Aus dem

Institut für Arbeitsmedizin, Sozialmedizin und Versorgungsforschung des Universitätsklinikums Tübingen

# Development of an assessment method for work-related musculoskeletal loads in the elbow region based on a systematic literature review and measurement-based occupational-scientific analyses

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## Dedication

„*Les choses n'ont que la valeur que nous leur attribuons.*“

Molière*

*Jean-Baptiste Poquelin (1622 – 1673) – French dramatist, theater director and actor

*Dedicated to my wife Carina and family.*

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# List of abbreviations

**Table 1.** Abbreviations.

| Abbreviation | | Explanation |
|---|---|---|
| A: | – | Assessment approach |
| ACGIH | – | American Conference of Governmental Industrial Hygienists |
| AdRULA | – | Adjusted Rapid Upper Limb Assessment |
| AF: | – | Arbeitsschutzfachleute mit fortgeschrittener messtechnischer Erfahrung (publication 3) |
| AG: | – | Arbeitsschutzfachleute mit geringer messtechnischer Erfahrung (publication 3) |
| AL | – | Action Limit |
| ArbSchG | – | Occupational Safety and Health Act |
| BAuA | – | Federal Institute for Occupational Safety and Health |
| BMAS | – | Federal Ministry of Labour and Social Affairs |
| BMI | – | Body mass index |
| B.S. | – | Benjamin Steinhilber |
| C. | – | Chapter |
| CH | – | Cohort study/studies |
| CI/CIs | – | Confidence interval/intervals |
| COPSOQ | – | Copenhagen Psychosocial Questionnaire |
| CUELA | – | Computer-assisted recording and long-term analysis of musculoskeletal loads |
| CRS | – | Case-referent study/studies |
| CSS | – | Cross-sectional study/studies |
| CTS | – | Carpal tunnel syndrome |
| D | – | Duty cycle |
| D.H.S. | – | David Henry Seidel |
| D.M.D. | – | Dirk M. Ditchen |
| DoF | – | Degrees of freedom |
| DUE | – | Distal upper extremity injury |
| EMG | – | Electromyography |
| EU-OSHA | – | European Agency for Safety and Health at Work |
| F | – | Frequency |
| GDA | – | Joint German Occupational Safety and Health Strategy |
| GEE | – | Generalized estimating equation |
| GRADE | – | Grading of Recommendations Assessment, Development and Evaluation |
| H. | – | Hypothesis |
| h/day | – | Hours per day |
| HAL | – | Hand Activity Level |
| HAV | – | Hand-arm vibration |
| HSE | – | Health and Safety Executive |
| HR | – | Hazard ratio/ratios |
| IASV | – | Institute of Occupational and Social Medicine and Health Services Research |
| ICD-10-GM | – | International Statistical Classification of Diseases and Related Health Problems (German Modification) |

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| IFA | – | Institute for Occupational Safety and Health of the German Social Accident Insurance |
| IRR | – | Incidence rate ratio/ratios |
| JEM/JEMs | – | Job exposure matrix/matrices |
| L5 | – | 5th lumbar vertebra |
| LE | – | Lateral epicondylitis |
| M. | – | Musculus |
| M.A.R. | – | Monika A. Rieger |
| Max | – | Maximum |
| ME | – | Medial epicondylitis |
| MEGAPHYS | – | Multilevel risk assessment of physical workload; German: 'Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz' |
| MeSH | – | Medical Subject Headings |
| Min | – | Minimum |
| MP | – | Kinematic micro-pause/pauses |
| MPF | – | Mean power frequency of the power spectra of angular data |
| MSD, MSDs | – | Musculoskeletal disorder/disorders |
| MSE | – | Muskel-Skelett-Erkrankungen (publication 3) |
| mTLV for HAL | – | Measurement-based Threshold Limit Value for Hand Activity Level |
| MVC | – | Maximum voluntary contraction |
| MVCP | – | Maximum voluntary contraction in percent |
| MVE | – | Maximal voluntary electric activity |
| n | – | Number (of e.g., participants, data sets) |
| NIRS | – | Near-infrared spectroscopy |
| NPF | – | Normalized peak force |
| NRC | – | National Research Council |
| no. | – | Number |
| O: | – | Output parameter |
| OA | – | Occupational health and safety professionals with advanced technical measurement experience |
| OM | – | Occupational health and safety professionals with minor technical measurement experience |
| OR/ORs | – | Odds ratio/ratios |
| P5 | – | 5th percentile (analogous to other percentiles) |
| PEROSH | – | Partnership for European Research in Occupational Safety and Health |
| PICO | – | Population, Intervention, Comparison, Outcome |
| PR | – | Prevalence ratio/ratios |
| PRISMA | – | Preferred Reporting Items for Systematic reviews and Meta-Analyses |
| Pronator | – | Pronator teres syndrome |
| Q. | – | (Research) question |
| r | – | Effect size |
| Radial | – | Radial tunnel syndrome |
| Ref. | – | Reference category |
| RepSc/RepScore | – | Repetition score |
| RMS | – | Root-mean-square |
| RULA | – | Rapid upper limb assessment |
| S | – | Scientist (with measurement expertise) |
| S: | – | Sensors |

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| S1 | – | Exposure sub-category 1 |
| SD | – | Standard deviation |
| SDE/SDEs | – | Specific disorder/disorders at the elbow |
| SENIAM | – | Surface EMG for non-invasive assessment of muscles |
| SF | – | Supplementary File |
| SI | – | Strain Index |
| Table S1 | – | Table supplementary file 1 |
| TCRS | – | Triple case-referent study/studies |
| Th1 | – | 1st Thoracic vertebrae |
| TLV for HAL | – | Threshold Limit Value for Hand Activity Level |
| U.M.H.-H. | – | Ulrike M. Hoehne-Hückstädt |
| UN | – | Ulnar neuropathy |
| US | – | United States |
| W: | – | Wissenschaftler (mit Mess-Expertise) (publication 3) |
| WRULDs | – | Work-related upper limb disorders |
| x | – | Variable |
| Z | – | Z-value |
| #1 | – | Risk-factor specification (number 1) |
| ω | – | Angular velocity |
| 95%-CI | – | 95 %-confidence interval |

# Preface

Owing to interdisciplinary linkage of occupational science and medicine, biomechanics and ergonomics, the presented research was carried out at the Institute of Occupational and Social Medicine and Health Services Research (IASV), University Hospital Tübingen, Germany. Separately from the doctoral project, I was employed as a research officer at IFA[1] as a staff of the MEGAPHYS[2] project (BAuA 2019b; DGUV 2020). Through this project, I was guaranteed access to research data from real workplaces, and I was allowed to use these data for my dissertation. Prof. Dr. Monika A. Rieger supervised the doctorate and thesis together with PD Dr. Benjamin Steinhilber.
Ethics committee of the University of Technology, Darmstadt, Germany, (EK 2/2013, EK 12/2015) approved MEGAPHYS. Additional approval for analyses planned for this thesis was obtained beforehand from the responsible ethics committee of the Medical Faculty of Eberhard Karls University, Tübingen, Germany (004/2016BO2). Additional experiments on animals or plants were not performed. Guidelines for good scientific practice (DFG 2019) and the Declaration of Helsinki (WMA 2013) were complied.
Within this thesis, three peer reviewed articles with first authorship were published and internationally and nationally presented at conferences. As the third manuscript was published in German, an English translation is presented in addition to the German reprint. All relevant research results and primary data were archived at IFA.
This thesis includes several chapters (C.). First, research background, state of research until data recording and objectives are presented (C. 1). C. 2 presents the main research findings namely the results of a systematic review, the development of a measurement-based assessment approach, as well as testing of the new approach at real workplaces and the categorization of several measurement-based assessment methods for the upper extremity. After the results are individually discussed and compared with current research (C. 3), they are summarized (C. 4). Bibliography (C. 5) and author's own contribution (C. 6) follow afterwards, as well as a list of thesis-related publications (C. 7). Finally, the supplementary material (C. 8), acknowledgement and curriculum vitae including a list of non-thesis related publications are presented.

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[1] Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), Alte Heerstraße 111, Sankt Augustin, 53757, Germany, DE.
[2] MEGAPHYS – German: ‘Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz‘.

# 1 Introduction

## 1.1 Research background

### *1.1.1 Work-related risk factors and upper extremity or elbow disorders – a retrospect*

The influence of physically heavy work, unfavorable movement patterns at work and work-related physical factors on the human musculoskeletal system has been studied for many years. As early as 1878, early records by the physician Dr. Ludwig Hirt on external (surgical) diseases of workers indicated associations between work-related, mechanical, or physical stimuli and diseases of muscles, connective tissue, and nerves (Schiebelsberger 2009). At the time of late industrialization, Dr. Hirt described specific work-related factors, which could be increasingly associated with certain diseases e.g., muscular inflammation due to work-related overload (Schiebelsberger 2009).
Movement-induced overload of arm muscles associated with tennis elbow (well-known disease in the elbow region) was also reported in a prestigious journal in 1886 (Pope and Plante 1886). Since these records from the late 19$^{th}$ century, research in the field of work-related physical risk factors and specific musculoskeletal disorders (MSDs) has been developed considerably. For example, circa 100 years after Dr. Hirt's discoveries, a study with a specific question was conducted to determine the prevalence of tenosynovitis and other upper extremity disorders that could be attributed to repetitive work in retail trade and assembly line in the food industry (Luopajarvi et al. 1979).

**Consequence 1:** Numerous systematic reviews have been published in the last three decades. These reports summarized in different ways associations between work-related risk factors and nonspecific complaints or specific MSDs of the upper extremities (Bernard 1997; da Costa and Vieira 2010; Descatha et al. 2016; Lietz et al. 2018; Melhorn et al. 2014; van der Molen et al. 2017; van Rijn et al. 2009a, b, 2010).

### *1.1.2 Overview of physiology and epidemiology of the upper extremity and elbow region*

The European Agency for Safety and Health at Work (EU-OSHA) and Health and Safety Executive (HSE) reported on work-related upper extremity diseases which ranged from 20 up to 45 % of all work-related MSDs (HSE 2017; Schneider et al. 2010). Of the total of 8.9 million days lost due to work-related MSDs in 2017, upper extremity diseases account for ≈ 44 % – more than back (≈ 36 %) or lower limb (≈ 20 %) disorders (HSE 2017). Work-related upper limb MSDs thus accounted for a large proportion of all MSDs and represent an important field of research.

A common work-related and well-known upper extremity MSD is carpal tunnel syndrome (CTS) of the wrist. It is designated as ICD-10-GM: G56.0 according to the International Statistical Classification of Diseases and Related Health Problems (German Modification, version valid for 2019; ICD-10-GM) as published by DIMDI 2018. Dale et al. 2013 previously reported on prevalences and incidences of CTS, summarizing six studies. The workgroup of Dale reported on prevalences from 2.6 to 12.4 % in individual studies and an overall prevalence across all studies considered of 7.8 % with a 95 %-confidence interval (95%-CI) of 7.1 to 8.6 %. In addition, the authors reported on incidences of 0.7 to 5.6 cases per 100 person-years, with an overall incidence across all studies of 2.3 cases per 100 person-years [95%-CI, (2.0, 2.7)].

When considering the upper extremity, not only the wrist but also the elbow region can be loaded and accompanied by specific inflammation, e.g., of nerves in the area of the elbow (van Rijn et al. 2009a). The elbow region includes the elbow joint (articulatio cubiti), where the humerus articulates with the ulna and radius. Furthermore, the prominent olecranon, protected by bursae, and the two bony appendages of the humerus (epicondylus medialis and epicondylus lateralis) belong to the elbow region. Ventral, superficial muscles of the forearm, such as Musculus (M.) pronator teres, M. flexor carpi radialis or M. flexor digitorum superficialis, originate at the medial epicondylus of the humerus. These muscles as well as profound, ventral, or radial muscles of the forearm, such as M. flexor carpi radialis or M. flexor digitorum superficialis with the tendinous attachment at the lateral epicondylus, belong to the elbow region as well. In addition, there are bony furrows for ulnar, median, and radial nerves (Sobotta 2004). More detailed information on anatomical basics, elbow joint structures, nerves or muscles are explained in further literature (Acosta Batlle et al. 2019; Ahmad et al. 2013; Cinque et al. 2020; Shiri and Viikari-Juntura 2011) and medical reference books (Aumüller et al. 2007; Sobotta 2004; Watts and Edwards 2020).

According to DIMDI 2018, a distinction is made in the elbow region between injuries related to a bursa, e.g., olecranon bursitis (ICD-10-GM: M70.2), other bursitis at the elbow (ICD-10-GM: M70.3), or other soft tissue diseases (ICD-10-GM: M70.8, M70.9), because of overuse and pressure. Acute injuries of nerves, muscles, tendons or open wounds at the elbow and forearm were also classified (ICD-10-GM: S51.0 to S59.9). Additionally, there were classifications of ulnar nerve lesions (cubital tunnel syndrome/ulnar nerve entrapment, ICD-10-GM: G56.2) or radial nerve lesions (radial tunnel syndrome, ICD-10-GM: G53.6). Specific diseases such as medial epicondylitis (ME, colloquially golfer's elbow, ICD-10-GM: M77.0) and lateral epicondylitis (LE, colloquially tennis elbow, ICD-10-GM: M77.1) are more prominent elbow MSDs that typically have longer underlying exposure times (DIMDI 2018).

A comprehensive systematic review on work-related risk factors and specific relevant disorders of the elbow referred to specific tendinopathies and neuropathies such as LE, ME, cubital tunnel syndrome, and radial tunnel syndrome (van Rijn et al. 2009a). Regarding cubital tunnel syndrome, these authors referred to primary studies of other scientists reporting an incidence of 24.7 per 100,000 person-years (Mondelli et al. 2005). Prevalences of 2.8 to 6.8 % in various occupational groups were mentioned as well (Descatha et al. 2004; Mondelli et al. 2006). In contrast, radial tunnel syndrome is less common and fewer information are available about this condition in relation to the working population (van Rijn et al. 2009a). This may be because radial tunnel syndrome is often mixed-up with epicondylitis (Roquelaure et al. 2000). A recent study of ulnar or radial entrapment neuropathies in Finland also reported on the rarity of these diseases (Hulkkonen et al. 2020) in contrast to e.g., CTS. More information on cubital or radial tunnel syndrome is described elsewhere (Descatha et al. 2004; Naam and Nemani 2012; Nakashian et al. 2020; Roquelaure et al. 2000; Svernlov et al. 2009; Tang 2020).

