Hamburg University of Applied Sciences
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A systematic review on the health aspects of the use of exoskeletons at the workplace and development of a survey on the attitude of employees

Master Thesis

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Abstract

Background: A majority of the European as well as the German workforce reported having been exposed to posture-related risks which play a major role in the development of musculoskeletal disorders and leads to a high number of days of incapacity to work and costs due to loss of production. Technology as forklifts, carts, hoists and industrial robots have shown to have a limited capacity to support the worker during different work tasks requiring flexibility and decision-making. With the rapid progress in technology, the use of occupational exoskeletons provides the opportunity to maintain the employees' flexibility, creativity and decision-making power while at the same time gain a less strenous workplace by providing external support. The aim of this scientific study is to systematically search, qualitatively assess, evaluate and present literature on physical and psychological health aspects associated with the use of occupational exoskeletons. Furthermore, the results of the systematic review are used for the conceptual development of a survey investigating the attitude of employees towards the use of exoskeletons.

Methods: A comprehensive literature search in ScienceDirect, PubMed, Cochrane Library, PsychInfo and Web of Science was conducted and the reference lists of relevant articles were screened. Information was gathered on potential physical and psychological health aspects associated with the use of occupational exoskeletons. Based on the results of the sytematic review a concept of a survey investigating the attitude of employees towards the use of exoskeletons at the workplace was developed.

Results and Conclusion: 38 studies could be identified, the majority of them being experimental laboratory studies. Results showed that the use of occupational exoskeletons has overall positive effects on the wearer in the form of physiological and biomechnical parameters as well as positive effects on psychological aspects as wearing comfort, the employees' attitude towards the use of occupational exoskeletons as well as the employees' valuation of the exoskeleton's effectiveness. Nevertheless, the results also showed the need for further research in this field as well as the need for the development of standardized tools to assess

physical and psychological health aspects associated with the use of occupational exoskeletons.
Based on the results of the previously conducted systematic review a conceptual survey in the form of a three-part questionnaire consisting of closed questions to measure the attitude of employees towards the use of exoskeletons at the workplace was developed. The three parts of the questionnaire allow for the meaurement of the employees' attitude towards occupational exoskeletons at three different points in time. Therefore, a possible change in the employees' attitude can be taken into accout.

Keywords: Exoskeleton, Physical Health, Psychological Health, Occupation, Industry, Work, Questionnaire, Attitude

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List of abbreviations

BDI	Beck Depression Inventory
BRCS	Brief Resilient Coping Scale
BUT- A	Body Uneasiness Test
COPSOQ	Copenhagen Psychosocial Questionnaire
FCA	Fiat Chrysler Automobile
Fragebogen über Beschwerden am Bewegungsapparat	Nordischer Fragebogen
Fragebogen zur subjektiven Beurteilung der Belastungen am Arbeitsplatz	Fragebogen nach SLESINA
LPD	Local perceived discomfort
MQAC	Modified quality assessment checklist
PegA	Psychische Belastungen erfassen – gesunde Arbeit gestalten
PLAD	Personal Lift Augmentation Device
PRISMA	Preferred Rating Items for Systematic Reviews and Meta-Analyses
RMS	Root mean square
RPD	Rating of perceived discomfort
RPE	Rating of perceived exertion
SIGN	Scottish Intercollegiate Guidelines Network
SUS	System Usability Scale
TAM2	Technology Acceptance Model 2
WAI	Work Ability Index
ZfAM	Institute for Occupational and Maritime Medicine (Zentralinstitut für Arbeitsmedizin und Maritime Medizin)
6MWT	Six Minutes Walk Test

1. Introduction

With reference to the "6th European Working Conditions Survey" (Parent-Thirion et al., 2017) which took place in 2015, the third largest working sector regarding the workforce in Europe is the industrial sector (17.0%) after "Commerce and hospitality" (19.0%) and "Other services" (18.0%). Employees in the construction sector are the most exposed to physical risks with the posture-related risks being the most prevalent in Europe. 61.0% of the employees reported having been exposed to posture-related risks which play a major role in the development of musculoskeletal disorders (Parent-Thirion et al., 2017).

Regarding the working conditions in Germany, in particular the working conditions related to physical risks, a study by the Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2017) showed that approximately 56.4% of all employed men and 48.6% of all employed women worked in a standing position in 2015. Additionally, 19.2% men and 14.2% women worked in workplaces with a forced posture and 24.1% men and 21.8% women had to lift weights heavier than 20 kilograms respectively 10 kilograms during a typical workday. The study also showed that many employees were often affected by multitasking, time and performance pressure as well as disturbances and interruptions at the workplace. Table 1 gives detailed information on the different psychological work conditions and the ratings of employees regarding the extent of strain resulting from these working conditions.

Tab. 1 Psychological working conditions in Germany

Working condition	Men (in %)	Women (in %)
Great performance and time pressure	56.4	55.9
Very fast working	37.3	44.9
Supervision of different tasks simultaneously	58.1	67.8
Frequent disturbances during work	41.7	52.3
Performance of unlearned work	8.4	7.5
Frequent confrontation with new tasks	45.5	39.1

Working at the performance limit	17.3	20.4
Combination: small errors – high financial losses	22.1	12.0

Considering different diagnosis groups regarding days of incapacity to work for the year 2015, musculoskeletal disorders caused the most days of incapacity to work with approximately 23.1%, followed by respiratory diseases with 13.1% and psychological disorders with 11.6%. According to an estimation of the Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2017) the costs due to loss of production amounted to 64 billion Euro in 2015. Approximately 14.1 billion Euro of these costs resulted from musculoskeletal disorders and 9.5 billion Euro from psychological disorders (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2017). Additionally, a high number of people entering early retirement due to a reduced capacity to work could be observed, especially for psychological disorders. In 2015 31.557 men and 42.677 women entered retirement due to a reduced capacity to work (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2017).

The most common solution for the reduction in the incidence of musculoskeletal disorders resulting from physically demanding tasks as lifting, lowering and carrying as well as manual material handling tasks has been the use of mechanical aids as carts, hoists or forklifts. Nevertheless, studies showed that most employees did not use such tools when the weights lifted were within the physical capabilities of the worker (Bewick & Gardner, 2000). Additionally, employees did not use such devices when the device was perceived as being time consuming, user-unfriendly and poorly positioned as well as making the construction process more difficult or when the devices were simply too large to be fitted in the work environment (Hermans, Hautekiet, Spaepen, Cobbaut, & Clerq, 1999).

The use of industrial robots that undertake physically and psychologically demanding tasks provides another solution to minimize physical and psychological strains and resulting diseases as well as days of incapacity to work in the industrial environment. The occupational use of robots is practicable as long as the performed tasks are monotonous and repetitive and do not require flexibility. But as soon as decisions have to be made and flexibility in the performance of the tasks is needed the use of industrial robots is no longer feasible or extensively expensive (de Looze, Bosch, Krause, Stadler, & O'Sullivan, 2016). Regarding these tasks the human capacity to "observe, decide and adopt proper actions within split seconds" (de Looze et al., 2016) is still needed. Therefore, employees are still exposed to physically and psychologically demanding tasks (de Looze et al., 2016).

In connection with the term "Industrie 4.0" which was formulated at the Hannover Messe in 2011 for the first time (Baumann et al., 2018), the topic "assistance systems" came up. These systems also encompass the use of exoskeletons apart from other systems, e.g. smartwatches or robots (Cernavin & Lemme, 2018). The idea of the development of an exoskeleton was derived from the biological exoskeleton that can be found in nature where it serves as a kind of shell on an animal, e.g. in a crab. The exoskeleton provides a surface for muscle attachment, builds a water-proof barrier, protects from desiccation and enables a sensory interaction with the environment (Yang, Zhang, Chen, Dong, & Zhang, 2008). Transferred to the human usage exoskeletons belong to the group of physically supporting assistance systems (Cernavin & Lemme, 2018). An exoskeleton is "a wearable device which consists of structural mechanism with actuators and sensors whose links and joints correspond to those of the human body" (Gopura, Kiguchi, & Bandara, 2011). Annex 1 gives an overview over different classifications of exoskeletons as described by de Looze et al. (2016). By using exoskeletons one combines the human intelligence with the power of the assisting system resulting in an enhancement of both structures that could not be achieved using each part independently (Yang et al., 2008). Therefore, if one uses exoskeletons in an industrial surrounding one would maintain the employees' flexibility, creativity and decision-making power and at the same time gain a less strenuous workplace by providing external support when needed (de Looze et al., 2016). The newspaper article "Mensch-Maschinen gegen Rückenschmerzen" by Hauck (2018) and the conference paper "The potential and acceptance of exoskeletons in industry" by de Looze, Krause, & O'Sullivan (2017) show the great interest in occupational exoskeletons within the German industrial and manufacturing market as well as on the international market. According to the estimates of the market researchers of BIS Research (2017) the demand for occupational exoskeletons increases constantly and the global wearable exoskeleton market is expected to reach a market volume of 4,65 billion US$ until the year 2026. Furthermore, German as well as international companies have already begun to develop exoskeletons for occupational purposes, e.g. German Bionics produced the Cray X and Noonee developed the "Chairless chair" (Hauck, 2018). But when considering the occupational use of exoskeletons potential effects on the physical and the psychological health of employees should be taken into account. Another aspect is the acceptance of employees towards the use of occupational exoskeletons as this is one of the most important preconditions for a successful implementation of this technology.

In the following paragraphs a short description of the object of research and the theoretical background will be given. Thereafter, the relevance of the scientific study, its purpose, the corresponding research questions and the methodical approach will be outlined. Additionally, the results will be presented and discussed. Based on the results of the systematic review the conceptual development of a survey investigating the attitude of employees towards the use of occupational exoskeletons will be described. Finally, a conclusion with recommendations for future research will be given.

1.1. Object of research

This scientific study deals with the physical and psychological health aspects associated with the use of exoskeletons at the workplace. Therefore, two key questions are to be discussed:

1. Which effects does the use of exoskeletons at the workplace have on the physical health of the employees?
2. Which effects does the occupational use of exoskeletons have on the psychological health of the employees?

Both key issues will be investigated by the conduction of a systematic literature research with a subsequent analysis of the results of the found literature.

In the context of the second key question the construct "acceptance" arises which also plays a major role in the use of industrial exoskeletons and related effects on the psychological health of employees.

Acceptance is defined as the willingness to approve a situation or fact. It can be distinguished with regard to the acceptance at a certain point of time and the change of acceptance over a specific period of time. A basis for the explanation of the construct acceptance is the theory “diffusion of innovations” which deals with the acceptance of new technologies (Prof. Dr. Lackes, 2018) which can directly be applied to the implementation of exoskeletons at the workplace and its associated psychological health aspects. As acceptance plays a major role in the implementation of new technologies, the second step in this scientific study is the conceptual development of a survey measuring the attitude of employees towards the use of exoskeletons at the workplace based on the results of the previously conducted systematic review.

1.2. Theoretical background

The most common fields of application of exoskeletons are rehabilitation and military use. The effectiveness of the use of exoskeletons in these fields has already been proven by various studies with regard to biomechanical and physical outcomes. The effects of rehabilitative and military exoskeletons on psychological health aspects have so far been neglected more specifically have not been studied comprehensively. Although most studies do not measure explicitly psychological health aspects at least some standardized questionnaires exist that measure psychological factors regarding the working life of employees. Apart from the use of exoskeletons for rehabilitative and military purposes the use of exoskeletons for power augmentation in the industrial environment has become of more interest in recent years (Yang et al., 2008). This development is at the same time accompanied by several considerations that have to be taken into account with regard to short- as well as long-time effects on the wearer as well as considerations regarding the development and implementation process of the exoskeletons at the workplace.

An overview over the different fields of application of exoskeletons as well as a short description of possible applications of exoskeletons in the industrial sector will be given. Additionally, the already existing standardized questionnaires measuring psychological health factors regarding the employees’ working life will be introduced in the following paragraphs.

1.2.1. Exoskeletons for rehabilitative purposes

The work on exoskeletons for rehabilitative purposes began in 1883 with Professor H. Wangenstein's work on an active lower-limp exoskeleton with the aim to help paraplegic patients to walk, run and jump again (J. L. Pons, Ceres, & Caldern, 2008, pp. 4–5). The first functional anthropomorphic exoskeleton to recover movement in paraplegics was developed by M. Vukobratovic in 1972 (Yang et al., 2008).

Recent studies have shown that the use of exoskeletons in rehabilitation is effective and at the same time safe and practical (Federici, Meloni, Bracalenti, & De Filippis, 2015; Louie, Eng, Lam, & Spinal Cord Injury Research Evidence (SCIRE) Research Team, 2015). The authors Louie et al. (2015) concluded in their systematic literature review that the use of active exoskeletons in the rehabilitation of individuals with spinal cord injury is useful as the exoskeleton provides the patient with the ability to walk again at modest speed. The authors included 15 studies in their review and extracted data regarding the gait speed as well as gait specific data, e.g. step length, distance and time walking. The participants completed a training program encompassing different phases from becoming familiar with the exoskeleton to stepping and walking with the exoskeleton. Results showed that the participants improved their mean gait speed from 0.28 m/s to 0.50 m/s and their distance walked in the 6 Minutes Walk Test (6MWT) from 70.1m to 163.3m. The authors reported the small number of participants in each study as well as the heterogeneity of the studies as main limitations in their systematic literature review. The systematic review by Federici et al. (2015) also showed that the use of active exoskeletons is a "safe and practical method in neurorehabilitation" and increases the "mobility, improve(s) functioning and reduce(s) the risk of secondary injury by reinstating a more normal gait pattern". Overall the authors included 27 studies in their systematic literature review and extracted data on, inter alia, measurements used in the included studies and key results. They criticized that nearly every study neglected to measure psychological factors besides biological and social factors when measuring the effectiveness of an assisting device, i.e. exoskeleton (Federici et al., 2015). One year later Milia et al. (2016) investigated in their study apart from the improvement in physical functions, e.g. muscle strength, joint range of motion or gait, also psychological effects with special focus on depression resulting from the use of exoskeletons in neurorehabilitation. The level of physical body function was measured using the

Ashworth scale for spasticity and the 6MWT. The psychological aspects were measured using the Beck Depression Inventory (BDI) as well as the Body Uneasiness Test (BUT-A). Overall 13 patients diagnosed with a spinal cord injury participated in the 4-weeks trial with at least 20 training sessions for 5 days per week. The duration of one session was 45 to 60 minutes. During the training sessions the participants wore an exoskeleton and were trained to walk. Measurements took place before and after treatment. Results showed an improvement in the distances walked during the 6MWT as well as a positive trend in the BDI and BUT-A scores.

1.2.2. Exoskeletons for military purposes

The development of exoskeletons for military purposes began in the 1960s when the US Department of Defense became interested in the development of an exoskeleton for military purposes allowing soldiers to walk longer distances while at the same time carry more weight in the form of military equipment (J. L. Pons et al., 2008, pp. 4–5; Yang et al., 2008). An example of an exoskeleton used for military purposes is the Berkeley Lower Extremity Exoskeleton (BLEEX) which is an energetically autonomous lower extremity exoskeleton which enables the wearer to carry an extra load of approximately 75kg on his / her back while at the same time remaining capable of walking on uneven terrain (Zoss, Kazerooni, & Chu, 2006).

1.2.3. Possible application of exoskeletons in industrial settings

As previously described, the interest in the industrial application of exoskeletons has increased significantly in recent years (de Looze et al., 2017; Yang et al., 2008). De Looze et al. (2017) conducted a stakeholder analysis to analyze the potential usefulness of exoskeletons in industry with regard to industrial performance and employees' health. Eight experts in the field of industrial manufacturing were interviewed about the "main general trends in manufacturing industry […], current and future developments in the value of human work within these trends, and about the needs in relation to any type of exoskeleton to be potentially used" (de Looze et al., 2017). Results showed the expected trends for the industrial manufacturing to be the following: As mechanization and automation increases, less workers are needed in the actual production, while at the same time more workers are needed in the pre-production planning, programming and engineering stages. The increased need for flexibility will lead to an increased number of workers employed in the highly automated production. Furthermore, due to the ageing workforce technology-based support is needed to ensure productivity and safety. The increase in injury prevalence due to physical loads on the workers results in requirement of technology-based support. (de Looze et al., 2017)

The interviewees mentioned the following main business and workforce needs that could be tackled by the application of occupational exoskeletons:

Need to:

- "increase the flexibility of production
- increase the flexibility of workers
- increase the productivity of manual work
- increase the quality of manual work
- reduce the physical load and the risks of injury" (de Looze et al., 2017).

These results point out the need for exoskeletons in future industrial manufacturing as well as the expected effects of the use of them.

1.2.4. Questionnaires measuring psychological factors regarding the working life

So far many standardized questionnaires exist that measure psychological factors regarding the working life of employees, e.g. the Copenhagen Psychosocial Questionnaire (COPSOQ), the Work Ability Index (WAI), the PegA questionnaire (Psychische Belastungen erfassen, gesunde Arbeit gestalten) or the Brief Resilient Coping Scale (BRCS). These questionnaires will be described in the following paragraphs.

1.2.4.1. Copenhagen Psychosocial Questionnaire (COPSOQ)

The COPSOQ is a scientifically validated questionnaire for the assessment of psychological stressors and strains at the workplace independent of the analyzed professional field. It is mainly used for occupational risk assessment. Originally, it was developed and validated by Kristensen and Borg of the Danish National institute for Occupational Health. In 2005 the Freiburg research centre for occupational sciences developed a German short version of the COPSOQ on the basis of the original questionnaire and validated it in a study comprising 2561 respondents (Nübling, Stößel, Hasselhorn, Michaelis, & Hofmann, 2006). The basis of the questionnaire is the occupational scientific model of a cause-and-effect-relationship between the characteristics of the working situation and the reactions to it of the employee. The questionnaire comprises 25 subscales with overall 87 questions which can be used individually. The subscales investigate the characteristics of the working situation, the structure of the company and the company's workforce as well as sociodemographic data of the participants. It requires approximately 20 minutes to answer all questions (Freiburger Forschungsstelle für Arbeitswissenschaften GmbH, 2018; Nübling et al., 2006).

The collected data can be evaluated according to each subscale individually. Therefore, a calculation of a total score is not necessary to be able to make statements on the strains and stressors at the workplace of the participant. After calculating the sub-scores for the subscales, the results can be compared to reference values of a database created by the Freiburg research centre for occupational sciences on behalf of the Federal Institute for Occupational Safety and Health in 2010. This database comprises comprehensive information on different employees employed in different sectors who completed the COPSOQ in the course of previous studies. By using this database the researcher is able to identify psychological exposure profiles and compare these profiles to the results of his / her own study (Freiburger Forschungsstelle für Arbeitswissenschaften GmbH, 2018).

1.2.4.2. Work Ability Index (WAI)

The WAI which was developed by a multidisciplinary study group of the Finnish Institute of Occupational Health in the 1980s measures the work ability of employees. The questionnaire consists of ten questions considering the demands of work, the worker's health and resources. The questions can be assigned to seven different categories resulting in an overall score of seven to 49 points. The validity and reliability of the questionnaire have been assessed in different studies. All items proved to be reliable in predicting work disability, retirement and mortality. The questionnaire has been translated into 24 languages (Hasselhorn & Freude, 2007; Ilmarinen, 2006).

1.2.4.3. Psychische Belastungen erfassen, gesunde Arbeit gestalten (PegA)

The PegA questionnaire is used for the structured assessment of working conditions in companies for risk assessment purposes. The questionnaire consists of three parts, firstly the working areas and main tasks, secondly the sociodemographic data and thirdly the working conditions. The third part consists of 43 questions regarding work tasks, work organization, social relationships and the working environment (Berufsgenossenschaft & Handel und Warenlogistik, 2016).

1.2.4.4. Brief Resilient Coping Scale (BRCS)

The Brief Resilient Coping Scale (BRCS) is a 4-item scale measuring the ability of adults to cope with stressful situations. The scale ranges from one, indicating that the statement stated does not describe the respondent's behavior at all, to five, indicating that the statement fully describes the respondent's behavior. The answering and evaluation of the scale takes approximately two minutes, respectively (Brahler, 2015, pp. 43–45; Sinclair & Wallston, 2004).

1.3. Relevance of this scientific study

Musculoskeletal disorders (23.1%), respiratory diseases (13.1%) and psychological disorders (11.6%) caused the most days of incapacity to work in 2015 in Germany. The costs due to loss of production amounted to 64 billion Euro, 14.1 billion Euro resulting from musculoskeletal disorders and 9.5 billion Euro from psychological disorders (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2017). Additionally, the study by the Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2017) showed that a high number of male as well as female employees stated having been affected by psychologically strenuous working conditions, e.g. great performance and time pressure, great responsibility for multiple simultaneous tasks and being required to work very fast (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2017).

Accordingly, primary preventive measurements should be taken to reduce physical and psychological strains at the workplace. One possible solution in the field of industrial work is the implementation of exoskeletons that support the employee in physically strenuous situations, e.g. lifting and carrying of weights, working in forced posture or working overhead. Exoskeletons are applied to reduce the risk of musculoskeletal disorders, e.g. low back pain. This reduction in physical strain would probably go along with a decrease in psychological stress as employees no longer have to worry about their physical health and associated consequences, e.g. reduction in the capacity to work. Additionally, the use of industrial exoskeletons might result in a more efficient execution of tasks which in turn might result in a reduction of time and performance pressure. Before implementing industrial exoskeletons a comprehensive investigation of the effects on the physical and psychological health of employees using these devices regularly should take place to avoid adverse consequences. A systematic literature research that summarizes results of previous studies is the appropriate measure to establish a basis for further studies. The following conceptual development of a survey measuring the attitude of employees towards the use of occupational exoskeletons based on the previously conducted systematic review serves as a starting point for the development of a standardized questionnaire for the occupational risk assessment preceding the implementation of primary prevention measures.

1.4. Purpose of this scientific study

This scientific study has two main objectives. Firstly, to identify, select, qualitatively assess and evaluate studies measuring health aspects - physical and psychological - resulting from the use of occupational exoskeletons and to summarize and present the main findings. Additionally, the need for further research will be pointed out. Secondly, to conceptually develop a survey investigating the employees' attitude towards the use of exoskeletons for overhead work tasks at the workplace.

2. Research questions and objectives

Based on the theoretical background and derived from the purpose of this scientific study the following research questions regarding the systematic literature research were derived:

- 1st research question: Which effects does the use of exoskeletons at the workplace have on the physical health of employees?
- 2nd research question: Which effects does the use of exoskeletons at the workplace have on the psychological health of employees?

The objectives of this study are the systematic search for literature assessing the effects of occupational exoskeletons on physical and psychological health aspects of employees, and the critical quality assessment as well as the presentation of the summarized results of the found literature. Furthermore, the results of the systematic review serve as the basis for the conceptual development of a survey investigating the attitude of employees towards the use of exoskeletons for overhead tasks at the workplace. The survey assesses factors contributing to or reducing the acceptance of employees working in a large industrial company with tasks characterized by regular and repetitive overhead manual handling tasks.

3. Methodology of the systematic review

The following paragraphs outline methodological aspects of the conducted systematic review on physical and psychological health aspects resulting from the use of exoskeletons at the workplace.

3.1. Study design

This study is a systematic review comprising of a systematic search for eligible literature assessing physical and / or psychological health aspects resulting from the use of occupational exoskeletons by employees; a quality assessment as well as a secondary analysis of the found literature and a presentation of results.

The “Methodology checklist 1: systematic reviews and meta-analyses” by the Scottish Intercollegiate Guidelines Network (2001) (SIGN) was used to structure this systematic review as well as to conduct the systematic search for eligible literature and report its results appropriately. In order to visualize the results of the systematic search, a modified version of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram (Moher, Liberati, Tetzlaff, & Altman, 2009) was used.

The research question was established applying the PICO-format with P = participants, I = intervention, C = comparisons and O = outcome. As the comparative intervention (C) is not of interest the formerly PICO-format is narrowed to the PIO-format. The research question was defined prior to the conduction of the systematic literature search.

The following paragraphs give an overview on the inclusion and exclusion criteria used to assess the found literature's eligibility (Table 2); on the databases and the search strategy used for the systematic search. Furthermore, methodological aspects concerning the study selection, the data extraction and the data synthesis process are described.

3.1.1. Inclusion Criteria and Exclusion Criteria

The following inclusion and exclusion criteria were established prior to the conduction of the systematic literature research.

3.1.1.1. Participants / Study population

The study population in the literature used for the systematic literature review included all workers employed in industrial workplaces, e.g. automotive industry or aviation industry as well as nursing. Employees of all ages and sexes were included. Studies investigating populations other than human beings as animals or insects were excluded.

3.1.1.2. Intervention / exposition

To be included in the systematic review the studies' main intervention / exposition was the use of occupational exoskeletons by employees. This intervention / exposition included all tasks performed in industrial or nursing workplaces assisted by passive or active exoskeletons, an exoskeleton supporting the whole body or just specific body parts as well as by an exoskeleton with an anthropomorphic or non-anthropomorphic fit. For detailed information on the different types of exoskeletons see ANNEX 1. Studies investigating physical and / or psychological health aspects of the use of exoskeletons by patients for rehabilitative or assistive purposes other than workplace-related tasks were excluded.

3.1.1.3. Outcome

All studies assessing physical and / or psychological health aspects regarding the use of occupational exoskeletons were acceptable. No exclusion criteria for the outcome were defined.

3.1.1.4. Study design

Studies with quantitative as well as qualitative study designs were included. Primary studies were preferred but also grey literature as conference papers, commentaries or policy statements were acceptable because of the innovative character of the study's topic and the therefore, expected small number of quantitative or qualitative studies. Books as well as book chapters were excluded because of their assumed missing actuality.

3.1.1.5. Language

Studies written in English or German were evaluated.

3.1.1.6. Publication period

The publication period of the included studies was unlimited until the date of the conduction of the systematic search to ensure that the vast majority of studies on this innovative topic were included in the review. Studies published after the conduction of the systematic research were not included.

3.1.1.7. Publication status

To be included in the systematic review, studies had to be published and their free full text had to be available. Studies not published until the conduction of the systematic review or studies without free full text availability were excluded.

Tab. 2 List of inclusion and exclusion criteria

	Inclusion criteria	**Exclusion criteria**
Participants / Study population	- Human beings - Employees of all ages and sexes employed in industrial workplaces - Employees of all ages and sexes employed in nursery	- Animals

Intervention / Exposition	- Execution of tasks assisted by an exoskeleton in the workplace environment	- Patients using exoskeletons to e.g. restore bodily functions
Outcome	- Physical health - Physical strains - Mental health - Psychological strains - Acceptance of the use of occupational exoskeletons - Job satisfaction - Experiences using an exoskeleton at the workplace	/
Study design	- Meta-analyses - Systematic reviews - Randomized Controlled Trials - Cohort Studies - Case-control studies - Observational studies - Qualitative study designs - Mixed-methods-designs - Intervention studies <u>Grey literature:</u> - Conference papers - Commentaries - Policy statements - Dissertations	- Books / Book chapters

Language	- German - English	- Other languages than German or English
Publication period	- Publication date prior to the conduction of the systematic search	- Studies published after the conduction of the systematic search
Publication status	- Published studies with free full texts available	- Unpublished studies - No full text availability

3.1.2. Databases

The systematic literature search was conducted from the 18th April until the 23rd April 2018 in five different data bases. The following databases were searched: ScienceDirect, PubMed, Cochrane Library, PsycInfo and Web of Science.
Additionally a search on Google Scholar was conducted and the results with the highest relevance were taken into consideration.

3.1.3. Search strategy

For the conduction of the systematic literature research two search strategies were generated as the systematic review includes studies assessing physical as well as psychological health aspects of the use of occupational exoskeletons and were used for the search in the above listed databases.
In addition to the electronic literature research, the literature references of the found literature were searched manually for further studies not identified by the previous search. The reference management program "Zotero" was used to organize and archive the found literature.

3.1.3.1. Search strategy 1: Physical health aspects

This search strategy comprised of two expositions, i.e. the use of an exoskeleton and its use in the work environment. Additionally search terms were generated to exclude studies assessing health aspects of the use of exoskeletons by patients as the study intended to investigate the physical and psychological health aspects of healthy workers in industrial settings. Therefore, the term "injury" was used as its link to exoskeletons clearly depicts the rehabilitative purpose of the application of an exoskeleton.

