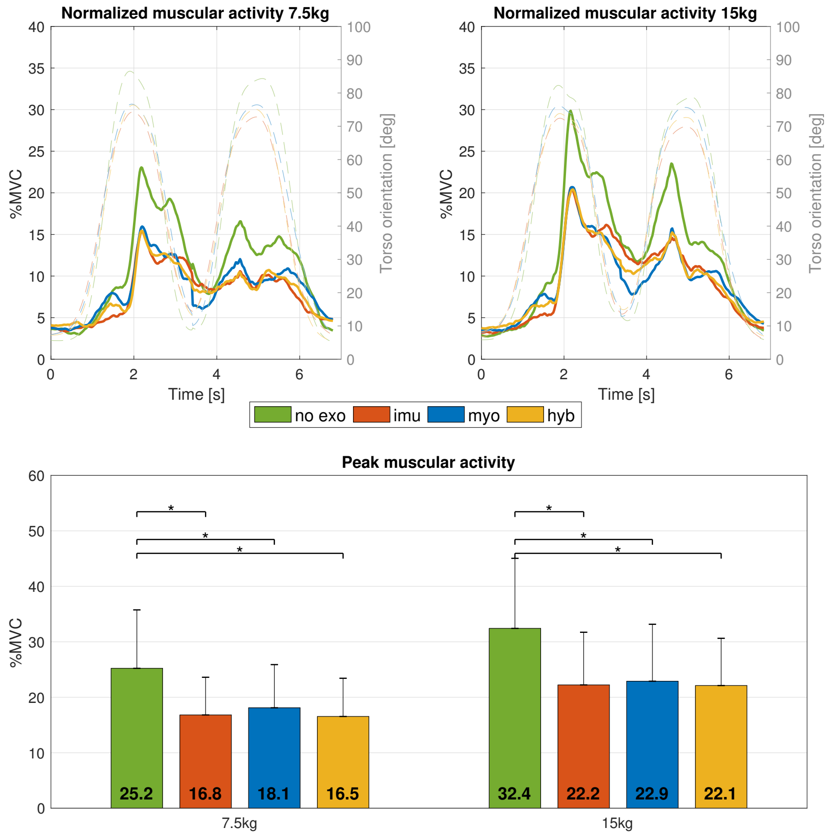

Figure 5. At the top graphs, the solid lines represent averaged EMG profiles (left and right iliocostalis) across all subjects in percentage maximal voluntary contraction (% MVC). The dashed lines show the corresponding torso inclination angle. In all cases, wearing the exoskeleton decreased the activity, with none of the three strategies prevailing. The isolated peak activations, at the bottom, indicate reductions of about 30%.

Discussion

The *imu* and *myo* strategies, each designed to address one of the two key factors determining the need for physical assistance during lifting tasks, should be considered together with their respective advantages and drawbacks, which may impact the practical use. The *imu* strategy is entirely transparent and unobtrusive to the user as it uses signals acquired by onboard sensors. However, as it cannot adjust to the variability of the external load, it may be a good solution to support against known loads, as is the case in static postures. In contrast, the *myo* strategy captures the additional load caused by the external object and therefore may be suitable for tasks involving repeated handling of unknown loads. Additionally, the wireless armband does not appear to be cumbersome to wear, nor distracting the wearer from the task at hand.

Interestingly, scaling up the assistance with the *imu* strategy would quickly make the device unusable due to inappropriate and excessive resistance to movements. This strategy may therefore be limited to supporting the user's own upper body. By contrast, *myo* lends itself more naturally to stronger, more powerful devices, capable of assisting manual handling of heavy material.

These experimental data indicate the effectiveness of the proposed prototype as commanded with each of the assistive strategies as tested. The data show reductions of 28% to 35% in peak muscle activation at the lower back across various conditions. Further research is needed to consider other factors, notably lifting speed, which will additionally improve the effectiveness of back-support exoskeletons.

Limitations of this study

Considering muscular activity as an evaluation metric is often a case of convenience, as it can be quite readily measured in a research laboratory with non-invasive technologies. On the other hand, joint loading, more directly connected with the risk of injury, can only be estimated indirectly and requires the use of additional technology (e.g. 3D motion capture and biomechanical analysis) and musculoskeletal models, which results in substantially more time-consuming testing procedures.

This experiment did not study muscular fatigue as it cannot be observed in such short trials. Also, the effect of this prototype on other body areas other than the lumbar spine were not considered. Evidence excluding extra loading on the legs due to the back-support exoskeleton was presented in (Huysamen, et al., 2018).

For an exoskeleton to be successfully adopted in industry as a product, there are many aspects which must be met, many of which are beyond the scope of this study. For instance, the device must have high acceptance by users, so that they feel encouraged to use it and it must be affordable and integrate well with existing infrastructure, so that employers are motivated to purchase it.

Conclusion

The versatility of active exoskeletons lies in their capability to modulate the physical assistance based on relevant task information. Our study shows two important factors of compressive loading during lifting tasks (inclination of the upper body and mass of the object handled) and that an unobtrusive sensor setup can acquire the necessary information to effectively modulate the assistance. The corresponding assistive strategy can be adjusted to user preference and to task variations, making the resulting exoskeleton versatile and intuitive.

Abstract

Active exoskeletons are potentially more effective and versatile than passive ones but designing them poses several additional challenges. An important open

challenge for active exoskeletons is associated with assistive strategies, by which the actuation forces are modulated relative to the user's movements and assistance needs. This paper addresses an element of this challenge for an active exoskeleton prototype aimed at reducing compressive loads on the lumbar spine, which is associated to the risk of musculoskeletal injury during manual material handling (i.e., repeatedly lifting objects). During manual handling tasks, two key factors related to biomechanical loading are posture, e.g. forward inclination of the torso, and external mass lifted. Specific control strategies, accounting for these two factors, were implemented and evaluated experimentally. The results indicate a significant reduction in muscular activity (circa. 30%) at the lower back when using the exoskeleton with the different strategies.

With such strategies, the proposed exoskeleton can quickly adjust to different task conditions (which makes it versatile compared to using multiple, task-specific devices) as well as to individual preference (which promotes user acceptance). Additionally, the strategies explored are potentially applicable to many exoskeleton types for industrial use.

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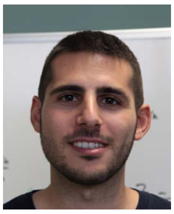

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FYSIEK

A passive lower-limb industrial exoskeleton

Subjective evaluation during and after simulated assembly

In recent years, exoskeletons have been seen as an opportunity to prevent work-related musculoskeletal complaints or to have employees with musculoskeletal complaints reintegrate sooner, faster or more easily. In this manuscript, we propose a passive lower-limb exoskeleton, which is interesting for employees who perform mainly standing work and where the use of a chair is not possible in terms of space and safety.