Overall, LE may affect 1 to 3 % of people in general population annually (Lai et al. 2018). Shiri and Viikari-Juntura 2011 analyzed in more detail and summarized studies to assess the prevalence and incidence of, e.g., lateral, or medial epicondylitis. The authors reported on an average prevalence of LE for general population of 0.7 to 4.0 %. The prevalence for the working population ranged from 0.3 to 12.2 % for LE. The prevalence for ME was lower (general population: 0.3 to 1.1 %; working population: 0.2 to 3.8 %). In contrast, prevalence of LE or ME for working population showed a wider range of 0.8 to 29.3 %. Shiri and Viikari-Juntura 2011 further mentioned an incidence for LE (general population: 0.3 to 1.1 %; working population: 2.0 to 4.0 %). The incidences for

ME (general population: 0.1 %; working population: ≤ 1.5 %), and LE or ME (general population: 0.4 %; working population: 0.6 to 3.7 %) were reported as well. There exist several work-related MSDs of the upper extremity such as De-Quervain's Disease or elbow-related ulnar nerve syndrome which were reported as valid for France by Descatha et al. 2018. In Italy e.g., tendonitis of the biceps (long head) or supraspinatus, or olecranon's bursitis were handled as work-related MSDs as well (Violante 2018). In this context, another author reported on similar well-known work-related diseases of the upper extremity valid in Germany such as "*diseases of tendons or tendon sheaths or tendon and muscle insertions (occupational disease no. 2101, 722 suspected cases in 2015), diseases caused by working with vibrating or pneumatic machines (occupational disease no. 2103, 423 suspected cases in 2015), pressure damages of nerves (occupational disease no. 2106, 98 suspected cases in 2015)*" (Ochsmann 2018, p. A255). Disorder number (no.) 2101 appears to be the one with the most suspected cases and therefore could be very relevant. Especially the two forms of epicondylitis belong to specific diseases of tendon sheaths and tendon gliding tissue (tendinitis or tendovaginitis) or tendon or muscle attachments according to the detailed definition of occupational disease no. 2101 as stated by Spahn et al. 2016. Statistics in the regular reports on occupational safety and health of the Federal Ministry of Labour and Social Affairs (BMAS) and the Federal Institute for Occupational Safety and Health (BAuA) primarily show an increase in absolute numbers for occupational disease no. 2101. The number of recognized occupational diseases no. 2101 that have forced the omission of all activities that are harmful to health has increased by 154 % over the last decade (reporting year 2008 to 2018), from 11 to 17 cases (BMAS and BAuA 2010, 2011, 2012, 2013, 2014a, b, 2016a, b, 2017, 2018, 2020). In certain years, however, the numbers were much higher, such as in the reporting year 2015, when 33 cases were registered (BMAS and BAuA 2016b).

**Interim conclusion 1:** Based on the national statistics of BMAS and BAuA and other studies as mentioned above, it should be emphasized that especially these two forms of epicondylitis (LE, ME) have relevance in Germany with regard to prevention of work-related diseases. Therefore, the elbow area and both forms of epicondylitis should be further investigated in occupational scientific research.

### *1.1.3 Economics associated with MSDs, upper extremity, and elbow-related diseases*

Work-related MSDs are a widespread issue in various workplaces and are associated with large impacts on economics. This is also confirmed by the statistics of BMAS and BAuA. According to the current statistics for the reporting year 2018 (BMAS and BAuA 2020), 124.8 million days of incapacity to work were registered in Germany due to MSDs (21.9 %). Although the percentage of days lost to work has remained similar over the last decade (on average about 22.8 %), the cost of lost production caused by MSD has increased almost continuously from €10.6 billion in 2008 to €18.5 billion in 2018. Likewise, over the last decade, the loss of gross value added due to MSDs has increased from €19.2 billion in 2008 to €31.7 billion in 2018 (BMAS and BAuA 2010, 2011, 2012, 2013, 2014a, b, 2016a, b, 2017, 2018, 2020).

Harris et al. 2011 reported on previous costs for distal upper extremity injuries (DUE), especially isolated for the wrist, elbow, and forearm. They referred to average cost of a DUE case, which was approximately US$6,977 to US$8,000 as indicated for the years 1986 and 1994 (Silverstein et al. 1986; Webster and Snook 1994). The cost of upper limb MSDs due to work loss, known as compensation costs, accounts for up to 65.1 % of the total cost in 1994 (Webster and Snook 1994). The median cost per case was US$824 and the total cost of upper extremity MSDs in the United States was US$563 million for compensation as indicated for the year 1994 by Webster and Snook as well. For lateral epicondylitis, a cohort study in the state of Minnesota in the United States reported a median cost of $660 and a median cost of $402 per patient over one year after diagnosis with regard to the year 2003 up to 2012 (Sanders et al. 2016). Other authors reported on workers diagnosed with rotator cuff syndrome (total claims: n = 17,083), epicondylitis (total claims: n = 11,897) and/or CTS (total claims: n = 27,148) in Washington State and associated average (rotator cuff syndrome: $17,410; LE: $8,099; CTS: $14,523) as well as median total costs per claim (rotator cuff syndrome: $2,114; LE: $734; CTS: $4,672) with respect to the period 1990 up to 1998 (Silverstein et al. 2002). In a follow-up, Anderson et al. 2015 reported on non-traumatic epicondylitis from 2002 to 2010 in Washington State, with direct claim costs of $55,121 on average (median: $19,484) during this period. Degen et al. 2018 reported on $4263 per patient as an average cost of surgical treatment for LE from 2007 to 2014, based on a sample of 83,518 cases in the United States.

**Interim conclusion 2:** It can be assumed that MSDs in general, but especially in the upper extremity and elbow region, are often associated with higher costs for treatment, compensation, and payments for work incapacity. Therefore, from an economic point of view, the investigation of work-related risk factors and associated MSDs of the upper extremity is appropriate to preventively protect employees from these diseases and to reduce costs for occupational diseases or specific elbow-related disorders.

### *1.1.4 Legal principles, laws, and regulations in Germany*

Valid methods are required to objectively assess workload in the elbow region and to protect employees from work-related risk factors and MSDs in this area (BAuA 2019b). According to the German Occupational Safety and Health Act (ArbSchG 1996), and the accident prevention regulation Principles of Prevention (DGUV 2013), employers are obliged to assess the working conditions and risk factors (BAuA 2019a, b). Above all, the German Occupational Safety and Health Act regulates in paragraph 4 (§ 4 I – III) that hazards should be avoided or kept low. In addition, the follow-up methods for occupational safety and health should correspond to the current state of the art in technology and occupational medicine. They should consider further research results and findings from occupational science (ArbSchG 1996). Furthermore, paragraph 5 refers to the legally required risk assessment, e.g., of physical impacts (§ 5 III).

As reported by BAuA 2019b, dealing with physical workload is also addressed in the Ordinance on Preventive Occupational Health Care (ARBMEDVV 2008), Occupational medical rule 13.2 (AMR 13.2 2014) and Ordinance on company safety and health (BETRSICHV 2015). After successful load assessment, e.g., in the elbow region, appropriate measures can be derived that are effective in primary prevention (reduction of elbow-related overload/diseases/complaints). Not only in primary, but also in secondary prevention (prevention of spread of disease) or tertiary prevention (avoiding consequential diseases or damage) relevant measures can be deduced (BAuA 2019b).

**Consequence 2:** To improve prevention and to adapt risk assessment methods according to technical progress of risk assessment of physical workloads, especially in the elbow region, a possible field of research is the compilation and classification of current methods for assessment of physical workload. If necessary, a new development of methods with the goal to strengthen the objective risk assessment should be performed.

### *1.1.5 State of scientific knowledge and preliminary investigations related to the elbow*

The unpublished report by Hartmann 2014 on frequencies, complaints, and risk factors which was submitted to the ergonomics department at IFA, formed the basis for some ideas for this thesis. Further detailed research was conducted for the elbow region. This means additional systematic reviews were investigated. A research gap was identified in these analyses related to the elbow region. As mentioned subsequently by Seidel et al. 2017, systematic reviews often provided predominantly qualitative information (e.g., for awkward postures or repetitiveness) on the association between work-related physical risk factors and elbow joint complaints or specific disorders at the elbow (SDEs) (Bernard 1997; da Costa and Vieira 2010; van Rijn et al. 2009a). Whereat, some reviews provided semi-quantitative information (Descatha et al. 2016; Melhorn et al. 2014; van Rijn et al. 2009a). Furthermore, Seidel et al. 2017 concluded by pointing out that such quantitative associations are relevant and necessary for prospective threshold definitions and assessment approach developments.

**Interim conclusion 3:** Purely quantitative information on work-related physical risk factors in the elbow region were lacking. Therefore, an updated systematic review of quantitative information on work-related risk factors associated with diseases of the elbow was required to reflect the current state of science.

In addition to systematic reviews concerning risk factors, reviews of different assessment approaches for physical workload (Grooten and Johanssons 2018; Nasrull Abdol Rahman and Syafiqa Abd Razak 2016; Takala et al. 2010) were examined. These papers mainly summarized assessment tools that were based on paper-and-pencil approaches, observational methods, expert estimations, or video analyses. Direct measurement-based assessments could not be identified within this research. But, during further narrative literature searches, isolated approaches were identified in which thresholds were defined to quantify workload in the distal upper extremity using measurement-based assessment methods. Here, however, the wrist area was the primary focus of investigation. A promising approach was described in this context by Hansson's research group (Hansson et al. 2009; Hansson et al. 2000; Hansson et al. 1996; Hansson et al. 2004a; Hansson et al. 2004b). These researchers showed that the kinematic parameters such as mean power frequency, angular velocity, and kinematic micro pauses can be used to estimate hand repetitions. These kinematic parameters have also been investigated by other scientists e.g., Arvidsson et al. 2003, Balogh et al. 2019, Nordander et al. 2013, Ohlsson et al. 1994 or Stål et al. 1999. For the wrist region, there exist already measurement-based assessment approaches linking some of these kinematic parameters. For instance, Schedlbauer et al. 2014 used in this context a traffic light approach. With this, flexion and extension movements of the wrist could be rated. Subsequent frequency analyses can be used to determine frequency and median velocity. The objective of this traffic light assessment was to estimate and quantify repetitive loading on the wrist.

**Interim conclusion 4:** Measurement-based approaches are required to assess work-related loading on hands, but particularly in the elbow region. In addition, measurement-based assessment methods for the distal upper extremity are needed in practice to assess exposures more accurately and objectively, especially for exposures that are difficult to capture through observation. The approach of Schedlbauer et al. 2014 seemed promising. It should be used as a basis for new developments. Moreover, this method should be further developed, scientifically substantiated, transferred and applied to the elbow region to be able to estimate work-related load of the entire distal upper extremity.

Since the early beginnings of exposure recording in hands and elbows with sensors as mentioned above, the technology has evolved rapidly. Today, new technology, improved sensors and updated software are already available for exposure estimations – e.g., as those reported by Barrero et al. 2012, Lin et al. 2018, Merino et al. 2019 or Plantard et al. 2017. It can therefore be assumed that in the next few years, technical development will continue and new or improved approaches for exposure assessment will also become available.

**Interim conclusion 5:** For this reason, another research focus should be a classification of current measurement-based assessment approaches for physical exposures. In this context different methods for objective risk assessment of the upper extremity should be presented. This primarily serves prevention of work-related physical hazards.

## 1.2 Objectives and research questions

Owing to high numbers of work-related musculoskeletal disorders, which are associated with high costs and absenteeism, preventive measures are needed. Especially in the relevant area like the elbow, preventive measures are required to protect workers from further overloading. Fulfilling this purpose and summarizing the preceding research background, three main research deficits have been identified for the elbow region.

First, substantial quantitative information on work-related physical risk factors in the elbow region is needed. This should be operationalized by a systematic review on quantitative information on work-related physical risk factors associated with SDEs. The following questions (Q.) are at the front.

- Q. 1 What specific quantitative work-related risk factors and exposures can be identified in current literature for the elbow region?
- Q. 2 How and to what extent can the associations between such risk factors and specific elbow disorders be quantitatively described?

Secondly, this quantitative information is further required for development of prospective objective workload assessment tools for the elbow region according to current state of research. This should be operationalized as follows. Based on the findings of the systematic review and additional references from narrative literature searches, the results should be filtered. Risk factors identified as relevant should be extracted. Considering these filtered results, the assessment approach of Schedlbauer et al. 2014 should be processed and further developed for the elbow region. The final assessment approach should be tested in practice as a pilot study using the measurement-based exposure data of the hand and elbow region – as well as medical outcome data of the hand and elbow area from the field cross-sectional study of the MEGAPHYS project (BAuA 2019b; DGUV 2020).

Q. 3 Can appropriate measurement parameters (e.g., kinematics, muscular load) be derived for the identified risk factors?

Q. 4 To what extent can quantitative criteria for the assessment of work-related elbow load be defined?

Q. 5 Can significant differences in the prevalence of complaints be described in workplaces with high exposure versus workplaces with low exposure?

Q. 6 To what extent can different load profiles be differentiated with respect to total load and assessed with consideration of different load levels for structures in the elbow region (surface electromyography, complaints, examination findings)?

Thirdly, due to an expected permanent development of sensor technology and assessment methods, a categorization of measurement-based approaches for assessment of physical exposure of the upper extremity is needed. This should be operationalized as follows. In addition to the developed assessment approach, other current measurement-based methods for risk assessment of physical workload on the upper extremities should be presented especially for occupational safety specialists or occupational safety and health officers based on narrative literature searching. The developed approach should be classified according to the current state of research. This will generally support objective risk assessment and prevention in the field of occupational safety and health.