The search terms within each category – exposition 1, exposition 2 and exclusions – were connected using the Boolean operator “OR”, whereas the categories themselves were linked using the Boolean Operator “AND” for the connection of the two different expositions and “NOT” for the connection with the exclusion category. Furthermore, for a few search terms truncations were used to search for all word variations, e.g. the search term exoskelet* can be used to search for “exoskeleton”, “exoskeletons” or “exoskeletal”. The used search terms as well as the linkage by the above mentioned Boolean Operators are illustrated in Table 3. The complete search string is provided below:
((exoskelet*) AND (occupation* OR job* OR "arm elevation" OR "manual handling" OR lifting OR "forward-bending" OR "forward bending" OR "static holding" OR "overhead work") NOT injury).

Tab. 3 Search terms: Physical health aspects

Exposition 1		Exposition 2		Exclusions
Exoskelet*	AND	Occupation*	NOT	Injury
		Job*		
		“Arm elevation”		
		“Manual handling”		
		Lifting		
		“Forward-bending”		
		“forward bending”		
		“Static holding”		
		“overhead work”		

3.1.3.2. Search strategy 2: Psychological health aspects

This search strategy comprised of the two above described expositions, i.e. the use of an exoskeleton and its use in the work environment, as well as of the outcome, i.e. the psychological health aspects. As in search strategy 1 additional search terms were generated to exclude studies investigating animals, e.g. crabs or insects, and studies assessing the health aspects resulting from the use of exoskeletons for rehabilitative purposes. The search terms within the categories – exposition 1, exposition 2, outcome and exclusions – were connected using the Boolean operator

"OR", whereas the categories themselves were linked using the Boolean operator "AND" for the connection between the two expositions and the outcome and the Boolean operator "NOT" for the connection with the exclusion category. As in search strategy 1 search terms were truncated. The used search terms as well as the linkage by the before-mentioned Boolean Operators can be found in Table 4. The complete search string is provided below:
(exoskelet*) AND (occupation* OR job* OR "arm elevation" OR "manual handling" OR lifting OR "forward-bending" OR "forward bending" OR "static holding" OR "overhead work") AND (acceptability OR acceptance OR attitude OR satisfaction OR usability OR willingness OR stress OR strain OR approval) NOT (injury OR ocean OR microb* OR zoo* OR chitosan OR fisherie* OR animal OR insect).

Tab. 4 Search terms: Psychological health aspects

Exposition 1		Exposition 2		Outcome		Exclusions
Exoskelet*	AND	Occupation*	AND	Acceptability	NOT	Injury
		Job*		Acceptance		Ocean
		"Arm elevation"		Attitude		Microb*
		"Manual handling"		Satisfaction		Zoo*
		Lifting		Usability		Chitosan
		"Forward-bending"		Willingness		Fisherie*
		"Forward bending"		Stress		Animal
		"Static holding"		Strain		Insect
		"Overhead work"		Approval		

3.1.4. Study selection

Studies extracted from the systematic search were first selected on the basis of the title and abstract based on the research question as well as the inclusion and exclusion criteria. If the title and the abstract did not provide enough information for the inclusion of the study in the systematic review, the full text was screened. Afterwards the found studies were screened for duplicates and assessed for inclusion via the above described inclusion and exclusion criteria. If a study did not meet the inclusion criteria it was excluded and categorized.

The remaining eligible studies were then assessed qualitatively. As most studies were experimental laboratory studies the quality assessment via SIGN methodology checklists (Scottish Intercollegiate Guidelines Network, 2001) was not possible. Therefore, a modified quality assessment checklist (MQAC) was developed to assess the quality of the experimental laboratory studies based on the SIGN “Methodology checklist 3: Cohort studies” (Scottish Intercollegiate Guidelines Network, 2001) and the “STROBE checklist for cohort, case-control and cross-sectional studies (combined)” (Institute of Social and Preventive Medicine, 2009). It comprises of 19 criteria assessing the study’s title and abstract, introduction, methods, results as well as its discussion. All criteria are weighted equally in the evaluation. The checklist reports whether the study is of high quality, whether it is acceptable or unacceptable. For a study to be rated as having a high quality at least twelve criteria have to be fulfilled and for being rated acceptable at least ten criteria have to be fulfilled. If a study fulfills just nine or less criteria its quality is rated as unacceptable. The modified checklist can be found in ANNEX 2. Studies that were conducted at the workplace of the participants were qualitatively assessed using the SIGN “Methodology Checklist 3: Cohort studies”. Other types of studies as Meta-analyses, systematic reviews, randomized controlled trials, and case-control studies were qualitatively assessed using the original checklists by SIGN (Scottish Intercollegiate Guidelines Network, 2001). The results were depicted in a modified version of the PRISMA flow diagram developed by Moher et al. (2009).

3.1.5. Data extraction

For the data extraction an Excel® spreadsheet was developed to extract the following data: Title of the study, author and year of publication, study design, investigation period, study population, country, aim / purpose of the study, exposition, measured outcomes, key results as well as the result of the quality assessment conducted in advance. The Excel® spreadsheet with an example can be found in ANNEX 3.

3.1.6. Data synthesis

Prior to the presentation of the summarized results of the individual studies, the results of identified systematic reviews were summarized and presented.
Afterwards the qualitative synthesis of the results of the included studies was conducted. The results were categorized in six main categories according to the work tasks to be supported by the exoskeleton:

- Work at head or overhead level
- Lifting and lowering (in a stooped position)
- Static holding (in a stooped position / bent forward)
- Walking aid while load carrying
- Patient lifting / transfer

Within each category the studies' results were presented chronologically starting with the oldest one. Additionally, a conclusion for every work task supported by an exoskeleton was drawn with regard to physical and psychological health aspects.

4. Results of the systematic review

After the review of the full-texts of the included studies it had to be concluded that the studies were too heterogeneous to conduct a quantitative analysis in the form of a meta-analysis. Therefore, the individual studies' results will be presented qualitatively in the following paragraphs.
First of all the results of the systematic literature research are described separately for the physical and the psychological health aspects. Afterwards a summary of the studies' characteristics is given, followed by an overview over the studies' main outcomes categorized by the work task to be supported by the exoskeleton under study. Each work task specific category concludes in a brief summary of the main findings.

4.1. Study selection

First of all, it has to be mentioned that the inclusion and exclusion criteria described in the methods section were very broad to make sure that a wide range of eligible studies could be found as the topic of this review had an innovative character and the number of published articles specifically on the topic of exoskeletons at work places was expected to be relatively low.

4.1.1. Physical health aspects

The systematic search in the databases ScienceDirect, PubMed, Cochrane Library, PsycInfo, Web of Science, and Google Scholar resulted in 564 results for the outcome "physical health aspects" plus 18 studies that could be identified by searching the reference lists of the found literature resulting in 582 results in total. After the removal of 29 duplicates, 553 results remained for the subsequent screening process of the title and abstract by applying the inclusion and exclusion criteria. 514 studies were excluded resulting in 39 remaining studies eligible for the full-text assessment. The three main reasons for the exclusion of the studies were: studies dealt with mechanics, physics or technology other than exoskeletons on e.g. photovoltaics, wind energy plants or virtual reality (N[1] = 176), assessment of physical and / or psychological health aspects resulting from the use of rehabilitative exoskeletons by patients (N = 70), and assessment of physical and / or psychological health aspects of the use of other assistive devices than exoskeletons or rehabilitative devices, e.g. ankle orthoses (N = 64). Further categories of excluded studies are depicted in Figure 1. The category "Others" comprises of study topics like nutrition/ dieting; education/studies; language; and law regulations that were described at the most two times. After the full-text screening three other studies had to be excluded, therefore 36 studies were ultimately included in the systematic review. Reasons for the exclusion of the studies after the full-text screening were: one study dealt with a robot arm assisting construction workers which was not obvious in the title nor in the abstract, one study only described possible improvements for an exoskeleton and the third study was a conference paper of a study that was already included. A detailed overview of the study selection process is illustrated in Figure 1.

[1] N = number of studies

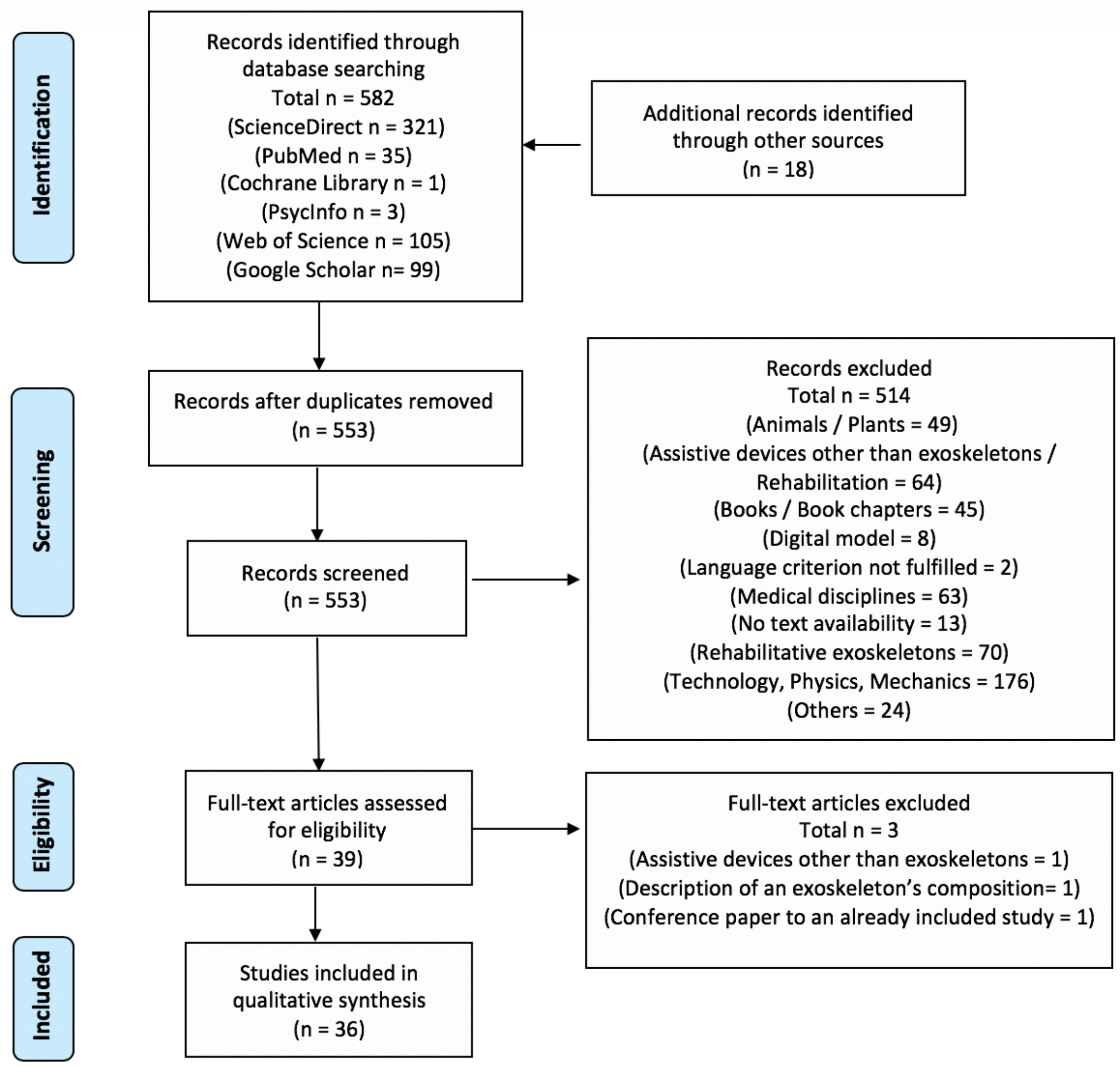

Fig. 1 Identification of relevant publications regarding physical health aspects

4.1.2. Psychological health aspects

For the outcome "psychological health aspects" the search resulted in 306 studies plus ten studies identified by screening the reference lists of the found literature, resulting in 316 studies in total. As can be seen in Figure 2, the search in the Cochrane Library resulted in no hits which might be due to the innovative character of the study question and therefore the absence of already conducted studies as well as systematic reviews. After the removal of ten duplicates 306 studies remained for the subsequent screening process of the title and abstract by applying the inclusion and exclusion criteria. 290 studies were excluded, resulting in 16 remaining studies for the full-text assessment. The three main reasons for the exclusion of 288 studies were: studies dealt with mechanics, physics or technology other than exoskeletons (N = 62), studies investigated the effects of rehabilitative or other assistive devices on patients and human beings, respectively (N = 51) or studies assessed the exoskeletons of animals (N = 50). No studies had to be excluded after the full-text screening, therefore 16 studies were ultimately included in the systematic review. A detailed overview of the study selection process is illustrated in Figure 2.

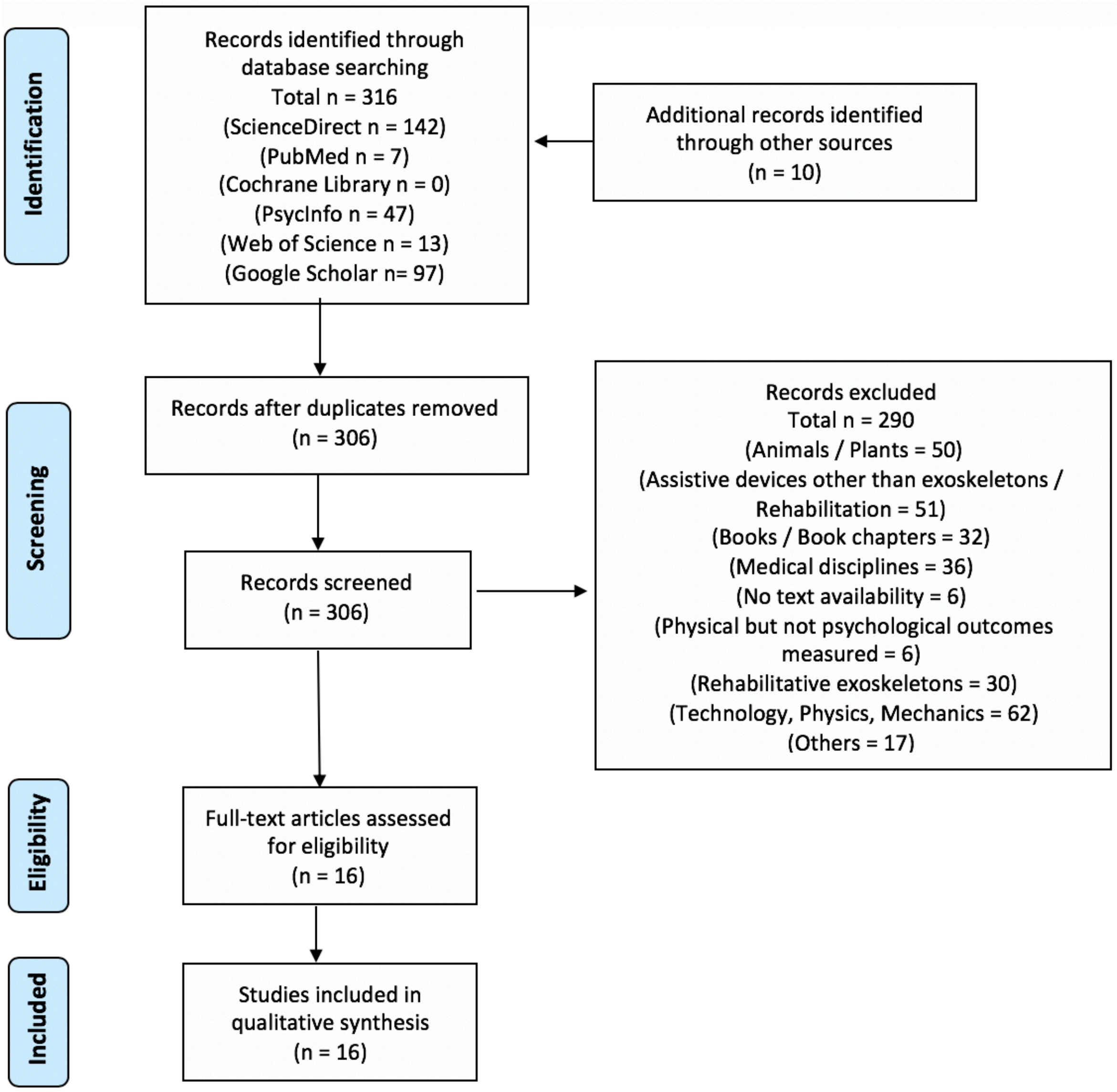

Fig. 2 Identification of relevant publications regarding psychological health aspects

Regarding the search results for both outcomes – physical as well as psychological health outcomes – 38 different studies could be extracted with 22 studies measuring only physical health aspects, 14 studies measuring physical as well as psychological health aspects, and two studies measuring only psychological health aspects as can be seen in Figure 3.

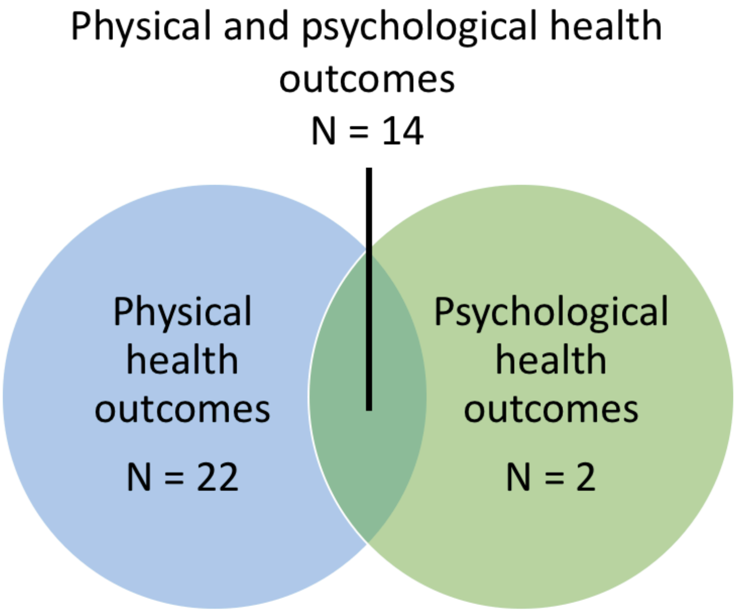

Fig. 3 Study allocation: Measured outcomes

4.2. Study characteristics

Out of the included studies 32 studies were experimental laboratory studies (Abdoli-Eramaki, Agnew, & Stevenson, 2006; Abdoli-Eramaki & Stevenson, 2007; Bosch, van Eck, Knitel, & de Looze, 2016; Butler & Wisner, 2017; Ciccarelli & Meyer, 2006; DeBusk, Babski-Reeves, & Chander, 2017; Frost, Abdoli-E, & Stevenson, 2009; Godwin et al., 2009; Gregorczyk et al., 2010; Heydari, Hoviattalab, Azghani, Ramezanzadehkoldeh, & Parnianpour, 2013; Huysamen et al., 2018; Kadota, Akai, Kawashima, & Kagawa, 2009; Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Alabdulkarim, et al., 2018; Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Jia, et al., 2018a; Kobayashi & Nozaki, 2007; Lotz, Agnew, Godwin, & Stevenson, 2009; Luo & Yu, 2013; Muramatsu, Umehara, & Kobayashi, 2013; Nakamura, Ichinose, & Kobayashi, 2017; Otten, Weidner, & Argubi-Wollesen, 2018; Panizzolo et al., 2016; Rashedi, Kim, Nussbaum, & Agnew, 2014; Spada, Ghibaudo, Gilotta, Gastaldi, & Cavatorta, 2017, 2018; Sylla, Bonnet, Colledani, & Fraisse, 2014; Takamitsu Aida, Hirokazu Nozaki, & Hiroshi Kobayashi, 2009; Theurel, Desbrosses, Roux, & Savescu, 2018; Ulrey & Fathallah, 2013; Wehner, Rempel, & Kazerooni, 2010; Weston, Alizadeh, Knapik, Wang, & Marras, 2018; Whitfield, Costigan, Stevenson,

& Smallman, 2014; Yu, Lee, Kim, & Han, 2016), five were cohort studies (Gillette & Stephenson, 2017; Graham, Agnew, & Stevenson, 2009; Hein, Pfitzer, & Lüth, 2016; Imamura, Tanaka, Suzuki, Takizawa, & Yamanaka, 2011; Liu et al., 2018), and one was a systematic literature review (de Looze et al., 2016). All studies were published between 2006 to 2018 in English language.

Studies included in this systematic review were mainly conducted in the United States (N = 12) as well as Canada and Japan (N = 7, respectively). Eight studies were conducted within the European area, namely in Italy and France (N = 3, respectively), Germany (N = 2) and the Netherlands (N = 1). One study was conducted in China (N = 1).

The following job tasks had to be performed in the studies with and without the help of an occupational exoskeleton in a simulated work environment or, in a minority of cases, at the workplace of the participants:

- Work at head or at overhead level (N = 12)
- Lifting and lowering of weights (in a stooped position) (N = 15)
- Static holding (in a stooped position / bent forward) (N = 5)
- Walking while carrying a load (N = 3)
- Patient lifting / transferring (N = 2)

The included studies only investigated healthy participants, due to the fact that the tested exoskeletons would be used by healthy employees at industrial or nursing workplaces. The number of participants investigated ranged from one to 31. The average age ranged from 20.8 to 51.5 years. Most studies included only male participants (N = 19 of 36), fewer studies included female as well as male participants (N = 10) and only two studies included only females, i.e. the studies were specially designed for females. In studies including both sexes, male participants outweighed female participants. In six studies the sex of the participants was not mentioned.

In these studies physical as well as psychological health aspects were measured which can be categorized as the following:

- Physical health aspects:
  - Metabolic cost / Load on the cardiovascular system (N = 7)
  - Muscle activity / strength (N = 30)
  - Joint kinematics (N = 13)
  - Joint kinetics (N = 9)
  - Others (N = 10)

- Psychological health aspects:
  - Wearing Comfort / Discomfort (N = 4)
  - Acceptance (N = 3)
  - Usability (N = 5)
  - Usefulness (N = 6)
  - Experienced fatigue regarding muscle strength (N = 12)
  - Others (N = 2)

The category “Others” comprises of outcome measures that were only measured rarely, e.g. postural control (Kim et al., 2018b) or dexterity (Liu et al., 2018).

Regarding the used statistical methods, most studies used a repeated measures analyses of variance (ANOVA) in combination with post-hoc tests like the “Least Significant Difference-Bonferroni Test” or the “Tukey’s honestly significant difference test” (N = 16). Seven studies used a paired t-test, one study used the “Wilcoxon-signed-rank-test” and another study the “Friedman test”. Six studies just reported means and standard deviations and ten studies reported no statistical methods overall.

A detailed overview over the studies’ characteristics can be found in ANNEX 4 to 6. Specific results are presented in section 4.4 “Results categorized by work task supported by the exoskeleton”.

4.3. Summarized results of the systematic review by de Looze et al. (2016)

In 2015 de Looze et al. (2016) (SIGN: High quality (++)) conducted the only systematic review on the use of occupational exoskeletons and their effects on the user which was identified in the systematic search. The aim of this systematic review was “(1) to provide an overview of “industrial” exoskeletons that have been developed or are under development, and (2) to assess the potential effect of these exoskeletons in terms of physical load reduction on the wearer.” (de Looze et al., 2016). An electronic search in the Scopus database was conducted using search terms as “exoskeleton, wearable device, assistive device and wearable robot”.

40 studies were included assessing 26 different - passive as well as active exoskeletons - assisting the wearer during stooped postures, static holding of a load and while lifting and lowering weights. Most included studies assessed the effects of the exoskeleton via physiological (EMG) and biomechanical (loading on the back, spinal

compression and shear forces) parameters. The overall result of the systematic review was that in general positive effects of the exoskeleton on the wearer were reported for the physiological as well as biomechanical parameters. De Looze et al. (2016) reported a decrease in back muscle activity by 10.0% to 70.0%, a decrease by 20.0% to 70.0% for arm and shoulder girdle muscle activity and a lowered internal force on the lumbar spine by 23.0% to 29.0% for different exoskeletons, e.g. for the "Personal Lift Augmentation Device (PLAD)". No statistical analyses with pooled data was conducted. But it has to be mentioned that the results presented in the review by de Looze et al. (2016) in some cases differ from the results presented in the studies included (Abdoli-Eramaki et al., 2006; Godwin et al., 2009; Lotz et al., 2009; Whitfield et al., 2014) in this systematic review. It is uncertain whether de Looze et al. (2016) calculated these results by summarizing the individual results and did not provide information on how this was done or whether they made a mistake.

4.4. Summarized results categorized by the work task supported by an exoskeleton

The following paragraphs give an overview over the summarized results of the included studies categorized by the work tasks to be supported by an occupational exoskeleton. The studies will be presented sorted by the author and the examined exoskeleton. Information will be given about the publication date, the result of the quality assessment, the study design, the number of participants included, the exoskeleton used for the study and on the main results of the study.

4.4.1. Work at head or at overhead level

4.4.1.1. Naito, Obinata, Nakayama, & Hase (2006): "Wearable Robot"

The study by Naito et al. (2006) (MQAC: Acceptable (+)) was an experimental laboratory study with the aim to describe the development of a wearable robot assisting carpentry workers during overhead work, i.e. fitting ceiling panels, and to evaluate the effectiveness of the designed exoskeleton. The authors developed a semi-active exoskeleton which covers the total back as well as the upper half of the thigh of the wearer. Additionally it is attached to the wearer's wrist. To assess the effectiveness of the developed exoskeleton the effect on the muscle activity of the biceps brachii and the deltoid muscle in three participants was measured. Naito et al.

(2006) reported that the magnitude of muscle output force is greater for both muscles performing the task without the support of the exoskeleton. No further information about the percentage reduction in muscle output force was given in the paper (Naito et al., 2006). This study was also included in the systematic review by de Looze et al. (2016) which reported a percentage reduction in the muscle activity for the forearm flexors, the biceps brachii muscle and the deltoid muscle by 56.0%, 29.0% and 77.0%, respectively for this study's results (de Looze et al., 2016).

4.4.1.2. Sylla et al. (2014): "ABLE upper limb exoskeleton"

In 2014 Sylla et al. also conducted an experimental laboratory study (MQAC: High quality (++)) to assess physical health aspects in the form of ground reaction forces, joint torques, joint angles and performance duration regarding the use of the ABLE upper limb exoskeleton. The ABLE upper limb active exoskeleton aims to support the weight of the wearer's arm as well as of the tool held by the wearer and is worn as a backpack with a splint-like arm rest. During the experiment eight presumably male, right-handed participants had to perform a simulated overhead screwing motion with and without the assistance of the exoskeleton. The above described biomechanical parameters were measured and inter-subject averages were compared. The study showed that vertical ground reaction forces could be reduced by up to 19% while wearing the exoskeleton but the authors stated that high values of the standard deviation might question this result. Unfortunately, no explicit value for the standard deviation was reported by the authors in the paper. Therefore, this statement cannot be verified. Concerning the vertical ground reaction forces in the medio-lateral and antero-posterior direction Sylla et al. (2014) showed that participants tended to lean aside or bend slightly forward to maintain their balance when wearing the exoskeleton. Regarding the joint angles of the participants' upper extremity the study showed that ABLE modified the users arm movements or forced the participant to follow the exoskeleton's movements instead of vice versa. Results showed a reduction in joint torques by 15.0% to 38.8% with the exoskeleton compared to the arm free condition. The authors reported that the participants needed on average one second longer to perform the task when wearing the ABLE upper limb exoskeleton. As no further data was provided on the time the participants needed to perform the tasks with and without the exoskeleton, this statement cannot be verified by the author of this scientific work. (Sylla et al., 2014).