Tessy Luger, Robert Seibt, Monika A. Rieger, Benjamin Steinhilber

Introduction
The use of exoskeletons in an occupational setting aims supporting workers in heavy load lifting or repetitive motions (de Looze et al., 2015). This also means that an indirect aim of using exoskeletons is to reduce the prevalence and incidence of work-related musculoskeletal complaints, since heavy loading and repetition are among its most important contributors (Da Costa & Vieira, 2010; Kausto et al., 2011; Mayer et al., 2012).
When evaluating exoskeletons in the laboratory or in the field, aspects such as biomechanics, energetics, safety, and subjective assessment can be included. Although highly dependent on and variable among individuals, subjective assessments are critical when it comes to acceptance and actual use of an exoskeleton in practice. Subjective assessments can be collected with respect to, e.g., usability, user acceptance, or discomfort. Several recent studies report the subjective assessments of different exoskeletons: Laevo®, Robo-Mate®, EksoVest®, EXHAUSS Stronger®, FORTIS®, and ShoulderX®.
The Robo-Mate® was assessed for its usability, which was rated acceptable (Huysamen et al., 2018). All of the seven exoskeletons mentioned above showed only little discomfort in target body regions or showed decreased discomfort when the exoskeleton was worn compared to when it was not worn (Bosch et al., 2016; Huysamen et al., 2018; Kim et al., 2018a; Kim et al,. 2018b; Theurel et al., 2018; Alabdulkarim & Nussbaum, 2019).

Figure 1. Chairless Chair®. Picture adapted from: https://www.noonee.com/ (© noonee AG).

Objective
The exoskeleton investigated in this study was the Chairless Chair® (noonee AG, Switzerland), which is a passive lower-limb exoskeleton that allows the standing worker to sit for short periods at different seat heights (Figure 1). The aim of this study was to evaluate subjective assessment of the Chairless Chair in different sitting heights (standing vs. high sitting and low sitting).
Note that the study results described in this manuscript are part of a larger study in which the overall goal was to perform a biomechanical-physiological evaluation of

Table 1. Questionnaire items on which participants replied on a 10-point scale, ranging from 1 (completely disagree) to 10 (completely agree).

General items	
1	The exoskeleton sat comfortably
2	The exoskeleton was easy to handle
3	I was able to work precisely with the exoskeleton
4	The exoskeleton is suitable for the simulated assembly task
5	I can imagine working with the exoskeleton over a longer time
Specific items	
1/2	The working posture was pleasant while sitting in the high/low configuration
3/4	I felt very safe while sitting in the high/low configuration
5/6	I would have liked to change my working posture while sitting in the high/low configuration

the Chairless Chair® in simulated assembly. Results of other parts of the study, i.e. muscle activity and posture evaluations, have already been presented at several national and international conferences (Luger et al. 2018a; Luger et al. 2018b; Luger et al. 2018c; Luger et al. under review). In summary, the muscle activity level of the calf muscle (gastrocnemius medialis) was lower in both low and high sitting on the Chairless Chair® compared to standing, and it was lower in low than in high sitting. The muscle activity level of the vastus lateralis was higher in both low and high sitting on the exoskeleton compared to standing, and it was lower in low than in high sitting. The muscle activity level of the trapezius descendens was higher in both low and high sitting compared to standing. The muscle activity level of the erector spinae lumbalis was higher in high sitting compared to low sitting and standing. The position sensors showed that there was less neck flexion but more back flexion in both low and high sitting compared to standing.

Methods

Forty-six healthy males participated, who had a mean age of 24.8 (SD ± 2.9) years old, a mean height of 182.6 (SD ± 5.5) cm, and a mean body mass of 78.1 (SD ± 8.7) kg. The ethical committee of the University Hospital Tübingen approved the protocol (Project Number 184/2017BO2), and all participants provided their written informed consent.

Seven different experimental conditions were compared, which are a combination of working posture and working height, including: (1) standing posture with optimal working height, (2) standing posture with too low working height, (3) high sitting posture with too high working height, (4) high sitting posture with optimal working height, (5) high sitting posture with too low working height, (6) low sitting posture with too high working height, (7) low sitting posture with optimal working height. The optimal working height was determined according to DIN EN ISO 14738:2009-07, where too low and too high were determined as a deviation of ± 10% from the optimal calculated working height.

During each of the seven conditions, participants performed simulated assembling for 21 minutes including screwing, clip fitting, and cable mounting. Before and after each condition, participated rated their discomfort level on an 11-point numeric rating scale ranging from 0 (no discomfort at all) to 10 (highest imaginable discomfort ever experienced). After the seventh condition, wearer comfort was assessed on a 10-point numeric rating scale ranging from 1 (completely disagree) to 10 (completely agree) using five general items and six specific items for high and low sitting configurations (Table 1).

A two-factor (working posture, working height) repeated measures analysis of variance (ANOVA) was performed on the discomfort data, using post hoc Student's T-Tests with Bonferroni-correction. No interaction term was included because we evaluated an incomplete factorial design. A paired T-Test was used on the six specific questionnaire items comparing the two working postures. The general questionnaire items were described with descriptive statistics. The statistical analyses were performed with JMP (JMP® 13.1.0, SAS Inc., Carry, NC, USA), with $\alpha = 0.05$ or $\alpha = 0.0167$ (Bonferroni-corrected post hoc tests).

Results

Ratings of discomfort significantly differed across the three working postures ($p < 0.01$). Standing had an average discomfort value of 0.57 (SD 1.09), which was significantly lower than low sitting with an average of 1.13 (SD 1.49; $p < 0.01$) and high sitting with an average of 1.37 (SD 1.49; $p < 0.01$). The body regions

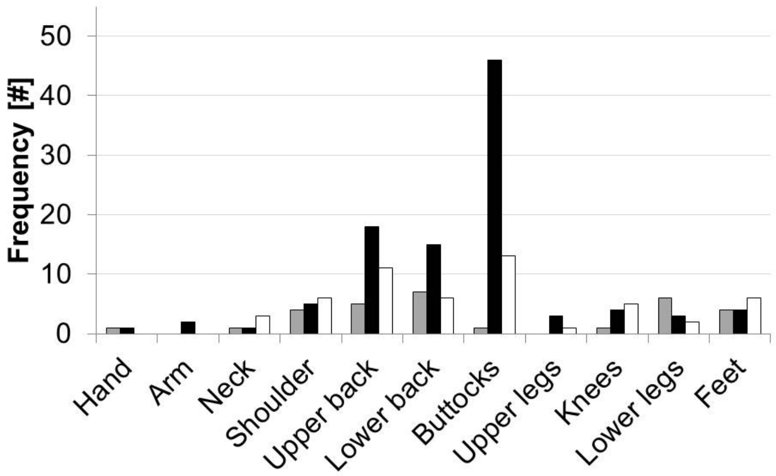

Figure 2. Frequency of reported discomfort per body region (≥ 1), stratified to working posture standing (grey), high sitting (black), and low sitting (white).

characterized with most discomfort are the buttocks and the back with highest prevalence in the high sitting conditions (Figure 2).