Q. 7 What other objective, measurement-based assessment methods exist besides the approach developed here?

Q. 8 To what extent are the methods available for usage in the working environment?

**The main question of this thesis was related to all three research topics:**

Is it possible to develop a measurement-based assessment method for the elbow region using a systematic literature review and measurement-based occupational-scientific analyses in the field and to present this assessment approach together with other technical methods to occupational safety specialists or occupational safety and health officers for objective risk assessment of physical exposures?

# 2 Results

## 2.1 Publication 1 – Seidel et al. 2019b

Seidel DH, Ditchen DM, Hoehne-Hückstädt UM, Rieger MA and Steinhilber B (2019) Quantitative Measures of Physical Risk Factors Associated with Work-Related Musculoskeletal Disorders of the Elbow: A Systematic Review. Int J Environ Res Public Health 16(130): 1-23. doi: 10.3390/ijerph16010130.

International Journal of
*Environmental Research and Public Health*

MDPI

*Review*

# Quantitative Measures of Physical Risk Factors Associated with Work-Related Musculoskeletal Disorders of the Elbow: A Systematic Review

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**Abstract:** Background: Work-related musculoskeletal disorders at the elbow are a common health problem, which highly impacts workers' well-being and performance. Besides existing qualitative information, there is a clear lack of quantitative information of physical risk factors associated with specific disorders at the elbow (SDEs). Objective: To provide evidence-based quantitative measures of physical risk factors associated with SDEs. Methods: Studies were searched from 2007 to 2017 in Medline, EMBASE, and Cochrane Work. The identified risk factors were grouped in main- and sub-categories of exposure using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework for rating evidence. Results: 133 different risk-factor specifications were identified in 10/524 articles and were grouped into 5 main- and 16 sub-categories of exposure. The risk factors were significantly associated with lateral epicondylitis, medial epicondylitis, or ulnar neuropathy. Significant risk factors such as wrist angular velocity (5°/s, with increasing prevalence ratio of 0.10%/(°/s), or forearm supination (≥45° and ≥5% of time combined with forceful lifting) were found. Conclusions: This review delivers a categorization of work-related physical risk-factor specifications for SDEs with a special focus on quantitative measures, ranked for evidence. These results may build the base for developing risk assessment methods and prospective preventive measures.

**Keywords:** elbow disorders; epicondylitis; ulnar neuropathy; quantitative measures; physical risk factors; work-related; force; repetition; posture

## 1. Introduction

Work-related musculoskeletal disorders are a common problem with great effects on workers' health and the global economy. Work-related upper limb disorders (WRULDs) account for 20% to 45% [1,2] of all work-related musculoskeletal disorders. Within the WRULDs, elbow diseases significantly impact workers health by accounting for approximately 20% of those occupational diseases [2]. According to the European Agency for Safety and Health at Work [2], the costs of WRULDs are estimated between 0.5% and 2.0% of the Gross National Product. In Great Britain, 3.9 million working days were lost due to WRULDs in 2016/2017 [1], which illustrates the great need for preventive measures.

The first step in developing adequate preventive measures is to identify work-related risk factors. Associations between WRULDs and physical risk factors have been reported for years [3–5]. Besides the hand, wrist, and shoulder, the elbow also seems to be affected by physical exposure arising from different occupational activities [6]. For instance, two literature reviews refer to repetitive movements, awkward hand and forearm postures, and external force interactions as possible risk factors for specific disorders at the elbow (SDEs) [3,4]. The focus of these reviews was to present qualitative information about the relationship between physical risk factors and SDEs, and thus, to identify targets of preventive measures.

To develop adequate risk assessment tools, more detailed information about relevant risk factors and their quantitative specifications are required. In this regard, the systematic review by van Rijn et al. [6] presents some quantitative exposure-response relationships between work-related factors and SDEs between 1966 and 2007 [6]. The authors found associations between four work-related SDEs (in descending order according to prevalence: lateral epicondylitis (LE), medial epicondylitis (ME), cubital tunnel syndrome, and radial tunnel syndrome) and certain risk-factor specifications at work. Besides psychosocial factors, they identified physical risk-factor specifications, such as handling tools >1 kg (odds ratio (OR) 2.10 to 3.00), handling loads >5 kg (2 times/min for more than 2 h per day (h/day)), high hand grip forces for >1 h/day (OR 2.20 to 2.60), repetitive movements >2 h/day over 9 to 19 or $\geq$20 years (OR 2.20 to 3.60), arm lifting or hand bending for more than 25 or 75% of working time (OR 2.00 to 7.40), or working with vibrating tools for >2 h/day (OR 2.20 to 2.90) [6].

Over the last decade, great advancements have been made in the application of technical devices to measure physical exposure at the workplace [7–10], and current knowledge about relevant risk factors for SDEs has grown significantly.

Therefore, we augmented the work of van Rijn et al. [6] and conducted a systematic review on work-related physical risk factors for SDEs between 2007 and 2017, focusing on quantitative measures. We predominantly focused on the same four diseases reported by van Rijn et al. [6]. However, we were also open to other relevant SDEs.

The aim was to deliver a valid source of reference values for preventive purposes and, in particular, for developing adequate risk assessment methods at the workplace.

## 2. Materials and Methods

### *2.1. Literature Search and Selection Process*

Our systematic procedure followed the item checklist for creating a systematic review by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [11,12] (Supplementary File I, Table S1).

One author (D.H.S.) performed the literature search using the databases MEDLINE, EMBASE, and Cochrane Work from September 2007 to February 2017. Additionally, reference lists and peer-reviewed grey literature were scanned manually. Our search strategy was developed a priori and was based on keywords, Medical Subject Headings (MeSH) terms, free texts, and shortcuts for SDEs also used in previously published reviews [4,6,11–18]. Relevant keywords were applied, such as elbow pathologies, epicondylitis (lateral, medial), cubital tunnel syndrome, radial tunnel syndrome, pronator teres syndrome, tendinopathy, tenosynovitis, tendovaginitis, occupational exposure, and risk factor. The complete search strategy, including all keywords, is available as supplementary material (Supplementary Files II–V, including Tables S2 and S3).

To select eligible publications, we followed the 4 steps of the PRISMA Flow Diagram (1: Identification, 2: Screening, 3: Eligibility, and 4: Included Articles [11,12], see Figure 1). D.H.S. performed steps 1 and 3, and steps 2 and 4 were performed independently and blinded by D.H.S. and B.S. In case of disagreement, decisions regarding inclusion, exclusion, or methodological quality scores were achieved through discussion or by consulting a third author (D.M.D.).

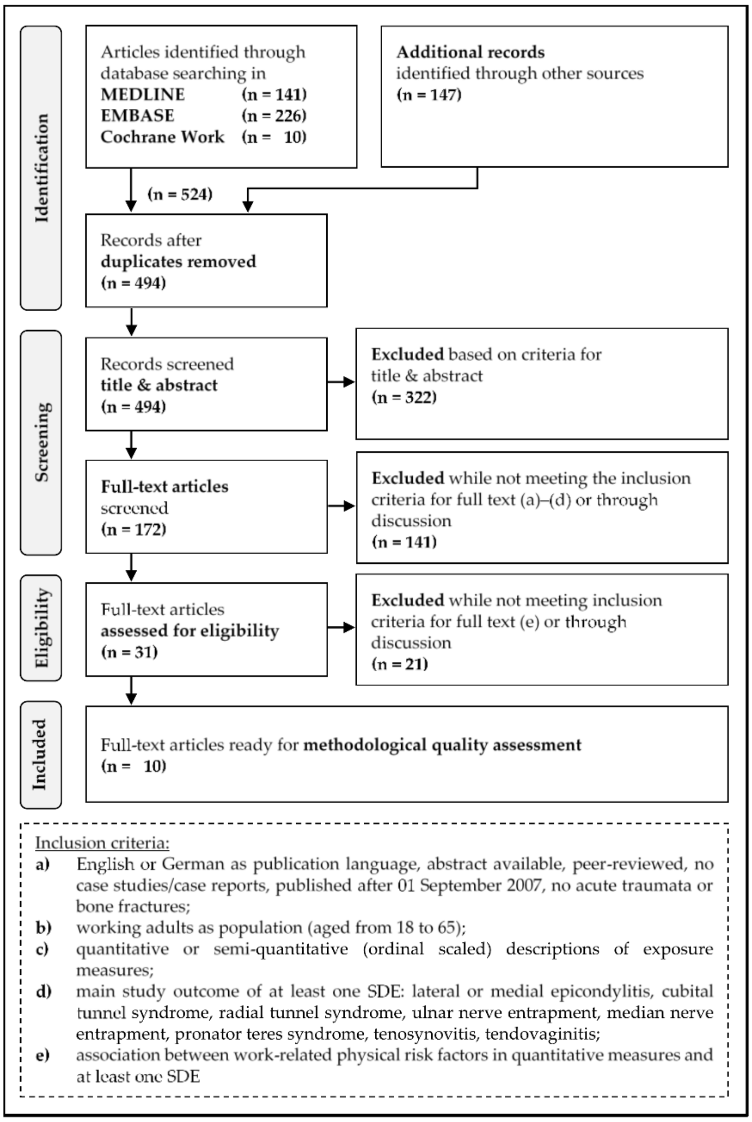


**Figure 1.** PRISMA Flow Diagram: This figure shows the study selection process of articles including physical risk factors associated with specific disorders at the elbow.

*2.2. Inclusion Criteria*

All inclusion criteria were defined a priori. That means: Studies that did not meet the scope, i.e., studies without pathologies at the elbow or information about physical exposures, animal studies, and human analgesic studies were sorted out in advance. We considered the review by van Rijn et al. [6] as our key paper and supplemented their inclusion criteria as follows:

(a) English or German as publication language, abstract available, peer-reviewed, no case studies/case reports, published after 01 September 2007, no acute traumata or bone fractures;
(b) working adults as population (aged from 18 to 65);
(c) quantitative or semi-quantitative (ordinal scaled) descriptions of exposure measures;
(d) main study outcome of at least one SDE: LE or ME, cubital tunnel syndrome, radial tunnel syndrome, ulnar nerve entrapment, median nerve entrapment, pronator teres syndrome, tenosynovitis, tendovaginitis;

(e) association between work-related physical risk factors in quantitative measures and at least one SDE.

The status of all articles concerning their inclusion is available in Supplementary File VI (Table S4). The PICO criteria (Population, Intervention, Comparison, Outcome) [11] were checked during steps 2 and 3.

### *2.3. Quality Assessment*

A priori, we composed a criteria list for general assessment of the methodological quality based on the one by van Rijn et al. [6], and augmented it with additional items according to Padula et al. [19] and Sanderson et al. [20]. The total list contains 18 items in 5 categories and 3 score decisions (available (+), not available (−), or unclear (?), see Table 1). This assessment tool was eligible for different study designs such as cohort studies (CH), cross-sectional studies (CSS) or case-referent studies (CRS).

**Table 1.** Applied general methodological quality assessment (study quality).

| | Criteria | Score |
|---|---|---|
| **Study population** | | |
| 1 | Study groups are (exposed and unexposed) clearly defined | +/−/? |
| 2 | Participation ≥70% | +/−/? |
| 3 | Cases ≥50 | +/−/? |
| **Assessment of exposure** (adequate description) | | |
| 4 | Exposure definition | +/−/? |
| 5 | Assessment of exposure | +/−/? |
| 6 | Blind for outcome status | +/−/? |
| **Assessment of outcome** (specific disorder, adequate description) | | |
| 7 | Outcome definition | +/−/? |
| 8 | Assessment method | +/−/? |
| 9 | Blind for exposure status | +/−/? |
| **Study design** | | |
| 10 | Prospective design | +/−/? |
| 11 | Inclusion and exclusion criteria | +/−/? |
| 12 | Follow-up period ≥1 year | +/−/? |
| 13 | Information between completers vs. withdrawals | +/−/? |
| 14 | Research question * | +/−/? |
| **Analysis and data presentation** | | |
| 15 | Data presentation identifying confounders | +/−/? |
| 16 | Consideration of confounders | +/−/? |
| 17 | Control for confounding | +/−/? |
| 18 | Statistical methods * | +/−/? |

*Legend:* Item checklist for methodological quality assessment adopted from [6]; *Score building:* information about an item is either: available (+), not available (−), or unclear (?) based on the original study; *Symbols:* * Items added according to [19,20]; Item 14: Was the research question or objective in this paper clearly stated and appropriate? Item 18: Did the authors include a sample size justification, power description, or variance and effect estimates?

According to Padula et al. [19] and Wong et al. [21], the levels of general methodological quality were classified into 3 categories:

- high (high frequency of positive values '+' ≥67% corresponds to a score ≥12),
- medium (medium frequency of positive values '+' 66% to 34% corresponds to a score 6 < 12), and
- low (low frequency of positive values '+' ≤33% corresponds to a score ≤6).

With our focus on a more detailed grading of exposure and outcome assessment, we also chose the scoring system by Sulsky et al. [22] and adapted their assessment method for the hip joint to the elbow joint (see Table 2).

**Table 2.** Applied quality assessment of exposure and outcome.

| Exposure Assessment | Score: Exposure * |
|---|---|
| Profession, job title, classification of occupation | 1 |
| Qualitative specification of exposure in different work activities (standing, sitting, static or dynamic movements) | 2 |
| Quantitative specification of exposure in different work activities/physical strains with information on intensity (e.g., repetition, force, load weight, awkward postures, or duration) | 3 |
| Quantitative specification of exposure (as above) with additional plausibility check (e.g., information on daily work output or special controls through video analysis) | 4 |
| Direct measurement or biomechanical model calculation of elbow strain with specification of quantitative information (e.g., repetition per time, force, load weight, awkward postures, holding time of awkward postures, amount/amplitudes, acceleration, velocity, torque) | 5 |
| **Assessment of Outcome** | **Score: Diagnosis **** |
| Self-reported elbow pain without clinical check | 1 |
| Medical history/clinical questionnaire without clinical check or diagnosis | 2 |
| Clinically noticeable reduction of movement, clinical check, imaging procedure results and diagnosis | 3 |

*Legend:* Score for exposure assessment: * Score 1 = low quality; Score 5 = high quality; Score for outcome assessment: ** Score 1 = low quality; Score 3 = high quality (modified according to [22]).