4.4.1.3. Rashedi et al. (2014): “Wearable assistive device (WADE)”

Rashedi et al. (2014) conducted an experimental laboratory study (MQAC: High quality (++)) to assess the efficacy of the use of the WADE exoskeleton for overhead work. The WADE exoskeleton is a passive exoskeleton consisting of an upper body vest that rests on the wearer’s shoulders and pelvis and is connected to a mechanical arm at the end of which a tool can be attached. During the experiment 12 male participants were required to conduct a simulated overhead task (“keeping a tool engaged with a hexagonal bolt that was oriented downward” (Rashedi et al., 2014)) with and without the support of the exoskeleton. Ratings of perceived discomfort (RPDs) of the upper arm, shoulder and lower back as well as an electromyography of the triceps brachii muscle, the anterior and middle deltoid muscle and the iliocostalis lumborum pars lumborum muscle were conducted. Additionally, the participants were encouraged to share their thoughts on the usability and on the pros and cons of the use of the WADE exoskeleton at the end of the experiment. Participants reported a significant reduction in RPDs for the upper arm and shoulder by 34.0% to 57.0% ($p < .0001$) when they wore the exoskeleton. The muscle amplitudes for the bilateral deltoideus muscle and the left triceps brachii also decreased by 36.0-56.0%. In contrast the physical demand on the lower back increased as the RPDs increased by approximately 24.0 to 48.0% and the muscle amplitudes increased by approximately 31.0 to 88.0%, depending on the weight of the used tool. Ten out of twelve participants stated they would consider using the WADE during daily work tasks consisting of heavy and light loads. All participants addressed the need for more flexibility to move the torso (Rashedi et al., 2014).

4.4.1.4. Butler & Wisner, (2017): “Personal ergonomic device (PED)”

The PED was used to test the hypothesis that the use of an exoskeleton increases productivity in static and dynamic tasks at head or at overhead level. The passive exoskeleton is worn like a backpack with splint-like arm rests for the upper arms. During the experimental laboratory study (MQAC: Unacceptable (-)) four male participants (two welders and two painters) performed a computer simulated welding or painting task. The performance quality was measured by criteria determined by the researchers and included experienced pain, deviating movements of the trunk, risk of injury as well as a decrease in performance quality measured by the simulator. The results showed that the painters’ as well as the welders’ productivity was improved by the use of the exoskeleton. The two painters improved their productivity by 26.8% and 53.1%, respectively. The welders' productivity increased by approximately 86.0% (Butler & Wisner, 2017). As the quality assessment of the study resulted in a poor quality the results should be interpreted with caution.

4.4.1.5. Weston et al. (2018): "Steadicam Fawcett Exoskeletal vest"

Weston et al. (2018) conducted an experimental laboratory study (MQAC: High quality (++)) to evaluate the effects of the use of an exoskeleton on the muscle activity and the spinal loads excerted on the lower back during a simulated hand tool use. The Steadicam Fawcett Exoskeletal vest is a passive exoskeleton worn like a backpack with the possibility to connect different mechanical arms to it, similar to the exoskeleton used by Rashedi et al. (2014). Peak and mean muscle forces as well as peak and mean three-dimensional spinal loads were measured in twelve male participants performing simulated tasks at head and at overhead level with a nut runner and a pneumatic impact wrench which were intended to represent tasks common in aviation manufacturing. The study resulted in a significant increase of peak muscle forces in the back extensors by 55.5% to 63.1% ($p < .001$) and a significant increase of mean muscle forces by 78.5% to 120.0% ($p < .001$) when the participants wore the exoskeleton. Also the peak and mean muscle forces for the abdominal internal oblique muscle (42.9% and 66.1%, respectively, $p < .03$) and for the abdominal external oblique muscle (32.2% and 41.8%, respectively, $p < .04$) increased significantly, whereas the muscle forces of the rectus abdominis muscle decreased significantly by 50.2% ($p = .036$). Regarding the spinal load excerted by the exoskeleton the peak and mean compressive spinal loads were significantly increased by 30.9% to 52.5% and 38.5% to 56.8%, respectively and were highest at the L4 / L5 level ($p < .001$). Peak and mean anterior / posterior shear loads were significantly increased by 26.0% and 30.0%, respectively ($p < .008$) (Weston et al., 2018).

4.4.1.6. Gillette & Stephenson (2017): "Shoulder support exoskeleton"

The study by Gillette and Stephenson (2017) (MQAC: High quality(++)) is one out of five cohort studies included in this systematic review. It aimed to assess the use of a passive exoskeleton on the muscle activity of the shoulder girdle and back muscles of employees working at head or at overhead level. The exoskeleton was worn like a "backpack frame with cuffs proximal to the elbow that support arm weight during overhead postures and transfer loads to the pelvis / hip." (Gillette & Stephenson, 2017). Two female and four male participants were included. The results showed a significant reduction in the maximum one second sustained EMG amplitude for the biceps brachii muscle of 18.0% (p = .01) and approaching significance for the deltoid muscle (p = .06) when using the exoskeleton. Additionally, the use of the exoskeleton resulted in a significant reduction of maximum one minute distributed EMG amplitudes for the biceps brachii muscle by 27.0% (p = .02) and for deltoid muscle by 23.0% (p = .04), whereas the reduction in erector spinae muscle activity did not reach significance (p = .07) (Gillette & Stephenson, 2017).

4.4.1.7. Spada et al. (2017, 2018): „Levitate Exoskeleton"

Spada et al. conducted an experimental laboratory study at the ergonomics laboratory of Fiat Chrysler Automobile (FCA) Manufacturing Engineering evaluating the applicability and usability of a passive upper limb exoskeleton for work tasks. This study consisted of two parts with the first part examining 29 male operators and the second part examining eleven FCA team leaders. The first part was published in 2017 (Spada et al.) (MQAC: High quality (++)) and the second part in 2018 (Spada et al.) (MQAC: High quality (++)) in two separate papers. In both studies the Levitate Exoskeleton was used which is a passive exoskeleton worn like a backpack with cuffs around the upper arms to support their weight while working at or at overhead level. Data was gathered on endurance time, muscle fatigue and discomfort, performance time and task precision. Additionally, semi-structured interviews were conducted assessing the experience of the workers with the use of the exoskeletons. Furthermore, participants were asked to fill out the usability metrics questionnaire as well as the Technology Acceptance Model 2 (TAM2) to assess usability and acceptance. Regarding the results for the 29 male operators, the exoskeleton increased the endurance time by 31.1% and participants stated to perceive less muscle fatigue and assessed the exoskeleton to be helpful. Performance time was similar in both conditions, whereas the task precision increased significantly by 33.6%. The assessment of the usability metrics questionnaire and TAM2 revealed that workers had a positive attitude towards the use of exoskeletons at the workplace as they considered them to be easy to use, effective and efficient but at the same time stated that the use should be on a voluntary basis (Spada et al., 2017). Regarding the eleven team leaders, similar results could be observed. The endurance time when wearing the exoskeleton was increased by 52.5% and the task precision increased by 34.0%. In general, the eleven team leaders rated the exoskeleton as being helpful but at the same time criticized the interference of the exoskeleton with the work environment (Spada et al., 2018).

4.4.1.8. Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Alabdulkarim, et al. (2018): “EksoVest®”

In 2018 Kim et al. (MQAC: High quality (++) evaluated the “impacts on worker safety and health, and task performance” of the use of the EksoVest® which is a passive exoskeleton similar to the Levitate Exoskeleton as it is worn like a backpack with armrests for the upper arms supporting the wearer during arm elevation. Six male and six female participants were included in the study and were asked to perform simulated repetitive drilling and light assembly tasks at head or at overhead level with and without the EksoVest®. Measured outcomes were: RPD scores for the neck, shoulder, upper arm, forearm, upper back, lower back and the leg; muscle activity and performance time and quality. The use of the EksoVest® reduced peak and mean muscle activity of the shoulder muscles significantly by approximately 45.0% and 50.0% ($p < .016 - .033$), depending on the work height and work task, respectively. The performance time was reduced by nearly 20.0% with the EksoVest® but the performance quality at overhead level decreased at the same time. The results did not indicate a change in RPD scores with and without the exoskeleton (Kim et al., 2018).

4.4.1.9. Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Jia, et al. (2018a): “EksoVest®”

Kim et al. (2018a) (MQAC: High quality (++)) conducted another study assessing the impact of the EksoVest® on workers’ safety, health and task performance but this time focused on potential adverse effects (donning / doffing times, shoulder range of motion, postural control, slip / trip risks, and spine loads). 14 male and 13 female participants were included and were asked to perform simulated repetitive drilling and light assembly tasks as well as walking on a track with a length of 15.5 meters. Donning times were significantly faster for female than for male participants (p = .04), whereas doffing times were nearly similar between females and males. The use of the exoskeleton resulted in a decrease of shoulder flexion and abduction by 2.6% and 10.0%, respectively, and the mean center of pressure velocity in anterior / posterior direction increased by approximately 12.0%. No significant difference concerning the slip / trip risk with and without the exoskeleton was observed. Depending on the work task and the working height the EksoVest® reduced peak anterior / posterior spinal shear forces by 29.5% on average but at the same time increased peak lateral spinal shear forces by 87.9% on average. Additionally, the EksoVest® reduced peak and mean spinal compression forces by 18.5 to 19.1% and 16.5 to 21.6% on average, respectively depending on the work task (Kim et al., 2018a).

4.4.1.10. Otten, Weidner, Argubi-Wollesen (2018): “LUCY exoskeleton“

In 2018 Otten et al. (MQAC: Acceptable (+)) developed a new version of the “LUCY exoskeleton” which is a passive exoskeleton worn like a backpack with armrests for the upper arms supporting the wearer during the elevation of the arms. To evaluate the performance of the new exoskeleton with regard to perceived exertion, perceived strength of support force and perceived force needed to lower the arms, the authors conducted an experimental laboratory study with eight participants, asking them to perform three different work tasks at overhead level with the exoskeleton with four different adjustments. Results showed that “LUCY” could reduce overall task effort. This was measured as the participants’ ratings regarding the perceived effort needed to complete the task (Borg CR-10); the subjective rating of felt support by the exoskeleton (six-point Likert scale ranging from -3 representing “too low” to +3 representing “too strong”) and the subjective ratings of the force needed to lower the arms against the force of the exoskeleton (six-point Likert scale ranging from 0 meaning “no force” to 6 meaning “strong force required”). In a second analysis the authors measured the muscle activity of the deltoid and latissimus dorsi muscle in three participants two of whom were male and one of whom were female. Results showed a significant reduction in deltoid muscle activity of 13.6% to 58.2% when using the exoskeleton. The muscle activity of the left latissimus dorsi muscle decreased for all participants by 15.0 to 41.7%. For the right latissimus dorsi muscle contradictory results were observed (Otten et al., 2018).

4.4.1.11. Liu et al. (2018): "Levitate Exoskeleton"

The cohort study by Liu et al. (2018) (MQAC: High quality (++)) investigated the use of the Levitate Exoskeleton during laparoscopic surgery regarding operators' fatigue, pain, stress and dexterity. The study comprised of three phases, with phase one investigating the surgeons' dexterity during simulated tasks derived from the Minnesota Manuel Dexterity Testing, the Purdue Pegboard Dexterity Test and the Fundamentals of Laparoscopic Surgery, phase two investigating the surgeons' experienced pain and fatigue while holding a laparoscopic camera in a laboratory environment simulating a laparoscopy and the third phase investigating the effects of the exoskeleton at the surgeons' workplace during laparoscopy. Overall 20 participants were included in the study of whom three had to be excluded because of their body composition not fitting the exoskeleton. Nine participants were tested in phase one as well as in phase two. For phase three seven out of the 20 included participants were investigated. There was no significant difference between wearing and not wearing the exoskeleton with regard to the surgeons' dexterity ($p = .15 - .84$). Concerning the surgeons' fatigue and pain, participants reported significantly less fatigue and a 70.0% decrease in pain scores was observed ($p = .019$). The predominant number of participants, six out of seven tested in phase three of the study, stated that they would incorporate an exoskeleton into their daily work (Liu et al., 2018).

4.4.1.12. Summary of the category: Work at head or at overhead level

In conclusion, most studies used an exoskeleton that can be worn as a backpack with arm cuffs for the upper arms to transfer the load of the arms and the used tools to the shoulders, pelvis or hip while working at head or at overhead level. Regarding the effects on muscle activity, all studies measuring upper arm and shoulder girdle and straight abdominal muscles' activity reported a reduction by approximately 13.6% to 77.0% and 50.2%, respectively (Gillette & Stephenson, 2017; Kim et al., 2018; Naito et al., 2006; Otten et al., 2018; Rashedi et al., 2014; Weston et al., 2018) and an increase in back extensor and oblique abdominal muscles activity by 31.0% to 88.0% and 32.2% to 66.1%, respectively (Rashedi et al., 2014; Weston et al., 2018). Concerning the joint kinematics studies reported a modification, i.e. a reduction of shoulder range of motion in the form of shoulder flexion and shoulder abduction by 2.6% to 10.0% (Kim et al., 2018b; Sylla et al., 2014). For the joint torques of the spinal column contradictory results are reported for the spinal compression and shear forces in the anterior / posterior and lateral direction. Wearing the exoskeleton during work tasks led to a reduction of RPDs for the upper arm and shoulder girdle by 34.0% to 57.0% (Liu et al., 2018; Rashedi et al., 2014; Spada et al., 2017) and an increase by 24.0% to 48.0% for the lower back region (Rashedi et al., 2014). In general, participants evaluated the use of an occupational exoskeleton as being beneficial (Liu et al., 2018; Spada et al., 2017, 2018).

4.4.2. Lifting and lowering

4.4.2.1. Abdoli-Eramaki et al. (2006) and Abdoli-Eramaki & Stevenson (2007): "Personal Lift Augmentation Device (PLAD)"

The first study in the category "Lifting and Lowering" is the experimental laboratory study by Abdoli-Eramaki et al. (2006) (MQAC: High quality (++)) which examined nine male participants to assess whether the muscular activity of the back and abdominal muscles is reduced or altered during the use of the Personal Lift Augmentation Device (PLAD). PLAD is a passive exoskeleton consisting of elastic elements that run almost parallel to the back extensor and leg muscles and assists the wearer during lifting and lowering by transferring forces excerted on the back to the shoulders, pelvic girdle and the knees. During the study participants were asked to lift a wooden container from the floor until they stood in an upright posture with and without the PLAD. Results showed a significant reduction in the lumbar erector spinae muscles' activity by 14.4% (SD 4.5%) and by 27.6% (SD 8.6%) for the thoracic erector spinae for the PLAD-condition compared to the No-PLAD-condition ($p = .0001$). No significant changes in muscle activity for the external obliquus abdominalis muscle and the rectus abdominis muscle were observed between the two conditions. Abdoli-Eramaki et al. (2006) reported no main effect of PLAD for lumbar and pelvis flexion and load acceleration ($p > .05$) but a main effect for trunk acceleration (p =

.01). Regarding the participants' experiences using the PLAD 50.0% reported discomfort, excessive force and loss of range of motion at the knees. Nevertheless, all participants reported having felt the support of the PLAD. Concerning the willingness-to-use, 20.0% stated that they would not use the exoskeleton at the workplace, 30.0% stated yes and 50.0% stated maybe if the wearing comfort was higher (Abdoli-Eramaki et al., 2006). This study was also included in the systematic review by de Looze et al. (2016).
In 2007 Abdoli-Eramaki & Stevenson (MQAC: High quality (++)) published further results of the study conducted in 2006 regarding the PLADS's effectiveness for asymmetric lifting. This study was also included in the systematic review by de Looze et al. (2016). For the muscle activity of the thoracic and lumbar erector spinae as well as the abdominal external oblique muscle results showed a decrease, whereby the decrease in the ipsilateral muscle was always smaller than in the contralateral muscle regarding the lifting side (right, left). A significant reduction in muscle activity for the thoracic erector spinae by 15.9% (p = .001) and 24.4% (p = .0001), for the lumbar erector by 22.6% (p = .0001) and 23.9% (p = .0001) and a non-significant reduction for the abdominal external oblique muscle by 4.6% and 34.9% regarding the ipsi- and the contralateral muscle could be observed. Concerning the joint kinetics a significant reduction in mean lateral bending by 30.0%, a decrease in mean rotational moment by 24.0% and a reduction in flexion-extension moment by 19,5% occurred (p = .001). All participants reported to feel the support of the PLAD, 10.0% reported compression on the shoulders and 40.0% compression on the knees by the PLAD (Abdoli-E & Stevenson, 2008; de Looze et al., 2016).

4.4.2.2. Takamitsu Aida et al. (2009): "Muscle Suit"

In their paper Takamitsu Aida et al. (2009) (MQAC: Unacceptable (-)) described the improvements made by them on the „Muscle Suit" and tested its effects on factory laborers in an experimental laboratory study. The "Muscle Suit" is an active exoskeleton using a McKibben-type actuator and is worn like a backpack with cuffs for the upper arms and thighs as well as splints for the lower arms to support factory laborers during work tasks. To test its effects on the human body three different experiments including static holding, lifting and lowering of a weight as well as assembling a tire were conducted with five male participants and their muscle activity was measured. Results showed a reduction in muscle activity by 40.0% to 70.0% for the biceps brachii muscle, by 31.0% to 80.0% for the triceps brachii muscle and by 37.0% to 40.0% for the erector spinae muscle throughout the three experiments. Due to the low quality of the study, the results should be interpreted with caution.

4.4.2.3. Kadota et al. (2009): "Power-assisted robot arm (PARM)"

In 2009 Kadota et al. (MQAC: Unacceptable (-)) conducted an experimental laboratory study to assess the effectiveness and usefulness of the "Power-assisted robot arm (PARM)". The PARM is a passive exoskeleton consisting of a vest for the upper body on which a back plate as well as splints for the upper and lower arm are attached to assist the user during lifting and carrying tasks. One male participant was included in the study and required to lift and lower an object from the floor. The authors stated that the muscle activity for the biceps brachii and brachioradialis muscle decreased while wearing the exoskeleton. No further information about the percentage reduction was given. Additionally, ten male participants were asked to rate the usefulness of the PARM on a 5-point Likert scale, ranging from 1 "not so useful" to 5 "very useful". The average score was more than 3.6. It has to be taken into account that the quality of the study was low and therefore the results should be interpreted carefully. This study was also included in the systematic review by de Looze et al. (2016) but the authors also have to state that no further information on the percentage reduction was reported by Kadota et al. (2009).

4.4.2.4. Frost et al. (2009): "Personal Lift Augmentation Device (PLAD)"

The experimental laboratory study by Frost et al. (2009) (MQAC: High quality (++)) which was also included in the systematic review by de Looze et al. (2016) used the PLAD exoskeleton described in paragraph 4.4.2.1.. 13 male participants were included to assess the effect of the PLAD on muscle activity, magnitude of lumbar spine flexion and the dynamic flexion / extension moment on L4/5 level during lifting and lowering tasks in three different lifting styles (stooped, squat, freestyle). Results showed a significant reduction in thoracic and lumbar erector spinae muscle by 11.0% to 43.0% and 10.0% to 40.0%, respectively for all three lifting techniques ($p < .05$). For the stooped lifting style a significant reduction in muscle activity by 19.0% to 46.0% for the biceps femoris and by 33.0% to 41.0% for the gluteus maximus could be observed (p < .05). No significant differences for the rectus abdominis and latissimus dorsi muscle could be observed with and without the exoskeleton. Concerning joint kinetics a significant reduction by 17.0% to 19.0% was reported for the flexion-extension moment (p < .05) (de Looze et al., 2016; Frost et al., 2009).

4.4.2.5. Lotz et al. (2009): "Personal Lift Augmentation Device (PLAD)"

In 2009 Lotz et al. conducted an experimental laboratory study (MQAC: High quality (++)) to investigate the effects of the PLAD on the muscle activity of the back muscles. Additionally, the cardiovascular load in the form of the heart rate and the participants' rating of perceived exertion (RPE) were measured. Ten male participants were included in the study and performed a repetitive lifting task with and without the exoskeleton. Results showed no significant differences for the heart rate between the two conditions (p > .05), whereas the RPE values increased significantly more in the no-PLAD-condition vs the PLAD-condition (57.0% vs. 25.0%, p < .001 - .05). Concerning the root mean square (RMS) values, the values for the thoracic as well as the lumbar erector spinae increased significantly more for the no-PLAD-condition compared to the PLAD-condition (104.0% vs. 22.0% and 88.0% vs. 26.0%, respectively, p < .05). The results indicated a significantly higher decrease in EMG median frequency values for the thoracic as well as the lumbar erector spinae in the no-PLAD vs. the PLAD-condition (12.0% vs. 0.33% and 20.0% vs. 0.4%, respectively, p < .05) (Lotz et al., 2009). This study was also included in the systematic review by de Looze et al. (2016).

4.4.2.6. Godwin et al. (2009): "Personal Lift Augmentation Device (PLAD)"

Godwin et al. (2009) conducted an experimental laboratory study (MQAC: High quality (++)) similar to the study by Lotz et al. (2009) as they hypothesized that the PLAD was more effective in reducing back muscle and cardiovascular fatigue in women than in men. Therefore, twelve female participants were included in the study and also performed a repetitive lifting task with and without the PLAD. Results showed no significant differences regarding the heart rate and back muscle endurance time for the no-PLAD and the PLAD-condition (p > .05). Regarding the RMS values the values for the thoracic as well as the lumbar erector spinae increased significantly more for the no-PLAD-condition compared to the PLAD-condition (91.0% vs. 3.0% and 104.0% vs. 16.0%, respectively, $p < .05$). Furthermore, the EMG mean frequency values for the thoracic and lumbar erector spinae decreased significantly more for the no-PLAD vs. the PLAD-condition (22.0% vs. 4.0% and 32.0% vs. 14.0%, respectively, $p < .01$). The isometric back muscle strength was significantly higher for the PLAD-condition than for the no-PLAD-condition after the lifting task ($p < .016$). Participants reported on pressure points at the shoulders, knees, lower back, thighs and feet. Nevertheless, 58.0% of the participants reported that they would use the exoskeleton during repetitive lifting tasks at work (Godwin et al., 2009). This study was also included in the systematic review by de Looze et al. (2016).

4.4.2.7. Wehner et al. (2010): "Wearable moment restoring device"

The study by Wehner et al. (2010) (MQAC: High quality (++)) which was also included in the systematic review by de Looze et al. (2016) was an experimental laboratory study with the aim to test a lower extremity exoskeleton intended to reduce forces on the lower back during manual material handling tasks with regard to spinal column compression forces and erector spinae muscle activity. The exoskeleton consists of a backplate with attached splints and cuffs for the lower extremity and foot plates. Five male and one female participant were included in the study and were asked to repeatedly lift and lower a box of two different weights of the ground. Results showed a reduction in erector spinae muscle activity by 44.0% to 54.0% depending on the weight lifted and a reduction in spinal compression forces for the lighter and heavier weight by 36.0% to 60.0%, respectively (de Looze et al., 2016; Wehner et al., 2010).

4.4.2.8. Ulrey & Fathallah (2013): „Bending non-demand return (BNDR)"

The passive "Bending non-demand return" (BNDR) exoskeleton consisting of a pelvic girdle, a breast plate as well as cuffs for the thighs and was used in the experimental laboratory study by Ulrey & Fathallah (2013) (MQAC: High quality (++)) which was also included in the systematic review by de Looze et al. (2016). The aim of the study was to assess the effect of a weight transferring exoskeleton on muscle activity and joint flexions in the stooped posture. Eleven male and seven female participants were included and were asked to lift a box of the ground, remain in this stooped posture while holding the box and then lower the box again with and without the exoskeleton. No statistically significant differences in muscle activity for the lumbar and thoracis erector spinae, the rectus abdominis and the tibialis anterior muscle were observed between the two conditions in the static bending phase when the BNDR was used, whereas a 17.0% reduction in biceps femoris muscle activity could be observed ($p < .0001$) (Ulrey & Fathallah, 2013). During the static bending phase the total torso angle was reduced by 17.4%. Regarding the lifting and extension phase significant reductions in the muscle activity of the lumbar and thoracic erector spinae and the biceps femoris muscle by 15.2%, 10.0% and 9.5% were observed. During the lifting flexion movement the total torso angle decreased by 16.7% and during the lifting extension moment by 17.1% (de Looze et al., 2016; Ulrey & Fathallah, 2013).

4.4.2.9. Muramatsu et al. (2013) and Nakamura et al. (2017): "Muscle Suit"

As in the study by Takamitsu Aida et al. (2009) also Muramatsu et al. (2013) (MQAC: Acceptable (+)) and Nakamura et al. (2017) (MQAC: Unacceptable (-)) described the implemented improvements on the "Muscle Suit" and reported findings of the quantitative investigation of the effects of the improved "Muscle Suit" on the muscles of the lower back while lifting and lowering a weight. In both experimental laboratory studies three male participants were included respectively. A 40.0% reduction for the lower back muscles could be observed while lifting a weight and wearing the "Muscle Suit" in the study by Muramatsu et al. (2013). Nakamura et al. (2017) also reported a reduction in lower back muscle activity as well as a reduction in arm muscle activity but did not provide further information on percentage reductions. As the quality of the study by Nakamura et al. (2017) was poor, results should be interpreted with caution.

4.4.2.10. Whitfield et al. (2014): "Personal Lift Augmentation Device (PLAD)"

The aim of the experimental laboratory study by Whitfield et al. (2014) (MQAC: High quality (++)) was to investigate the effect of the PLAD exoskeleton on the oxygen consumption of 15 male participants during a repetitive lifting task with a light weight. The PLAD exoskeleton has already been described in paragraph 4.4.2.1.. During the repetitive lifting task oxygen consumption as well as the muscle activity of the thoracic and lumbar erector spinae, gluteus maximus, biceps femoris and rectus femoris muscle were measured. Results showed no significant difference of the oxygen consumption between the two conditions – wearing and not wearing the exoskeleton (p = .49). Regarding the muscle activity a significant reduction in muscle activity (14.0%, p = .032) for the thoracic erector spinae in the lowering phase could be observed. The muscle activity of the biceps femoris muscle was significantly reduced by 8.4% (p = .014) in the lifting phase. The differences found for the remaining muscles were not statistically significant (Whitfield et al., 2014). The study was also included in the systematic review by de Looze et al. (2016).

4.4.2.11. DeBusk et al. (2017): "StrongArm® ergoskeleton"

In this experimental laboratory study DeBusk et al. (2017) (MQAC: High quality (++)) assessed the influence of the "StrongArm® ergoskeleton" on the flexion angles of the knee and the hip during a lifting task. The "StrongArm® ergoskeleton" is a passive exoskeleton worn like a backpack and is attached to the pelvic girdle. Additional hand cables can be attached. Four male and two female right-handed participants were included in the study and were required to lift a weight corresponding to 10.0% and 20.0% of their body weight. Participants were also asked to rate their perceived discomfort on the Borg-CR 10 scale. The following results were observed:

- Time in hip flexion < 30° was significantly greater in the 10.0% body weight condition than in the 20.0% body weight condition (p = .034)
- Time in hip flexion > 90° was significantly greater in the 20.0% body weight than in the 10.0% body weight condition (p = .035)
- Time in knee flexion between 75-145° was significantly greater in the 20.0% body weight than in the 10.0% body weight condition (p = .031)
- Time in knee flexion > 145° was significantly greater in the 10.0% body weight condition than in the 20.0% body weight condition (p = .017)

- Average knee flexion >145° was significantly greater in the 10.0% body weight condition than in the 20.0% body weight condition ($p = .022$).

Regarding the RPDs the 20.0% body weight condition resulted in statistically greater ratings than the 10.0% body weight condition ($p = .004$) (DeBusk et al., 2017).

4.4.2.12. Huysamen et al. (2018): "Industrial exoskeleton"

In 2018 Huysamen et al. conducted an experimental laboratory study (MQAC: High quality (++)) to "assess the effect of the exoskeleton on muscle activity, musculo-skeletal effort, contact pressure, local perceived pressure and subjective usability" (Huysamen et al., 2018) for cyclical lifting and lowering tasks. The exoskeleton used is an active exoskeleton consisting of shoulder straps, a pelvic girdle with the actuator attached to it as well as cuffs for the thighs. Twelve male participants were included and asked to repetitively lift and lower a box mid-shin height to waist height for five times. Results showed a significant reduction in erector spinae and biceps femoris muscle activity by 12.0% to 15.0% and 5.0%, respectively when wearing the exoskeleton ($p < .01$). The perceived effort scores for the trunk were reduced by 9.4% to 11.4% and for the legs by 4.5% to 8.1%, but only the reduction for the trunk was found to be significant ($p < .01$). Participants reported to feel the highest pressure on the trunk and the least on the shoulders. Six out of ten participants rated the usability on the System Usability Score with scores above the acceptable usability criterion (Huysamen et al., 2018).