The five general questionnaire items revealed that wearer comfort was rated fair to good (Figure 3), i.e. all items scored on average almost 7 or higher on the 10-point scale. The six specific questionnaire items (Figure 4) showed that low sitting on the Chairless Chair® scored higher for pleasant working posture than high sitting ($p < 0.01$) and scored higher for feeling safe than high sitting ($p < 0.01$). The third questionnaire item about the question whether participants preferred to change their working posture did not significantly differ between low and high sitting on the exoskeleton ($p = 0.0638$).

Conclusion

The positive results of the subjective evaluation, i.e. a low reported level of discomfort of 1.4 on an 11-point numeric rating scale and a fair rating of wearer comfort of 7.9 on a 10-point numeric rating scale, suggest that the Chairless Chair® has the potential to be used in the occupational field. However, it might be worth comparing the evaluated exoskeleton to a regular chair situation, to see whether there are detrimental effects of using the Chairless Chair® instead of a regular chair. We note that the high sitting condition was characterized with most discomfort and lowest wearer comfort, which should be considered in applying the Chairless Chair®, collaborated with the feedback of 'having the feeling to slide off the sitting pads', which could be a hint for the manufacturer to improve the sitting mechanism and fabric.

A field feasibility study would be highly valuable to give a better view on the user acceptability of the Chairless Chair®. An additional expert and/or user evaluation of workplaces suitable to implement the Chairless Chair® as well as a directive on how long and often employees may use the Chairless Chair® during a work shift without expecting any detrimental effects would be helpful for both researchers and practical ergonomists.

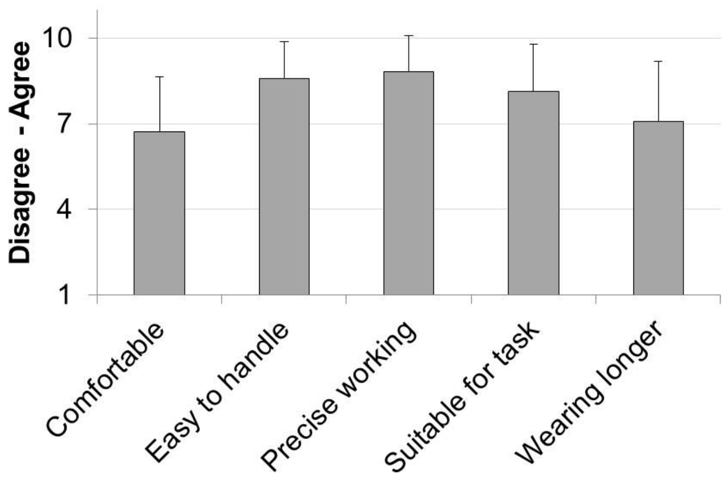

Figure 3. Average response (error bars are SD) to general questionnaire items regarding wearer comfort, rated using a 10-point numeric rating scale (1 = completely disagree; 10 = completely agree). The questionnaire items are listed in Table 1.

Funding

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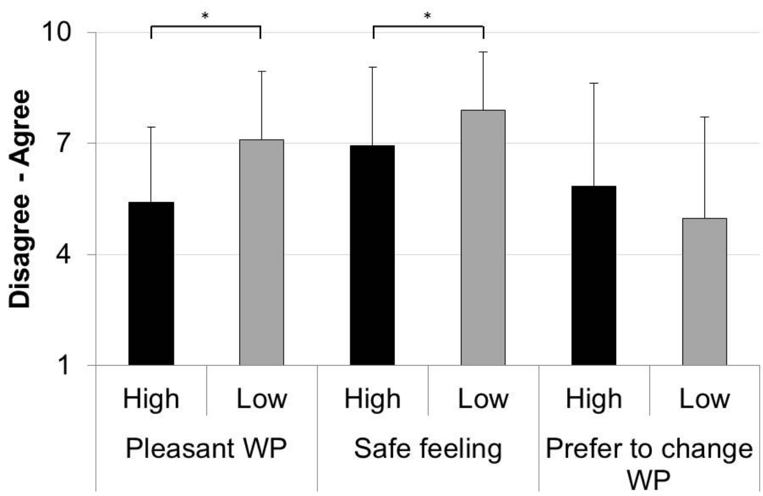

Figure 4. The average response (error bars represent SD) to the specific questionnaire items regarding wearer comfort in low (grey) and high (black) sitting on the exoskeleton, rated using a 10-point numeric rating scale (1 = completely disagree, 10 = completely agree). The questionnaire items are listed in Table 1.

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TOOLBOX

A concept car in the airport

Why a concept car design approach also inspires baggage handling software design

This article describes a recent project where the concept car design approach, as used in the car industry, is applied to the airport's baggage control software to instigate such a big leap. In the car industry it is common to envision innovative ideas in a concept car. This approach brings unique benefits and proofs to be attractive to customers as well as to designers, engineers and management. It visualizes ideas in an attractive, tangible way, such that the value of the ideas can be validated with different customers and users before much effort is put in making it work.

Odeke Lenior

Imagine you are traveling from a busy airport to a lovely holiday destination for which you have just checked in your bag. Behind the scenes different organisations, people, processes and advanced, automated systems are trying to ensure that your bag gets onto your flight, on time. Those of us who have been waiting at the reclaim carrousel and did not meet their expected bag, know the feeling of (temporarily) losing their bag. Airports and airlines understand that their air travel business is largely about the passenger experience and therefore about their emotion. Nonetheless, baggage handling is a complex process.

To succesfully meet your bag at the reclaim carrousel of your holiday destination requires a smooth baggage handling operation of all parties involved. Tasks and responsibilities are split over airport personnel as well as over airlines, security-, baggage handling- and maintenance companies (see Figure 1).

The complexity of these processes relates to several aspects the baggage control room needs to deal with, one being the baggage flow (number of bags/hour). A single terminal at a busy European airport processes, for example, approximately 12.000 bags an hour.
In these baggage handling processes many human factor challenges can be found. One of the most important is matching the user's experience and expectations with the technical challenges behind the 'screen'. How can a complex system be fine-tuned to the individual? The