### *2.4. Level of Evidence and Data Analysis*

References (author, date), study characteristics (design, samples/population attributes), outcomes, and relevant physical risk factors (definitions, declarations, exposure assessments, measures with corresponding 95%-confidence intervals (CIs)), sex/specific information, outcome assessments, and confounder adjustments) were extracted from the included original articles (via text, tables, and graphics [23]) by D.H.S. Risk-factor specifications will be reported as given in the original studies. If the data are presented as adjusted (e.g., for gender by multivariate statistical analyses) and unadjusted (univariate statistical analyses) findings, then only the adjusted results will be reported. We further reported all kind of relative risk indicator measures such as ORs, hazard ratios, or prevalence ratios.

For easier reading, potential risk factors will be divided in statistically significant and non-significant results based on the $p$-value (<0.05) and the lower 95%-CI limit (>1.0) [24].

Single results were gathered in main- and sub-categories of exposure, similar to Melhorn et al. [14]. Following van Rijn et al. [6], the attributed scores of the quality assessment, as well as evidence levels were taken into account for data interpretation. To assess the validity and evidence of the results, we used an established method in systematic reviews (GRADE—Grading of Recommendations Assessment, Development and Evaluation [25]): All evidence judgments and bias assessments for potential risk factors were achieved for sub-categories of exposure by applying the special GRADE framework for prognostic factor research [26–29].

A calculation of the results in the form of a meta-analysis would be considered only for very homogeneous designs of the included studies.

## 3. Results

### *3.1. Included Studies*

From 524 identified articles, including 30 duplicates, 494 articles were scanned via title and abstract. After that, 322 articles were excluded with an initial agreement of 84.21% between the two authors D.H.S. and B.S., and a moderate interrater agreement (Kappa = 0.60 [30]). 141 of the remaining 172 articles were excluded after full text screening, and another 21 were excluded during eligibility assessment.

Studies were typically excluded due to a lack of quantitative measures of risk factors and the indication of diffuse elbow disorders without clear diagnosis (e.g., complaints or pain). Results of two systematic reviews [4,6] and one meta-analysis [5] which were already presented in included primary studies, were not listed additionally.

The selection of the studies is shown in Figure 1. Finally, 10 studies met our inclusion criteria and were used for further procedures such as assessing the study quality or extracting risk-factor specifications.

### *3.2. Quality of the Included Studies*

#### 3.2.1. Methodological Quality

Five relevant cross-sectional studies (1 with high [31], 4 with medium quality [32–35]) were identified. Furthermore, 3 high-quality cohort studies [36–38], one high-quality triple case-referent study [39] and one medium quality case-referent study [40] were included. Overall quality of the included studies was rated as high. As the studies showed very different designs, pooling for a meta-analysis did not seem to be reasonable. In general, the main weaknesses in the designs of the included studies were low participation rates, unclear definitions of exposed and unexposed groups, lack of information about blinding status of the examiners (exposure and outcome), and minor reported statistical methods.

#### 3.2.2. Quality of Exposure and Outcome Assessment

The exposure assessment showed scores of "1" ($n$ = 1 [39]), "3" ($n$ = 6 [32,33,35,36,38,40]), and "5" ($n$ = 3 [31,34,37]), while the outcome assessment was scored with the highest possible score ("3") in all included studies. In other words, all studies chose at least physical examinations to investigate the outcome, but only three of them [31,34,37] chose measurements for the assessment of exposure. The results are presented in Table 3 (in order of decreasing score for general methodological quality).

### *3.3. Physical Risk Factors Associated with SDEs*

Only half of the included studies [31,33,34,37,39] described the risk-factor specifications in detail, providing clear definitions of these factors and giving additional further information on the examined exposures. All risk factors (including information on study design, subject groups, exposure and outcome determination and further study attributes) were listed in the Supplementary File VII (Table S5) in alphabetical order of the authors.

All included studies provided a total of 133 different risk-factor specifications (numbered from #1 to #133). Of these, 3 specifications (#26 [37]; #9 [38]; #42 [38]) were reported twice, first as the results of a cross-sectional study and then in a subsequent longitudinal cohort study. Dividing all specifications in statistically significant and non-significant associations led to 44 different significant associations (#1 to #44) and to 89 different non-significant (#45 to #133) associations. The significant associations are shown in Table 4 and in most cases the statistical analyses were adjusted for at least one confounder such as age or gender ($n$ = 32). Twelve of the significant risk-factor specifications indicate a dose-response relationship when pairs for the same exposure were compiled (#3 and #4 [39]; #13 and #14 [36]; #16 and #17 [34]; #29 and #30 [31]; #31 and #32 [31]; #41 and #42 [32]). In 14 specifications both significant and non-significant associations between risk factors and specific SDEs were found (#2, #9, #10, #12, #13, #16, #17, #19, #22, #26, #40, #41, #42, and #43). All non-significant associations are listed in Supplementary File VIII (Table S6). These were predominantly based on univariate analyses (60 out of 89 non-significant associations).

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**Table 3.** Quality assessment of included studies.

| Reference | Study Design | Exposure Assessment Score * | Outcome Assessment Score * | General Methodological Quality Assessment (see Table 1 and chapter "Quality assessment" in "Material and Methods" **) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **Score** | **Quality** |
| Fan et al. (2009) [31] | CSS | 5 | 3 | + | + | – | + | + | + | + | + | – | + | + | + | – | + | + | + | + | – | 14 | high |
| Fan et al. (2014) [37] | CH | 5 | 3 | – | – | + | + | + | + | + | + | – | + | + | + | – | + | + | + | + | – | 13 | high |
| Herquelot et al. (2013b) [38] | CH | 3 | 3 | – | – | + | + | + | – | + | + | – | + | + | + | + | + | + | + | + | – | 13 | high |
| Descatha et al. (2013) [36] | CH | 3 | 3 | – | – | + | + | + | – | + | + | – | + | + | + | + | + | + | + | + | – | 13 | high |
| Svendsen et al. (2012) [39] | TCRS | 1 | 3 | – | – | + | + | + | – | + | + | – | – | + | – | + | + | + | + | + | + | 12 | high |
| Nordander et al. (2009) [33] | CSS | 3 | 3 | – | + | – | + | + | + | + | + | – | – | – | – | + | + | + | + | + | – | 11 | medium |
| Walker-Bone et al. (2012) [35] | CSS | 3 | 3 | – | – | + | + | + | – | + | + | – | – | + | – | – | + | + | + | + | – | 10 | medium |
| Herquelot et al. (2013a) [32] | CSS | 3 | 3 | – | – | + | + | + | – | + | + | – | – | + | – | – | + | + | + | + | – | 10 | medium |
| Nordander et al. (2013) [34] | CSS | 5 | 3 | – | + | – | + | + | + | + | + | – | – | – | – | – | + | + | + | + | – | 10 | medium |
| Spahn et al. (2016) [40] | CRS | 3 | 3 | + | + | + | – | – | – | + | + | – | – | + | – | – | + | + | + | + | – | 10 | medium |
| Total item score | | | | 2 | 4 | 7 | 9 | 9 | 4 | 10 | 10 | 0 | 4 | 8 | 4 | 4 | 10 | 10 | 10 | 10 | 1 | 12 | high |

*Legend: Study design*: CSS = cross-sectional study; CH = cohort study; TCRS = triple case-referent study; CRS = case-referent study; *Symbols:* * Exposure Assessment Score: modified according to [22], max. quality score = "5"; Outcome Assessment Score: modified according to [22], max. quality score = "3"; descriptions and decision aids presented in Table 2; ** see Table 1 and Section 2.3; assessment according to [6], modified according to [19,20]; max. quality score = "18"; quality classification according to [19,21].

Significant associations between physical exposures and SDEs have only been verified for LE (9 studies [31–38,40]), ME (4 studies [33–36]), and for ulnar neuropathy (UN, 1 study [39]). Non-significant associations for these could be found as well (LE, 8 studies [31–34,36–38,40]; ME, 3 studies [33,34,36]; UN, 1 study [39]) while one study [33] also reported on two other diseases (radial tunnel syndrome, pronator teres syndrome) but with non-significant associations. All associated physical risk factors can be categorized into 5 main exposure groups (force, repetition, posture/movement, vibration, and combined exposures) and 16 sub-categories of exposure. The distribution of all risk-factor specifications among the 5 main exposure groups (inclusive numbers of different exposure determinations, numbers of referring studies) were presented in Figure 2 (for more details about risk-factor specifications and exposure categories: see Table 4, Supplementary File VII (Table S5), Supplementary File VIII (Table S6)).

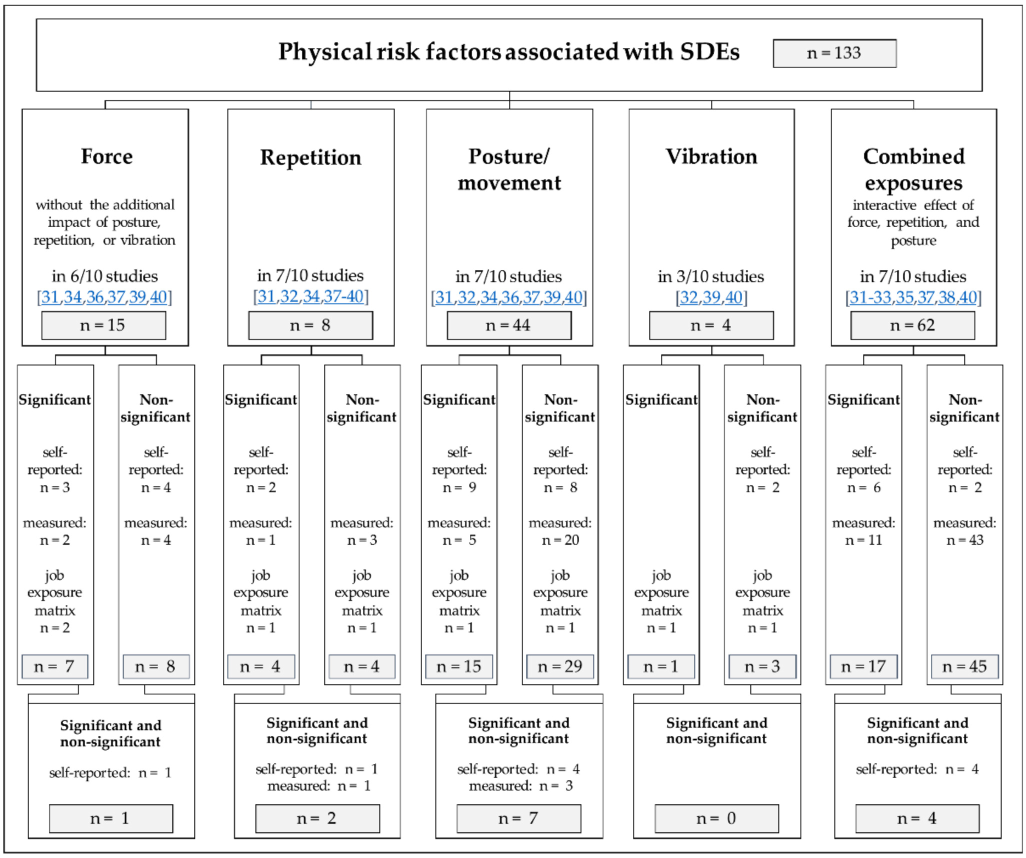


**Figure 2.** Distribution of physical risk factors associated with SDEs: The graph shows the distribution of all risk-factor specifications among the 5 main exposure groups with numbers of different exposure determinations and numbers of referring studies.

**Table 4.** Overview of relevant physical risk factors significantly associated with the development of specific disorders at the elbow.