4.4.2.13. Theurel et al. (2018): "EXHAUSS Stronger® exoskeleton"

Theurel et al. (2018) (MQAC: High quality (++)) conducted an experimental laboratory study to determine the effect of the "EXHAUSS Stronger® exoskeleton" on muscle activity, upper arm kinematics and cardiac load during manual handling tasks. The "EXHAUSS Stronger® exoskeleton" is a passive exoskeleton consisting of a wearable vest connected to two mechanical arms actuated by springs. Four male and four female participants were included in the study and performed three different tasks: lifting and lowering a weight, walking while carrying a load and box stacking and unstacking with and without the exoskeleton. During the lifting task deltoid muscle activity significantly increased ($p < .01$), while the muscle activity of the triceps brachii and tibialis anterior muscle significantly increased ($p < .01$ and $p < .001$, respectively) when wearing the exoskeleton. No differences in muscle activity for the erector spinae muscle was found. Regarding the walking task the muscle activity for the triceps brachii muscle significantly decreased ($p < .05$), whereas no significant differences were found for the other muscles when wearing the exoskeleton vs. not wearing the exoskeleton. For the stacking tasks a significant reduction in deltoid muscle activity ($p < .001$), a significant increase in triceps brachii muscle activity ($p < .01$), and no significant findings for the remaining muscles could be reported while wearing the exoskeleton. During all tasks a modification of the joint kinematics for the wrist, elbow or shoulder could be observed. Cardiac load was similar between the two conditions concerning the walking and stacking task and was higher in the lifting task, approaching significance ($p= .058$). The ratings of perceived exertion were also similar for the two conditions in the lifting and stacking tasks but significantly lower during the walking task ($p < .05$) (Theurel et al., 2018).

4.4.2.14. Summary of the category: Lifting and Lowering

In summary fourteen out of fifteen studies (Abdoli-E & Stevenson, 2008; Abdoli-Eramaki et al., 2006; Frost et al., 2009; Godwin et al., 2009; Huysamen et al., 2018; Kadota et al., 2009; Lotz et al., 2009; Muramatsu et al., 2013; Nakamura et al., 2017; Takamitsu Aida et al., 2009; Theurel et al., 2018; Ulrey & Fathallah, 2013; Wehner et al., 2010; Whitfield et al., 2014) examined the effects of the use of exoskeletons on the muscle activity of the arm and shoulder girdle muscles, the erector spinae muscle or the leg muscles. Regarding the arm and shoulder muscles most studies reported a reduction in muscle activity by 31.0% to 80.0% (Kadota et al., 2009; Nakamura et al., 2017; Takamitsu Aida et al., 2009). Concerning the erector spinae muscles a reduction in muscle activity by 11.0% to 54.0% was observed (Abdoli-E & Stevenson, 2008; Abdoli-Eramaki et al., 2006; Frost et al., 2009; Godwin et al., 2009; Huysamen et al., 2018; Lotz et al., 2009; Muramatsu et al., 2013; Nakamura et al., 2017; Takamitsu Aida et al., 2009; Ulrey & Fathallah, 2013; Wehner et al., 2010; Whitfield et al., 2014). For the biceps femoris muscle activity also a reduction by 5.0% to 46.0% was observed (Frost et al., 2009; Huysamen et al., 2018; Ulrey & Fathallah, 2013; Whitfield et al., 2014), whereas the results for the tibialis anterior were contradictory (Theurel et al., 2018; Ulrey & Fathallah, 2013). Concerning the joint kinematics a modification of natural movements e.g., of the upper extremity or the trunk could be assumed (Abdoli-Eramaki & Stevenson, 2007; Theurel et al., 2018; Ulrey & Fathallah, 2013). With regard to the joint kinetics a reduction of spinal compression forces by 36.0% to 60.0% could be observed (Wehner et al., 2010). Flexion-extension moments decreased by 17.0% to 19.5% (Abdoli-E & Stevenson, 2008; Frost et al., 2009). In relation to subjective outcome parameters, most participants rated the exoskeleton to be uncomfortable and tiring to wear (Abdoli-E & Stevenson, 2008; Abdoli-Eramaki et al., 2006; DeBusk et al., 2017; Godwin et al., 2009; Huysamen et al., 2018), whereas the participants' rating of the usefulness as well as the willingness-to-use the exoskeleton was predominantly positive (Abdoli-Eramaki et al., 2006; Godwin et al., 2009; Huysamen et al., 2018; Kadota et al., 2009). Apart from the other studies Godwin et al. (2009), Lotz et al. (2009) and Theurel et al. (2018) measured the effect on the heart rate while wearing an exoskeleton but found contradictory results.

4.4.3. Static holding (stooped work / bent forward)

4.4.3.1. Kobayashi & Nozaki (2007): "Muscle Suit"

The first study in the category "Static holding" is the experimental laboratory study by Kobayashi & Nozaki (2007) (MQAC: Acceptable (+)) which was also included in the systematic review by de Looze et al. (2016). It aimed to describe a new mechanism for the "Muscle Suit" exoskeleton regarding the shoulder joint and test its feasibility. The described "Muscle Suit" is the same used by Muramatsu et al. (2013); Nakamura et al. (2017) and Takamitsu Aida et al. (2009). To test its feasibility five male participants were included in the study and were asked to statically hold a box weighing ten kilograms, for two times each, wearing and not wearing the exoskeleton. The muscle activity of the biceps brachii, triceps brachii and the erector spinae muscle was measured. Results showed a significant reduction in muscle activity by 70.0% for the biceps brachii, by 80.0% for the triceps brachii and by 40.0% for the erector spinae muscle ($p < .05$) (de Looze et al., 2016; Kobayashi & Nozaki, 2007).

4.4.3.2. Graham et al. (2009): "Personal Lift Augmentation Device (PLAD)"

The cohort study by Graham et al. (2009) (MQAC: High quality (++)) aimed to assess the effects of PLAD on the lower back during static forward bending of employees working in the automotive assembly. The PLAD was already described in paragraph 4.4.2.1.. The study was also included in the systematic review by de Looze et al. (2016). Graham et al. (2009) included eight male and two female participants in their study and assessed muscle activity, joint kinetics as well as subjectively rated factors as RPEs during a two hour working period with and without the PLAD. Results showed a significant 25.0% and 15.0% reduction in muscle activity for the thoracic and lumbar erector spinae, respectively ($p < .05$). No significant differences were found for the rectus abdominis muscle. Concerning joint kinetics a significant 12.0% and 18.0% reduction in spinal compression at the height of L3 and T9, respectively, could be observed ($p < .02$). Participants indicated a significant 16.0% decrease in RPEs ($p = .006$) and a 52.0% subjective estimate of off-loading of the lower back (de Looze et al., 2016; Graham et al., 2009).

4.4.3.3. Heydari et al. (2013): "Wearable assistive device (WAD)"

In 2013 Heydari et al. conducted an experimental laboratory study (MQAC: High quality (++)) to investigate the effect of the "Wearable assistive device (WAD)" on the activity of the trunk muscles during static holding tasks. The WAD is a passive exoskeleton consisting of a vest that covers the shoulders as well as eight elastic bands, four of which run parallelly to the erector spinae muscles and four of which run diagonally on the back. In the height of the pelvis a small backpack is attached. The legs are surrounded by two cuffs, one around the thigh and one around the lower leg terminating in a foot plate. 15 male participants were included in the study and were asked to stand upright and bend forward for a flexion angle of 30° and 60° holding three different weights in their hands. Results showed a significant decrease in muscle activity for the thoracic and lumbar erector spinae (12.9% – 30.0%, $p = .001$, 18.7% – 23.7%, $p = .001$ respectively), for the latissimus dorsi muscle (12.2% – 27.8%, $p = .001$) and for the abdominal external and internal oblique muscles (10.9% – 20.0%, $p = .001$, 5.2% – 17.3%, $p = .009$, respectively), whereas the muscle activity for the rectus abdominis muscle significantly increased by 7.1% to 10.9% ($p = .004$) depending on the lifted weight and the flexion angle. Concerning the joint kinetics the use of the WAD resulted in a decrease by 23.0% for the sagittal external moment and in a decrease for the lumbar moment by 22.5% to 43.0%. Participants reported that the WAD was effective in reducing loads on the spine while at the same time not inducing discomfort on the shoulder or knee joints (Heydari et al., 2013)

4.4.3.4. Luo & Yu (2013): "Wearable stooping-assist device (WSAD)"

In 2013 Luo & Yu conducted an experimental laboratory study (MQAC: Acceptable (+)) with the aim to describe the development process of the "Wearable stooping-assist device (WSAD)" and test its effectiveness by measuring the muscle activity of the back and abdominal muscles during forward bending of the upper body between 0°, 30°, 60° and 90° with and without the WSAD. The study was also included in the systematic review by de Looze et al. (2016). The WSAD is an active exoskeleton consisting of breast and shoulder bands to attach it to the upper body. From the breast band two elastic bands run parallelly to the erector spinae muscle and end at the pelvis band at which the servo motor is attached. The lower part of the exoskeleton consists of bands running parallelly to the sides of the legs terminating in foot plates. In order to assess the effectiveness of the WSAD Luo & Yu (2013) included one healthy male participant in their study and measured the muscle activity of the back and abdominal muscles in the above described positions. Results showed reductions in muscle activity of the thoracic erector spinae, the lumbar erector spinae, the latissimus dorsi and the rectus abdominis muscle by 30.0% to 42.0%, 34.0% to 47.0%, 18.0% to 28.0% and 4.0% to 9.0%, respectively, depending on the different positions. (de Looze et al., 2016; Luo & Yu, 2013).

4.4.3.5. Bosch et al. (2016): "Laevo"

The experimental laboratory study by Bosch et al. (2016) (MQAC: High quality (++)) aimed at investigating the effect of the Laevo exoskeleton on the muscle activity of the back, abdominal and leg muscles as well as "local perceived discomfort" (LPD) during a simulated assembly task in a stooped posture. The "Laevo" is a passive exoskeleton consisting of three different types of pads – two chest pads, one back pad and two thigh pads. The pads are connected through a circular tube with spring-like characteristics. Nine male and nine female participants were included in the study and performed a simulated assembly task as well as a holding task with and without the exoskeleton while bending forward for 40°. Results showed a significant reduction in muscle activity for the trapezius muscles, the erector spinae iliocostalis, the erector spinae longissimus and the biceps femoris by 44.0% to 50.0% ($p < .001$), 38.0% to 44.0% ($p < .001$), 35.0% to 37.0% ($p = .001$) and 20.0% to 24.0% ($p = .006$ and $p < .001$), respectively. There were no significant differences between the two conditions for the abdominal muscles. When wearing the exoskeleton participants tended to bent forward on average 5.2° more in the assembly task ($p = .001$) than without the exoskeleton. Participants reported significantly lower local perceived discomfort (LPD) values for the back while wearing the exoskeleton ($p = .021$), whereas the LPD values for the chest significantly increased ($p = .023$). The endurance time was three times higher when the participants wore the exoskeleton ($p < .001$) (Bosch et al., 2016).

4.4.3.6. Summary of the category: Static holding (stooped work / bent forward)

All included studies measured the effect of an exoskeleton on the muscle activity of either the shoulder girdle, back and abdominal or the leg muscles. For the trapezius and the biceps brachii muscles a reduction in muscle activity by 44.0% to 80.0% and 70.0%, respectively, could be observed (Bosch et al., 2016; Kobayashi & Nozaki, 2007). Regarding the back muscles a reduction by 10.0% to 47.0% in muscle activity was reported (Bosch et al., 2016; Graham et al., 2009; Heydari et al., 2013; Kobayashi & Nozaki, 2007; Luo & Yu, 2013). Most studies reported no significant differences in muscle activity for the abdominal muscles (Bosch et al., 2016; Graham et al., 2009; Luo & Yu, 2013), whereas a significant reduction of the muscle activity of the leg muscles by 20.0% to 24.0% could be observed (Bosch et al., 2016). Regarding joint kinetics the use of an exoskeleton resulted in a decrease in spinal compression by 12.0% to 18.0% and a decrease in lumbar moment by 22.5% to 43.0% (Graham et al., 2009; Heydari et al., 2013). Participants reported an off loading of the spine by 52.0% (Graham et al., 2009; Heydari et al., 2013). Contradictory results concerning LPDs and RPEs could be observed (Bosch et al., 2016; Graham et al., 2009; Heydari et al., 2013).

4.4.4. Walking while load carrying

4.4.4.1. Gregorczyk et al. (2010): „EXO“

Gregorczyk et al. (2010) conducted an experimental laboratory study (MQAC: High quality (++)) to assess the effects of a passive lower extremity exoskeleton on the metabolic load and gait biomechanics of soldiers while walking. The exoskeleton used was the “EXO” which consists of a back plate with straps passing over the user’s shoulders, a belt encircling the waist, two cuffs for the thighs, bindings for the footplates as well as connecting bars between the hip, thigh and foot sections. Nine male soldiers were included in the study and asked to walk fully equipped on a treadmill with and without the exoskeleton. The use of the exoskeleton resulted in a significant increase of oxygen uptake scaled to the body mass by 60.0% and in an increase of oxygen uptake scaled to the total mass by 41.0% ($p < .05$). Additionally, the joint kinematics were significantly altered as the trunk range of motion increased by 34.0%, the knee and ankle range of motion decreased by 10.0% and 18.0%, respectively ($p < .05$). Furthermore the ground reaction forces were significantly affected ($p < .05$) (Gregorczyk et al., 2010).

4.4.4.2. Panizzolo et al. (2016): “Exosuit”

In 2016 Panizzolo et al. conducted an experimental laboratory study (MQAC: High quality (++)) with seven male participants to investigate the effect of the active exoskeleton “Exosuit” on the metabolic cost, muscle activity, joint kinematics and kinetics while walking. The “Exosuit” consists of a waist belt, two thigh straps and two calf straps. During the experiment the participants were required to walk on a treadmill with and without the exoskeleton carrying an additional weight of 30.0% of their body weight in a backpack. The use of the exoskeleton resulted in a significant reduction in metabolic power by 35.2 (SD 23.0) Watts ($p = .02$). Additionally, the muscle activity of the vastus lateralis and soleus muscle was reduced by 4.7% (7.0, $p < .005$) and 8.9% (9.8, $p < .025$), respectively. With regard to the joint kinematics the ankle range of motion as well as the knee range of motion decreased significantly ($p = .001$ and $p = .012$, respectively). Concerning the joint kinetics, the knee extension moment decreased significantly ($p = .011$), the knee flexion moment increased significantly ($p = .001$), the ankle power generation increased significantly (p = .016) and the knee power absorption decreased significantly (p = .003). The spatio-temporal parameters were not significantly affected (Panizzolo et al., 2016).

4.4.4.3. Yu et al. (2016): "Underactuated Exoskeleton"

In this experimental laboratory study Yu et al. (2016) (MQAC: High quality (++)) developed an underactuated exoskeleton and investigated its feasibility in terms of muscle activity reduction of the lower extremity. The exoskeleton used is a quasi-active exoskeleton consisting of a backpack with the actuators attached to it as well as a frame running parallel to the legs of the wearer down to the feet. Five male participants were included in the study. Muscle activity of the rectus femoris and gastrocnemius muscle was measured while participants walked on even ground or climbed stairs. Results showed a reduction in rectus femoris and gastrocnemius activity for level walking by 20.0% to 39.0% and 20.0% to 51.0%, respectively and for climbing stairs by 48.0% to 53.0% and 16.0% to 43.0%, respectively (Yu et al., 2016).

4.4.4.4. Summary of the category: Walking while load carrying

Concerning the metabolic load contradictory results were observed as Gregorczyk et al. (2010) reported an increase in oxygen uptake and Panizzolo et al. (2016) a decrease in metabolic power. Regarding joint kinematics a decrease in knee and ankle range of motion by 10.0% and 18.0% respectively could be observed (Gregorczyk et al., 2010; Panizzolo et al., 2016). Joint kinematics in the form of ground reaction forces, joint extension and flexion moments as well as joint power generation and absorption were significantly affected (Gregorczyk et al., 2010; Panizzolo et al., 2016). The studies by Panizzolo et al. (2016) and Yu et al. (2016) resulted in a reduction in the muscle activity of the leg muscles by 4.7% to 51.0% while level walking and a reduction by 16.0% to 53.0% while climbing stairs.

4.4.5. Patient lifting / transfer

4.4.5.1. Imamura et al. (2011): "Smart Suit Light (SSL)"

In this cohort study (MQAC: Unacceptable (-)) Imamura et al. (2011) estimated the subjective ratings on the passive exoskeleton "Smart Suit Light" (SSL) in terms of fatigue, comfort and efficacy of the exoskeleton, firstly on the "prototype 1" and sec-ondly on the improved "prototype 2" . The SSL is a suit consisting of a vest for the upper body, a waist belt and cuffs for the thighs. These structures are connected via elastic straps. The SSL is intended to support nursing staff while lifting or transferring patients. One male and 19 female participants were included in the study and were asked to rate the above described parameters before and after one work day. Regarding the "prototype 1" results showed no significant difference between ratings on fatigue comparing the no-SSL- to the SSL-condition. Concerning the perceived effectiveness of the SSL more than half the participants rating the SSL to be comfortable also rated the exoskeleton to be effective. Participants who rated the SSL to be uncomfortable rated the exoskeleton to be ineffective. Regarding the improved "prototype 2" compared to the "prototype 1" participants rating the wearing comfort as "poor" decreased by 25.0%. This reduction went along with an increase in the rating of the effectiveness of the exoskeleton as well as of its ability to reduce fatigue (Imamura et al., 2011). As the quality assessment resulted in a poor quality of the study, results should be interpreted with caution.

4.4.5.2. Hein et al. (2016): "Smart Suit Light (SSL) and Rakunie"

Hein et al. (2016) (MQAC: High quality (++)) also conducted a cohort study using the SSL and additionally the Rakunie exoskeleton to assess the acceptance of nursery staff. The SSL was the same exoskeleton as used by Imamura et al. (2011). The Rakunie is a suit covering the upper torso and the pelvic girdle and at the same time connects the pelvic girdle and the rear thighs with elastic straps. Eight female participants wore the SSL and six female participants wore the Rakunie during one work day. Participants were asked to fill out a questionnaire measuring wearing comfort, perceived support, acceptance and muscle fatigue. The main finding of the study was that the participants rated the Rakunie more positively than the SSL. The willingness-to-use the Rakunie was higher than for the SSL. Additionally, a significant correlation between wearing comfort and acceptance could be found independent of the exoskeleton worn during the study (r_{SP}= 0.84, p = .01) (Hein et al., 2016).

4.4.5.3. Summary of the category: Patient lifting / transfer

Both cohort studies investigated nursery staff's acceptance towards the use of exoskeletons at the workplace. Results showed that the acceptance of the use of exoskeletons was strongly dependent on the wearing comfort (Hein et al., 2016; Imamura et al., 2011).

5. Discussion of the systematic review

Overall 38 different studies were found, 22 of which measured only physical health aspects, two of which measured only psychological health aspects and 14 of which measured both outcomes. The studies were published between 2006 and 2018 with the predominant portion (N = 34) being published after 2008 which shows the high interest in the application of occupational exoskeletons. Predominantly experimental laboratory studies (N = 32), five cohort studies and one systematic review could be extracted. Most studies were conducted in North America, Europe or Asia. The included studies investigated the use of occupational exoskeletons by healthy employees in industrial and nursing work environments. Tasks under study were categorized in 1) Work at head or at overhead level, 2) Lifting and lowering of weights (in a stooped position), 3) Static holding (in a stooped position / bent forward), 4) Walking while load carrying and 5) Patient lifting / transferring.

The use of an occupational exoskeleton resulted in a reduction of arm, shoulder girdle and leg muscle activity. The muscle activity of the back extensor muscles was also reduced for most work tasks, except for tasks at head or at overhead level back muscle activity increased. Concerning the abdominal muscle activity contradictory results were reported throughout the studies. Furthermore, the use of an exoskeleton led to an alteration of joint kinematics in the form of a reduction in joint range of motion of the joint covered by the exoskeleton. The use of an occupational exoskeleton led to a reduction in spinal compression forces and joint movement moments for almost all work tasks supported by the exoskeleton. The only exception were once more work tasks at head or at overhead level for which contradictory results were reported. Concerning the psychological health outcomes contradictory results for the RPDs and LPDs were found, whereas the ratings of the usefulness of as well as the willingness-to-use the exoskeleton at the workplace were generally positive.

Results showed that the acceptance of the use of the exoskeleton was strongly dependent on the wearing comfort.

5.1. Study results in context

5.1.1. Exoskeletons for the industrial application

The interest in occupational exoskeletons and their application in industrial environments just arose recently. Therefore, only one further systematic review (de Looze et al., 2016) could be identified to compare the results of this scientific study to. This shows once more the innovative character of this topic. As the systematic review by de Looze et al. was conducted in 2016 this scientific study includes most studies also identified by de Looze et al. (2016) plus additional studies published after 2016. Most studies identified in this scientific study were experimental laboratory studies investigating the physical and psychological health aspects of prototypes of exoskeletons not being commercially available yet. Only five cohort studies which took place at the participants' workplace were included. Both the experimental laboratory studies as well as the cohort studies comprised of small sample sizes of maximally 31 participants. This finding was equivalent to the results of the systematic review by de Looze et al. (2016). A possible explanation for the use of small sample sizes as well as the study design of experimental laboratory studies might be that the development of exoskeletons for the work place is still at the development stage which is also represented by the high number (N = 26) of different exoskeletons used in the studies.

With reference to the main results, both this scientific study and the systematic review by de Looze et al. (2016) came to similar results regarding the physical health aspects associated with the use of occupational exoskeletons. Most studies reported positive effects of the exoskeleton on the wearer in the form of physiological and biomechanical parameters, e.g. reduction in muscle activity, spinal compression forces and joint movement moments. These results correspond to previous results of studies investigating the use of exoskeletons for rehabilitative purposes. Patients were inter alia able to walk a longer distance with a higher speed using an exoskeleton compared to not using an exoskeleton. Additionally, the risk for secondary injury was reduced by the use of these devices (Federici et al., 2015; Louie et al., 2015). As the use of exoskeletons to support handicapped persons has already proven to be effective this knowledge might be used as a starting point for the comprehensive investigation on the application of exoskeletons at the workplace in order to support healthy workers when executing demanding work tasks.

Other than in this scientific review de Looze et al. (2016) did not report on the psychological health aspects associated with the use of occupational exoskeletons. This finding also applies to the results of this systematic review regarding the low number of studies measuring psychological health aspects. Only two studies could be identified which exclusively measured psychological health aspects in the form of wearing comfort and acceptance. In the previously mentioned 14 studies measuring physical as well as psychological health aspects the measurement of the psychological outcomes played a subordinate role. Most studies used qualitative interviews only asking for the participants' opinion on the use of exoskeletons at the workplace or questionnaires which were not described further. Only two studies used standardized questionnaires – the Technology Acceptance Model 2 (TAM2) and the System Usability Scale (SUS). This finding regarding the use of occupational exoskeletons as well as the findings by Federici et al. (2015) that most studies investigating the use of rehabilitative exoskeletons do not consider the impact on the psychological well-being of the wearer show the need for future research in the area of psychological health aspects associated with the use of occupational exoskeletons and the need for the development of standardized tools to measure these aspects and make the results comparable. For this reason the development of a questionnaire investigating the acceptance of employees using exoskeletons at the workplace as done in paragraphs "6. Methodology of the conceptual development of a survey" and "7. Results of the conceptual development of a survey" of this scientific study is necessary and justified.

5.1.2. Influencing factors for the implementation of occupational exoskeletons

Apart from the physical and psychological effects of the exoskeleton on the wearer other factors have to be taken into account when developing and implementing occupational exoskeletons. Except for the previously described factor wearing comfort other factors also relating to the complex design process of the exoskeleton play an important role, e.g. the selection of the material processed with regard to the weight, the robustness towards different environmental and work-related influences, the selection of actuators and the corresponding control unit in active and semi-active exoskeletons as well as the design of the incorporated so-called anthropomorphic joints. Already in 1995 Crowell III published guidelines for the development of a full-body exoskeleton for military purposes but as technical progress goes on, new guidelines have to be developed and be adjusted to current scientific research.

Another important factor regarding the implementation of occupational exoskeletons are safety standards including different risk scenarios, e.g. using the exoskeleton in- and outdoors, behaviour in emergency situations while wearing the exoskeleton, behaviour in case of malfunction of the exoskeleton, to ensure a safe use by employees. These safety standards do also have to deal with the possible employers' and employees' temptation to increase the working load due to the increase in strength provided by the exoskeleton as this would torpedo the primary purpose of the exoskeleton, namely the decrease in physical as well as psychological stress and strains. Although the use of exoskeletons for rehabilitative purposes is governed by ISO 13482, no international standard exists for the use of occupational exoskeletons, yet (Maxwell, 2017; O'Sullivan, Nugent, & van der Vorm, 2015). This lack of international safety standards for the use of occupational exoskeletons might be a hindrance to the implementation of these types of exoskeletons and should be tackled as soon as possible. In September 2017 the organisation "ASTM International" formed a working group to "address this standard's vacuum" (Maxwell, 2017). The working group agreed that they will predominantly focus on the following five issues concerning the development and implementation of occupational exoskeletons in the years to come: "Design and manufacturing; Human factors and ergonomics; Task performance and environmental considerations; Maintenance and disposal; and security and information technology." (Maxwell, 2017). Therefore, a first step in the right direction has been made but further research is needed to help developing international safety standards.

5.1.3. Discussion of the methodological approach of the systematic review

A systematic review was conducted to answer the research question on physical and psychological health impacts of employees associated with the use of occupational exoskeletons comprehensively and to form the scientific basis for the conceptual development of a survey investigating the attitude of employees towards the use of exoskeletons at their workplace.

The research question and the inclusion as well as the exclusion criteria were developed using the PICO system. The results of this scientific study were structured and reported according to the “Methodological checklist 1: systematic reviews and meta-analyses” by the Scottish Intercollegiate Guidelines Network (2001) and visualized using a modified version of the “PRISMA Flow-Diagram” by Moher et al. (2009) as these systems are good and practical tools for evidence based practice . Due to the heterogeneity of the included studies the conduction of a meta-analysis was not possible.

Regarding the search strategy broad search terms were used to ensure a comprehensive search that would identify as many studies as possible as the topic was very innovative. It was expected that no universally used terms regarding this topic already existed. Additionally, truncations were used to search for all possible word variations.

Regarding the study selection a high number of studies had to be excluded due to the above described broad search terms which also identified studies investigating for e.g. animals like crabs as they also have an exoskeleton.

The results of this systematic review as well as the results of the systematic review by de Looze et al. (2016) showed that the topic “use of occupational exoskeletons” has not been comprehensively researched, yet. This is reflected by the presence of mostly experimental laboratory studies with a small number of participants. Therefore, the use of a standardized quality assessment tool, e.g. the methodology checklists by the Scottish Intercollegiate Guidelines Network (2001) for different study designs, was not possible. Nevertheless, in order to assess the quality of the included laboratory experimental studies, a quality assessment tool based on the checklists by the Scottish Intercollegiate Guidelines Network (2001) and the Institute of Social and Preventive Medicine (2009) was developed. Studies measuring physical and / or psychological health aspects associated with the use of an occupational exoskeleton which were conducted at the participants’ workplace were categorized as cohort studies or when applicable as randomized controlled trials and were then qualitatively assessed using the original “Methodological checklist 2: Controlled trials”

and the “Methodological checklists 3: Cohort studies” by the Scottish Intercollegiate Guidelines Network (2001).
Concerning the assessment of publication bias as recommended in the “Methodology checklist 1: Systematic reviews and Meta-analyses” by the Scottish Intercollegiate Guidelines Network (2001), publication bias was not assessed in the included studies as it was considered that no publication bias already existed due to the innovative character of the topic and the missing comprehensive scientific research in this field.