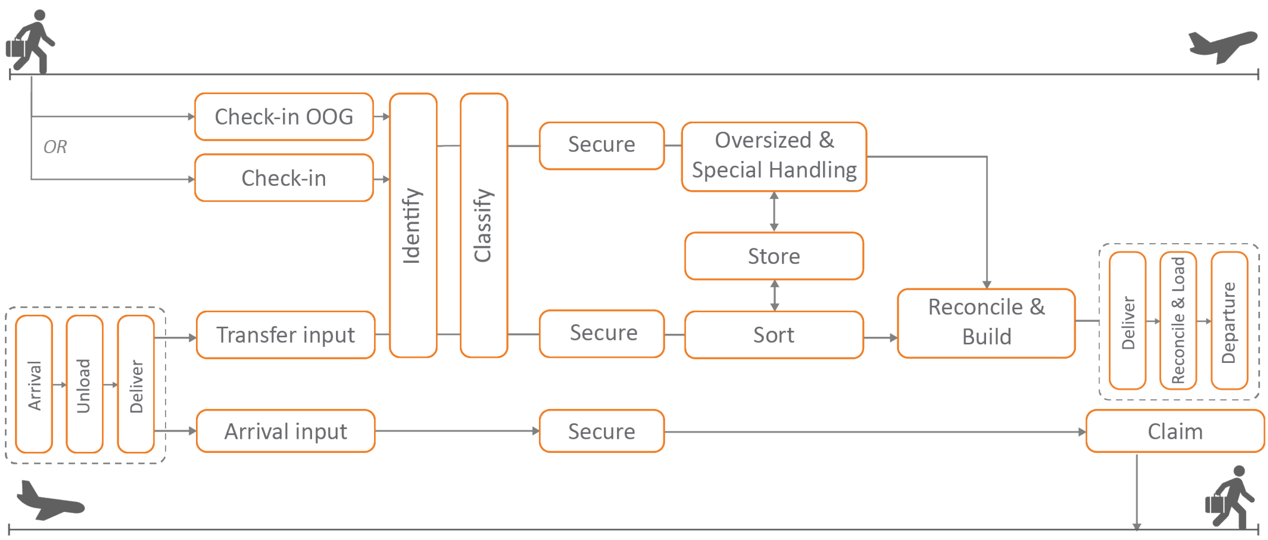


Figure 1. Overview of the different baggage processes.

automotive industry has decades of experience in tackling these issues by developing concept cars to make big leaps in designing increasingly complex systems with individual preferences and user experiences. It is designed to show future, potentially ground-breaking concepts of which the car manufacturer likes to know what is appealing to the public and what is not. They are one-off cars build for the purpose of testing the potential customer's response to new ideas and thus decrease the risk of the commercial car's development (Crea, 2015), which is costly and time-consuming. Developing a concept car allows the manufacturer to understand which ideas should be followed up now and which can be left out for the next version of a car. A concept car can feel weird to some users, because it takes time to understand a concept that is responding to the future instead of to the current needs. So, if a specific aspect is currently disliked, does it need to be thrown away or might it be desired (in a slightly different form) in a later version of the car?

This article focuses on the car industry's concept car approach that is being used to bring the user experience of the baggage handling software to the next level. However, before we look at how this approach can be applied, we first briefly discuss the more traditional approach used in the domain of baggage handling.

Evolutions in more than ten years of baggage design and operation

In 2003 an HTA (see text box) was created for the operations and maintenance of a large baggage system (Lenior, 2006). In the detailed design phase, discussions upon what the user interface exactly should look like were taking quite some time and effort. At the time the solid HTA approach sped up making the right user interface design choices. It brought more clarity in the roles and responsibilities of the different organisations involved and identified the exact split in the user interfaces.

HTA - Hierarchical Task Analysis (Kirwan and Ainsworth, 1992)

HTA is a structured approach to describe the users' tasks. Start with the main goal that needs to be achieved and split it up into tasks to achieve that goal. Then break down each task into subtasks, until sufficient understanding of the user's actions is found. For each (sub) task aspects like the sequence, duration, frequency and the user role can be described. An analysis that results in a base for the user interface designs and provides clarity upon roles and responsibilities.

Since the baggage system in the airport terminal mentioned above went live, the organisation of baggage monitoring and control has changed and requires updates to its process. The multi-terminal airport has consolidated all baggage control rooms into a single, airport-wide room (see Figure 2). Though different terminals at this stage still use different software applications, this centralisation allows for more efficient sharing of knowledge, operators and baggage system capacities.

Furthermore, technology and its integration in society has changed substantially in ten years' time. Artificial intelligence for example has taken a leap, also in private use. Having intuitive smartphones and tablets with apps that support the user by 'spontaneously' providing suggestions (e.g., 'it will take you 20 minutes to travel to work if you leave now') has resulted in higher expectations by users from technology and a more individualized and smoother user experience.

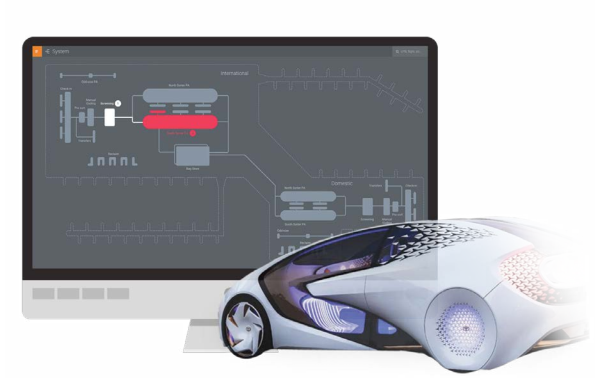
Figure 2. A baggage control room with a variety of software- and communication systems.

With this new context in mind, it was time to re-envisage the baggage software tools. Besides doing gradual software upgrades, based upon changes in legislation or user requests, this led to an explorative project with a completely fresh view on what is desired to optimally support the baggage operation.

Project concept car

In 2017 our *concept car* project started. This project aimed on bringing the user experience of the baggage control software to the next level. The assignment was to design an innovative, easy-to-use and attractive user interface that fully focuses on the main goal to be achieved; getting each bag on the right flight, at the right time.
This project was executed in close cooperation with a strategic design agency, that makes attractive and useful products and uses design as a power to change and improve (www.fabrique.nl, 2018). After having the whole team on the same page with regards to the baggage handling contexts, a creative session was held to set the first idea directions for the concept car. An important aspect that needed quite some discussion, was the decision upon the appropriate timeframe. This timeframe needed to balance fitting the world as it is, because it should be possible to start development now, as well as being innovative and fitting the near future. Even though certain parts of the concept car are expected to be launched sooner, a timeframe of four years out, as also used in the car industry to launch a new car (Meijia Sarmiento, 2018) appeared to be quite appropriate.

Subsequently, a so-called *pressure cooker*, which resembles a *design sprint* (Knapp, Zeratsky and Kowitz, 2016) started; an agile approach to build a prototype with a small team in just five days. This prototype, the concept car, consisted of an attractive, interactive set of user interface designs and was first tested internally. Feedback was gathered via presentations and discussions with colleagues in baggage design, sales



and engineering. After another iteration, the concept car was taken to control room operators and their management at three airports to receive feedback. Interviews were held, and observations made whilst users were asked to perform certain tasks with the prototypes. Management was involved as the solution impacts the way work is organised. To set the right expectations, the name concept car was first briefly explained, internally as well as with customers. Responses on this approach for new concept development and user's involvement were positive, even though choices on certain concepts were challenged. For example, this future concept car looked at the users' experience of map and navigation technology with seamless zooming and decision support that invited users to easily share their comments and ideas. After all, a concept car in a car show also evokes all sorts of reactions.

The reactions on the prototype of the software steered decisions upon which aspects needed to be developed more and which aspects of the prototype are not desired in the foreseen future. After the users' decisions were considered, the development project phasing could be defined and the technical feasibility study for only the desired features could be finalized, all resulting in a better indication of the required development budget.

At this moment of writing, the software development of the next generation of baggage control software has started. An agile project that uses Scrum (see box) and several user centred/design thinking methods. In this quickly changing world, with more and more technology integrated into our lives, it is essential to keep on validating the solution and being able to adapt to the new learnings. Lessons on how to best scrum, with a team of user experience- and visual designers, front-end and back-end developers in the technical baggage environment are crucial, but out of the scope of this article.