| Exposure (Main- and Sub-Category (S) *) | | | Significant Risk-Factor Specification | Reference | Outcome | Gender | Measure (95%-CI) | | Adjustment |
|---|---|---|---|---|---|---|---|---|---|
| Force | S1 Maximum force | #1 | Maximum forceful efforts of the Hand >1 h/day | [40] | LE | Men | OR | 6.90 (2.70, 17.50) | (g) |
| | | | | | LE | Women | OR | 9.60 (3.10, 30.40) | (g) |
| | S2 Forceful exertion | #2 | Hand in forceful grip on average ≥4 h/day | [36] | ME | - | OR | 3.80 (1.50, 9.60) | (a) |
| | | | | | LE/ME | - | OR | 2.80 (1.40, 5.80) | (a) |
| | | #3 | <10% maximum voluntary contraction across a full working day | [39] | UN | - | OR | 2.73 (1.42, 5.25) | (h) |
| | | #4 | 10 to 29% maximum voluntary contraction across a full working day | [39] | UN | - | OR | 3.85 (2.04, 7.24) | (h) |
| | S3 Hand as tool | #5 | Patting with the hand >1 h/day | [40] | LE | Men | OR | 13.80 (2.90, 66.10) | (g) |
| | S4 Manual load handling | #6 | Forceful lifting (≥4.5 kg) >0% of time | [31] | LE | - | OR | 2.65 (1.21, 5.83) | (i) |
| | | #7 | Forceful lifting (≥4.5 kg) ≥2 times/min | [31] | LE | - | OR | 3.06 (1.28, 7.27) | (i) |
| Repetition | S5 High repetition | #8 | >3 motion sequences/sec or at least 10,000 times/h for >1 h/day | [40] | LE | Men | OR | 10.60 (4.00, 28.30) | (g) |
| | | | | | LE | Women | OR | 11.00 (2.60, 45.10) | (g) |
| | S6 Repetitiveness | #9 | Doing repetitive tasks ≥4 h/day | [32] | LE | Women | OR | 2.46 (1.30, 4.65) | (a) |
| | | | | [38] | LE | Men | IRR | 2.80 (1.20, 6.20) | (n) |
| | | #10 | Wrist angular velocity (5°/s) in [%/(°/s)] | [34] | ME | - | PR | 0.10 (0.10, 0.20) | (g) |
| | | #11 | Repetitive elbow or wrist movements (≥4/min) ≥2.5 h/day | [39] | UN | - | OR | 2.22 (1.41, 3.51) | (j) |
| Posture/movement | S7 Overhead work | #12 | Overhead working >1 h/day | [40] | LE | Men | OR | 12.00 (3.20, 43.80) | (g) |
| | S8 Hand movements | #13 | Frequent wrist bending or twisting on average 2 to 4 h/day | [36] | ME | - | OR | 4.90 (1.10, 20.70) | (a) |
| | | | | | LE/ME | - | OR | 3.90 (1.10, 13.80) | (a) |
| | | #14 | Frequent wrist bending or twisting on average ≥4 h/day | [36] | LE | - | OR | 4.40 (1.50, 13.10) | (a) |
| | | | | | ME | - | OR | 8.20 (2.40, 27.90) | (a) |
| | | | | | LE/ME | - | OR | 6.90 (2.40, 19.90) | (a) |
| | | #15 | Frequent wrist bending ≥4 h/day and forearm rotating on average ≥2 h/day | [36] | LE | - | OR | 2.50 (1.10, 5.30) | (b) |
| | | | | | ME | - | OR | 3.10 (1.40, 6.80) | (b) |
| | | | | | LE/ME | - | OR | 3.00 (1.60, 5.80) | (b) |
| | | | | | LE/ME | Men | OR | 2.80 (1.20, 6.20) | (b) |
| | | | | | LE/ME | Women | OR | 3.60 (1.20, 11.00) | (b) |
| | | #16 | Wrist flexion (−40.0°) in [%/°] | [34] | LE | - | PR | 0.30 (0.04, 0.60) | (g) |
| | | #17 | Wrist flexion (−20.0°) in [%/°] | [34] | ME | - | PR | 0.08 (0.01, 0.10) | (g) |
| | | #18 | Wrist extension >1 h/day | [40] | LE | Men | OR | 12.00 (3.00, 47.90) | (g) |
| | | | | | LE | Women | OR | 7.50 (1.80, 31.60) | (g) |
| | | #19 | Wrist flexion >1 h/day | [40] | LE | Men | OR | 4.20 (1.20, 14.80) | (g) |
| | | #20 | Extreme wrist bending >2 h/day | [32] | LE | Men | OR | 2.27 (1.30, 3.97) | (a) |
| | | | | | LE | Women | OR | 1.98 (1.04, 3.75) | (a) |
| | S9 Forearm and elbow movements | #21 | Elbow flexion/extension >2 h/day | [32] | LE | Men | OR | 2.41 (1.38, 4.22) | (a) |
| | | | | | LE | Women | OR | 2.65 (1.40, 5.02) | (a) |
| | | #22 | Forearm rotating (also twisting, or screwing motion) ≥4 h/day | [36] | LE | - | OR | 2.70 (1.20, 6.20) | (a) |
| | | | | | LE/ME | - | OR | 2.70 (1.30, 5.40) | (a) |
| | S10 Non-neutral posture | #23 | Non-neutral posture (elbow flexion >100°, or ≥near maximal pronation/supination; or wrist deviation (>5° radial, >10° ulnar) or >15° palmar/dorsal flexion) ≥2 h/day pronation/supination) | [39] | UN | - | OR | 1.82 (1.15, 2.89) | (j) |
| | | #24 | Forearm rotation ≥45° for ≥45% time and duty cycle ≥10% of time | [37] | LE | - | HR | 3.10 (1.05, 9.15) | (a) |
| | | #25 | Forearm pronation ≥45° for ≥40% time and duty cycle ≥10% of time | [37] | LE | - | HR | 2.25 (1.09, 4.66) | (e) |
| | | #26 | Forearm supination ≥45° for ≥5% time | [31] | LE | - | OR | 2.25 (1.13, 4.50) | (i) |

**Table 4.** *Cont.*

| Exposure (Main- and Sub-Category (S) *) | | | Significant Risk-Factor Specification | Reference | Outcome | Gender | Measure (95%-CI) | | Adjustment |
|---|---|---|---|---|---|---|---|---|---|
| Vibration | S12 Hand-arm vibration | #27 | Hand-arm vibration: acceleration ≥3 m/s² ≥1 h/day | [39] | UN | - | OR | 2.19 (1.05, 4.56) | (j) |
| Combined Exposures | S13 Force and repetition | #28 | Maximum forceful efforts of the hand and repetition >1 h/day | [40] | LE | Men | OR | 14.70 (5.20, 41.50) | (g) |
| | | | | | LE | Women | OR | 29.30 (3.40, 34.80) | (g) |
| | | #29 | Frequency of forceful exertions (≥44.1 N or ≥4.5 kg) ≤1 to <5 times/min | [31] | LE | - | OR | 4.47 (1.57, 13.71) | (d) |
| | | #30 | Frequency of forceful exertions (≥44.1 N or ≥4.5 kg) ≥5 times/min | [31] | LE | - | OR | 5.17 (1.78, 15.02) | (d) |
| | | #31 | Duty cycle of forceful exertions (≥44.1 N or ≥4.5 kg) from ≤3 to <15% time | [31] | LE | - | OR | 3.36 (1.28, 8.84) | (i) |
| | | #32 | Duty cycle of forceful exertions (≥44.1 N or ≥4.5 kg) for ≥15% time | [31] | LE | - | OR | 3.00 (1.13, 7.96) | (i) |
| | S14 Posture and force | #33 | Forearm supination ≥45° and forceful lifting (≥4.5 kg) in [% time] | [31] | LE | - | OR | 3.65 (1.47, 9.07) | (i) |
| | | #34 | Forearm supination ≥45° ≥5% (duty cycle) and forceful lifting (≥4.5 kg) >0% of time | [31] | LE | - | OR | 2.98 (1.18, 7.55) | (d) |
| | | #35 | Forearm supination ≥45° for <5% time and lifting (≥4.5 kg) ≥3% of time | [37] | LE | - | HR | 2.09 (1.02, 4.27) | (a) |
| | | #36 | Forearm supination ≥45° for <5% time and any power grip (≥44.1 N) | [37] | LE | - | HR | 2.86 (1.41, 5.82) | (a) |
| | | #37 | Forearm rotation ≥45° for ≥45% time and any power grip (≥44.1 N) | [37] | LE | - | HR | 2.83 (1.16, 6.90) | (a) |
| | | #38 | Forearm pronation ≥45° for ≥40% time and any power grip (≥44.1 N) | [37] | LE | - | HR | 2.80 (1.35, 5.77) | (e) |
| | | #39 | Forearm pronation ≥45° for ≥40% time and lifting (≥4.5 kg) ≥3% of time | [37] | LE | - | HR | 2.50 (1.19, 5.24) | (e) |
| | | #40 | Forceful exertion (turning) >1 h/day | [40] | LE | Men | OR | 4.70 (1.40, 16.20) | (g) |
| | | #41 | Hard physical exertion (BORG Score 14 to 20) and 1 elbow movement | [32] | LE | Men | OR | 3.78 (1.85, 7.70) | (m) |
| | | #42 | Hard physical exertion (BORG Score 14 to 20) and 2 elbow movements (elbow movements = elbow flexion/extension >2 h/day and wrist bending >2 h/day | [32] | LE | Men | OR | 5.27 (1.93, 14.37) | (a) |
| | | | High physical exertion with elbow flexion/extension >2 h/day and extreme wrist bending >2 h/day (at follow-up investigation) | [38] | LE | Men | IRR | 2.70 (1.10, 6.10) | (f) |
| | | | High physical exertion with elbow flexion/extension >2 h/day and extreme wrist bending >2 h/day (at baseline and at follow-up investigation) | [38] | LE | Men | IRR | 3.20 (1.50, 6.40) | (f) |
| | | | | | LE | Women | IRR | 3.30 (1.40, 7.60) | (f) |
| | S15 Repetition and posture | #43 | Repetitive/constrained work with >30 s or >50% of cycle time (involved same fundamental cycle) vs. >50% (working time) involved prolonged awkward postures | [33] | ME | Men | PR | 4.00 (1.10, 15.00) | (c) |
| | | #44 | Repetitive bending/straightening of the elbow >1 h/day | [35] | LE | - | OR | 2.50 (1.20, 5.30) | (k) |
| | | | | | ME | - | OR | 5.30 (1.90, 14.90) | (k) |

*Legend:* * Forceful exertions were only shown for power grip, details for pinch grip were shown in Supplementary File VII (Table S5); sub-categories of exposure S11 and S16 are not significant and are not presented here. *Outcome:* UN = ulnar neuropathy; LE = lateral epicondylitis; ME = medial epicondylitis; LE/ME = lateral and/or medial epicondylitis; *Measure:* odds ratio (OR); hazard ratio (HR); incidence rate ratio (IRR); prevalence ratio (PR); *Adjustment:* (a) = univariate analysis; (b) = multivariate analysis; adjustment not reported; (c) = adjustment not reported; (d) = final model (age, gender, body mass index (BMI), smoking status, personal, psychosocial, and work organizational variables); (e) = adjusted for age and gender; (f) = adjusted for age and combined physical work exposure including physical exertion and elbow movements; (g) = sex-adjusted; (h) = fully adjusted for body mass index, pack-years of smoking (continuous), alcohol consumption (continuous), side-specific fractures (never/ever), full anesthesia within a 5-year period up to the index year (no/yes), predisposing disorders (no/yes), use of crutches within a 5-year period up to the index year (no/yes), hand-arm intensive sports (0, 1, 2) and weight loss ≥10 kg within half a year during a 5-year period up to the index year (no/yes) and all occupational exposure variables in Table 2 of [39]; (i) = adjusted for age (continuous), gender, BMI (continuous); (j) = partly adjusted for body mass index, pack-years of smoking (continuous), alcohol consumption (continuous), side-specific fractures (never/ever), full anesthesia within a 5-year period up to the index year (no/yes), predisposing disorders (no/yes), use of crutches within a 5-year period up to the index year (no/yes), hand–arm intensive sports (0, 1, 2) and weight loss ≥10 kg within half a year during a 5-year period up to the index year (no/yes); (k) = multivariate analyses; adjusted for vitality, white/blue collar, age in four age bands and sex; (m) = adjusted for individual characteristics, repetition, combined physical work exposure including physical exertion, elbow flexion/extension and wrist bending, and social support with aggregation of low categories for combined physical work exposure; (n) = adjusted for age and repetitiveness.

### 3.3.1. Force

Risk factors #3 and #4 (forceful work with <10 or 10 to 29% of maximal strength, defined by [41]) were significantly associated with UN (OR 2.73 to 3.85) [39]. For this, a dose-response relationship was presented with multivariate analysis.

Hand in forceful grip ≥4 h/day was described as a significant risk factor both for ME (OR 3.80) and for LE and ME (OR 2.80) [36]. Less than 4 h (#46, #47) showed no significant associations. All these results were supported by univariate analyses.

Spahn et al. [40] found high ORs for maximum force >1 h/day (#1) for LE in men (OR 6.90) and in women (OR 9.60). Moreover, patting with the hand for >1 h/day (#5) was highly associated with LE in men (OR 13.80). These two specifications were supported by sex-adjusted calculations. On the other hand, constant moving or lifting or carrying of loads (#51, #52) were not significantly associated with LE.

Forceful lifting >0% of time and forceful lifting (≥2 times/min) were identified as two further significant risk-factor specifications for LE (OR 2.65 to 3.06) [31]. These results were adjusted for age (continuously), gender and BMI (continuously). Fan and colleagues [31,37] defined forceful exertion as pinch grip force ≥8.9 N or power grip force ≥44.1 N and forceful lifting with an object weight of 0.9 kg (pinch grip) or 4.5 kg (power grip), considering other studies [42–44]. Lifting ≥3% time (#50 [37]) or less than 2 times/min (#53 [31]) was not significant for LE, in contrast. Furthermore, non-significant results could be found for different levels of muscular activity (#48, #49) via sex-adjusted analysis [34].

### 3.3.2. Repetition

More than 4 wrist or elbow movements per minute ≥2.5 h/day (#11) were significantly associated with UN (OR 2.22) by using partly adjusted models [39]. If the exposure time was less than 2 h/day (#57), associations between risk factors and elbow disorders were not found to statistically significant.

Doing repetitive tasks >4 h/day (#9) was only identified as a risk factor for LE in women (OR 2.46) in one cross-sectional study [32]. However, this result of a univariate analysis could not be confirmed in adjusted models, neither for men nor for women. Another cohort study defined this type of exposure as a risk factor for LE in men (incidence rate ratio (IRR) 2.80) [38]. This gender specific result in the cohort study adjusted for age and repetitiveness was only significant if information of baseline and follow-up investigation were implemented in the models.

Spahn et al. [40] reported that repetitions >3/s for >1 h/day (#8) could be a significant risk factor for LE in men (OR 10.60) and women (OR 11.00).

Nordander and colleagues [34] reported about elevated prevalence rates (significant for ME but not for LE) with increasing wrist angular velocity (risk factor #10).

Longer duty cycles (#54 [37]) or repetitive shoulder movements (#55, #56 [31]), on the other hand, showed no significant associations with LE.

### 3.3.3. Posture/Movement

Spahn et al. [40] reported non-specific wrist extension >1 h/day as a significant risk factor for LE in men (OR 12.00) and women (OR 7.50), and non-specific wrist flexion >1 h/day was significantly associated with LE but only in men (OR 4.20). The authors also identified overhead working >1 h/day as a significant high risk for LE in men (OR 12.00), but not in women. Arm holding in front of the body or swinging movements of the arm >1 h/day (#66, #67) as well as general postures such as standing, sitting or PC work >1 h/day (risk factors #84 to #86) showed no significant associations in men and women.