5.2. Strengths and limitations of the systematic review

The following paragraphs give an overview on the strengths and limitations of the studies included in this systematic review as well as on the strengths and limitations of the systematic review itself.

5.2.1. Included studies

The major strength of the studies included in this systematic review is the novelty of the topic studied. As the topic of the use of occupational exoskeletons came up only recently (Yang et al., 2008) these studies build the basis towards a comprehensive analysis of the positive and negative physical and psychological health aspects resulting from the use of an exoskeleton at the workplace.
The following limitations of the included studies have to be mentioned:
First of all, most studies had a small sample size consisting predominantly of young healthy male participants not employed in the occupation the exoskeleton is intended for. Furthermore, most studies were experimental laboratory studies simulating work tasks considered to be a reflection of the real-world work tasks. Therefore, the results cannot be generalized to the whole working population, especially to women and older employees who might additionally have a medical history, e.g. musculoskeletal or cardiovascular diseases.
Another limitation is the imbalance between the measurement of physical and psychological health aspects with the physical health aspects being measured much more often. Therefore, a lack of results regarding the psychological health aspects exists.

The last limitation concerns the measurement of long-term effects of the use of occupational exoskeletons. All studies measured only short-term effects without considering potential long term side effects like, e.g. muscular atrophy.

5.2.2. Systematic review

The systematic review also has strengths and limitations regarding the study selection as well as the conduction of the review itself.

The first strength to be mentioned is its novelty. To the knowledge of the author no other systematic review exists on both the physical and the psychological health aspects associated with the use of occupational exoskeletons.

Secondly, a comprehensive search strategy was used to answer the research question by applying the PICO format for the development of inclusion and exclusion criteria. Furthermore, broad search terms as well as truncations were used to ensure that as many studies as possible were found using the search strategy. Additionally, the search in four different databases – ScienceDirect, PubMed, PsychInfo and Web of Science – can be positively rated as they cover medical as well as technical fields.

Thirdly, most studies included in the systematic review had a high quality but it has to be taken into account that the quality assessment was mainly done by applying a self-developed quality assessment tool based on the quality assessment tools by Scottish Intercollegiate Guidelines Network (2001) and Institute of Social and Preventive Medicine (2009) which at the same time is a limitation of this scientific study extended by the fact that only the author of this scientific study was responsible for the quality assessment as well as the selection of eligible studies.

In addition the following limitations have to be mentioned: Only studies in English or German language with free full-text availability were included. Therefore, a selection and publication bias might have occurred.

Furthermore, the heterogeneity of the included studies made it impossible to pool the studies' individual results and conduct a meta-analysis which would have had a higher level of evidence.

6. Methodology of the conceptual development of a survey

As described in section "1.4. Purpose of this scientific study" it was intended to develop a conceptual survey measuring the attitude of employees towards the use of occupational exoskeletons based on the results of the scientific review which had been conducted in advance. The conceptual survey was intended to be used during a study by the Institute for Occupational and Maritime Medicine (Zentralinstitut für Arbeitsmedizin und Maritime Medizin (ZfAM)) which will be conducted in a large industrial company in which predominantly tasks at head or at overhead level are performed. Therefore, the focus of the survey was set on overhead work supported by an occupational exoskeleton.

The following paragraphs deal with the methodology applied during the conceptual development of the survey including a definition of the study population, the study design of the developed survey as well as a short description of the methodological approach.

The conduction of the study including the application of the developed conceptual survey as well as the development of a standardized tool based on the results of the first test run will take place after the completion of this master thesis. Therefore, the description of these processes was not included in this scientific study.

6.1. Definition of the study population

The target group investigated by the survey consisted of male as well as female employees working in industrial settings in which tasks at head or at overhead level were regularly performed throughout the workday, e.g. riveting or drilling. The survey was intended to be applicable to healthy employees as the use of occupational exoskeletons was intended as primary prevention measure.

6.2. Study design of the survey

The previously conducted systematic literature search, as recommended by Bortz & Döring (2006) for the development of an assessment tool, on, inter alia, instruments measuring the attitude of employees towards the use of occupational exoskeletons concluded that no instrument for this purpose existed, yet. Therefore, the questionnaire approach was chosen to assess the attitude of employees towards the use of occupational exoskeletons to support work tasks at head or at overhead level as the use of a questionnaire results in precise information on topics not being researched or not being comprehensively researched, yet (Reinders, Ditton, Gräsel, & Gniewosz, 2011, p. 54).

6.3. Methodological approach of the conceptual development of a survey

The results of the previously conducted systematic review regarding the measured psychological outcomes as well as the tools, i.e. questionnaires and rating scales, used in the included studies formed the basis for the conceptual development of the questionnaire, especially for the part of the questionnaire measuring the attitude of the surveyed employees towards the use of occupational exoskeletons at the workplace.

Furthermore, parts of or complete questionnaires that had already been used in studies investigating the acceptance of employees towards occupational exoskeletons which were identified during the conduction of the systematic review were included. Already standardized and validated questionnaires were preferably included. Nevertheless, a possibly missing standardization and validation of the identified tool was no exclusion criterion for the use of the tool in the conceptual questionnaire.

In addition, eligible questions derived from a personal communication with a cooperation partner of the ZfAM were included in the conceptual survey.

Ultimately, questions were developed based on the author’s perception of the importance for the topic as well as on a brainstorming with the author’s supervisor and co-worker.

Therefore, the development of the questionnaire took place on quasi three different levels of evidence.

When a draft of the questionnaire had been developed, it was discussed with the author’s supervisor and co-worker. Improvements and changes to the questionnaire were discussed and agreed on in consensus.

7. Results of the conceptual development of a survey

The purpose of the questionnaire was, as previously described, to assess the employees’ attitude towards the use of occupational exoskeletons for work at overhead level.

As the construct acceptance - a component of a person's attitude – can, inter alia, be subdivided into the change of acceptance over a specific period of time and be explained by the theory "diffusion of innovations" (Prof. Dr. Lackes, 2018) which describes the development of the acceptance of new technologies by users, the questionnaire comprises of three different sections representing three different points in time during the implementation of occupational exoskeletons at the work-place ranging from time point zero (T0) to time point one and two (T1 and T2).

T0 represents the point in time before the surveyed employees will have worn and worked with the exoskeleton. This point of time is mainly used to gain general information about the employees and their work by assessing the employees' general health and medical history as well as the employees' work place and the working tasks regularly performed at these work places.

T1 is the point of time immediately after the first use of the exoskeleton whereby the first use will take place preferably at the employees' workplace but under study conditions or in an experimental laboratory setting. This additionally allows for the assessment of the effectiveness of the exoskeleton in the form of physical parameters as muscle activity, load on the cardiovascular system, joint kinematics and joint kinetics as was done in the studies included in the previously conducted systematic review. Therefore, it can be assumed that in later studies in which the developed questionnaire will be used also measurements assessing the before-mentioned parameters will take place. At this point of time the employees' first experiences with the assistive device will be measured.

T3 will take place approximately three to six months after the employees' first use of the exoskeleton at the workplace. Information will be gathered on the employees' attitude towards the regular use of the exoskeleton at the workplace. The information gathered at T3 can be compared to T2 allowing for the interpretation of the change of the employees' attitude.

The following three sections were developed:

- "Anamnese, Gesundheit und Arbeit"
- "Erste Erfahrungen im Umgang mit dem Exoskelett"
- "Erfahrungen im regelmäßigen Gebrauch des Exoskeletts am Arbeitsplatz".

Section 1 to 3 of the questionnaire can be found in ANNEX 7 to 9. The source the individual question is derived from is stated in brackets.

As the study using the conceptual survey is intended to take place after the conduction of this master thesis the title of the questionnaire “Einsatz von Exoskeletten am Arbeitsplatz” is fictious and functions as a placeholder until the actual name of the study will be defined.

The following paragraphs give a detailed overview over the included questionnaires, the detailed structure and content of Section 1 to 3 as well as the evaluation of the conceptual questionnaire.

7.1. Included questionnaires

The systematic review showed that 16 studies (Abdoli-E & Stevenson, 2008; Abdoli-Eramaki et al., 2006; Bosch et al., 2016; DeBusk et al., 2017; Godwin et al., 2009; Graham et al., 2009; Hein et al., 2016; Heydari et al., 2013; Huysamen et al., 2018; Imamura et al., 2011; Kadota et al., 2009; Otten et al., 2018; Rashedi et al., 2014; Spada et al., 2017, 2018; Theurel et al., 2018) could be identified that measured psychological health aspects in employees using an occupational exoskeleton. Most studies used qualitative interviews, focus groups or questionnaires that were not described in detail. Only two studies used quantitative tools - the Technology Acceptance Model 2 (TAM2) (Spada et al., 2017, 2018) and the System Usability Questionnaire (SUS) (Huysamen et al., 2018; Spada et al., 2017). Based on these results the TAM2 and the SUS were looked at closer but it was found that no German translation was available for the TAM2, so that only the German version of the SUS was included in the questionnaire to measure the attitude of employees towards the use of occupational exoskeletons at the workplace. The SUS was developed in 1986 by John Brooke and is a ten-item scale which provides the researcher with an overview over the participant’s assessment of the usability of a newly implemented technology. The participant is asked to rate ten statements on a 5-point Likert scale ranging from strongly disagree to strongly agree. The subsequently calculated score ranges from zero to 100, zero meaning no usability and 100 meaning perfect usability. The tool has already been used during several studies and has proven to be robust and reliable (Brooke, 1986). To make the numerical score more tangible and help researches to determine participants’ absolute ratings of usability, Bangor, Kortum, & Miller (2009) tested in their study whether the numerical scoring scale could be transferred to a scale consisting of adjectives. The scale is a 7-point adjective-anchored Likert scale and consists of the following degrees: worst imaginable, awful, poor, ok, good, excellent and best imaginable. The adjective-anchored Likert scale was added as the eleventh question to the original SUS scale and used during 1000 SUS surveys. Results showed that the SUS numerical scores highly correlated with the seven-point adjective-anchored Likert scale ($r = .822$, $p < .01$) (Bangor et al., 2009). Based on these results, the adjective rating scale was determined to be used for the translation of the numerical scale of the participants' SUS-scores into the absolute rating of the usability of occupational exoskeletons in this questionnaire.

Additionally, already standardized and validated questionnaires like the German versions of the WAI, the COPSOQ and the "Fragebogen zur subjektiven Einschätzung der Belastung am Arbeitsplatz (Fragebogen nach SLESINA)" were included as they measure the work ability in the form of physical as well as psychological dimensions (Hasselhorn & Freude, 2007) and physical as well as psychological stressors and strains at the workplace independent of the analyzed professional field (Freiburger Forschungsstelle für Arbeitswissenschaften GmbH, 2018; Institut für Arbeitsmedizin, Sicherheitstechnik und Ergonomie e.V. (ASER), 2018) which are factors contributing to or diminishing acceptance. Regarding the WAI the short form of the questionnaire as a whole was included as all individual questions are needed to calculate the total score representing the employee's ability to work as described in section "2.1.4.2. Work Ability Index (WAI)" and therefore cannot be used individually. In contrast to this the questions of the "Fragebogen nach SLESINA" can be used individually as they are evaluated descriptively and do not sum up to a total score. Therefore, and due to the fact that many questions of the "Fragebogen nach SLESINA" ask for the same information as the WAI, only specific questions of the "Fragebogen nach SLESINA" were included in the questionnaire. They were intended to gain additional information on the employee's work place and work tasks. As described in section "2.1.4.1. Copenhagen Psychosocial Questionnaire (COPSOQ)" the COPSOQ comprises 25 subscales which can be individually evaluated and compared to reference values of a database created by the Freiburg research centre for occupational sciences (Freiburger Forschungsstelle für Arbeitswissenschaften GmbH, 2018). For the conceptual development of this ques-

tionnaire, the subscales “Quantitative Anforderungen”, “Vorhersehbarkeit”, “Führungsqualität (mittel)”, “Unsicherheit des Arbeitsplatzes”, “Arbeitszufriedenheit (lang)”, “Copenhagen Burnout Inventory (CBI), Skala: personal burnout” and “Lebenszufriedenheit (Satisfaction with life scale, SWLS) were used as they assess factors possibly influencing the attitude of the employees’ attitude towards the use of occupational exoskeletons at the workplace.
Furthermore, the “Fragebogen über Beschwerden am Bewegungsapparat (Nordischer Fragebogen)” was included in total as it provides information on the participants’ medical history regarding musculoskeletal disorders. It was chosen for inclusion as pre-existing diseases might have an influence on the employees’ perception of the effectiveness of the exoskeleton and therefore their attitude towards the use of this assistive device at the workplace.

Apart from questions stemming from already existing questionnaires, questions developed by the author on the basis of perceived importance for the topic were included additionally, e.g. sociodemographic data or questions on shiftwork.

Additionally, questions derived from a personal communication from a cooperation partner (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV), Sankt Augustin, 2018) of the ZfAM were included in the conceptual survey by the author of this scientific work.

7.2. “Anamnese, Gesundheit und Arbeit”

The first section of the questionnaire “Anamnese, Gesundheit und Arbeit” has been structured as recommended by Reinders et al. (2011, pp. 54-58) starting with an introduction in the form of a short text informing the participants about the study, its purpose and the procedure of filling in the questionnaire. The introduction is followed by introductory questions regarding the participant’s sociodemographic data, followed by questions regarding the employee’s medical history and his or her work place and work tasks. As the first and the second section of the questionnaire will be filled in on the same day at the points in time T0 and T1, respectively, the author forewent concluding the first section of the questionnaire. The conclusion in the form of comments by the participants regarding the topic of the study as well as the questionnaire itself is included in the second section “Erste Erfahrungen im Umgang mit dem Exoskelett”.

The first section consists of 55 questions subdivided into five major categories, namely: „Angaben zur Person“, „Arbeitsplatz / berufliche Tätigkeit“, „Arbeit und Gesundheit“, „Arbeiten über Schulterniveau“ and „Vorkenntnisse und Erwartungen zu Exoskeletten“.

7.2.1. Angaben zur Person

This part comprises of questions regarding the participants’ sex, age, nationality, education, height and weight which were developed by the author as well as derived from the “Nordischer Fragebogen”. These questions were included as they allow for the comparison of the main characteristics of the participants and at the same time ensure that the study sample is not too heterogenous to draw conclusions regarding the general population, rather say workers employed in the same industrial sector.

7.2.2. Arbeitsplatz / berufliche Tätigkeit

The following part includes questions regarding the employees’ work place, work tasks, workplace conditions as well as psychological factors associated with work and were in part developed by the author and in part derived from the COPSOQ’s subscales “B1: Quantitative Anforderungen”, “B6: Vorhersehbarkeit”, “B7:Führungsqualität”, “B9: Unsicherheit des Arbeitsplatzes”, “B11: Arbeitszufriedenheit”; the “Fragebogen nach SLESINA” and the “Nordischer Fragebogen”.

Questions ten to twelve gather information on physical aspects, e.g. body postures during work, and environmental working conditions, e.g. noise, heat or dust. The assessment of physical and environmental working conditions is important to be able to quantify the physical demand at the workplace under study and at the same time assess this physical demand in relation to the support provided by the exoskeleton.

Questions 13, 14, 16 and 26 ask for the employee’s field of work; questions 15, 17, 18 and 27 provide information on the employee’s job history and questions 19 to 25 give detailed information on the employee’s working hours with special reference to shift work as the study including the developed questionnaire was intended to be conducted in a company with shift workplaces. By means of these questions a detailed job profile can be generated. This is important as different job profiles might have a different influence on the employee's rating on the effectiveness and subsequently on the attitude of the employee towards the use of an occupational exoskeleton. As the results of the systematic review have shown, the use of exoskeletons for work at head or at overhead level resulted in a reduction in shoulder muscle activity of 13.6% to 77.0% and at the same time in an increase in back muscle activity by 31.0% to 88.0%. Whereas for work tasks that require lifting of heavy loads also a reduction in shoulder muscle activity by 31.0% to 80.0% could be shown but also a reduction in back muscle activity by 11.0% to 54.0%. Therefore, the employee performing the lifting task might rate the effectiveness of the exoskeleton higher and might be more positive towards the use of exoskeletons at the workplace than an employee performing predominantly work tasks at head or at overhead level.

The last part of the section "Arbeit / berufliche Tätigkeit" gives information on the psychological working conditions (Questions 28 to 30), specifically social relationships at the workplace and job satisfaction. Job satisfaction is associated with the employee's job performance and his or her general health (Kauffeld, 2011) which might have an influence on the employee's attitude towards the use of occupational exoskeletons at the workplace. Social relationships to co-workers supporting or disliking the implementation of occupational exoskeletons might influence the employee's attitude. Therefore, the assessment of psychological working conditions plays an important role in the implementation process of these assistive devices.

7.2.3. Arbeit und Gesundheit

The third part of the questionnaire section "Anamnese, Gesundheit und Arbeit" deals with the category "Arbeit und Gesundheit" which comprises of the complete short form of the WAI, the complete "Nordischer Fragebogen" and the subscales "B13: Copenhagen Burnout Inventory (CBI), Skala: personal burnout" and "B15: Lebenszufriedenheit (Satisfaction with life scale, SWLS)" of the COPSOQ. This part is intended to assess the employee's health as well as medical history as pre-existing health conditions might have an influence on the possibilities of the use of the occupational exoskeleton and therefore on the employee's attitude towards and the willingness to use the exoskeleton at the workplace. Furthermore, the knowledge of pre-existing health conditions is important for the measurement of, e.g. muscle activity, load on the cardiovascular system, joint kinematics and joint kinetics, which presumably will also take place during the study.

7.2.4. Arbeiten über Schulterniveau

As already mentioned the study using this conceptual questionnaire will take place in an industrial company in which mainly work tasks at head or at overhead level are performed. Therefore, the part "Arbeiten über Schulterniveau" was included in the first section of the questionnaire to gain further knowledge on the employee's handedness, the performed work tasks in the company as well as of the quantity of the performance of tasks at head or at overhead level and the employee's rating on the perceived physical and psychological demands resulting from these working conditions. This part is intended to supplement the job profile derived from the questions of the part "Arbeit / berufliche Tätigkeit". The questions were in part developed by the author and in part derived from a personal communication from a cooperation partner (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV), Sankt Augustin, 2018) of the ZfAM.

7.3. "Erste Erfahrungen im Umgang mit dem Exoskelett"

The second section „Erste Erfahrungen im Umgang mit dem Exoskelett" of the questionnaire will be filled in by the employees under study at the same day as the section „Anamnese, Gesundheit und Arbeit". This section is structured as recommended by Reinders et al. (2011), starting with an introductory text informing the participant about the questionnaire's purpose, its length and the procedure of filling it in. The following parts of the questionnaire deal with the main topic, namely the employees' first experiences with the use of the exoskeleton. The questionnaire concludes with free-text fields for comments regarding the topic as well as the survey itself.

The questionnaire overall consists of 16 questions regarding the first use of the exoskeleton (questions 1 to 14) as well as the comments section (questions 15 and 16). The questions 1 to 14 can further be subdivided into questions measuring physical and psychological aspects of the use of the exoskeleton as both aspects have an influence on the employees' attitude towards the use of these assistive devices. These questions were developed by the author as well as derived from a personal communication from a cooperation partner of the ZfAM and the SUS. They will be described in the following paragraphs in detail.

7.3.1. "Erste Erfahrungen im Umgang mit dem Exoskelett" – physical aspects

Questions 1 to 11 measure physical aspects of the use of occupational exoskeletons whereby question 8 measures both physical as well as psychological aspects. As done in the study by Otten et al. (2018) which was identified during the conduction of the systematic review the questions 1 to 4:

- measure the percentage reduction in task effort due to the use of the exoskeleton,
- identify the task mostly supported by the exoskeleton
- identify the body area the most support is felt in
- measure the perceived support generated by the exoskeleton.

The results of these questions can be used for the improvement of the exoskeleton as well as the identification of the work tasks to be supported mainly at the employee's workplace.
Questions 5 to 7 gather information on the employee's dexterity, precision and working speed as perceived by the employee. These questions were included as they were identified during the conduction of the systematic review in the studies by Liu et al. (2018) and Spada et al. (2017, 2018) and these issues have an influence on the attitude towards and the willingness to use the exoskeleton at the workplace. It can be expected that an employee perceiving the exoskeleton to be hindering the work processes and at the same time diminishing the work quality will develop a negative attitude towards the exoskeleton and will sooner or later reject to wear the exoskeleton at the workplace.

Question 8 measures physical as well as psychological aspects as described above. This question asks for aspects concerning work as well as personal aspects affected by the use of exoskeletons at the workplace. This question helps to assess the different aspects affected by the use of the exoskeleton and its influence on the employee's attitude towards the use of occupational exoskeletons.

Questions 9 to 11 ask for pressure points and the intensity of the perceived pressure resulting from the use of the exoskeleton and were included as a high number of the studies included in the systematic review (Abdoli-E & Stevenson, 2008; Bosch et al., 2016; DeBusk et al., 2017; Godwin et al., 2009; Hein et al., 2016; Heydari et al., 2013; Huysamen et al., 2018; Imamura et al., 2011; Kim, Nussbaum, Mokhlespour Esfahani, Alemi, Alabdulkarim, et al., 2018; Liu et al., 2018; Rashedi et al., 2014; Spada et al., 2017) also asked for these aspects. Additionally, the perception of pressure points might have an influence on the wearing comfort of the exoskeleton which is correlated with the acceptance of the exoskeleton as Hein et al. (2016) have shown in their study.

7.3.2. “Erste Erfahrungen im Umgang mit dem Exoskelett” – psychological aspects

Questions 12 to 14 measure psychological aspects associated with the use of occupational exoskeletons.

Questions 12 and 13 assess the wearing comfort as well as factors influencing the employee’s assessment of the exoskeleton’s wearing comfort. These questions were included as the wearing comfort is correlated with the employee’s acceptance of the technology as has been shown in the study by Hein et al. (2016) which was also included in the previously conducted systematic review.

The last question (question 14) consists of the SUS measuring the usability of the exoskeleton. This scale was included as the employee’s rating of the system’s usability might have an impact on the employee’s attitude towards and his / her willingness to use the device during work. Additionally, the SUS allows the researcher to calculate a total score of the usability of the exoskeleton and translate the numerical score in an absolute score in the form of an adjective describing the usability of the exoskeleton as already described in section “7.1. Included questionnaires”.

7.4. “Erfahrungen im regelmäßigen Gebrauch des Exoskeletts am Arbeitsplatz”

The third and last section of the questionnaire „Erfahrungem im regelmäßigen Gebrauch des Exoskeletts am Arbeitsplatz“ will be filled in by the participating employee after three and six months after the initial measurements. It can be expected that this period of time is long enough for the employee to get used to the regular use of the exoskeleton as well as to be able to assess possible changes in physical as well as psychological health aspects.

The structure as well as the content of this section is nearly similar to the second section “Erste Erfahrungen im Umgang mit dem Exoskelett”. It is also structured as recommended by Reinders et al. (2011) starting with an introduction, leading over to the main topic of the study and concluding in free-text questions enabling the participant to state comments regarding the questionnaire as well as the study itself. Concerning the content of this section, six additional questions, developed by the author taking into account the WAI as well as the “Nordischer Fragebogen”, were included regarding the work shift during which the exoskeleton was mainly used, the employee’s work ability as well as his or her sport-related activities whereas the remaining 16 questions were the same as the ones in the second section. Therefore, the total third section consists of 22 questions allowing for the assessment of the change in the employee’s attitude towards the use of exoskeletons at the workplace over a period of three or six months depending on the date of the survey.

The question regarding the work shift during which the exoskeleton was mainly used (question 1) was included as the work shift might have an influence on the kind of tasks performed with the exoskeleton which might result in different experiences with the exoskeleton. Additionally, it might have an influence on the employee’s attitude towards the use of the exoskeleton. An employee wearing the exoskeleton during the night might be concerned that in case of an emergency or a disfunction of the exoskeleton less staff might be present to help.

Question 2 to 4 relating to the employee’s work ability were included to compare his or her work ability at the start of the study to his or her work ability after three or six months which also might be an indicator for the effectiveness of the exoskeleton.

The questions concerning the employee’s sports-related habits were included as they provide information on the employee’s physical activity over a specific period of time. During the conceptual development of the questionnaire it was assumed that the use of an exoskeleton at the workplace results in less physical fatigue during work which in turn results in more physical resources after work to perform physical activity.

7.5. Evaluation of the conceptual survey

With respect to the evaluation of all three sections of the questionnaire a total score reflecting the employee's attitude towards the use of an exoskeleton at the workplace cannot be computed. Rather most questions can be evaluated descriptively, e.g. the sociodemographic data or the employee's workplace. These questions are intended to provide information on the population under study in general and at the same time on its comparability.

Additionally, subscores in the form of the work ability index or scores representing the different subscales of the COPSOQ can be calculated.

The included SUS can be evaluated as described in section "7.1. Included questionnaires" resulting in a total adjective-anchored rating of the usability of the exoskeleton at the workplace.

The results of the descriptively evaluated questions as well as the different scores derived from the standardized questionnaires build the basis for the assessment of the employee's attitude towards the use of occupational exoskeletons.

8. Discussion of the conceptual development of a survey

One purpose of this study was the conceptual development of a survey that measures the attitude of employees towards the use of occupational exoskeletons for work tasks at head or at overhead level on the basis of the results of a previously conducted systematic review.

The systematic review identified the TAM2 and the SUS that measured the acceptance of employees towards the use of technology and the system usability of those new technologies but it had to be concluded that each individual questionnaire was not sufficient enough to measure the attitude of employees using occupational exoskeletons for work at head or at overhead level. Therefore, the SUS was chosen based on the criterion that a German translation was available to build the basis for the conceptual development of a survey and was complemented by the WAI, parts of the COPSOQ, the "Nordischer Fragebogen", parts of the "Fragebogen nach

SLESINA" as well as questions developed by the author in consensus with her supervisor and co-worker. Additionally, questions derived from a personal communication from the ZfAM's cooperation partner were included.

The final questionnaire consists of three sections, namely "Anamnese, Gesundheit und Arbeit", "Erste Erfahrunge im Umgang mit dem Exoskelett" and "Erfahrungen im regelmäßigen Gebrauch des Exoskeletts am Arbeitsplatz". The first section comprises 55 questions, the second section 16 questions and the third section 22 questions.

8.1. Discussion of the methodological approach of the conceptual development of a survey

To measure the attitude of employees towards the use of exoskeleton at the workplace to support work tasks at overhead level, the questionnaire approach incorporating closed questions was chosen as a survey using a questionnaire results in precise information on topics not being researched or not being comprehensively researched, yet (Reinders et al., 2011, p. 54). Additionally, the criterion objectivity, specifically the objectivity of application, objectivity of analysis and objectivity of interpretation can easily be fulfilled using a questionnaire consisting of closed questions (Bortz & Döring, 2006, p. 195). The quality criteria reliability and validity have to be tested at a later stage because of the conceptual character of the developed questionnaire and the study using the questionnaire that will start at a later time.

Items in the form of standardized and validated questionnaires as the WAI and the COPSOQ and questionnaires used during previous studies as the SUS, the "Nordischer Fragebogen" and the "Fragebogen nach SLESINA" were included. Additionally, items developed by the author in consensus with her supervisor and co-worker and items derived from a personal communication of one of the ZfAM's cooperation partners were included on the basis of the results of a systematic literature research as recommended by Bortz & Döring (2006, p. 213) to ensure that all necessary information as well as already existing measurement tools were identified and incorporated in the development process.

8.2. Strengths and limitations of the conceptual development of a survey

The questionnaire approach was chosen as it is cost-effective and at the same time provides the possibility to survey a large number of participants regarding diverse aspects of the studied topic in a relatively short time. Another strength of this study was the development of a questionnaire based on the results of a previously conducted systematic review which ensured that all relevant information as well as already existing measurement tools possibly eligible for the measurement of the attitude of employees towards the use of occupational exoskeletons for the work at head or at overhead level were identified and assessed. Furthermore, the use of closed questions had the advantage that the participants did not have to think about language or grammar while answering the questionnaire. Additionally, using closed questions results in a higher inter-subject comparability. A further strength concerning the conceptual development of a survey investigating this topic is the innovative character of the topic. To the author's knowledge no other measurement tool exists that measures the attitude of employees towards the use of occupational exoskeletons. Therefore, this concept of a survey might form the basis for the development of a standardized tool.