Concluding thoughts

The use of technologies in different markets and in the home environment (e.g. smart speakers, use of smartphones to control household equipment) has substantially grown the last years. This heavily influences the expectations of the user in a work environment. It

Intelligence in baggage control systems

User interfaces in the baggage control room are amongst others a planning system to allocate baggage processes and flights to specific system resources, a SCADA system to monitor the status of the baggage equipment with an integrated CCTV system to show camera footage of specific baggage areas and a real-time Operational Dashboard to have insight in the performance of the baggage processes. This dashboard provides insight in situations that create 'traffic jams' in the system. For example, when there is a backpack strap that gets stuck and blocks the flow or when there's an abnormal peak in the number of late bags arriving with delayed flights, the smart baggage system will indicate that and re-route bags.

therefore becomes more important to understand the needs and desires of the future professional user and the goals he or she needs to achieve.

These new technologies are also for engineers great to use in their products. It is however still important to exactly understand the user's goals. So, how difficult is it to stick to a user-centred design approach in this fast changing, increasing technology driven, world? Especially when the exact users of the system and their responsibilities are becoming less fixed. A challenge for the human factors professional as well as for various kinds of designers to keep on putting the user first. Engineers however do like it when attractive, challenging solutions are created with new technologies.

In this article two methods have been touched upon which differ in approach as well as in appliance. The method of HTA is a more verbal approach that looks at the main and sub goals to be achieved. It was time-consuming to create but helped in detailing the user interface designs. Nowadays having more easy-to-use software available that could speed up HTA work, I would like to see what HTA still can bring in this quickly changing world.

The second method, that of the concept car approach via a design sprint, is more high level; in a short period of time it visualizes how innovative ideas could work in a tangible user interaction design. This makes it possible to quickly evoke reactions and get feedback from users if or how they would use it.

Concept car in the airport

So, why do concept cars inspire the airport's baggage world?

The approach has shown that it works to create an attractive visualisation of the future baggage control software and enabled prospect users to more easily provide their feedback. Bringing in the emotion of a concept car made it easier for direct colleagues as well as for future users and management. to comment on the design of the software.

Properly balancing the people, business and technology aspects will result in a safe and enjoyable operator experience. When the concept car has turned into a driving car, i.e. when the software will be fully developed and operational at different airports the coming years, we're eager to learn whether the design for the baggage control operators in the end translates into a more pleasant passenger experience. No waiting at a reclaim carrousel for a bag that never shows up.

Summary

Airports and airlines understand that their passenger's experience is one of the most important aspects in the air travel business; for a large part of travelling is emotion. How baggage is processed is part of that passenger experience. Baggage handling at the larger airports is quite a complex process in which many organizations need to collaborate. The challenge for baggage system designers is to not only design a system that meets the performance and capacity requirements for the logistical challenges, but to also ensure that the system is optimally used. An optimal design for the baggage control room operator minimizes errors and delays, such that each bag reaches the correct destination on time. For each airport there are differences in the challenges they face to achieve this, for example because of differences in size, space, organisation, passenger- and baggage flows. This implies that, besides enhancements required by changes in legislation or technology, baggage control software is often enhanced based upon user requests for a specific situation. The result is that there are continuous step-by-step improvements, but it misses out on the big leap forward.

Scrum to develop software products

Scrum (www.scrumguides.org, 2018) is an iterative framework to develop software products in a flexible way. It accepts that complex problems cannot be fully defined up front, that things change and that unpredictable challenges will always be there, for which a fully planned approach is not suitable. In short sprints (1-4 weeks) with a small, multidisciplinary team (3-9 people) working products will be delivered and shown to the stakeholders, such that it quickly becomes clear whether the project is on the right track.

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FYSIEK

Praktijkervaring met exoskeletten

Door de inzet van een exoskelet lijkt de mens sterker dan ooit en lijkt geen fysieke uitdaging te veel. Exoskeletten bieden steeds vaker een oplossing voor fysieke (over)belasting. Tot op heden worden exoskeletten voornamelijk gebruikt voor mensen met ernstige lichamelijke beperkingen. Echter, ze worden steeds meer breder ingezet. Hieronder een overzicht van praktijkervaringen.

Linda ten Katen, Floris Lindeman en Agnes Feddema

Exoskeletten worden toegepast in werksituaties waar veel boven het hoofd gewerkt wordt, grote reikafstanden moeten worden overbrugd en waar op vaste hoogte gewerkt wordt, zoals aan een lopende band. Ook bij tillen, bukken en andere werkhoudingen waarbij de fysieke statische overbelasting hoog is kunnen exoskeletten een toegevoegde waarde hebben.
We zien toenemende aandacht voor exoskeletten in diverse werkgebieden, met name in grote productieomgevingen. De komende jaren zal duidelijk worden welke impact exoskeletten gaan hebben op de werkomgeving en fysieke belasting van medewerkers. De exoskeletten zijn continu in ontwikkeling, gedreven door een toenemende marktvraag en groeiende praktijkervaring. Exoskeletten worden hierdoor steeds beter toepasbaar en er komen meer toepassingsgebieden. Ik behandel in dit artikel een aantal exoskeletten waarmee in de praktijk al gewerkt wordt en waarvan toepassingsmogelijkheden en fysieke voordelen te verwachten zijn. De producten worden op dit moment op grote schaal in pilots en proefplaatsingen toegepast. Daarnaast worden ze al bij diverse bedrijven dagelijks gebruikt. In dit artikel lees je de mogelijke toepassingsgebieden voor de industriële werkomgeving.

Het menselijk lichaam extern versterken en fysieke belasting reduceren

Grote en zware voorwerpen worden vaak met industriële hulpmiddelen verplaatst, zoals heftrucks, kranen, en liften. Naarmate voorwerpen kleiner worden, is er meer handarbeid nodig. Zo worden pallets verplaatst met een palletwagen en worden kleinere voorwerpen of pakketten veelal manueel verplaatst. Juist hier ontstaat kans op fysieke overbelasting. Om deze fysieke overbelasting aan te pakken, kijkt men in eerste instantie naar de bron. Het elimineren van de fysieke belasting bij de bron is altijd de meest optimale oplossing. Soms kan een omgeving niet of moeilijk aangepast worden en voldoen hulpmiddelen niet of onvoldoende. Wat zou het dan mooi zijn als de mens sterker kan worden. Als bronaanpak niet mogelijk is en de omgeving niet of moeilijk aangepast kan worden, kan een exoskelet uitkomst bieden. Het exoskelet zorgt ervoor dat de mens 'sterker' wordt. De primaire functie van een exoskelet is het ondersteunen van een of meerdere lichaamsdelen, waardoor het lichaam minder wordt belast. Een exoskelet wordt ingezet om klachten te voorkomen of een aangedaan lichaamsdeel te ontlasten. Het doel hiervan is enerzijds het verlichten van de bestaande werkzaamheden bij (dreigende) fysieke klachten en anderzijds preventief. Bij een preventieve inzet kan een slechte werkhouding voorkomen worden waardoor deze risicofactor wordt gereduceerd. Het toevoegen van werklast moet nooit het doel worden. Als er werklast wordt toegevoegd, kan dit een negatief effect hebben op de andere (niet beschermde) lichaamsdelen.