A significant dose-response relationship was shown for frequently wrist bending or twisting for at least 2 h/day, which was associated with LE or ME (#13, #14, and #15). On the other hand, such bending or twisting for less than 2 h/day (#58) was not significantly associated with these disorders [36]. The same exposure for 2 to 4 h/day showed some significant associations with ME or LE/ME (OR 3.90 to 4.90), but not for LE only. Stronger associations occurred for wrist bending >4 h/day (#14) and the development of LE, ME or LE/ME (OR 4.40 to 8.20). All these results were based on univariate analyses. Furthermore, the risk for developing LE or LE/ME was significantly more than doubled (OR 2.70) if daily work involved forearm rotating for more than 4 h (#22). For <4 h forearm rotating per day (#68, #69) no significant results could be detected. The authors were able to find significant associations for men and women with LE, ME or LE/ME (OR 2.50 to 3.60) using multivariate analyses.

In contrast, other authors identified wrist bending or elbow flexion/extension for >2 h/day as a risk factor for LE in men (OR 2.27 to 2.41) and in women (OR 1.98 to 2.65) supported by univariate analyses [32].

Nordander et al. [34] demonstrated the association of wrist flexion and the prevalence of LE and ME: Each increasing degree of the wrist flexion angle (start at −40.0°, risk factor #16) was significantly associated with a 0.3% increased prevalence ratio (PR) of LE but not for ME. For ME, a 1° increase in the wrist flexion angle (start at −20.0°, risk factor #17) correlated with a 0.08% increase in PR. However, such sex-adjusted analyses were not significant for LE or ME at 0° flexion angle (#62).

In one study, non-neutral posture of the elbow or wrist ≥2 h/day (#23) was significantly associated with UN (OR 1.82) [39]. In these partly adjusted analyses, however, the associations between non-neutral postures of elbow or wrist ≥1 to <2 h/day (#70) were not significant. (Non-neutral postures were defined by the authors [39] as elbow flexion >100°, or ≥near maximal pronation/supination or wrist deviation (>5° radial, >10° ulnar) or >15° palmar/dorsal flexion according to other literature [45,46]).

Higher hazard ratios (HR) for LE (HR 2.25 to 3.10) are related to forearm pronation ≥45° for ≥40% of working time and ≥10% time of a duty cycle, and rotation (supination or pronation) ≥45° for ≥45% of working time and ≥10% time of a duty cycle, respectively [37]. Seventeen further risk-factor specifications (#60, #61, #64, #65, #71 to #83), reported by these authors, about unfavorable wrist flexion/extension or forearm pronation, supination, or rotation over time did not exhibit significant associations in univariate analyses or in adjusted ones for age and gender.

Although forearm supination ≥45° for ≥5% of working time (#26) did not show any significant associations in the cohort study [37] but was mentioned as a further risk-factor specification for LE (OR 2.25) in a cross-sectional study [31]. The latter result was proofed by analyses adjusted for age, gender, and BMI. Various frequencies of shoulder movements (#55, #56) were not significant as well as wrist radial deviation <5° or ulnar deviation ≥20° for ≥4% of time (#59) [31].

#### 3.3.4. Vibration

Svendsen and colleagues [39] described hand-arm vibrations (HAV) with acceleration ≥3 $m/s^2$ for >1 h/day as a significant risk factor (#27) for UN (OR 2.19) based on a job exposure matrix. Their result was based on models adjusted for age, gender, and BMI. On the other hand, vibrations >0 to <1 h/day were not significant for UN in their study. For LE, there were non-significant associations with the use of vibrating hand tools >2 h (#88 [32]) or vibration stress >1 h/day (#89 [40]).

#### 3.3.5. Combined Exposures

Forearm supination ≥45° for more than 5% of the working time combined with forceful lifting (≥4.5 kg object weight, risk factor #33, #34 [31]) was found in several adjusted analyses to be a risk factor for LE (OR 2.98 to 3.65). More favorable postures or lower forces (#91) as well as the effect of forearm supination ≥45° ≥5% (duty cycle) or forceful lifting (≥4.5 kg) >0% of time (#92) did not show significant associations with LE. In addition, these authors reported dose-response relationships of forceful exertions (≥44.1 N or ≥4.5 kg, (#29 to #32)) as times per minute or as percent of a duty cycle with significant effects (OR 3.00 to 5.17), supported by adjustments for several confounders.

Forearm pronation ≥45° for ≥40% of working time combined with one additional factor (any power grip (#38), lifting ≥3% of working time (#39)) was significantly associated with LE (HR 2.50 to 2.80) [37]. For this purpose, age- and gender-adjusted analyses were used. Furthermore, forearm supination ≥45° for less than 5% of working time combined with any power grip (#36) or lifting ≥3% of time (#35) showed higher significant hazard ratios for LE (HR 2.09 to 2.89), as did forearm rotation ≥45° for more than 45% of working time combined with any power grip (HR 2.83, risk factor #37). These results were based on univariate analyses. Besides frequency of forceful exertions (≥44.1 N or ≥4.5 kg) ≥2 times/min (#90), the authors demonstrated 40 further risk-factor specifications (#93 to # 117, #119 to #133) as effects of combined forces, postures, or repetitions. However, these did not reach statistical significance, although different models were used.

Other authors reported about combined physical exposures (defined as mostly hard physical exertion, corresponding to a level equal or greater than 14 on the 6 to 20 BORG Scale [47], combined with elbow movements >2 h/day) as a risk factor for LE in men and women. Elbow movements were defined as elbow flexion/extension more than 2 h/day and wrist bending more than 2 h/day [32,38]. The associated risk increased with greater numbers of elbow movements in men (OR 3.78 to 5.27) but not in women in the cross-sectional study [32]. Non-significant associations were found as well for less hard physical exertion (BORG Score 6 to 13 [47]) or less than 2 elbow movements [32].

In the subsequent cohort study [38] significant results could be shown for men and women (IRR 3.20 to 3.30), but only if the data of baseline and follow-up investigation were implemented in age and combined physical work exposure adjusted analyses.

Repetitive tasks executed with maximum force >1 h/day (#28) were significantly associated via sex-adjusted analyses with LE in men (OR 14.70) and in women (OR 29.30), whereas forceful turning >1 h/day (#40) was only significantly associated with LE in men (OR 4.70) but not in women [40].

Walker-Bone et al. [35] identified through multivariate analyses a significant relationship between repetitive bending or straightening of the elbow >1 h/day (#44) and the development of LE (OR 2.50) and ME (OR 5.30) in men and in women.

Nordander et al. [33] found a high PR for ME (4.00) associated with work-related repetitive movements (cycle time >30 s) or constrained postures (>50% of working time). This specification was defined by previous information [48] and the result was significant only in men (no adjustments reported). Other disorders such as LE, radial tunnel syndrome or pronator teres syndrome were not significantly associated with this risk-factor specification (#43) [33].

#### 3.3.6. Evidence of Sub-Categories of Exposure

The GRADE evidence for prognostic factors was performed for all significant and non-significant associations.

For this purpose, the sub-categories of exposure (S1 to S16) were rated and assigned to the 4 possible gradations of the evidence evaluation (according to [26]) as follows:

- *High evidence* (*n* = 7): S2 (Forceful exertion), S4 (Manual load handling), S6 (Repetitiveness), S8 (Hand movements), S10 (Non-neutral posture), S13 (Force and repetition), S14 (Posture and force)
- *Moderate evidence* (*n* = 1): S16 (Posture and repetition and force)
- *Low evidence* (*n* = 3): S5 (High repetition), S9 (Forearm and elbow movements), S12 (Hand–arm vibration)
- *Very low evidence* (*n* = 5): S1 (Maximum force), S3 (Hand as tool), S7 (Overhead work), S11 (Body posture), S15 (Repetition and posture)

All evidence ratings are presented in Table 5.

**Table 5.** Rating evidence by using Grading of Recommendations, Assessment, Development and Evaluation (GRADE) according to [26,27].

| Exposure (Main- and Sub-Category (S)) | | Risk Factors | | *n* | Number of Studies | Number of Cohorts | Outcome | Uni-/Multivariate Analyses | | | | | | GRADE Factors (According to [26,27]) | | | | | | | | GRADE Evidence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | + | 0 | — | + | 0 | — | I | II * | III | IV | V | VI ** | VII | VIII | |
| Force | S1 | Maximum force | #1 | 197 | 1 [40] | 0 | LE | | | | 2 | 0 | 0 | 1 | 2↓ | n. a. | 1↓ | 1↓ | ✔ | ↑ | † | Very low |
| | S2 | Forceful exertion | #2 to #4, #46 to #49 | 8055 | 3 [34,36,39] | 1 | LE; ME LE/ME; UN | 2 | 7 | 0 | 2 | 1 | 2 | 2 | 2↓ | ✔ | ✔ | ✔ | 1↓ | ↑ | ↑ | High |
| | S3 | Hand as tool | #5 | 197 | 1 [40] | 0 | LE | | | | 1 | 0 | 0 | 1 | 2↓ | n. a. | 1↓ | 1↓ | ✔ | ↑ | † | Very low |
| | S4 | Manual load handling | #6, #7, #50 to #53 | 930 | 3 [31,37,40] | 1 | LE | 0 | 1 | 0 | 2 | 3 | 0 | 3 | 1✔ | ✔ | ✔ | 1↓ | ✔ | ↑ | ↑ | High |
| Rep-etition | S5 | High repetition | #8 | 197 | 1 [40] | 0 | LE | | | | 2 | 0 | 0 | 1 | 2↓ | n. a. | ✔ | 1↓ | ✔ | ↑ | † | Low |
| | S6 | Repetitiveness | #9 to #11, #54 to #57 | 11391 | 6 [31,32,34,37–39] | 2 | LE; ME; UN | 1 | 1 | 0 | 3 | 11 | 0 | 3 | 1✔ | 1↓ | ✔ | ✔ | ✔ | † | † | High |
| Posture/Movement | S7 | Overhead work | #12 | 197 | 1 [40] | 0 | LE | | | | 1 | 1 | 0 | 1 | 2↓ | n. a. | 1↓ | 1↓ | ✔ | ↑ | † | Very low |
| | S8 | Hand movements | #13 to #20, #58 to 63 | 8399 | 6 [31,32,34,36,37,40] | 2 | LE; ME; LE/ME | 7 | 5 | 0 | 10 | 7 | 0 | 3 | 2↓ | ✔ | ✔ | 1↓ | 1↓ | ↑ | ↑ | High |
| | S9 | Forearm and elbow movements | #21, #22, #66 to #69 | 5014 | 3 [32,36,40] | 1 | LE; ME LE/ME | 4 | 7 | 0 | 0 | 4 | 0 | 2 | 2↓ | ✔ | ✔ | 1↓ | 1↓ | ↑ | † | Low |
| | S10 | Non-neutral posture | #23 to #26, #64, #65, #70 to #83 | 5029 | 3 [31,37,39] | 1 | LE; UN | 1 | 14 | 0 | 3 | 3 | 0 | 3 | 1✔ | ✔ | ✔ | 1↓ | ✔ | † | † | High |
| | S11 | Body posture | #84 to #86 | 197 | 1 [40] | 0 | LE | | | | 0 | 6 | 0 | 1 | 2↓ | n. a. | 1↓ | 1↓ | ✔ | † | † | Very low |
| Vibration | S12 | Hand–arm vibration | #27, #87 to #89 | 8203 | 3 [32,39,40] | 0 | LE; UN | 0 | 2 | 0 | 1 | 2 | 0 | 1 | 2↓ | ✔ | ✔ | ✔ | ✔ | † | † | Low |
| Combined exposure | S13 | Force and repetition | #28 to #32, #90 | 930 | 3 [31,37,40] | 1 | LE | 0 | 1 | 0 | 6 | 0 | 0 | 3 | 1✔ | ✔ | ✔ | 1↓ | ✔ | ↑ | ↑ | High |
| | S14 | Posture and force | #33 to #42, #45, #91 to #118 | 4640 | 5 [31,32,37,38,40] | 2 | LE | 4 | 22 | 0 | 9 | 15 | 0 | 3 | 1✔ | 1↓ | ✔ | 1↓ | ✔ | ↑ | ↑ | High |
| | S15 | Repetition and posture | #43, #44 | 8690 | 2 [33,35] | 0 | LE; ME; Pronator; Radial | | | | 3 | 6 | 0 | 1 | 2↓ | 1↓ | ✔ | 1↓ | ✔ | ↑ | † | Very low |
| | S16 | Posture and repetition and force | #119 to #133 | 611 | 1 [37] | 1 | LE | 0 | 15 | 0 | | | | 3 | 1✔ | n. a. | ✔ | 1↓ | 1↓ | † | † | Moderate |

*Legend:* table layout, column descriptions according to different authors [26,27]; *Shortcuts:* *n* = number of participants; *Outcome:* UN = ulnar neuropathy; LE = lateral epicondylitis; ME = medial epicondylitis, LE/ME = lateral and/or medial epicondylitis, Radial = Radial tunnel syndrome, Pronator = Pronator teres syndrome; *Uni-/Multivariate Analyses:* type of analysis univariate/multivariate; + = number of significant effects with a positive value; 0 = number of non-significant effects; — = number of significant effects with a negative value; *GRADE factors:* I = phase of investigation; II = study limitations; III = inconsistency; IV = indirectness; V = imprecision; VI = publication bias; VII = moderate/large effect size; VIII = dose effect; *Symbols:* ↓ significant downgrading; ✔ no serious limitations/no downgrading); n. a. = not applicable; ↑ significant upgrading; † no upgrading; * Bias assessment according to [28,29]; ** overall quality of evidence was downgraded by phase of investigation: no downgrading.

## 4. Discussion

### *4.1. Quality of the Included Studies*

#### 4.1.1. Study Design

Ten studies met our criteria, whereby both Fan et al. [31,37] and Herquelot et al. [32,38] published a cross-sectional study as the baseline of a cohort study and the follow-up of the same cohort in another article, respectively.