But this study also has some limitations that have to be mentioned. No qualitative pilot interviews were conducted in advance that might have identified further items related to the topic. The use of the free-text field at the end of the questionnaire asking for further comments by the participant concerning the use of exoskeletons at the workplace might compensate this limitation. Additionally, the use of closed questions might result in the participants not feeling represented by the predefined answers. This might result in missing or biased results. The last limitation to mention concerning methodological aspects is the missing conduction of a pilot study with the subsequent conduction of the item, factor as well as the reliability analyses but as a pilot study using the conceptual survey is already planned, it is expected that in later stages validation studies will take place. Nevertheless, it has to be taken into account that the conduction of a validation study might be problematic because of the innovative character of the studied topic and the missing nation-wide/comprehensive use of occupational exoskeletons so far. Additionally, the companies implementing exoskeletons into their work environment differ widely concerning the work tasks supported by an exoskeleton.

Apart from methodological aspects one limitation regarding the survey's content also has to be discussed. The survey does not consider the participant's previous knowledge on the use of exoskeletons at the workplace. Participants who have already gathered knowledge on occupational exoskeletons through the media or family, friends or acquaintances might have a preconceived opinion that might lead to a better or worse personal rating of the effectiveness as well as the attitude towards the use of occupational exoskeletons. The results of the survey might therefore be biased by this previous knowledge.

9. Conclusion

The systematic review showed that the use of occupational exoskeletons to support employees during diverse manual handling tasks is an innovative topic that has become of high interest in recent years. Preliminary experimental laboratory studies showed positive effects of the use of occupational exoskeletons with regard to mainly physical but also psychological health aspects. But it has to be taken into account that these studies cannot be applied to the general working population as they did not reflect actual work tasks, working environments and generally included small sample sizes consisting predominantly of young, healthy male participants. This shows the great need for future research.

The systematic review also showed that up till now only few studies have investigated the psychological health aspects associated with the use of occupational exoskeletons. In addition, it demonstrated the lack of standardized tools to measure the psychological health aspects regarding the use of occupational exoskeletons. The developed conceptual questionnaire presented in this scientific study might serve as the basis for the development of standardized and validated measurement tools to be able to make statements concerning the physical as well as the psychological health aspects associated with the use of exoskeletons at the workplace.

Apart from physical and psychological health aspects underlying factors for the implementation of occupation exoskeletons, e.g. the development of international safety standards, play a crucial role.

9.1. Recommendations for future research

The following recommendations for future research can be given:

- Conduction of studies at the actual workplace investigating the effect of the exoskeleton used during actual work tasks on the physical as well as psychological health of employees including a representative sample size consisting of male as well as female participants of all ages.
- Development of standardized tools to assess psychological health aspects regarding the use of occupational exoskeletons to be able to measure physical as well as psychological outcomes adequately.
- Assessment of short-term as well as long-term effects of the use of occupational exoskeletons to be able to derive recommendations for practice.
- Development of international safety standards to ensure the safe use of exoskeletons and set a standard for the development of occupational exoskeletons.

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Statutory Declaration

I hereby declare that I wrote this thesis without any assistance and used only the aids listed. Any material taken from other works, either as a quote or idea have been indicated under “Sources”.

Place / Date / Signature

Annex

ANNEX 1 Types of exoskeletons

Category	Subcategory	Explanation
Active	/	- Contains one or more actuators reinforcing the human's power and supporting the human joints - Actuators can be electric motors, hydraulic actuators, pneumatic muscles, other types
Passive	/	- No actuators but passive systems like springs or dampers storing energy generated by human motion and using this as required to support motion or posture
Supported body part(s)	- Lower body exoskeleton - Upper body exoskeleton - Full body exoskeleton - Single-joint exoskeleton	- Used in the form of a passive or active exoskeleton
Degree to which the exoskeleton resembles the human body	- Anthropomorphic type	- Consists of joints with rotational axes → enables the same movements as a human joint → large degree of freedom
	- Non-anthropomorphic type	- Consists of joints for specific tasks → limited movement, e.g. two-dimensional

ANNEX 2 Modified quality assessment checklist

	Yes	No	Can't say
Title and abstract			
Indicate the study's design			
Abstract provides an informative summary			
Introduction			
Background information is given			
The study addresses an appropriate and clearly focused question			
The importance of the study question is clear			
Assumptions are made explicit and objectives are stated			
Methods			
Choice of study design is justified			
Description of the setting including different time points, e.g. period of recruitment, data collection			
Outcomes are clearly defined			
The outcomes are measured appropriately / The method of assessment of the exposure is reliable			
Statistical methods are clearly defined			
Results			
Number of participants is stated			
Descriptives of the participants' characteristics			
Main results are reported			
The results provide information of relevance			
Are the results of the study directly applicable to employees using occupational exoskeletons?			
Discussion			
Key results are summarized with reference to the study objectives			
Limitations of the study are discussed			
Other information			
If funded, source of funding and the role of the funders are given			

Overall assessment of the study[2]			
	High quality (++)	Acceptable (+)	Unacceptable (0)
How well was the study conducted?			

[2] Overall score: 19 Criteria
High quality: Majority of criteria met: 12 Criteria fulfilled (60 %)
Acceptable: Most criteria met: 10 Criteria fulfilled (≥ 50 - ≤ 60 %)
Unacceptable: Most criteria not met: ≤ 9 Criteria fulfilled (< 50 %)

ANNEX 3 Data extraction: Excel® speadsheet

Title of the study	Author	Year	Study design	Investigation period	Population	Country	Aim / Objectives	Exposition / Type of exoskeleton used	Measured outcomes	Key results	Quality assessment
Wearable stooping-assist device in reducing risk of low back disorders during stooped work	Luo, Z. & Yu, Y.	2013	Experimental laboratory study	?	1 healthy male participant No further information is given	China	1) To develop a portable and wearbale stooping-assist device 2) To evaluate the effectiveness of the WSAD by measuring the muscle activity of the erector spinae, the latissimus dorsi and the rectus abdominis via electromyography	Wearable stooping-assist device (WSAD) Intended to transfer the spine forces during forward bending to the shoulders, top anterior aspect of the thorax, posterior aspect of the pelvis and the soles of the shoes	Muscle activity: Electromyography of the thoracic erector spinae, the lumbar erector spinae, the latissimus dorsi and the rectus abdominis	Upright standing position: WSAD has no sig. effects on the TES; LES; LD and RA 45° trunk flexion: WSAD sig. reduced EMG amplitude of the TES; LES and LD, but not of the RA Reductions of 30%, 34%, 18% and 4%, respectively 60° trunk flexion: WSAD sig. reduced EMG amplitude of the TES; LES and LD, but not of the RA Reductions of 35%, 40%, 22% and 6%, respectively 90° trunk flexion: WSAD sig. reduced EMG	Acceptable (+) 10 / 19 criteria fulfilled

ANNEX 4 Study characteristics: Experimental laboratory studies

Reference + Country	**Task to be supported**	**Participants**	**Measured Outcomes**	**Statistical methods**
Abdoli-Eramaki et al. (2006) Canada	Lifting and lowering	N = 9 Sex: male Age M[3]: 23.9y (4.58)[4] Height M: 1.84m (0.067) Weight M: 83kg (10.99)	Muscle activity / strength Joint kinetics	Repeated measures ANOVA Bonferroni post hoc test $p < .05$
Abdoli-Eramaki et al. (2008) Canada	Static holding (in a stooped position / bent forward)	N = 9 Sex: male Age M: 23.9y (4.58) Height M: 1.84m (0.067) Weight M: 83kg (10.99)	Muscle activity / strength Joint kinetics Joint kinematics Comfort / Discomfort Usefulness	Repeated measures ANOVA $p < .05$
Bosch et al. (2016) Netherlands	Static holding (in a stooped position / bent forward)	N = 18 Sex: 9 males, 9 females Age M: 25y (8) Height M: 1.76m (0.1) Weight M: 71kg (12.4)	Muscle activity / strength Joint kinematics Comfort / Discomfort	ANOVA Paired t-test $p < .05$
Butler et al. (2016) USA	Work at head or at overhead level	N = 4 Sex: male Age: ?	Others: Performance quality	?

[3] M = Mean
[4] Numbers in brackets represent the standard deviation

		Height: ? Weight: ?		
DeBusk et al. (2017) USA	Lifting and lowering	N = 6 Sex: 4 males, 2 females Age M: 21.7y (2.3) Height M: 177cm (3.4) Weight M: 77.1kg (17.9)	Joint Kinematics Comfort / Discomfort Fatigue Usability	Repeated measures ANOVA Paired t-test $p < .05$
Frost et al. (2009) Canada	Static holding (in a stooped position / bent forward)	N = 13 Sex: male Age M: 20.9y (3.8) Height M: 1.84m (0.05) Weight M: 82kg (9.2)	Muscle activity / strength Joint kinematics	Repeated measures ANOVA $p < .05$
Godwin et al. (2009) Canada	Static holding (in a stooped position / bent forward)	N = 12 Sex: female Age M: 30y (13) Height M: 170cm (1.79) Weight M: 69.3kg (6.6)	Muscle activity / strength Comfort / Discomfort Fatigue	Repeated measures ANOVA $p < .05$
Gregorczyk et al. (2010) USA	Walking while carrying a load	N = 9 Sex: male Age M: 20.8y (3.8) Height M: 1.77m (0.05)	Metabolic load / Load on the cardiovascular system Joint kinetics	Repeated measures ANOVA

		Weight M: 75.2kg (9.8)	Joint kinematics	
Heydari et al. (2013) ?	Static holding (in a stooped position / bent forward)	N = 15 Sex: male Age M: 24y (2.5) Height M: 179cm (5.9) Weight M: 70kg (7.9)	Muscle activity Comfort / Discomfort Usefulness Joint kinetics	Repeated measures ANOVA Bonferroni post hoc test p < .05
Huysamen et al. (2017) Italy	Lifting and lowering	N = 12 Sex: male Age M: 27y (2) Height M: 179.4cm (0.656) Weight M: 75.38kg (10.1)	Muscle activity / strength Comfort / Discomfort Usability	Wilcoxon-signed-rank-test p < .05
Kadota et al. (2009) Japan	Lifting and lowering	N = ? Age: ? Height: ? Weight: ?	Muscle activity / strength Usefulness	?
Kim et al. (2018a) USA	Work at head or at overhead level	N = 12 Sex: 6 males, 6 females Males: Age M: 32.5y (11.8) Height M: 172.3m (4.6)	Muscle activity / strength Comfort / Discomfort Others: Performance time / quality)	Repeated measures ANOVA Tukey's HSD test Paired t-test p < .05

		Weight M: 72.6kg (9.1) Females: Age M: 22.5y (1.5) Height M: 169.7m (5.2) Weight M: 63.8kg (6.2)		
Kim et al. (2018b) USA	Work at head or at over-head level	N = 27 Sex: 14 males, 13 fe-males Age: ?[5] Height: ? Weight: ?	Joint kinetics Joint kinemat-ics Others: Pos-tural control, Slip and trip risk	Repeated measures ANOVA Tukey's HSD test p < .05
Kobayashi et al. (2007) Japan	Static holding (in a stooped position / bent forward)	N = 5 Sex: male Age: ? Height: ? Weight: ?	Muscle activ-ity / strength	Paired t-test p < .05
Lotz et al. (2009) Canada	Static holding (in a stooped position / bent forward)	N = 10 Sex: male Age M: 22 (3.8) Height M: 1.83m (0.03) Weight M: 85.3kg (8.7)	Metabolic cost / Load on the cardiovascular system Muscle activ-ity / strength Comfort / Dis-comfort Fatigue	Repeated measures ANOVA Paired t-test p < .05

[5] Average age, height and weight reported only for subgroups as not all participants took place in every measurement

Luo et al. (2013) China	Static holding (in a stooped position / bent forward)	N = 1 Sex: male Age: ? Height: ? Weight: ?	Muscle activity / strength	?
Muramatsu et al. (2013) Japan	Lifting and lowering	N = 3 Sex: male Age: ? Height: ? Weight: ?	Muscle activity / strength	?
Naito et al. (2006) Japan	Work at head or at overhead level	N = 3 Sex: ? Age: ? Height: ? Weight: ?	Joint kinematics Muscle activity / strength	?
Nakamura et al. (2017) Japan	Lifting and lowering	N = 3 Age: ? Height: ? Weight: ?	Muscle activity / strength	?
Otten et al. (2018) Germany	Work at head or at overhead level	N = 8 Sex: ? Age: ? Height: ? Weight: ?	Muscle activity / strength Comfort / Discomfort Fatigue	Friedman test Bonferroni post hoc test $p < .05$
Panizzolo et al. (2016) USA	Walking while load carrying	N = 7 Sex: ? Age M: 29.3y (6.2) Height M: 1.80m (0.07) Weight M: 77.9kg (8.3)	Metabolic cost / Load on the cardiovascular system Muscle activity / strength Joint kinematics	Repeated measures ANOVA Bonferroni post hoc test $p < .05$

Rashedi et al. (2014) USA	Work at head or at over-head level	N = 12 Sex: male Age M: 27y (2.6) Height M: 176cm (4.6) Weight M: 76kg (4.6)	Muscle activ-ity / strength Comfort / Dis-comfort Usability	Repeated measures ANOVA Tukey's HSD test $p < .05$
Seungnam et al. (2016) ?	Walking while load carrying	N = 5 Sex: male Age R[6]: 30-38y Height R: 173-180cm Weight R: 65-80kg	Muscle activ-ity / strength	?
Spada et al. (2017) Italy	Work at head or at over-head level	N = 31 Sex: male Age M: 51.5y (4.7) Height M: 174.9cm (.3) Weight M: 81.6kg (9.1)	Acceptance Usability Comfort / Dis-comfort Others: En-durance time	Mean Stand-ard deviation
Spada et al. (2018) Italy	Work at head or at over-head level	N = 31 Sex: male Age M: 51.5y (4.7) Height M: 174.9cm (.3) Weight M: 81.6kg (9.1)	Acceptance Comfort / Dis-comfort Others: Dex-terity, Endur-ance time	Mean Standard de-viation

[6] R = Range

Sylla et al. (2014) France	Work at head or at overhead level	N = 8 Sex: ? Age M: 24y (7) Height M: 1.70m (0.05) Weight M: 63kg (11)	Joint kinetics Others: Performance time	Mean Standard deviation
Takamitsu et al. (2009) Japan	Lifting and lowering	N = 5 Sex: male Age: ? Height: ? Weight: ?	Muscle activity / strength	?
Theurel et al. (2018) France	Lifting and lowering	N = 8 Sex: 4 males, 4 females Males: Age M: 33y (3) Height M: 179cm (3) Weight M: 78kg (3) Females: Age M: 31y (2) Height M: 166cm (4) Weight M: 62kg (10)	Metabolic cost / Load on the cardiovascular system Muscle activity / strength Joint kinematics Comfort / Discomfort Fatigue Others: Postutal control	Mean Standard deviation
Ulrey et al. (2013) USA	Lifting and lowering	N = 18	Muscle activity / strength	ANOVA Tukey's HSD test

		Sex: 11 males, 7 females Age M: 26y (8.9) Height M: 172.5cm (13.44) Weight M: 714.6N (94.12)	Joint kinematics	$p < .05$
Wehner et al. (2009) USA	Lifting and lowering	N = 6 Sex: 5 males, 1 female Age M: 27.7y (6) Height M: 1.75m (0.06) Weight M: 67.7kg (7.2)	Muscle activity / strength Joint kinetics	?
Weston et al. (2017) USA	Work at head or at overhead level	N = 12 Sex: male Age M: 25.3y (6) Height M: 184.4cm (5.2) Weight M: 81.9kg (9.8)	Muscle activity / strength Joint kinetics	Repeated measures ANOVA Tukey's HSD test $p < .05$
Whitfield et al. (2014) Canada	Static holding (in a stooped position / bent forward)	N = 15 Sex: male Age M: 22.1y (2.6)	Metabolic cost / Load on the cardiovascular system	Paired t-test $p < .05$

		Height M: 1.81m (0.08) Weight M: 81.6kg (9.2)	Muscle activity / strength Joint kinematics	

ANNEX 5 Study characteristics: Cohort studies

Reference + Country	**Taks to be supported**	**Participants**	**Measured Outcomes**	**Statistical methods**
Gillette et al. (2017) USA	Work at head or at over-head level	N = 6 Sex: 4 males, 2 females Age M: 41y (7) Height M: 1.71m (0.08) Weight M: 76kg (11)	Muscle activ-ity / strength	Paired t-test $p < .05$
Graham et al. (2009) Canada	Static holding (in a stooped position / bent forward)	N = 10 Sex: 8 males, 2 females Age: ? Height M: 177.3cm (6.8) Weight M: 78.1kg (8.8)	Muscle activ-ity / strength Joint kinemat-ics Acceptance	Repeated measures ANOVA $p < .05$
Liu et al. (2018) USA	Work at head or at over-head level	N = 23 Sex: ? Age: ? Height: ? Weight: ?	Comfort / Dis-comfort Fatigue Usability Others: Dex-terity	Mean Standard de-viation
Hein et al. (2016) Germany	Patient lifting / transfer	N = 8 Sex: female Age R: 25-59 Height: ? Weight: ?	Acceptance Comfort / Dis-comfort	Mean Standard de-viation Confidence intervals
Imamura et al. (2011)	Patient lifting / transfer	N = 20	Comfort / Dis-comfort	?

Japan		Sex: 1 male, 19 females Age R: 20-69 Height: ? Weight: ?	Fatigue	

ANNEX 6 Study characteristics: Systematic Review

Reference + Country	**Number of included studies**	**Search terms**	**Inclusion Criteria**	**Exclusion Criteria**	**Statistical methods**
De Looze et al. (2016) ?	40	Exoskeleton Wearable device Assistive device Wearable robot	Exoskeletons with an occupational purpose	Exoskeletons without an occupational purpose Exoskeletons covering the hand or wrist	No statistical methods conducted due to the heterogeneity of the included studies

ANNEX 7 Questionnaire: „Exoskelette am Arbeitsplatz – Anamnese, Gesundheit und Arbeit“

„Einsatz von Exoskeletten am Arbeitsplatz“

- Abschnitt 1: vor Beginn der Messungen auszufüllen -

Liebe Teilnehmerin, lieber Teilnehmer,

vielen Dank für Ihr Interesse an unserer Befragung. In unserem Projekt „Einsatz von Exoskeletten am Arbeitsplatz“ geht es um die Ent- und Belastungen sowie Beanspruchungen bei Exoskelett-unterstützten Tätigkeiten und die Einschätzung der Nutzung von Exoskeletten am Arbeitsplatz durch die Arbeitnehmer/innen.

Bei der Beantwortung der Fragen gibt es keine richtigen oder falschen Antworten. Wir interessieren uns für Ihre individuellen Angaben bzw. Einschätzungen.

Dieser Fragebogen gliedert sich in zwei eigenständige Teile. Der erste Teil gibt Auskunft über Ihren Arbeitsplatz, Ihre Arbeitstätigkeiten sowie Ihre Gesundheit und Vorerkrankungen und wird zu Beginn der Untersuchung ausgefüllt.

Nach Abschluss der Messungen an Ihrem Arbeitsplatz erhalten Sie den zweiten Abschnitt des Fragebogens, in dem Ihre ersten subjektiven Erfahrungen mit dem Exoskelett erfragt werden.

Die Bearbeitung des gesamten Fragebogens wird ca. 20-25 Minuten in Anspruch nehmen. Wir bitten Sie, sich ausreichend Zeit zu nehmen.

Die erhobenen Daten werden ausschließlich für wissenschaftliche Zwecke verwendet, die Auswertung erfolgt pseudonymisiert und unter Einhaltung der gesetzlichen Vorschriften des Datenschutzes (EU-DSGVO).

Sollten Sie versehentlich eine auf Sie nicht zutreffende Antwort angekreuzt haben, schwärzen Sie den Kreis bitte komplett und kreuzen anschließend die richtige, auf Sie zutreffende Antwort an.

Vielen Dank für Ihre Teilnahme!

Angaben zur Person

1. **Welches Geschlecht haben Sie? (Autor)**

   - O Männlich
   - O Weiblich
   - O Anderes (bitte angeben):_______________

2. **Wie alt sind Sie? Bitte geben Sie den Tag, den Monat und das Jahr Ihrer Geburt an. (Autor)**

Bitte nutze Sie das folgende Format: TT.MM.JJJJ

[   ]

3. **Bitte geben Sie Ihre Größe in <u>cm</u> an. (Autor)**

[   ] cm

4. **Bitte geben Sie Ihr aktuelles Gewicht in <u>kg</u> an. (Autor)**

[   ] kg

5. **Welche Nationalität haben Sie? (Nordischer Fragebogen)**

   - O Deutsch
   - O Andere (bitte angeben):_______________

6. **Welchen höchsten Schulabschluss haben Sie? (Autor)**

   - O Fachabitur / Abitur
   - O Fachhochschulreife
   - O Realschulabschluss, Mittlere Reife
   - O Abschluss – Polytechnische Oberschule
   - O Haupt- / Volksschulabschluss
   - O Kein Abschluss
   - O Anderes (bitte angeben):_______________

7. Welchen höchsten beruflichen Ausbildungsabschluss haben Sie? (Autor)

- O Meister/in, Techniker/in oder gleichwertiger Fachschulabschluss
- O Berufsqualifizierender Abschluss an einer Berufsfachschule, Kollegschule
- O Berufsausbildung im dualen System
- O Abgeschlossene Lehre
- O Ich befinde mich noch in der beruflichen Ausbildung / Lehre.
- O Ich habe keine Lehre / berufliche Ausbildung absolviert.

8. Haben Sie eine Hochschule / Fachhochschule besucht? (Autor)

- O Universität (wissenschaftliche Hochschule)
- O Fachhochschule (auch Ingenieurschule, Hochschule (FH) für angewandte Wissenschaften)
- O Berufsakademie
- O Ich habe keine Fach- / Hochschule besucht. → bitte bei Frage 10 weiter!

9. Falls Sie eine Fach- / Hochschule besucht haben: Wie ist die Bezeichnung Ihres höchsten Abschlusses? (Autor)

- O Bachelor
- O Master
- O Diplom, Staatsexamen, Magister oder vergleichbarer Abschluss
- O Promotion
- O Andere (bitte angeben):_______________

Arbeitsplatz / berufliche Tätigkeit

Die folgenden Fragen geben Auskunft über Ihren Arbeitsplatz sowie Ihre berufliche Tätigkeit. Bitte beantworten Sie alle Fragen, auch wenn Ihnen diese als nicht vollkommen zutreffend bezüglich Ihres Arbeitsplatzes / Ihrer beruflichen Tätigkeit erscheinen.

10. Wie würden Sie Ihre Tätigkeit bei der Arbeit beschreiben? (Autor; Fragebogen nach SLESINA)

	Immer	Oft	Manch mal	Selten	Nie
Bei der Arbeit sitze ich überwiegend.	O	O	O	O	O
Bei der Arbeit stehe ich überwiegend.	O	O	O	O	O
Bei der Arbeit gehe ich überwiegend.	O	O	O	O	O
Ich führe körperlich schwere Arbeit aus (Heben/Halten/Tragen/Ziehen/Schieb-en schwerer Lasten).	O	O	O	O	O
Ich arbeite überwiegend in einer ungünstigen Arbeitshaltung bzw. in Zwangshaltungen (kniend, gebeugt, Ausführung von Überkopf-Arbeiten)	O	O	O	O	O
Bei der Arbeit führe ich einförmige Arbeiten aus.	O	O	O	O	O
Meine Arbeit bedarf Handgeschicklichkeit.	O	O	O	O	O
Ich kann mir meine Arbeit selbständig einteilen.	O	O	O	O	O
Meine Arbeit ist taktgebunden.	O	O	O	O	O
Bei meiner Arbeit herrscht Termin- bzw. Zeitdruck.	O	O	O	O	O

11. Wie oft sind Sie den folgenden Einflüssen bei Ihrer Arbeit ausgesetzt? (Autor; Fragebogen nach SLESINA)

	Immer	Oft	Manch-mal	Selten	Nie fast nie
Lärm	O	O	O	O	O
Wärme / Hitze	O	O	O	O	O
Nässe / Feuchtigkeit	O	O	O	O	O
Ungünstige Beleuchtung	O	O	O	O	O
Zugluft	O	O	O	O	O
Chemische Stoffe	O	O	O	O	O
Staub / Schmutz	O	O	O	O	O
Gerüche / Dämpfe	O	O	O	O	O
Vibrationen / Schwingungen	O	O	O	O	O

12. Die folgenden Fragen betreffen die Anforderungen bei Ihrer Arbeit. (COPSOQ, B1: Quantitative Anforderungen)

	Immer	Oft	Manch mal	Selten	Nie fast nie
Müssen Sie sehr schnell arbeiten?	O	O	O	O	O
Ist Ihre Arbeit ungleich verteilt, so dass sie sich auftürmt?	O	O	O	O	O
Wie oft kommt es vor, dass Sie nicht genug Zeit haben, alle Ihre Aufgaben zu erledigen?	O	O	O	O	O
Müssen Sie Überstunden machen?	O	O	O	O	O

13. In welchem Bereich sind Sie derzeit vor allem tätig? (Autor)

- O Strukturmontage
- O Ausrüstungsmontage
- O Ausstattungsmontage

14. Zu welcher Berufsgruppe gehören Sie? (Autor)

- O Strukturmechaniker
- O Ausrüstungsmechaniker
- O Ausstattungsmechaniker

15. Bitte geben Sie die Anzahl Ihrer Berufsjahre in <u>Jahren</u> an. (Autor)

[ ] Jahre

16. Bitte geben Sie Ihre derzeitige Tätigkeit an. (Autor)

- O Nieten der Längsnähte P‘10
- O Bohren der Längsnaht Unterschale
- O Spantkopplungen Oberschale
- O Andere (bitte angeben):_______________

17. Wie lange üben Sie diese Tätigkeit bereits bei Ihrem derzeitigen Arbeitgeber aus? Bitte geben Sie die Anzahl der <u>Jahre</u> an. (Nordischer Fragebogen)

[ ] Jahre

18. Wie lange haben Sie diese Tätigkeit <u>insgesamt</u>, also auch bei anderen Arbeitgebern, ausgeübt? Bitte geben Sie die Anzahl der <u>Jahre</u> an. (Nordischer Fragebogen)

[ ] Jahre

19. Wie arbeiten Sie zurzeit? Bitte geben Sie die Anzahl der Stunden pro Woche an (Regelarbeitszeit + Überstunden) (Nordischer Fragebogen)

- O Vollzeit (h/Woche):_______________
- O Teilzeit (h/Woche):_______________

20. In welcher Schicht arbeiten Sie? Wenn nötig, kreuzen Sie alle auf Sie zutreffenden Antworten an. (Autor)

- O Frühschicht (Schichtbeginn: 6:00 Uhr)
- O Spätschicht (Schichtbeginn: 13:00 Uhr)
- O Nachtschicht (Schichtbeginn: 21:00 Uhr, bzw. sonntags: 22:00 Uhr)

21. Bitte geben Sie an, wie häufig Sie in der letzten Woche (Sonntag bis Freitag) in der jeweiligen Schicht gearbeitet haben. (Autor)

- O Frühschicht:_______________ -mal.
- O Spätschicht:_______________ -mal.
- O Nachtschicht:_______________ -mal.