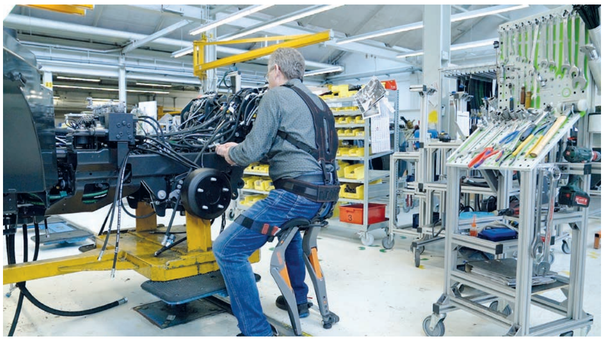
Diversiteit en gebruiksgemak

De afgelopen jaren zijn er veel exoskeletten geïntroduceerd op de markt. De toepassingen variëren van medische tot industriële werkomgevingen. De exoskeletten ondersteunen verschillende lichaamsdelen, zoals benen, rug, schouders en/of armen. Enkele exoskeletten (Chairless Chair en Skelex) worden initieel goed geaccepteerd door de gebruikers. Hoe de acceptatie op langere termijn is, zal nog moeten blijken. De exoskeletten die ik benoem worden gekenmerkt door gebruiksgemak. De producten zijn relatief eenvoudig aan te trekken en zitten niet in de weg wanneer je ermee werkt. De bedoeling is dat de gebruiker niet belemmerd wordt bij handelingen.

Skelex voor reikafstanden en bovenhands werken

Skelex is een dynamische ondersteuning voor de armen, waarbij het exoskelet het gewicht van de armen ondersteunt en de gebruiker een gewichtloos gevoel in de armen biedt. Hierdoor verminderen de spieractiviteit en vermoeidheid. Het exoskelet wordt aangetrokken over de kleding en bevestigd met een buik- en borstband. De armpads ondersteunen de armen. De ondersteuning kan nauwkeurig worden ingesteld op het gewicht van de

Afbeelding 1. Skelex toegepast bij bovenhandse werkzaamheden (http://www.skelex.com/).



Afbeelding 2. Chairless Chair toegepast in de praktijk (https://www.noonee.com/).

armen (http://www.skelex.com/). De Skelex wordt ingezet bij werkzaamheden met reikafstanden en waar boven schouderhoogte gewerkt wordt (afbeelding 1).
Recent is Skelex ingezet bij een medewerker die woningen stript en opnieuw opbouwt, waarbij de werkzaamheden afwisselend bovenhands en onderhands zijn. Bij werkzaamheden bovenhands ervaarde de gebruiker direct verlichting van nek- en schouderklachten. Bij de overige werkzaamheden werd het exoskelet niet als belemmerend ervaren. De gebruiker vond het product prettig zitten en wil graag een langere periode het product gaan gebruiken.

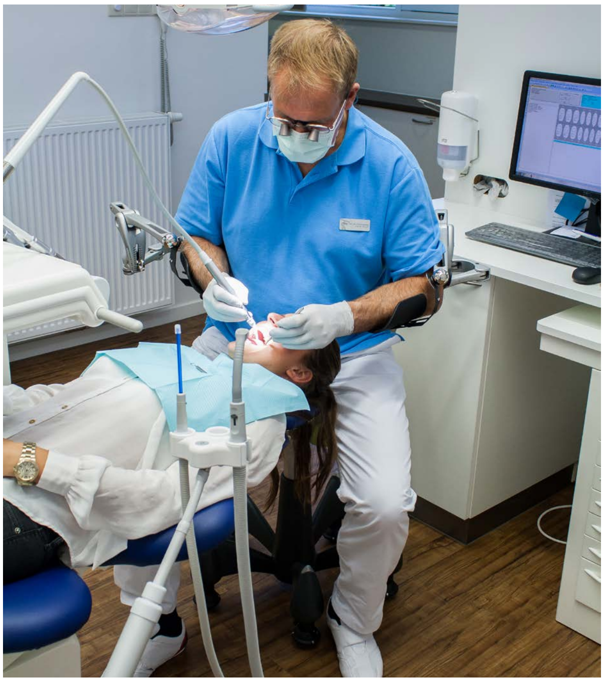
Chairless Chair voor een goede werkhouding

De Chairless Chair ondersteunt de benen en ontlast de rug. De 'mobiele stoel' beweegt letterlijk met de gebruiker mee. De Chairless Chair is traploos in hoogte instelbaar en heeft een memory voor de laatst gebruikte positie. Dit exoskelet wordt veel toegepast bij werkplekken waarbij men langdurig staand moet werken, waar stoelen niet efficiënt ingezet kunnen worden of waar frequent afgewisseld wordt tussen zittend en staand werken. De inzet van de Chairless Chair kan statische overbelasting in nek, rug en schouder verminderen of voorkomen (https://www.noonee.com/).
Recent hebben we het exoskelet door een lasbedrijf in Nederland laten testen. Hier is het exoskelet toegepast bij een lasser die laswerkzaamheden verricht in verschillende houdingen, zowel zittend als staand. De stabiliteit en bewegingsvrijheid van de Chairless Chair werden door deze lasser als positief ervaren.
Bij een autofabrikant in Duitsland loopt een pilot met de Chairless Chair op onder andere de assemblagelijn (afbeelding 2). Momenteel wordt het product ook getest in de spuiterij van dezelfde Duitse autofabrikant. De meeste werknemers ervaarden subjectief een werklastverlichting. Concrete resultaten kunnen alleen worden verkregen na een langere periode van gebruik.

Edero bij krachtsverlies en langdurig reiken

De Edero biedt veel bewegingsvrijheid en neemt de activiteit van de arm over, waardoor je je arm niet hoeft in te spannen. Dankzij het veercompensatiesysteem kan de Edero het volledige gewicht van de arm overnemen. Je kunt zelf instellen in hoeverre het gewicht van de arm gecompenseerd moet worden. De Edero armondersteuning wordt ingezet bij werknemers waarbij sprake is van krachtverlies in hun arm of bij werkzaamheden waar reikafstanden voorkomen. In de praktijk zien we dit product terugkomen in onder andere tandheelkunde (afbeelding 3), kantoorwerk, chirurgen, schilders en naaisters (http://www.armonproducts.com/).

Voor een kunstenaar die schilderijen maakt is de Edero ingezet om schouder- en armklachten te verminderen. De gebruiker ervaarde geen beperking in beweging en kon pijnvrij werken en tegelijk werken aan het herstel van de schouder- en armklachten. De spierbelasting in de arm werd aanzienlijk verminderd. Bij een bedrijf in Nederland dat verpakkingsmaterialen vervaardigt ten behoeve van de vleesindustrie is de Edero ingezet om de fysieke belasting van medewerkers te verminderen. Werknemers werken hier met een naaimachine, waarbij sprake is van langdurig reiken en repeterende handelingen, waardoor de belasting op één



Afbeelding 3. Het gebruik van een Edero door een tandarts (http://www.armonproducts.com/).