The methodological quality score for the included studies ranged from 10 (medium) to 14 (high) on a scale from 0 to 18. The main reason for not achieving the highest quality standards was a lack of blinding the exposure investigators with respect to the outcome or vice versa. This phenomenon seems to be wide spread in the related field of research, as other authors also mentioned this lack of quality [27]. Although all studies generally distinguished between exposed and non-exposed cases, the decision criteria were sometimes described very unclearly. Missing information on distributions of age, gender, or sport/leisure time, for example, led to a lower quality score of individual studies. The quality score also decreased due to a lack of information on sample size justification or power description. However, this information is very important for the reliability of a study and in our opinion should always be reported. Our final study pool contains 30% prospective longitudinal studies (cohort studies), 20% case/triple CRS, and 50% studies with a cross-sectional design ($n$ = 10, see Table 3). Thus, this study pool lacks longitudinal studies for more valid proof of the outlined associations. On the other hand, this seems to be a general problem, as longitudinal studies are more time and cost consuming than CSS. Van Rijn et al. [6] reported similar results in their review: 15% cohort studies, 15% CRS and 70% CSS ($n$ = 13).

#### 4.1.2. Elbow Disorders and Outcome Assessment

We found a high homogeneity among the studies for assessment of outcome, since all studies showed the highest quality score for this criterion (physical examination including clinical noticeable reduction of movement, clinical check, imaging procedure results and diagnosis). While our key paper included only 3/13 studies with more than 50 cases per investigation [6], 7/10 studies fulfilled this criterion in our review, indicating that elbow disorders may have become more important in today's working environment. Finally, the studies included in our review focused predominantly on the same elbow disorders as van Rijn et al. [6] did (LE, ME, and UN). They described LE and ME as the most common disorders at the elbow, followed by cubital tunnel syndrome, which corresponds to UN in our review. Further disorders such as radial tunnel syndrome or pronator teres syndrome were investigated only in one study [33] and showed only non-significant effects for one risk-factor specification (#43). One reason for this could be that radial tunnel syndrome is one of the rare specific elbow diseases (IRR men 2.97 (1.9, 4.1), IRR women 1.42 (0.7, 2.2) per 100,000 years [14,49]) and is generally not as common as LE (IRR men 1.0 (0.7, 1.3), IRR women 0.9 (0.6, 1.3) per 100 workers) [38].

#### 4.1.3. Exposure Assessment

A high-quality exposure assessment (score = "5") could only be found for 3 of the included studies [31,34,37]. This assessment quality mainly refers to the validity of quantitative physical exposures, since exposure measures are considered to have the highest quality when they are based on direct measurements or biomechanical model calculation.

Fan et al. [31,37] used time-based posture analysis via software and video frames, time studies, and force gauges, both at baseline and after 3.5 years follow-up. Nordander and colleagues [34] applied biaxial flexible electro-goniometers to measure wrist postures and movements. Additionally, they used surface electromyography (EMG) to record muscular load of the right forearm extensors in a sub-sample [34].

With regard to the review by van Rijn and colleagues [6], who included only 1 study with a similar high-quality exposure assessment, this may reflect technical progress in measurement equipment, which has become more applicable for use in the field. Nevertheless, the majority of our included studies performed exposure assessments at a lower quality level based on self-reports [32,35,36,38,40], on task-related exposure classifications [33], and on exposure classifications via job exposure matrix (JEM) and expert rating [39].

From an economic point of view, surveys or self-reports are superior to measurements. However, by trying to gain specific and detailed information about the association of exposure and the risk of developing specific disorders, quality standards—both for exposure and outcome assessment—should be as high as possible to our opinion.

### *4.2. Significant and Non-Significant Risk Factors*

Force, repetition, posture/movement, vibration, and combined exposures were identified as the main exposure categories. These main categories contain 44 significant risk-factor specifications for developing at least one SDE. 89 non-significant specifications were reported by 9/10 studies. All 133 risk-factors specifications in total were summarized to 16 sub-categories of exposure, which were used for evidence ratings (see Table 5). These categories were similar to those reported by other authors [14].

Although most of the significant results were adjusted for at least one confounder, the interpretation of results from univariate analyses must nevertheless be carried out cautiously. In these univariate analyses, the true associative effect of a significant risk-factor specification could be covered by confounders. Results from multivariate analyses (adjusted for confounders) therefore appear somewhat more valid and should be preferred to results from univariate analyses.

Melhorn et al. [14] described e.g., gender with insufficient evidence for the development of LE or ME. The increasing age, on the other hand, increases the risk of developing LE or ME. At UN, these authors even attributed a strong evidence to age and some evidence to gender. We have tried to take these aspects into account by using predominantly adjusted results, if they were available. Furthermore, adjusting the statistical analysis to one or two potential confounders (e.g., age or gender) indirectly implies the influence of age and gender on SDE. However only very few of the included studies directly investigated an interaction of work-related physical risk factors and factors such as age, gender, or others (such as job experience) on SDE. Confounders such as job types played a very minor role for our aim, because we focused on movement executions (including forces, repetitions, postures, vibrations, and combinations) and not on job titles or job types in general.

#### 4.2.1. Force

This main exposure category contains 15 risk-factor specifications divided into 4 sub-categories with significant associations for LE, ME, and UN. These results were based on 6/10 studies and are consistent with the findings of van Rijn et al. [6]. Two sub-categories were rated with high evidence (Forceful exertion, Manual load handling), the other two sub-categories only with low (Hand as tool) or very low (Maximum force) evidence values.

Subsequently, although in the sub-categories "Hand as tool" and "Maximum force" high ORs were reported, those high risks have to be interpreted with caution, since the source study [40] was only rated with an assessment score of "3" (on a scale from 1 to 5, i.e., based on self-reports) and medium overall study quality. Moreover, isolated force exertions without the influence of posture or movement are unlikely to occur at the workplace. Therefore, values based on objective measurements using procedures such as EMG or force gauges might provide more reliable quantitative information as shown for manual handling of loads [31]. More precise exposure definitions of the force exposure sub-categories with high evidence ratings might support this presumption.

#### 4.2.2. Repetition

Repetition was a significant risk factor in 50% of the included studies and was confirmed for LE, ME, and UN, in both men and women. Van Rijn et al. [6] also outlined repetitive movements as a risk factor for LE and ME, but not for UN.

In contrast to force, repetition features higher evidence values ranging from low (S5 High repetition) to high (S6 Repetitiveness).

The 4 corresponding significant risk-factor specifications ranged from overall descriptions such as repetitive tasks ≥4 h/day [32,38] to very specific, measurement-based variables regarding wrist angular velocity [34]. To our opinion, results for very fast repetitions with more than 3 events per second (#8 [40]), derived from self-reports or surveys, should be interpreted carefully as they might be accompanied by strong recall bias, especially since the number of cases is small for a generalizable statement. As measurement-based exposure assessment shows the highest quality score, the related values might be most valid to assess repetitive tasks.

Previous systematic reviews [4,6] regarding work-related disorders at the elbow did not detect similar risk factors such as wrist angular velocity with high-quality scoring.

#### 4.2.3. Posture/Movement

Work-related awkward postures or movements of the upper limbs were associated with increased risks for elbow disorders in 70% of our included studies. From the 133 presented risk-factor specifications 44 were attributed to this main category and were predominantly linked to LE or ME, both in men and women, and seldom to UN. In 3 out of 10 included studies we found high exposure quality scores. One of them used objective measurements (wrist flexion [34]) and the other two used video-based analysis of non-neutral forearm postures ([31,37], see Supplementary File VII (Table S5)). However, 10/15 of the significant and 13/29 non-significant risk-factor specifications were recorded via self-administrated questionnaires, interviews, or JEMs.

Melhorn et al. [14] reported some evidence for awkward postures and showed aspects for posture as an independent risk factor. The wide range of evidence in our 5 corresponding sub-categories of exposure (S7 to S11, evidence: very low to high) might be due to their "easy to observe" status compared to factors such as force, vibration, or repetition. As observational studies are wide spread, the posture/movement (e.g., overhead work, #12) might be overrated compared to factors that are difficult to observe and require complex measurements to be detected validly.

Moreover, only one study in our results described overhead work (>1 h/day) as associated with LE in men [40]. The authors stated their study might be limited because of small sample sizes, which may affect the investigated associations. These findings are consistent with the results by van Rijn and colleagues [6], as their review contains only 1/13 studies mentioning "overhead work" as associated with LE in men and women. The authors reported static postures were linked with specific elbow disorders. However, we cannot confirm this in our review.

#### 4.2.4. Vibration

Although various studies included HAV into their exposure assessment [32,39,40], only one study mentioned HAV (>1 h/day) as a significant risk factor (for UN [39]). However, this association should be interpreted carefully, as the exposure assessment in this study was based on job titles and JEMs, respectively (exposure score "1"). Similarly to the moderate evidence for HAV, other authors reported insufficient evidence in relation to vibration [14].

One study also dealt with vibrations and pinch or power grip [31]. However, no statistical analyses were performed by the authors, which could indicate any association between vibration and LE. Therefore, we did not include these specifications in our results.

Van Rijn et al. [6] controversially discussed the relationship between LE and work-related vibrations. They included 3/13 studies assessing vibrations by self-reports with dissenting results regarding the associated disorders.

This might be a further hint that vibrations, especially hand-arm vibrations, are difficult to estimate by pure interviews or self-reports and need to be measured in future work for a valid quantitative specification.

4.2.5. Combined Exposure

In our key paper [6], only qualitative relationships between LE and combinations of either force, repetition, or posture were outlined in 2/13 studies, although one of them used electromyography (EMG) and video for exposure assessment. In contrast, 70% of our studies illustrated the effect of combined exposures for 17 significant and 45 non-significant individual risk-factor specifications. Significant associations were predominantly demonstrated for LE in men and women, and were sporadically detected for ME in both sexes, but not for UN. Two studies [31,40] presented quantitative measures for the combination of force and repetition. The application of continuous EMG or force measures seems to be a suitable approach to quantitatively determine the risk of specific exposure combinations. Two studies found a dose-response relationship between EMG and force and elbow disorders [31,37].

Contrary to this, other quantitative information about the combined effect of repetition and awkward postures or movements (e.g., #44) were collected by self-reports and do not provide such detailed results [35].

The 4 corresponding sub-categories show a wide spectrum of studies with evidence ratings from very low (S15 Repetition and posture) to moderate (S16 Posture and repetition and force) up to high (S13 Force and repetition; S14 Posture and force). In addition, more significant associations could be identified in combined exposures of force and posture or repetition (S13, S14) than in posture and repetition (S15). Melhorn and colleagues [14] showed similar evidence ratings for grouped qualitative information on different risk factors specifications. They found a strong evidence for the combination of force and repetition or force and posture, whereas the evidence for Posture and repetition was rather classified as insufficient. In our results, 15/17 significant associations (#28 to #42) include the combination of force and either repetition or posture. In 11 of these 17 risk-factor specifications (#29 to #39), the specifications were measured, and the results were largely supported by adjusted models. The evidence also increased once force was involved. Based on our analyses and the work of Melhorn et al. [14], we believe that force combined with one additional exposure (posture or repetition) could have a major impact on the development of SDEs. Therefore, we would attribute greater importance to the significant quantitative risk-factor specifications (#28 to #42) than to the factors #43 and #44. On the other hand, the high ORs for factor #28 (maximum forceful efforts of the hand and repetition >1 h/day) should not be weighted too heavily, as the number of cases supported by one study [40] is small here. Finally, the high portion of measurement-based risk-factor specifications may support our assumption of the increased application of technical devices in epidemiological studies over the last years.

*4.3. Strengths and Limitations*

Our systematic literature review excels in a mixed search strategy including established methods (e.g., PICO [11], PRISMA [11,12]), various literature databases, peer-reviewed grey literature, and manual searching. This conservative approach was combined with a quality assurance procedure adapting the GRADE method for rating evidence [26–29]. For methodological quality assessment, we modified a published scoring system for rating hip exposures and hip outcomes [22] to address the elbow.

We relied on the risk-factor definitions that were available in the original studies even if they have been very heterogenous. However, with the help of the exposure assessment score, we at least tried to classify the exposure determination qualitatively.

We reported quantitative information instead of using a pure qualitative approach. Moreover, we demonstrated the impact of combined physical exposures on the development of SDEs. Thus, our results may help to develop or evaluate elaborated risk assessment methods for the elbow.

Our study focused on work-related physical exposure and neglected other possible risk factors, such as psychosocial influences which should be mentioned as a limitation or at least as a potential factor to be considered when continuing research on work-related risk factors and elbow disorders.

Most of the studies in this review used different study designs and several types of exposure descriptions and showed a high heterogeneity with respect to the quality of exposure assessment. Therefore, a meta-analysis was not feasible.

In addition, our search was time-restricted to one decade (2007 to 2017), and we are aware of missing information because of our rigorous exclusion criteria (e.g., publication language or specific study designs).

The inclusion of both cross-sectional and longitudinal studies may have elicited the high heterogeneity of the reported risk estimates, such as OR, PR, HR, or IRR, and made it difficult to compare their results. On the other hand, the exclusion of any of these study types would have led to a lack of information about potential risk factors.

We have tried to reduce the publication bias by presenting significant and non-significant results. Furthermore, we intended to keep the bias low with the help of evidence and bias assessment. However, we are aware that recall, information, and publication bias of the individual included studies nevertheless could have affected our results in some way. The small number of included studies may limit the general applicability of our findings.

We have presented EMG as a measurement data-based method and equated it with a high score for exposure assessment. However, EMG could be limited as well. Reasons for this could be, among other things, cross talk, loosening of electrodes during a measurement, high amount of subcutaneous fat tissue (electrode-skin impedance) or differences in the applied electrode attachment [50,51]. Nevertheless, EMG seems to be an adequate method to measure some of the relevant exposures and was one of the few methods that indicated measured exposures in our included studies.

## 5. Conclusions

Our study filled a gap in quantitative information about the association between work-related physical risk factors and SDEs, as the latest systematic approach on this topic was in 2007. We focused on quantitative measures of risk factors and combinations of risk factors. We identified 133 risk-factor specifications (44 significant, 89 non-significant), grouped them into 5 main- and 16 sub-categories of exposure, and assessed their scientific evidence.