22. Sie arbeiten in einem selbst organisierten Team (SOT) und können Ihre Schichten in Absprache mit Ihren Kollegen selbst festlegen. Bitte kreuzen Sie in dem nachfolgenden Kalender an, in welchen Schichten Sie in den letzten 14 Tagen gearbeitet haben. (Autor)

Wochentag	Frühschicht (Beginn: 6:00 Uhr)	Spätschicht (Beginn: 13:00 Uhr)	Nachtschicht (Beginn: 21:00 bzw. 22:00 Uhr)	Ich habe nicht gearbeitet.
Sonntag	O	O	O	O
Montag	O	O	O	O
Dienstag	O	O	O	O
Mittwoch	O	O	O	O
Donnerstag	O	O	O	O
Freitag	O	O	O	O
Samstag	O	O	O	O
Sonntag	O	O	O	O
Montag	O	O	O	O
Dienstag	O	O	O	O
Mittwoch	O	O	O	O
Donnerstag	O	O	O	O
Freitag	O	O	O	O
Samstag	O	O	O	O

23. Aus welchen Gründen haben Sie bzw. hat sich Ihr Team für diese Einteilung der Schichten entschieden? (Autor)

____

____

____

____

____

____

____

24. Behalten Sie bzw. Ihr SOT dauerhaft die gleiche Schichteinteilung bei? (Autor)

O Ja → weiter bei Frage 26

O Nein

25. Bitte beschreiben Sie kurz, inwieweit die Schichteinteilung innerhalb Ihres SOTs variiert. Ist die Einteilung der Schichten an ein bestimmtes Team-internes System gekoppelt oder teilen Sie Ihre Schichten nach Ihren persönlichen Präferenzen ein? (Autor)

____

____

____

____

____

____

____

26. Welche Stellung nehmen Sie innerhalb Ihres derzeitigen SOTs (selbst organisiertes Team) ein? (Autor)

- O Sprecher des SOTs
- O Teammitglied des SOTs

27. Welche anderen Tätigkeiten haben Sie in Ihrem Leben bisher ausgeübt (Lehre, Studium, Wehrdienst, Berufstätigkeiten usw.)? Wie lange dauerten diese? Falls der vorgesehene Platz in der Tabelle nicht ausreicht, verwenden Sie bitte die Rückseite dieses Bogens. (Nordischer Fragebogen)

Zeitraum von – bis	Bezeichnung der Tätigkeit

28. Nun einige Fragen zu Regelungen und Abläufen bei Ihrer Arbeit (COPSOQ, B6: Vorhersehbarkeit; B9: Unsicherheit des Arbeitsplatzes)

	In sehr hohem Maße	In hohem Maße	Zum Teil	In geringem Maße	In sehr geringem Maße
Werden Sie rechtzeitig im Voraus über Veränderungen an Ihrem Arbeitsplatz informiert, z.B. über wichtige Entscheidungen, Veränderungen oder Pläne für die Zukunft? (z.B. den Einsatz des Exoskeletts)	○	○	○	○	○
Erhalten Sie alle Informationen, die Sie brauchen, um Ihre Arbeit gut zu erledigen? (z.B. die Arbeit mit dem Exoskelett)	○	○	○	○	○
Machen Sie sich Sorgen, dass Sie arbeitslos werden?	○	○	○	○	○
Machen Sie sich Sorgen, dass neue Technologien Sie überflüssig machen?	○	○	○	○	○
Machen Sie sich Sorgen, dass es schwierig für Sie wäre, eine neue Arbeit zu finden, wenn Sie arbeitslos würden?	○	○	○	○	○
Machen Sie sich Sorgen, dass man Sie gegen Ihren Willen auf eine andere Arbeitsstelle versetzen könnte?	○	○	○	○	○

29. Bitte schätzen Sie ein, in welchem Maß Ihr unmittelbarer Vorgesetzter…. (Bitte je eine Angabe pro Zeile. Wenn Sie keinen Vorgesetzten haben, kreuzen Sie bitte die Spalte ganz rechts an.) (COPSOQ, B7: Führungsqualität)

	In sehr hohem Maße	In hohem Maße	Zum Teil	In geringem Maße	In sehr geringem Maße	Habe keinen Vorgesetzten
… für gute Entwicklungsmöglichkeiten der einzelnen Mitarbeiter sorgt.	○	○	○	○	○	○
… der Arbeitszufriedenheit einen hohen Stellenwert beimisst.	○	○	○	○	○	○
… die Arbeit gut plant.	○	○	○	○	○	○
… Konflikte gut löst.	○	○	○	○	○	○

30. Wenn Sie Ihre Arbeitssituation insgesamt betrachten, wie zufrieden sind Sie mit… (Bitte je eine Angabe pro Zeile) (COPSOQ, B11: Arbeitszufriedenheit)

	Sehr zufrieden	Zufrieden	Un-zufrieden	Sehr unzufrieden
… Ihren Berufsperspektiven?	○	○	○	○
… den Leuten, mit denen Sie arbeiten?	○	○	○	○
… den körperlichen Arbeitsbedingungen?	○	○	○	○
… der Art und Weise, wie Ihre Abteilung geführt wird?	○	○	○	○
… der Art und Weise, wie Ihre Fähigkeiten genutzt werden?	○	○	○	○
… den Herausforderungen und Fertigkeiten, die Ihre Arbeit beinhaltet?	○	○	○	○
… Ihrer Arbeit insgesamt, unter Berücksichtigung aller Umstände?	○	○	○	○

Arbeit und Gesundheit

Nun möchten wir Ihnen einige Fragen stellen, die Auskunft über Ihre Gesundheit und Arbeitsfähigkeit geben. Hierzu verwenden wir standardisierte Fragebögen, deren Fragen nicht verändert werden sollten. Bitte beantworten Sie die folgenden Fragen auch dann, wenn Sie Ihnen als nicht vollkommen zutreffend bezogen auf Ihre Tätigkeit / Ihren Arbeitsplatz erscheinen.

31. Rauchen Sie? (Nordischer Fragebogen)

- O Ja
- O Nein

32. Treiben Sie regelmäßig Sport? Wenn ja, welchen? (Nordischer Fragebogen)

- O Ja, Sportart:_______________
- O Nein

33. Wie viele Stunden betreiben Sie den zuvor angegebenen Sport pro Woche? (Nordischer Fragebogen)

[   ] Stunden / Woche

34. Aktueller Gesundheitszustand (WAI)

Wenn Sie den besten denkbaren Gesundheitszustand mit 10 Punkten bewerten und den schlechtesten denkbaren mit 0 Punkten: Wie viele Punkte vergeben Sie dann für Ihren derzeitigen Gesundheitszustand? Bitte kreuzen Sie die entsprechende Zahl an.

	0	1	2	3	4	5	6	7	8	9	10	
Schlechtester denkbarer Gesundheits-zustand	O	O	O	O	O	O	O	O	O	O	O	Bester denkbarer Gesundheits-zustand

35. Sind Sie bei der Arbeit… (WAI)

- O …vorwiegend geistig tätig?
- O …vorwiegend körperlich tätig?
- O …etwa gleichermaßen geistig und körperlich tätig?

36. Derzeitige Arbeitsfähigkeit im Vergleich zu der besten, je erreichten Arbeitsfähigkeit (WAI)

Wenn Sie Ihre beste, je erreichte Arbeitsfähigkeit mit 10 Punkten bewerten: Wie viele Punkte würden Sie dann für Ihre derzeitige Arbeitsfähigkeit geben? (0 bedeutet, dass Sie derzeit arbeitsunfähig sind)

	0	1	2	3	4	5	6	7	8	9	10	
Völlig arbeitsunfähig	O	O	O	O	O	O	O	O	O	O	O	Derzeit die beste Arbeitsfähigkeit

37. Arbeitsfähigkeit in Bezug auf die Arbeitsanforderungen (WAI)

	Sehr gut	Eher gut	Mittel-mäßig	Eher schlecht	Sehr schlecht
Wie schätzen Sie Ihre derzeitige Arbeitsfähigkeit in Bezug auf die körperlichen Arbeitsanforderungen ein?	O	O	O	O	O
Wie schätzen Sie Ihre derzeitige Arbeitsfähigkeit in Bezug auf die psychischen Arbeitsanforderungen ein?	O	O	O	O	O

38. Anzahl der aktuellen ärztlich diagnostizierten Krankheiten (WAI)

Kreuzen Sie in der folgenden Liste Ihre Krankheiten oder Verletzungen an. Geben Sie bitte auch an, ob ein Arzt diese Krankheiten diagnostiziert oder behandelt hat.

	Eigene Diagnose	Diagnose vom Arzt	Liegt nicht vor
Unfallverletzungen (z.B. des Rückens, der Glieder, Verbrennungen)	O	O	O
Erkrankungen des Muskel-Skelett-Systems von Rücken, Gliedern oder anderen Körperteilen (z.B. wiederholte Schmerzen in den Gelenken oder Muskeln, Ischias, Rheuma, Wirbelsäulenerkrankungen)	O	O	O
Herz-Kreislauf-Erkrankungen (z.B. Bluthochdruck, Herzkrankheiten, Herzinfarkt)	O	O	O
Atemwegserkrankungen (z.B. wiederholte Atemwegsinfektionen, chronische Bronchitis, Bronchialasthma)	O	O	O

Psychische Beeinträchtigungen (z.B. Depressionen, Angstzustände, chronische Schlaflosigkeit, psychovegetatives Erschöpfungssyndrom)	O	O	O
Neurologische und sensorische Erkrankungen (z.B. Tinnitus, Augenerkrankungen, Migräne, Epilepsie)	O	O	O
Erkrankungen des Verdauungssystems (z.B. der Gallenblase, Leber, Bauchspeicheldrüse, Darm)	O	O	O
Erkrankungen im Urogenitaltrakt (z.B. Harnwegsinfektionen, gynäkologische Erkrankungen)	O	O	O
Hautkrankheiten (z.B. allergischer Hautausschlag, Ekzem)	O	O	O
Tumore / Krebs	O	O	O
Hormon- / Stoffwechselerkrankungen (z.B. Diabetes, Fettleibigkeit, Schilddrüsenprobleme)	O	O	O
Krankheiten des Blutes (z.B. Anämie)	O	O	O
Angeborene Leiden /Erkrankungen	O	O	O
Andere Leiden oder Krankheiten (bitte angeben):_______________	O	O	O
Andere Leiden oder Krankheiten (bitte angeben):_______________	O	O	O
Andere Leiden oder Krankheiten (bitte angeben):_______________	O	O	O

39. Geschätzte Beeinträchtigung der Arbeitsleistung durch die Krankheit (WAI)

Behindert Sie derzeit eine Erkrankung oder Verletzung bei der Arbeit? Falls nötig, kreuzen Sie bitte mehr als eine Antwort-Möglichkeit an.

- O Keine Beeinträchtigung / Ich habe keine Erkrankungen
- O Ich kann meine Arbeit ausführen, habe aber Beschwerden
- O Ich bin manchmal gezwungen, langsamer zu arbeiten oder meine Arbeitsmethode zu ändern
- O Ich bin oft gezwungen, langsamer zu arbeiten oder meine Arbeitsmethode zu ändern
- O Wegen meiner Krankheit bin ich nur in der Lage, Teilzeitarbeit zu verrichten
- O Meiner Meinung nach bin ich völlig arbeitsunfähig

40. Gab es bisher einen Arbeitsplatzwechsel aus gesundheitlichen Gründen? (Nordischer Fragebogen)

- O Nein
- O Ja

41. Krankenstand im vergangenen Jahr (12 Monate) (WAI)

Wie viele ganze Tage blieben Sie auf Grund eines gesundheitlichen Problems (Krankheit, Gesundheitsvorsorge oder Untersuchung) im letzten Jahr (12 Monate) der Arbeit fern?

- O Überhaupt keinen
- O Höchstens 9 Tage
- O 10-24 Tage
- O 25-99 Tage
- O 100-365 Tage

42. Einschätzung der eigenen Arbeitsfähigkeit in zwei Jahren (WAI)

Glauben Sie, dass Sie, ausgehend von Ihrem jetzigen Gesundheitszustand, Ihre derzeitige Arbeit auch in den nächsten zwei Jahren ausüben können?

Unwahrscheinlich	Nicht sicher	Ziemlich sicher
O	O	O

43. Psychische Leistungsreserven (WAI)

Haben Sie in letzter Zeit Ihre täglichen Aufgaben mit Freude erledigt?

Häufig	Eher häufig	Manchmal	Eher selten	Niemals
O	O	O	O	O

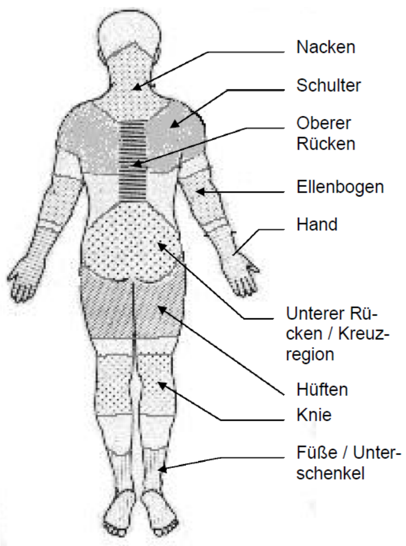
Waren Sie in letzter Zeit rege und aktiv?

Immer	Eher häufig	Manchmal	Eher selten	Niemals
O	O	O	O	O

Waren Sie in letzter Zeit zuversichtlich, was die Zukunft betrifft?

Ständig	Eher häufig	Manchmal	Eher selten	Niemals
O	O	O	O	O

Beschwerden am Stütz- und Bewegungsapparat (Nordischer Fragebogen)



In den nächsten Fragen sollen Sie angeben, ob Sie in einem bestimmten Körperbereich schon einmal Schmerzen oder Beschwerden hatten. Die Körperregionen, die in den nächsten Fragen abgefragt werden, wurden in der links abgebildeten kleinen Figur eingezeichnet.

Die Grenzen zwischen den Körperregionen können auch ineinander übergehen. Sie entscheiden bitte selbst, welche Körperbereiche betroffen sind.

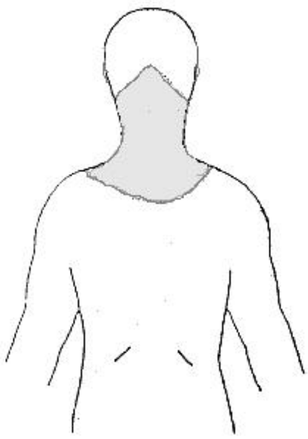
Unter Schmerzen sind sowohl punktförmige und eng begrenzte Schmerzen bis hin zu nicht genau lokalisierbaren und nicht genau beschreibbaren Schmerzempfindungen in den angegebenen Körperregionen zu verstehen.

Bitte berücksichtigen Sie auch Schmerzen, wenn Sie in einen anderen Körperbereich (z.B. Ischias-Schmerz) ausstrahlen! In Zweifelsfällen versuchen Sie bitte die am meisten zutreffende Antwort zu geben!

44. Allgemeine Angaben zu Beschwerden im Muskel-Skelett-System (Nordischer Fragebogen)

	Diese beiden Spalten sind nur zu beantworten, wenn die Fragen in der 1. Spalte (links) mit „Ja“ beantwortet wurden.	
Hatten Sie während der letzten 12 Monate zu irgendeiner Zeit Beschwerden oder Schmerzen in folgenden Körperregionen?	Waren Sie wegen der Beschwerden in den letzten 12 Monaten irgendwann nicht in der Lage, ihre normale Arbeit zu tun (beruflich, zu Hause oder Freizeitbeschäftigungen?)	Hatten Sie während der letzten 7 Tage irgendwann Beschwerden?
Nackenregion ○ Nein ○ Ja	○ Nein ○ Ja	○ Nein ○ Ja
Ellenbogenregion ○ Nein ○ Ja, rechts ○ Ja, links ○ Ja, beidseits	○ Nein ○ Ja	○ Nein ○ Ja
Handgelenke / Hände ○ Nein ○ Ja, rechts ○ Ja, links ○ Ja, beidseits	○ Nein ○ Ja	○ Nein ○ Ja
Oberer Rücken / Brustwirbelsäule ○ Nein ○ Ja	○ Nein ○ Ja	○ Nein ○ Ja
Unterer Rücken (Kreuz) ○ Nein ○ Ja	○ Nein ○ Ja	○ Nein ○ Ja
Ein oder beide Hüften / Oberschenkel ○ Nein ○ Ja	○ Nein ○ Ja	○ Nein ○ Ja
Ein oder beide Knie ○ Nein ○ Ja	○ Nein ○ Ja	○ Nein ○ Ja
Ein oder beide Knöchel / Füße ○ Nein ○ Ja	○ Nein ○ Ja	○ Nein ○ Ja

45. Fragen zu Beschwerden in der Nackenregion / Halswirbelsäule (Nordischer Fragebogen)

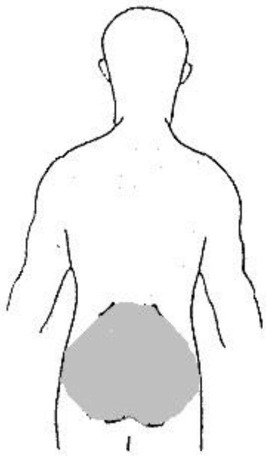


Unter Nackenbeschwerden werden Stechen, Schmerzen und Missempfindungen in dem schraffierten Gebiet zusammengefasst.
Bitte konzentrieren Sie sich ausschließlich auf diesen Bereich, berücksichtigen Sie nicht Beschwerden, die in benachbarten Körperteilen auftreten. Solche Beschwerden, z.B. im Schultergebiet, werden gesondert erfragt.
Bitte beantworten Sie die Fragen durch Einsetzen von Kreuzen in die Antwortfelder – ein Kreuz für jede Frage. In Zweifelsfällen versuchen Sie, die am meisten zutreffende Antwort zu geben.

Hatten Sie irgendwann in Ihrem Leben Beschwerden im Nacken bzw. im Bereich der Halswirbelsäule (schraffierter Bereich)?	O Nein	O Ja
Falls sie keine Beschwerden hatten, fahren Sie bitte mit der Beantwortung der Frage 46 fort!		
Waren Sie jemals wegen dieser Nackenbeschwerden im Krankenhaus	O Nein	O Ja
Mussten Sie aufgrund von Nackenbeschwerden irgendwann einmal Ihre Arbeitsstelle oder berufliche Tätigkeit wechseln	O Nein	O Ja
Bitte geben Sie an, wie lange Sie in den letzten 12 Monaten insgesamt	O Niemals (bzw. 0 Tage) O 1-7 Tage O 8-30 Tage	

Nackenbeschwerden verspürt haben! Falls Sie mehrfach krank waren, addieren Sie bitte alle Zeitabschnitte	O Mehr als 30 Tage, jedoch nicht täglich O Jeden Tag	
Falls Sie im letzten Jahr keine Nackenschmerzen hatten, fahren Sie bitte bei Frage 46 fort.		
Haben die Nackenschmerzen Sie veranlasst, Ihre Aktivitäten während der letzten 12 Monate einzuschränken?	Arbeitsaktivitäten O Nein Freizeitaktivitäten O Nein	Arbeitsaktivitäten O Ja Freizeitaktivitäten O Ja
Über welche Zeitspanne haben die Nackenbeschwerden Ihre normale Arbeit (beruflich oder Hausarbeit) während der letzten 12 Monate behindert?	O So stark waren die Beschwerden nicht O 1-7 Tage O 8-30 Tage O Mehr als 30 Tage	
Haben Sie wegen Ihrer Nackenbeschwerden einen Arzt, einen Chiropraktiker oder Physiotherapeuten o.ä. aufgesucht?	O Nein	O Ja
Hatten Sie in der letzten Woche bzw. in den letzten 7 Tagen irgendwann Beschwerden in der Nackenregion?	O Nein	O Ja

46. Fragen zu Beschwerden im unteren Rücken (Kreuz / Lendenwirbelsäule) (Nordischer Fragebogen)



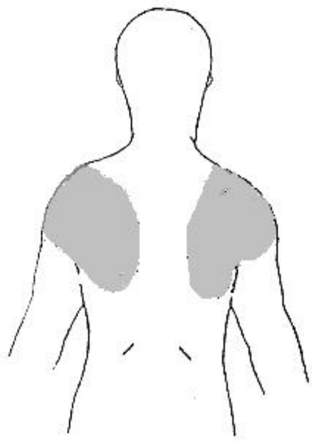
Die folgenden Fragen beziehen sich auf den schraffierten Körperteil. Bei Beschwerden im Kreuz sind z.B. gemeint: lokaler punktförmiger Schmerz, nicht genau lokalisierbare Schmerzen oder nicht genau zu beschreibende Schmerzempfindungen in dem schraffierten Gebiet, unabhängig davon, ob der Schmerz in ein Bein oder beide Beine ausstrahlt (Ischias)

Bitte beantworten Sie die Fragen durch Einsetzen von Kreuzen in die Antwortfelder – <u>ein</u> Kreuz für jede Frage. In Zweifelsfällen versuchen Sie, die am besten zutreffende Antwort zu geben.

Hatten Sie irgendwann in Ihrem Leben Beschwerden im Kreuz bzw. im Bereich der Lendenwirbelsäule (schraffierter Bereich)?	O Nein	O Ja
Falls sie <u>keine</u> Beschwerden hatten, fahren Sie bitte mit der Beantwortung der Frage 47 fort!		
Waren Sie jemals wegen dieser Rückenbeschwerden im Krankenhaus	O Nein	O Ja
Mussten Sie aufgrund von Rückenbeschwerden irgendwann einmal Ihre Arbeitsstelle oder berufliche Tätigkeit wechseln	O Nein	O Ja
Bitte geben Sie an, wie lange Sie in den letzten 12 Monaten	O Niemals (bzw. 0 Tage) O 1-7 Tage	

insgesamt Rückenbeschwerden verspürt haben! Falls Sie mehrfach krank waren, addieren Sie bitte alle Zeitabschnitte	O 8-30 Tage O Mehr als 30 Tage, jedoch nicht täglich O Jeden Tag	
Falls Sie im letzten Jahr keine Rückenschmerzen hatten, fahren Sie bitte bei Frage 47 fort.		
Haben die Rückenschmerzen Sie veranlasst, Ihre Aktivitäten während der letzten 12 Monate einzuschränken?	Arbeitsaktivitäten O Nein Freizeitaktivitäten O Nein	Arbeitsaktivitäten O Ja Freizeitaktivitäten O Ja
Über welche Zeitspanne haben die Rückenbeschwerden Ihre normale Arbeit (beruflich oder Hausarbeit) während der letzten 12 Monate behindert?	O So stark waren die Beschwerden nicht O 1-7 Tage O 8-30 Tage O Mehr als 30 Tage	
Haben Sie wegen Ihrer Rückenbeschwerden einen Arzt, einen Chiropraktiker oder Physiotherapeuten o.ä. aufgesucht?	O Nein	O Ja
Hatten Sie in der letzten Woche bzw. in den letzten 7 Tagen irgendwann Rückenbeschwerden ?	O Nein	O Ja

47. Fragen zu Beschwerden in den Schultern (Nordischer Fragebogen)



Unter Schulterbeschwerden werden Stechen, Schmerzen und Missempfindungen in den oben gekennzeichneten Bereichen zusammengefasst.
Bitte konzentrieren Sie sich hier ausschließlich auf diesen Bereich, berücksichtigen Sie nicht Beschwerden, die in benachbarten Bereichen (z.B. Nacken) auftreten.
Bitte beantworten Sie die Fragen durch Einsetzen von Kreuzen in die Antwortfelder – <u>ein</u> Kreuz für jede Frage. In Zweifelsfällen versuchen Sie, die am besten zutreffende Antwort zu geben.

Hatten Sie irgendwann in Ihrem Leben Beschwerden in den Schultern (schraffierter Bereich)?	O Nein	O Ja
Falls sie <u>keine</u> Beschwerden hatten, fahren Sie bitte mit der Beantwortung der Frage 48 fort!		
Waren Sie jemals wegen Ihrer Schulterbeschwerden im Krankenhaus?	O Nein	O Ja
Wurden Sie im Bereich der Schultern während eines Unfalles verletzt?	O Nein	O Ja, links O Ja, rechts O Ja, beidseitig
Mussten Sie aufgrund von Schulterbeschwerden irgendwann einmal Ihre Arbeitsstelle oder berufliche Tätigkeit wechseln?	O Nein	O Ja

Bitte geben Sie an, wie lange Sie in den letzten 12 Monaten insgesamt Schulterbeschwerden verspürt haben! Falls Sie mehrfach krank waren, addieren Sie bitte alle Zeitabschnitte	O Niemals (bzw. 0 Tage) O 1-7 Tage O 8-30 Tage O Mehr als 30 Tage, jedoch nicht täglich O Jeden Tag	
Falls Sie im letzten Jahr <u>keine</u> Schulterschmerzen hatten, fahren Sie bitte bei Frage 48 fort.		
Haben die Schulterbeschwerden Sie veranlasst, Ihre Aktivitäten während der letzten 12 Monate einzuschränken?	Arbeitsaktivitäten O Nein Freizeitaktivitäten O Nein	Arbeitsaktivitäten O Ja Freizeitaktivitäten O Ja
Über welche Zeitspanne haben die Schulterbeschwerden Ihre normale Arbeit (beruflich oder Hausarbeit) während der letzten 12 Monate behindert?	O So stark waren die Beschwerden nicht O 1-7 Tage O 8-30 Tage O Mehr als 30 Tage	
Haben Sie wegen Ihrer Schulterbeschwerden einen Arzt, einen Chiropraktiker oder Physiotherapeuten o.ä. aufgesucht?	O Nein	O Ja
Hatten Sie in der letzten Woche bzw. in den letzten 7 Tagen irgendwann Schulterbeschwerden ?	O Nein	O Ja

48. Energie und psychisches Wohlbefinden: Bitte geben Sie für jede der folgenden Aussagen an, inwieweit sie für Sie zutrifft. (Bitte je eine Angabe pro Zeile). (COPSOQ, B13: Copenhagen Burnout Inventory (CBI))

	Immer	Oft	Manch-mal	Selten	Nie / fast nie
Wie häufig fühlen Sie sich müde?	○	○	○	○	○
Wie häufig sind Sie körperlich erschöpft?	○	○	○	○	○
Wie häufig sind Sie emotional erschöpft?	○	○	○	○	○
Wie häufig denken Sie: „Ich kann nicht mehr?“	○	○	○	○	○
Wie häufig fühlen Sie sich ausgelaugt?	○	○	○	○	○
Wie häufig fühlen Sie sich schwach und krankheitsanfällig?	○	○	○	○	○

49. Nachfolgend finden Sie fünf Aussagen, denen Sie zustimmen oder nicht zustimmen können. Die Aussagen beziehen sich auf Ihr Leben insgesamt, also nicht nur auf die Arbeit. (Bitte je eine Angabe pro Zeile). (COPSOQ, B15: Lebenszufriedenheit (Satisfaction with life scale (SWLS))

	Stimme genau zu	Stimme zu	Stimme eher zu	Weder noch	Stimme eher nicht zu	Stimme nicht zu	Stimme überhaupt nicht zu
In den meisten Bereichen entspricht mein Leben meinen Idealvorstellungen	○	○	○	○	○	○	○
Meine Lebensbedingungen sind ausgezeichnet.	○	○	○	○	○	○	○
Ich bin mit meinem Leben zufrieden.	○	○	○	○	○	○	○
Bisher habe ich die wesentlichen	○	○	○	○	○	○	○

Dinge erreicht, die ich mir für mein Leben wünsche.							
Wenn ich mein Leben noch einmal leben könnte, würde ich kaum etwas ändern	○	○	○	○	○	○	○

Arbeiten über Schulterniveau

Die nun folgenden Fragen beziehen sich hauptsächlich auf Tätigkeiten, die auf bzw. über Schulterniveau durchgeführt werden, z.B. Bohrung und Vernietung der Längsnähte.