Afbeelding 4. Laevo in de praktijk (http://www.laevo.nl/).

arm vrij hoog is. Enkele van deze medewerkers ervaarden nek en schouderklachten, welke afnamen door de inzet van de Edero. Na deze succesvolle proefperiode is besloten de Edero voor meerdere medewerkers preventief in te zetten.

Laevo ontlast de rug

Laevo is een exoskelet voor ontlasting van de rug. Laevo maakt voorovergebogen werken en tillen minder belastend. De borststeun biedt letterlijk steun aan de rug. De kracht die normaal gesproken op je rug terecht komt, wordt namelijk overgebracht via de borststeun naar de benen. De gewrichten hebben een bereik waarbinnen het exoskelet steun biedt. Dit bereik is instelbaar, waardoor de Laevo te gebruiken is bij verschillende toepassingen, zoals statisch in een (licht) voorovergebogen houding staan of tillen (http://www.laevo.nl/).
De Laevo is gebruikt bij een bedrijf met bagageafhandeling. Bij de werkstations waar de voornaamste werkzaamheden veelvuldig voorover buigen en tillen zijn, werd het product als zeer positief ervaren (afbeelding 4). Op plekken waar teveel variatie in plek en houding plaatsvindt, zoals combinaties met zitten en bukken, werden meer belemmeringen ervaren. Het product zet ik daarnaast in bij voorovergebogen werk bij bijvoorbeeld een lange medewerker aan een lopende band.

Implementatie, toepassing en training

Ieder exoskelet kent zijn eigen voor- en nadelen. Op dit moment worden exoskeletten nog relatief vaak curatief ingezet om de duurzame inzetbaarheid van de individuele medewerker te vergroten. Voor deze toepassing worden vergoedingen aangesproken of is de werkgever bereid om te investeren in het behoud van de individuele medewerker. Arbeidsdeskundigen hebben hierbij een belangrijke signaalfunctie. Ook de interesse en ervaring met exoskeletten voor een bredere inzet groeit. Voor een goede implementatie en toepassing is het van belang kritische succesfactoren te identificeren. Op dit moment zijn deze gebaseerd op onze eerste praktijkervaringen.
Het is van belang een goede taakhandelingsanalyse uit te voeren. Ieder exoskelet kent zijn eigen toepassingsgebied of -gebieden. Het is dan ook van belang het juiste product te selecteren voor het juiste werk. Onnodige risico's dienen gemeden te worden. Zo kan een Chairless Chair niet gebruikt worden in situaties met opstapjes en trappen; een Laevo niet bij veel wisselende taken, in het bijzonder gecombineerd met zitten; een Edero niet bij staand werk; een Skelex kent op dit moment nog beperkingen bij gebruik in medische settings voor infectiepreventie. Op dit moment worden er professionals getraind voor het zorgvuldig beoordelen van werkplekken en werktaken voor het gebruik van exoskeletten en het begeleiden van de medewerkers in gebruik van deze producten. Deze professionals zijn veelal ergonomen, arbeids- of bedrijfsfysiotherapeuten.
Al pretendeert iedere fabrikant dat de producten makkelijk zijn in gebruik, een goede producttraining is een voorwaarde voor succes. Ieder product kent eigen instelmogelijkheden en maatvoeringen. Een goede maatvoering en instelling is voorwaarde om prettig te kunnen werken. Niet iedere medewerker kan zelf de producten goed instellen. Goede begeleiding bij het aanmeten en instellen wordt per product anders georganiseerd: bij Edero doet een leverancier dit zelf; bij Laevo ligt de deskundigheid bij de fabrikant; bij Chairless Chair en Skelex zijn er (onafhankelijke) professionals gecertificeerd en opgeleid voor het deskundig begeleiden.

Conclusie

Exoskeletten zijn volop in ontwikkeling. Ieder exoskelet heeft eigen kenmerken en toepassingsmogelijkheden. Exoskeletten bieden mogelijkheden bij het reduceren van fysieke (over)belasting. De productgroep is jong en de ervaring met de producten groeit. Op dit moment is de Skelex een goede ondersteuning voor de armen, Laevo voor de rug, Chairless Chair ontlast de rug en Edero ontlast de arm. Er zijn volop nieuwe mogelijkheden, waarbij ik verwacht dat exoskeletten een prominente rol gaan krijgen bij fysiek belaste beroepen. Hierdoor zullen we hopelijk zien dat fysieke klachten minder kans krijgen. Wat het exacte effect zal zijn en welke impact de producten gaan hebben zal de toekomst uitwijzen.

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COGNITIEF

Human Factors en octrooien

Alles bij de hand

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Deze internationale aanvraag is doorgezet naar USA, Europa, Australië, Canada, Brazilië, China, Korea en Japan.

Alex Hogeweg

Wie denkt dat octrooien saai leesvoer opleveren, die heeft gelijk. Octrooipublicaties zijn bepaald geen romans. En vaak komt er ook nog geen einde aan. Deze aanvraag heeft 265 pagina's! Wie leest dat nou? Het antwoord is: niemand, of eigenlijk bijna niemand. Minder dan één op de duizend octrooien wordt daadwerkelijk gebruikt in een rechtzaak en dus door een rechter en advocaat gelezen.
Natuurlijk dient een octrooipublicatie ook ter info, om lezers te tonen wat al bekend is en wat eventueel al/nog beschermd is, en natuurlijk: in welk land.
Oké, nu naar dit octrooi, of eigenlijk octrooien. Deze ene aanvraag heeft inmiddels geleid tot maar liefst zeven octrooien in Amerika. In de andere landen loopt de verleningsprocedure nog. De aanvraag gaat over de problemen van een chirurg die te veel tools moet hanteren. We kennen allemaal de verhalen van de net geopereerde patiënt, die na enige tijd overlijdt als gevolg van in de buik achtergebleven klemmen of scharen. Inmiddels is dat probleem grotendeels opgelost door vooraf en achteraf alle hulpmiddelen nauwkeurig te wegen. Maar ja, sommige tools, zoals een hechtnaald, zijn erg licht…
Om het de chirurg makkelijker te maken bij het overzicht houden op zijn hechtnaalden, heeft het Amerikaanse bedrijf Sherp Fluidics iets simpels bedacht. In figuur 1A is te zien dat een chirurg een soort band om zijn onderarm heeft waarop een platform 145 is bevestigd. Het platform 145 bevat een hechtnaaldenpakket 101 en een naaldenvergaarbak 331. Hiermee blijven de naalden zowel bij de aanvoer als bij de afvoer, binnen het directe gezichtsveld 313 van de chirurg. Daardoor wordt de chirurg niet onnodig afgeleid bij de hechttaken. Natuurlijk kunnen ook andere tools op het platform 145 bevestigd worden, zoals schaartjes. In een geavanceerde versie heeft de naaldenvergaarbak 331 zelfs een elektronische naaldenteller.
En natuurlijk kan het platform op duizend en een andere plek en wijze op de chirurg worden aangebracht. Deze opties worden allemaal uitvoerig in de aanvraag beschreven, zucht. Een hele eenvoudige variant is getoond in figuur 3. Daar is te zien dat de hechtnaalden 103 op een doekje 101 zijn geprikt. Het doekje 101 is vastgeplakt op de hand van de chirurg. Is dat nou ook een octrooi waard? Kennelijk wel.