50. Händigkeit: Welche Hand benutzen Sie bevorzugt für die Ausführung von anspruchsvollen und feinmotorischen Arbeiten, z.B. Schreiben, Zähne putzen, etc.? (Autor)

- O Links
- O Rechts

51. Wie viele Stunden müssen Sie durchschnittlich pro Woche mit den Händen über den Schultern arbeiten? (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))

- O 0 bis unter 5 Stunden
- O 5 bis unter 10 Stunden
- O 10 bis unter 15 Stunden
- O 15 bis unter 20 Stunden
- O 20 bis unter 25 Stunden
- O 25 bis unter 30 Stunden
- O 30 bis unter 35 Stunden
- O Mehr als 35 Stunden

52. Wie belastend (körperlich anstrengend) empfinden Sie das Arbeiten über Schulterniveau in Ihrem Beruf auf einer Skala von 0 bis 10? (0 bedeutet gar nicht belastend, 10 bedeutet sehr belastend) (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))

	0	1	2	3	4	5	6	7	8	9	10	
Gar nicht belastend	O	O	O	O	O	O	O	O	O	O	O	Sehr belastend

53. Welche Haltung /Tätigkeit bei der Arbeit über Schulterniveau empfinden Sie als am meisten belastend für Ihren Körper? (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))

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54. Markieren Sie anhand der nachfolgenden Skizze und Bezeichnungen die Stelle, an der Sie die höchste Belastung empfinden. (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))

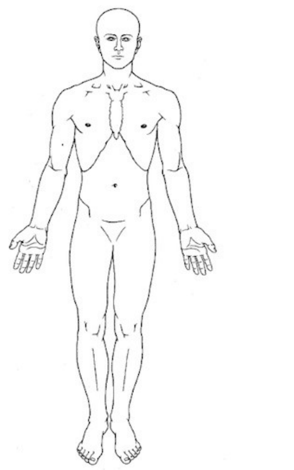
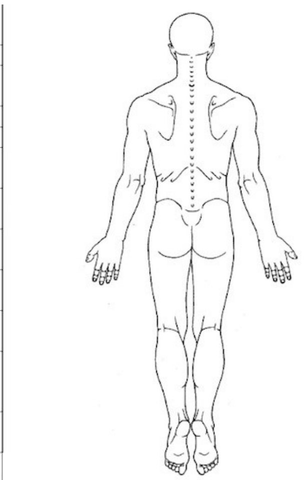


Abb. 3.1: Übersicht des ganzen Körpers: Vorderseite und linke Seite

Kopf	vorne	hinten
Nacken		
Schulter	vorne	hinten
Brustkorb		
Oberer Rücken		
Ellbogen	innen	aussen
Hand	beugeseitig	streckseitig
Unterer Rücken	links	rechts
Kreuz/Gesäß	links	rechts
Hüften	links	rechts
Knie	vorne links	hinten rechts
Unterschenkel	vorne	hinten
Füße	innen	außen



...: Rückseite und rechte Seite

55. Sind Sie bei der Arbeit über Schulterniveau auf weitere Hilfsmittel wie z.B. eine Trittleiter angewiesen? (Autor)

- O Ja
- O Nein
- O Wenn ja, welche/s?:_______________

Vielen Dank für Ihre Teilnahme!

ANNEX 8 Questionnaire: „Exoskelette am Arbeitsplatz – Erste Erfahrungen im Umgang mit dem Exoskelett“

„Einsatz von Exoskeletten am Arbeitsplatz

- Abschnitt 2: am Untersuchungstag nach Durchführung der Messungen auszufüllen -

Liebe Teilnehmerin, lieber Teilnehmer,

bitte füllen Sie nun den zweiten Abschnitt des Fragebogens zu Ihren ersten subjektiven Erfahrungen mit dem Exoskelett aus und geben diesen anschließend bei dem Studienpersonal vor Ort ab.

Bei der Beantwortung der Fragen gibt es keine richtigen oder falschen Antworten. Wir interessieren uns für Ihre individuellen Angaben bzw. Einschätzungen.

Die Bearbeitung des Fragebogens wird ca. 10-15 Minuten in Anspruch nehmen. Wir bitten Sie, sich ausreichend Zeit zu nehmen.

Die erhobenen Daten werden ausschließlich für wissenschaftliche Zwecke verwendet, die Auswertung erfolgt pseudonymisiert und unter Einhaltung der gesetzlichen Vorschriften des Datenschutzes (EU-DSGVO).

Sollten Sie versehentlich eine auf Sie nicht zutreffende Antwort angekreuzt haben, schwärzen Sie den Kreis bitte komplett und kreuzen anschließend die richtige, auf Sie zutreffende Antwort an.

Vielen Dank für Ihre Teilnahme!

Arbeiten mit dem Exoskelett

Der nun folgende Abschnitt beinhaltet Fragen zur Durchführung Ihrer Arbeit mit der Unterstützung eines Exoskeletts.

1. **Wie stark spüren Sie die Entlastung durch das Exoskelett? (0% bedeutet überhaupt nicht, 50% bedeutet sehr stark) (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))**

	0%	10%	20%	30%	40%	50%
Entlastung in Prozent	O	O	O	O	O	O

2. **Bei welcher Tätigkeit / Situation spüren Sie die meiste Unterstützung durch das Exoskelett? (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))**

O Anheben von Lasten über Schulterniveau

O Absetzen von Lasten über Schulterniveau

O Halten von Lasten über Schulterniveau

O Halten der Arme ohne zusätzliche Last

3. **Wo empfinden Sie die Entlastung durch das Exoskelett bei der zuvor angegebenen Tätigkeit / Situation am meisten? (Persönliche Mitteilung: Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))**

Bitte markieren Sie anhand der nachfolgenden Skizze und Bezeichnungen die Stelle, an der Sie die höchste Entlastung empfinden.

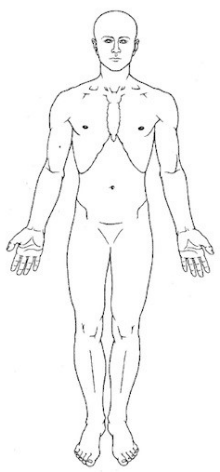
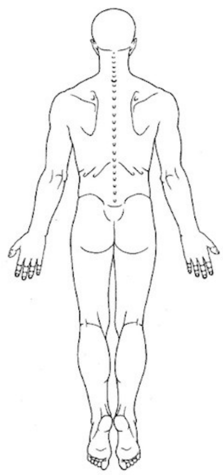


Abb. 3.1: Übersicht des ganzen Körpers: Vorderseite und linke Seite

Kopf	
vorne	hinten
Nacken	
Schulter	
vorne	hinten
Brustkorb	
Oberer Rücken	
Ellbogen	
innen	aussen
Hand	
beugeseitig	streckseitig
Unterer Rücken	
links	rechts
Kreuz/Gesäß	
links	rechts
Hüften	
links	rechts
Knie	
vorne	hinten
links	rechts
Unterschenkel	
vorne	hinten
Füße	
innen	außen



...: Rückseite und rechte Seite

4. **Bitte beurteilen Sie anhand der folgenden Skala die Unterstützungsleistung des Exoskeletts. (Autor)**

(Zu gering bedeutet in diesem Kontext, dass Sie sich eine größere Unterstützung durch das Exoskelett wünschen. Zu stark wiederum bedeutet, dass die unterstützende Kraft des Exoskeletts zu groß war, sodass sie z.B. beim Zurückführen der Arme neben den Körper sehr viel Kraft aufbringen mussten bzw. in der Durchführung Ihrer Tätigkeit behindert wurden.)

Zu gering	Angemessen	Zu stark
○	○	○

5. **Verändert das Exoskelett Ihre Geschicklichkeit? (Autor)**

Hiermit ist gemeint, ob das Exoskelett Einfluss darauf nimmt, wie Sie sich bewegen, Ihre Tätigkeit ausführen und im und mit Ihrem Arbeitsumfeld agieren.

○ Ja, positiv
○ Ja, negativ
○ Nein

6. **Verändert das Exoskelett Ihre Präzision bei der Durchführung erforderlicher Arbeitsschritte? (Autor)**

Hiermit ist gemeint, ob das Exoskelett Einfluss darauf hat, ob Sie Handgriffe, die für die Ausführung Ihrer Arbeit erforderlich sind, weiterhin ebenso genau ausführen können wie ohne das Exoskelett.

○ Ja, positiv
○ Ja, negativ
○ Nein

7. **Bitte bewerten Sie ihre aktuelle Arbeitsgeschwindigkeit mit dem Exoskelett im Vergleich zu Ihrer Arbeitsgeschwindigkeit ohne das Exoskelett. (Autor)**

Langsamer	Gleichbleibend	Schneller
○	○	○

8. Beeinflusst das Tragen des Exoskelettes einen oder mehrere der folgenden Punkte während der Messuntersuchung? (Autor)

Kreuzen Sie bitte alle auf Sie zutreffenden Antwortmöglichkeiten an.

- O Lichtverhältnisse am Arbeitsplatz durch z.B. Schattenwurf
- O Vermehrter Platzbedarf
- O Zeit, die benötigt wird, um z.B. in die Pause zu gehen, das WC zu benutzen etc.
- O Zeit, die benötigt wird, um mit der Arbeit zu beginnen (Anlegen des Exoskeletts)
- O Nutzung weiterer Hilfsmittel, z.B. einer Trittleiter
- O Anderes (bitte angeben):_______________

9. Übt das Exoskelett während des Tragens einen unangenehmen Druck aus? (Autor)

- O Ja
- O Nein

10. Bitte umkreisen Sie in der nachfolgenden Skizze die Körperregionen, in denen das Exoskelett einen unangenehmen Druck ausübt. (Autor)

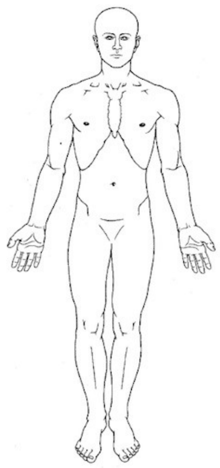
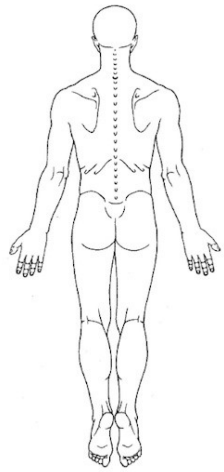


Abb. 3.1: Übersicht des ganzen Körpers: Vorderseite und linke Seite

Kopf	
vorne	hinten
Nacken	
Schulter	
vorne	hinten
Brustkorb	
Oberer Rücken	
Ellbogen	
innen	aussen
Hand	
beugeseitig	streckseitig
Unterer Rücken	
links	rechts
Kreuz/Gesäß	
links	rechts
Hüften	
links	rechts
Knie	
vorne	hinten
links	rechts
Unterschenkel	
vorne	hinten
Füße	
innen	außen



...: Rückseite und rechte Seite

11. Wie stark ist der stärkste Druck, der durch das Exoskelett auf Ihren Körper / auf eine Körperregion ausgeübt wird? (Autor)

	0	1	2	3	4	5	6	7	8	9	10	
Gar kein Druck	O	O	O	O	O	O	O	O	O	O	O	Sehr starker, unangenehmer Druck

12. Bitte bewerten Sie den Tragekomfort des Exoskelettes auf einer Skala von 0 bis 10. (0 bedeutet kein Tragekomfort, 10 bedeutet höchster Tragekomfort) (Autor)

	0	1	2	3	4	5	6	7	8	9	10	
Gar kein Trage-komfort	O	O	O	O	O	O	O	O	O	O	O	Höchster Tragekomfort

13. Welche der folgenden Punkte haben Einfluss auf Ihre Bewertung des Tragekomforts des Exoskelettes gehabt? (Autor)

Kreuzen Sie bitte alle auf Sie zutreffenden Antwortmöglichkeiten an.

	Positiv ☺		**Negativ ☹**
O	Passform	O	Passform
O	Bewegungsfreiheit	O	Bewegungseinschränkungen
O	Material (ausreichend atmungsaktiv)	O	Material (Schweißbildung)
O	Druckpunkte	O	Druckpunkte
O	Handhabbarkeit beim An- und Ausziehen	O	Handhabbarkeit beim An- und Ausziehen
O	Gewicht des Exoskeletts	O	Gewicht des Exoskeletts
O	Anderes (bitte angeben):_______________	O	Anderes (bitte angeben):_______________

14. Die folgenden Fragen betreffen die Gebrauchstauglichkeit des Exoskeletts (SUS)

	Stimme gar nicht zu	Stimme eher nicht zu	Weder noch	Stimme eher zu	Stimme voll zu
Ich kann mir gut vorstellen, das Exoskelett regelmäßig zu nutzen.	O	O	O	O	O
Ich empfinde das Exoskelett als unnötig komplex.	O	O	O	O	O

Ich empfinde das Exoskelett als einfach zu nutzen.	○	○	○	○	○
Ich denke, dass ich technischen Support brauchen würde, um das Exoskelett zu nutzen.	○	○	○	○	○
Ich finde, dass mich das Exoskelett in meinen Aufgaben am Arbeitsplatz unterstützt.	○	○	○	○	○
Ich finde, dass mich das Exoskelett in der für meine Tätigkeit nötigen Bewegungsfreiheit einschränkt.	○	○	○	○	○
Ich kann mir vorstellen, dass die meisten Leute das Exoskelett schnell zu beherrschen lernen.	○	○	○	○	○
Ich empfinde die Bedienung als sehr umständlich.	○	○	○	○	○
Ich habe mich mit der Nutzung des Exoskeletts sehr sicher gefühlt.	○	○	○	○	○
Ich musste eine Menge Dinge lernen, bevor ich mit dem Exoskelett arbeiten konnte.	○	○	○	○	○

Freitext-Anmerkungen

Im letzten Abschnitt des Fragebogens erhalten Sie die Möglichkeit, Vorschläge, Wünsche, Erwartungen an die Benutzung des Exoskeletts an Ihrem Arbeitsplatz sowie Anmerkungen zu diesem Fragebogen und der Befragung im Allgemeinen zu äußern. Bitte bedenken Sie jedoch, dass Ihre Aussagen wörtlich in die Auswertung und in die Ergebnispräsentation übernommen werden. Formulieren Sie Ihre Aussagen aus diesem Grund bitte so, dass keine Rückschlüsse auf Sie selbst oder andere Personen möglich sind.

15. Haben Sie Vorschläge / Wünsche / Erwartungen an den Gebrauch eines Exoskeletts an Ihrem Arbeitsplatz? (Autor)

16. Haben Sie weitere Anmerkungen zum Fragebogen oder zur Befragung allgemein? (Autor)

Vielen Dank für Ihre Teilnahme!

ANNEX 9 Questionnaire: „Exoskelette am Arbeitsplatz - Erfahrungen im regelmäßigen Gebrauch des Exoskeletts am Arbeitsplatz“

„Einsatz von Exoskeletten am Arbeitsplatz“

- Abschnitt 3: nach 3 bzw. 6 Monaten auszufüllen -

Liebe Teilnehmerin, lieber Teilnehmer,

vielen Dank für Ihr weiterhin bestehendes Interesse an unserer Befragung. In unserem Projekt „Einsatz von Exoskeletten am Arbeitsplatz“ möchten wir die Entwicklung der Ent- und Belastungen sowie Beanspruchungen bei Exoskelett-unterstützten Tätigkeiten und die Einschätzung der Nutzung von Exoskeletten am Arbeitsplatz durch Arbeitnehmer/innen im zeitlichen Verlauf von 3 bzw. 6 Monaten untersuchen. Aus diesem Grund senden wir Ihnen den nachfolgenden Fragebogen zu.

Bei der Beantwortung der Fragen gibt es keine richtigen oder falschen Antworten. Wir interessieren uns für Ihre individuellen Angaben bzw. Einschätzungen.

Die Bearbeitung des Fragebogens wird ca. 15-20 Minuten in Anspruch nehmen. Wir bitten Sie, sich ausreichend Zeit zu nehmen.

Die erhobenen Daten werden ausschließlich für wissenschaftliche Zwecke verwendet, die Auswertung erfolgt pseudonymisiert und unter Einhaltung der gesetzlichen Vorschriften des Datenschutzes (EU-DSGVO).

Sollten Sie versehentlich eine auf Sie nicht zutreffende Antwort angekreuzt haben, schwärzen Sie den Kreis bitte komplett und kreuzen anschließend die richtige, auf Sie zutreffende Antwort an.

Vielen Dank für Ihre Teilnahme!

Arbeiten mit dem Exoskelett

Der nun folgende Abschnitt beinhaltet Fragen zur Durchführung Ihrer Arbeit mit der Unterstützung eines Exoskeletts. Bitte berücksichtigen Sie hierbei die Arbeit mit dem Exoskelett in den letzten drei bzw. sechs Monaten.

1. In welcher Schicht tragen Sie das Exoskelett überwiegend? (Autor)

- O Frühschicht (Schichtbeginn: 6.00 Uhr)
- O Spätschicht (Schichtbeginn: 13:00 Uhr)
- O Nachtschicht (Schichtbeginn: 21:00 Uhr, bzw. sonntags: 22:00 Uhr)

2. Derzeitige Arbeitsfähigkeit im Vergleich zu der besten je erreichten Arbeitsfähigkeit (Autor)

Wenn Sie Ihre beste je erreichte Arbeitsfähigkeit mit 10 Punkten bewerten: Wie viele Punkte würden Sie dann für Ihre derzeitige Arbeitsfähigkeit, <u>unterstützt durch das Exoskelett,</u> geben? (0 bedeutet, dass Sie derzeit arbeitsunfähig sind)

	0	1	2	3	4	5	6	7	8	9	10	
Völlig arbeitsunfähig	O	O	O	O	O	O	O	O	O	O	O	Derzeit die beste Arbeitsfähigkeit

3. Arbeitsfähigkeit in Bezug auf die Arbeitsanforderungen (WAI)

	Sehr gut	Eher gut	Mittel-mäßig	Eher schlecht	Sehr schlecht
Wie schätzen Sie Ihre derzeitige Arbeitsfähigkeit in Bezug auf die körperlichen Arbeitsanforderungen ein?	O	O	O	O	O
Wie schätzen Sie Ihre derzeitige Arbeitsfähigkeit in Bezug auf die psychischen Arbeitsanforderungen ein?	O	O	O	O	O

4. Einschätzung der eigenen Arbeitsfähigkeit in zehn Jahren (Autor)

Glauben Sie, dass Sie, ausgehend von Ihrem jetzigen Gesundheitszustand, Ihre derzeitige Arbeit unterstützt durch das Exoskelett auch in den nächsten zehn Jahren ausüben können?

Unwahrscheinlich	Nicht sicher	Ziemlich sicher
O	O	O

5. Wie stark spüren Sie die Entlastung durch das Exoskelett? (0% bedeutet überhaupt nicht, 50% bedeutet sehr stark) (Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))

	0%	10%	20%	30%	40%	50%
Entlastung in Prozent	O	O	O	O	O	O

6. Bei welcher Tätigkeit / Situation spüren Sie die meiste Unterstützung durch das Exoskelett? (Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))

- O Anheben von Lasten über Schulterniveau
- O Absetzen von Lasten über Schulterniveau
- O Halten von Lasten über Schulterniveau
- O Halten der Arme ohne zusätzliche Last

7. Wo empfinden Sie die Entlastung durch das Exoskelett bei der zuvor angegebenen Tätigkeit / Situation am meisten? (Institut für Arbeitsschutz (IFA) der Deutschen Gesetzlichen Unfallversicherung (DGUV))

Bitte markieren Sie anhand der nachfolgenden Skizze und Bezeichnungen die Stelle, an der sie die höchste Entlastung empfinden.

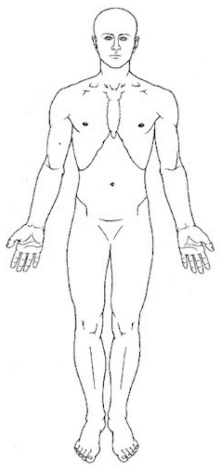
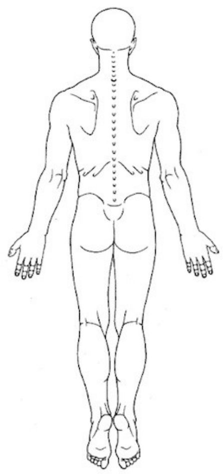


Abb. 3.1: Übersicht des ganzen Körpers: Vorderseite und linke Seite

Kopf	
vorne	hinten
Nacken	
Schulter	
vorne	hinten
Brustkorb	
Oberer Rücken	
Ellbogen	
innen	aussen
Hand	
beugeseitig	streckseitig
Unterer Rücken	
links	rechts
Kreuz/Gesäß	
links	rechts
Hüften	
links	rechts
Knie	
vorne	hinten
links	rechts
Unterschenkel	
vorne	hinten
Füße	
innen	außen



...rs: Rückseite und rechte Seite

8. Bitte beurteilen Sie anhand der folgenden Skala die Unterstützungsleistung des Exoskeletts. (Autor)

(Zu gering bedeutet in diesem Kontext, dass Sie sich eine größere Unterstützung durch das Exoskelett wünschen. Zu stark wiederum bedeutet, dass die unterstützende Kraft des Exoskeletts zu groß war, sodass sie z.B. beim Zurückführen der Arme neben den Körper sehr viel Kraft aufbringen mussten bzw. in der Durchführung Ihrer Tätigkeit behindert wurden.)

Zu gering	Angemessen	Zu stark
○	○	○

9. Verändert das Exoskelett Ihre Geschicklichkeit? (Autor)

Hiermit ist gemeint, ob das Exoskelett Einfluss darauf nimmt, wie Sie sich bewegen, Ihre Tätigkeit ausführen und im und mit Ihrem Arbeitsumfeld agieren.

- ○ Ja, positiv
- ○ Ja, negativ
- ○ Nein

10. Verändert das Exoskelett Ihre Präzision bei der Durchführung erforderlicher Arbeitsschritte? (Autor)

Hiermit ist gemeint, ob das Exoskelett Einfluss darauf hat, ob Sie Handgriffe, die für die Ausführung Ihrer Arbeit erforderlich sind, weiterhin ebenso genau ausführen können wie ohne das Exoskelett.

- ○ Ja, positiv
- ○ Ja, negativ
- ○ Nein

11. Bitte bewerten Sie ihre aktuelle Arbeitsgeschwindigkeit mit dem Exoskelett im Vergleich zu Ihrer Arbeitsgeschwindigkeit ohne das Exoskelett. (Autor)

Langsamer	Gleichbleibend	Schneller
○	○	○

12. Beeinflusst das Tragen des Exoskelettes einen oder mehrere der folgenden Punkte? (Autor)

Kreuzen Sie bitte alle auf Sie zutreffenden Antwortmöglichkeiten an.

- ○ Lichtverhältnisse am Arbeitsplatz durch z.B. Schattenwurf
- ○ Vermehrter Platzbedarf
- ○ Zeit, die benötigt wird, um z.B. in die Pause zu gehen, das WC zu benutzen etc.
- ○ Zeit, die benötigt wird, um mit der Arbeit zu beginnen
- ○ Wohlbefinden, wenn das Exoskelett mit Kollegen geteilt wird
- ○ Nutzung weiterer Hilfsmittel, z.B. einer Trittleiter
- ○ Anderes (bitte angeben):_______________

13. Übt das Exoskelett während des Tragens einen unangenehmen Druck aus? (Autor)

- ○ Ja
- ○ Nein

14. Bitte umkreisen Sie in der nachfolgenden Skizze die Körperregionen, in denen das Exoskelett einen unangenehmen Druck ausübt. (Autor)

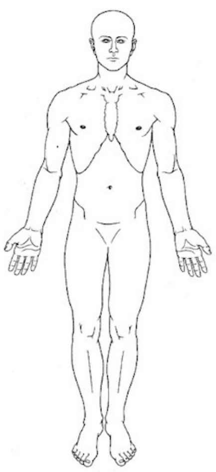
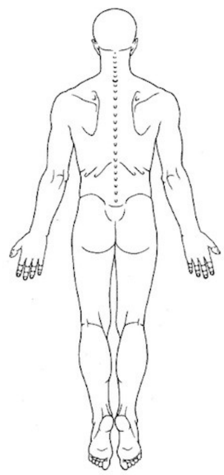


Abb. 3.1: Übersicht des ganzen Körpers: Vorderseite und linke Seite

	Kopf	
vorne		hinten
	Nacken	
	Schulter	
vorne		hinten
	Brustkorb	
	Oberer Rücken	
	Ellbogen	
innen		aussen
	Hand	
beugeseitig		streckseitig
	Unterer Rücken	
links		rechts
	Kreuz/Gesäß	
links		rechts
	Hüften	
links		rechts
	Knie	
vorne		hinten
links		rechts
	Unterschenkel	
vorne		hinten
	Füße	
innen		außen



Rückseite und rechte Seite

15. Wie stark ist der stärkste Druck, der durch das Exoskelett auf Ihren Körper / auf eine Körperregion ausgeübt wird? (Autor)

	0	1	2	3	4	5	6	7	8	9	10	
Gar kein Druck	O	O	O	O	O	O	O	O	O	O	O	Sehr starker, unangenehmer Druck

16. Bitte bewerten Sie den Tragekomfort des Exoskelettes auf einer Skala von 0 bis 10. (0 bedeutet kein Tragekomfort, 10 bedeutet höchster Tragekomfort) (Autor)

	0	1	2	3	4	5	6	7	8	9	10	
Gar kein Trage-komfort	O	O	O	O	O	O	O	O	O	O	O	Höchster Tragekomfort

17. Welche der folgenden Punkte haben Einfluss auf Ihre Bewertung des Tragekomforts des Exoskelettes gehabt? (Autor)

Kreuzen Sie bitte alle auf Sie zutreffenden Antwortmöglichkeiten an.

Positiv ☺		Negativ ☹	
O	Passform	O	Passform
O	Bewegungsfreiheit	O	Bewegungseinschränkungen
O	Material (ausreichend atmungsaktiv)	O	Material (Schweißbildung)
O	Druckpunkte	O	Druckpunkte
O	Handhabbarkeit beim An- und Ausziehen	O	Handhabbarkeit beim An- und Ausziehen
O	Gewicht des Exoskeletts	O	Gewicht des Exoskeletts
O	Anderes (bitte angeben):_______________	O	Anderes (bitte angeben):_______________

18. Die folgenden Fragen betreffen die Gebrauchstauglichkeit des Exoskeletts (SUS)

	Stimme gar nicht zu	Stimme eher nicht zu	Weder nicht	Stimme eher zu	Stimme voll zu
Ich kann mir gut vorstellen, das Exoskelett weiterhin regelmäßig zu nutzen.	O	O	O	O	O
Ich empfinde das Exoskelett als unnötig komplex.	O	O	O	O	O
Ich empfinde das Exoskelett als einfach zu nutzen.	O	O	O	O	O
Ich denke, dass ich technischen Support brauchen würde, um das Exoskelett zu nutzen.	O	O	O	O	O
Ich finde, dass mich das Exoskelett in meinen Aufgaben am Arbeitsplatz unterstützt.	O	O	O	O	O
Ich finde, dass mich das Exoskelett in der für meine Tätigkeit nötigen Bewegungsfreiheit einschränkt.	O	O	O	O	O
Ich kann mir vorstellen, dass die meisten Leute das Exoskelett schnell zu beherrschen lernen.	O	O	O	O	O
Ich empfinde die Bedienung als sehr umständlich.	O	O	O	O	O
Ich habe mich mit der Nutzung des Exoskeletts sehr sicher gefühlt.	O	O	O	O	O
Ich musste eine Menge Dinge lernen, bevor ich mit dem Exoskelett arbeiten konnte.	O	O	O	O	O

19. Treiben Sie regelmäßig Sport? Wenn ja, welchen? (Nordischer Fragebogen)

- O Ja, Sportart:_______________
- O Nein

20. Wie viele <u>Stunden</u> betreiben Sie den zuvor angegebenen Sport <u>pro Woche</u>? (Nordischer Fragebogen)

[   ] Stunden / Woche

Freitext-Anmerkungen

Im letzten Abschnitt des Fragebogens erhalten Sie die Möglichkeit, Vorschläge, Wünsche, Erwartungen an die Benutzung des Exoskeletts an Ihrem Arbeitsplatz sowie Anmerkungen zu diesem Fragebogen und der Befragung im Allgemeinen zu äußern. Bitte bedenken Sie jedoch, dass Ihre Aussagen wörtlich in die Auswertung und in die Ergebnispräsentation übernommen werden. Formulieren Sie Ihre Aussagen aus diesem Grund bitte so, dass keine Rückschlüsse auf Sie selbst oder andere Personen möglich sind.

21. Haben Sie Vorschläge / Wünsche / Erwartungen an den Gebrauch eines Exoskeletts an Ihrem Arbeitsplatz? (Autor)

22. Haben Sie weitere Anmerkungen zum Fragebogen oder zur Befragung allgemein? (Autor)

Vielen Dank für Ihre Teilnahme!