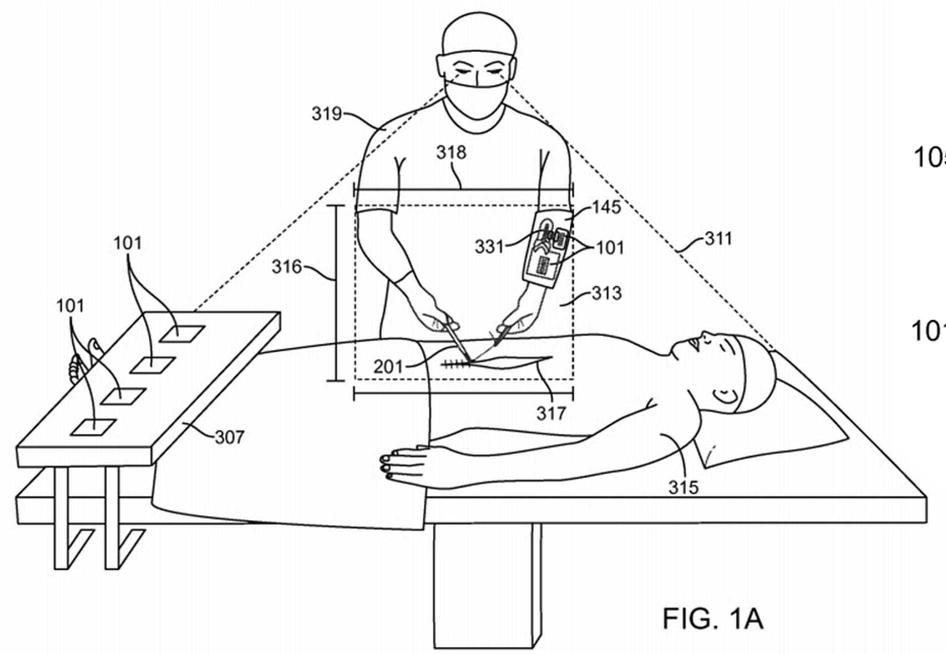

FIG. 1A

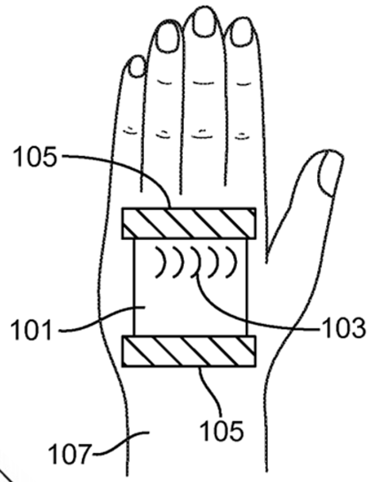

FIG. 3

Enthousiasme en nieuwe activiteiten

Met veel enthousiasme zijn we als bestuur 2019 gestart! Bij deze een update van de activiteiten en onderwerpen waar we ons momenteel zoal op richten. Heb je suggesties, vragen of wil je graag meedenken over een bepaald onderwerp? Laat het ons weten!

Nieuw bestuurslid

Allereerst is er een extra lid aan het bestuur toegevoegd: Bas van den Berg. Bas heeft ruime ervaring als bestuurslid en penningmeester bij verschillende organisaties en stichtingen. Bovendien is Bas werkzaam bij het valorisatieteam van de faculteit Industrieel Ontwerpen in Delft en daardoor goed op de hoogte van subsidiemogelijkheden en landelijke initiatieven op het gebied van ergonomie en user-centered design. In de loop van komend jaar hopen we Bas tijdens de algemene ledenvergadering voor te dragen als nieuwe penningmeester van HFNL. Bas, welkom!

Congres Human Factors NL: 28 en 29 november 2019

Onlangs is de congrescommissie voor het eerst bij elkaar gekomen, bestaande uit Erik Saathof (voorzitter), Sonja Paus Buzink (secretaris), Chantal Alleblas (communicatie), Reinier Hoftijzer (penningmeester), Leonie Visser en Marijke Melles (voorzitter Human Factors NL). We gaan ons uiterste best doen weer een inspirerend congres neer te zetten met prikkelende keynotes, interactieve workshops en verdiepende parallelle sessies voor onderlinge kennisuitwisseling. En natuurlijk zal er alle gelegenheid zijn elkaar te spreken. Er beginnen zich al leden (en niet-leden) te melden die interesse hebben een bijdrage te leveren. Heb je ook interesse een presentatie, demonstratie, workshop of masterclass te verzorgen? Laat het ons weten via communicatie@humanfactors.nl. Binnenkort meer over de locatie en het congresthema. Noteer de datum alvast in de agenda!

Nieuwsbrief en verdere communicatie

Zoals ongetwijfeld is opgemerkt hebben we nieuw leven geblazen in onze digitale nieuwsbrief. De HFNL-nieuwsbrief zal iedere drie maanden verschijnen en geeft informatie over activiteiten en ander relevant nieuws voor onze leden. Heb je nieuws dat je graag wilt delen via onze nieuwsbrief of website? Geef het door via communicatie@humanfactors.nl. Nieuwsberichten, oproepen of vragen kunnen ook gepost worden op de HFNL LinkedIn-groep.

Bijeenkomsten

De eerstvolgende HFNL-bijeenkomsten zijn een bedrijfsbijeenkomst bij ASML in Veldhoven en een themabijeenkomst over exoskeletten in Delft.
Hou de agenda op onze website in de gaten voor programma-informatie en inschrijving voor onze eigen HFNL-bijeenkomsten, en ook voor interessante bijeenkomsten van andere organisaties en zusterverenigingen.

Kennisdeling en zichtbaarheid vakgebied

Om de kennisdeling op het gebied van human factors en ergonomie te vergroten werken we aan een update van onze website. Met name de algemene informatie over human factors gaan we vernieuwen en aanvullen naar aanleiding van nationale en internationale ontwikkelingen op human factors-gebied. Daarbij bieden we ook een overzicht van de verschillende onderzoeksgroepen in Nederland met links naar relevante publicaties en contactpersonen. Doe je onderzoek op het gebied van human factors en heb je publicaties of andere informatie om te delen binnen het Human Factors NL netwerk -en daar buiten? Laat het ons weten!

Bestuur Human Factors NL

Marijke Melles (voorzitter)
Sander Vries (secretaris)
Reinier Hoftijzer (penningmeester en ledenadministratie)
Bas van den Berg