Within the 16 sub-categories we found evidence ratings from very low to high based on a few studies only.

This highlights the need for further research in this area especially addressing the potential dose-response relationship of work-related exposures and specific disorders of the elbow. In this context, we consider the work of Fan et al. [31,37] and Nordander et al. [34] as important examples for assessing work-related physical risk factor of SDEs. Such objective measures may help to better describe the dose-response relationships between risk factors and SDEs in the future.

However, our results may be the base for developing or evaluating elaborated risk assessment methods for the elbow and, thus, an important step in preventing work-related disorders at the elbow. Furthermore, we would like to encourage other researchers to apply objective measures of exposure assessment in epidemiological studies to create an objective database and to better understand the impact of physical risk factors on WRULDs in the future. Therefore, this approach may be valuable for use in future research on WRULDs.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/1660-4601/16/1/130/s1, File I Table S1: PRISMA checklist adopted from Moher et al. [12] and modified, File II Table S2: MEDLINE search strategy—3 February 2017; File III MEDLINE search string—3 February 2017; File IV Table S3: EMBASE search strategy—8 February 2017; File V Cochrane Work search strategy—6 January 2017; File VI Table S4: Documentation of all included and excluded studies; File VII Table S5: All relevant results of all included studies (incl. study attributes); File VIII Table S6: Overview of relevant physical risk factors non-significantly associated with the development of SDEs.

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## Abbreviations

| | |
|---|---|
| BMI | body mass index |
| CH | cohort study/studies |
| CIs | confidence intervals |
| CRS | case-referent study/studies |
| CSS | cross-sectional study/studies |
| EMG | electromyography |
| GRADE | Grading of Recommendations Assessment, Development and Evaluation |
| HAV | hand–arm vibrations |
| h/day | hours per day |
| HR | hazard ratio |
| IRR | incidence rate ratio |
| JEM | job exposure matrix |
| LE | lateral epicondylitis |
| ME | medial epicondylitis |
| MeSH | Medical Subject Headings |
| MVC | maximum voluntary contraction |
| MVE | maximal voluntary electric activity |
| OR | odds ratio |
| PICO | Population, Intervention, Comparison, Outcome |
| PR | prevalence ratios |
| PRISMA | Preferred Reporting Items for Systematic reviews and Meta-Analyses |
| Pronator | Pronator teres syndrome |
| Radial | Radial tunnel syndrome |
| S1 | exposure sub-category 1 |
| SDEs | specific disorders at the elbow |
| TCRS | triple case-referent study/studies |
| UN | ulnar neuropathy |
| WRULDs | work-related upper limb disorders |

## References

1. Health and Safety Executive (HSE). Work-Related Musculoskeletal Disorders (WRMSDs) Statistics in Great Britain 2017. Available online: www.hse.gov.uk/statistics/causdis/musculoskeletal/msd.pdf (accessed on 18 May 2018).
2. European Agency for Safety and Health at Work (EU-OSHA). *OSH in Figures: Work-Related Musculoskeletal Disorders in the EU-Facts and Figures*; Publications Office of the European Union: Luxembourg, 2010; pp. 1–179.
3. Bernard, B.P. *Musculoskeletal Disorders and Work Place Factors—A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity and Low Back*; U.S. Department of Health and Human Services, National Institute of Occupational Safety and Health (NIOSH): Cincinnati, OH, USA, 1997; pp. 1–590.

4. Da Costa, B.R.; Vieira, E.R. Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies. *Am. J. Ind. Med.* **2010**, *53*, 285–323. [CrossRef] [PubMed]
5. Descatha, A.; Albo, F.; Leclerc, A.; Carton, M.; Godeau, D.; Roquelaure, Y.; Petit, A.; Aublet-Cuvelier, A. Lateral epicondylitis and physical exposure at work? A review of prospective studies and meta-analysis. *Arthritis Care Res.* **2016**, *68*, 1681–1687. [CrossRef]
6. Van Rijn, R.M.; Huisstede, B.M.; Koes, B.W.; Burdorf, A. Associations between work-related factors and specific disorders at the elbow: A systematic literature review. *Rheumatology* **2009**, *48*, 528–536. [CrossRef]
7. Ellegast, R.; Hermanns, I.; Schiefer, C. Workload assessment in field using the ambulatory cuela system. In *ICDHM 2009: Digital Human Modeling*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 221–226.
8. Longo, A.; Meulenbroek, R.; Haid, T.; Federolf, P. Postural reconfiguration and cycle-to-cycle variability in patients with work-related musculoskeletal disorders compared to healthy controls and in relation to pain emerging during a repetitive movement task. *Clin. Biomech.* **2018**, *54*, 103–110. [CrossRef]
9. Schiefer, C.; Kraus, T.; Ellegast, R.P.; Ochsmann, E. A technical support tool for joint range of motion determination in functional diagnostics—An inter-rater study. *J. Occup. Med. Toxicol.* **2015**, *10*, 16. [CrossRef]
10. Wouda, F.J.; Giuberti, M.; Bellusci, G.; Veltink, P.H. Estimation of full-body poses using only five inertial sensors: An eager or lazy learning approach? *Sensors* **2016**, *16*, 2138. [CrossRef] [PubMed]
11. Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gotzsche, P.C.; Ioannidis, J.P.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The prisma statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *J. Clin. Epidemiol.* **2009**, *62*, e1–e34. [CrossRef] [PubMed]
12. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred reporting items for systematic reviews and meta-analyses: The prisma statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef] [PubMed]
13. Mattioli, S.; Zanardi, F.; Baldasseroni, A.; Schaafsma, F.; Cooke, R.M.; Mancini, G.; Fierro, M.; Santangelo, C.; Farioli, A.; Fucksia, S.; et al. Search strings for the study of putative occupational determinants of disease. *Occup. Environ. Med.* **2010**, *67*, 436–443. [CrossRef] [PubMed]
14. Melhorn, J.M.; Talmage, J.B.; Ackerman, W.E., III; Hyman, M.H. *Ama Guides to the Evaluation of Disease and Injury Causation*, 2nd ed.; American Medical Association: Chicago, IL, USA, 2014; pp. 1–792.
15. PEROSH. Perosh—Osh Evidence Clearinghouse of Systematic Reviews: Partnership for European Research in Occupational Safety and Health. 2014. Available online: http://www.perosh.eu/wp-content/uploads/2013/06/PEROSH-Clearinghouse-Methods_Last-update-June-2014.pdf (accessed on 9 May 2016).
16. Schaafsma, F.; Hulshof, C.; Verbeek, J.; Bos, J.; Dyserinck, H.; van Dijk, F. Developing search strategies in medline on the occupational origin of diseases. *Am. J. Ind. Med.* **2006**, *49*, 127–137. [CrossRef]
17. Verbeek, J.; Salmi, J.; Pasternack, I.; Jauhiainen, M.; Laamanen, I.; Schaafsma, F.; Hulshof, C.; van Dijk, F. A search strategy for occupational health intervention studies. *Occup. Environ. Med.* **2005**, *62*, 682–687. [CrossRef] [PubMed]
18. Van Tulder, M.; Furlan, A.; Bombardier, C.; Bouter, L. Updated method guidelines for systematic reviews in the cochrane collaboration back review group. *Spine* **2003**, *28*, 1290–1299. [CrossRef] [PubMed]
19. Padula, R.S.; Comper, M.L.C.; Sparer, E.H.; Dennerlein, J.T. Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review. *Appl. Ergon.* **2017**, *58*, 386–397. [CrossRef] [PubMed]
20. Sanderson, S.; Tatt, I.D.; Higgins, J.P. Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: A systematic review and annotated bibliography. *Int. J. Epidemiol.* **2007**, *36*, 666–676. [CrossRef] [PubMed]
21. Wong, W.C.; Cheung, C.S.; Hart, G.J. Development of a quality assessment tool for systematic reviews of observational studies (qatso) of hiv prevalence in men having sex with men and associated risk behaviours. *Emerg. Themes Epidemiol.* **2008**, *5*, 23. [CrossRef] [PubMed]
22. Sulsky, S.I.; Carlton, L.; Bochmann, F.; Ellegast, R.; Glitsch, U.; Hartmann, B.; Pallapies, D.; Seidel, D.; Sun, Y. Epidemiological evidence for work load as a risk factor for osteoarthritis of the hip: A systematic review. *PLoS ONE* **2012**, *7*, e31521. [CrossRef] [PubMed]
23. Boschman, J.S.; van der Molen, H.F.; Sluiter, J.K.; Frings-Dresen, M.H. Occupational demands and health effects for bricklayers and construction supervisors: A systematic review. *Am. J. Ind. Med.* **2011**, *54*, 55–77. [CrossRef]

24. Du Prel, J.B.; Hommel, G.; Rohrig, B.; Blettner, M. Confidence interval or p-value?: Part 4 of a series on evaluation of scientific publications. *Dtsch. Arztebl. Int.* **2009**, *106*, 335–339. [CrossRef]
25. Howard, J.; Piacentino, J.; MacMahon, K.; Schulte, P. Using systematic review in occupational safety and health. *Am. J. Ind. Med.* **2017**, *60*, 921–929. [CrossRef]
26. Huguet, A.; Hayden, J.A.; Stinson, J.; McGrath, P.J.; Chambers, C.T.; Tougas, M.E.; Wozney, L. Judging the quality of evidence in reviews of prognostic factor research: Adapting the grade framework. *Syst. Rev.* **2013**, *2*, 71. [CrossRef]
27. Van der Molen, H.F.; Foresti, C.; Daams, J.G.; Frings-Dresen, M.H.W.; Kuijer, P. Work-related risk factors for specific shoulder disorders: A systematic review and meta-analysis. *Occup. Environ. Med.* **2017**, *74*, 745–755. [CrossRef] [PubMed]
28. Hayden, J.A.; Cote, P.; Bombardier, C. Evaluation of the quality of prognosis studies in systematic reviews. *Ann. Intern. Med.* **2006**, *144*, 427–437. [CrossRef]
29. Hayden, J.A.; van der Windt, D.A.; Cartwright, J.L.; Cote, P.; Bombardier, C. Assessing bias in studies of prognostic factors. *Ann. Intern. Med.* **2013**, *158*, 280–286. [CrossRef] [PubMed]
30. Viera, A.J.; Garrett, J.M. Understanding interobserver agreement: The kappa statistic. *Fam. Med.* **2005**, *37*, 360–363. [PubMed]
31. Fan, Z.J.; Silverstein, B.A.; Bao, S.; Bonauto, D.K.; Howard, N.L.; Spielholz, P.O.; Smith, C.K.; Polissar, N.L.; Viikari-Juntura, E. Quantitative exposure-response relations between physical workload and prevalence of lateral epicondylitis in a working population. *Am. J. Ind. Med.* **2009**, *52*, 479–490. [CrossRef] [PubMed]
32. Herquelot, E.; Bodin, J.; Roquelaure, Y.; Ha, C.; Leclerc, A.; Goldberg, M.; Zins, M.; Descatha, A. Work-related risk factors for lateral epicondylitis and other cause of elbow pain in the working population. *Am. J. Ind. Med.* **2013**, *56*, 400–409. [CrossRef] [PubMed]
33. Nordander, C.; Ohlsson, K.; Akesson, I.; Arvidsson, I.; Balogh, I.; Hansson, G.A.; Stromberg, U.; Rittner, R.; Skerfving, S. Risk of musculoskeletal disorders among females and males in repetitive/constrained work. *Ergonomics* **2009**, *52*, 1226–1239. [CrossRef] [PubMed]
34. Nordander, C.; Ohlsson, K.; Akesson, I.; Arvidsson, I.; Balogh, I.; Hansson, G.A.; Stromberg, U.; Rittner, R.; Skerfving, S. Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands—A synthesis of group-level data on exposure and response obtained using uniform methods of data collection. *Appl. Ergon.* **2013**, *44*, 241–253. [CrossRef]
35. Walker-Bone, K.; Palmer, K.T.; Reading, I.; Coggon, D.; Cooper, C. Occupation and epicondylitis: A population-based study. *Rheumatology* **2012**, *51*, 305–310. [CrossRef]
36. Descatha, A.; Dale, A.M.; Jaegers, L.; Herquelot, E.; Evanoff, B. Self-reported physical exposure association with medial and lateral epicondylitis incidence in a large longitudinal study. *Occup. Environ. Med.* **2013**, *70*, 670–673. [CrossRef]
37. Fan, Z.J.; Silverstein, B.A.; Bao, S.; Bonauto, D.K.; Howard, N.L.; Smith, C.K. The association between combination of hand force and forearm posture and incidence of lateral epicondylitis in a working population. *Hum. Factors* **2014**, *56*, 151–165. [CrossRef] [PubMed]
38. Herquelot, E.; Gueguen, A.; Roquelaure, Y.; Bodin, J.; Serazin, C.; Ha, C.; Leclerc, A.; Goldberg, M.; Zins, M.; Descatha, A. Work-related risk factors for incidence of lateral epicondylitis in a large working population. *Scand. J. Work Environ. Health* **2013**, *39*, 578–588. [CrossRef] [PubMed]
39. Svendsen, S.W.; Johnsen, B.; Fuglsang-Frederiksen, A.; Frost, P. Ulnar neuropathy and ulnar neuropathy-like symptoms in relation to biomechanical exposures assessed by a job exposure matrix: A triple case-referent study. *Occup. Environ. Med.* **2012**, *69*, 773–780. [CrossRef] [PubMed]
40. Spahn, G.; Lipfert, J.-U.; Schmidt, A.; Maurer, C.; Dein, W.; Hartmann, B.; Hofmann, G.O.; Schiele, R. Risk factors for the lateral epicondylitis—Results from a case-control study. *Arbeitsmed Sozialmed Umweltmed* **2016**, *51*, 360–368.
41. Moore, J.S.; Garg, A. The strain index: A proposed method to analyze jobs for risk of distal upper extremity disorders. *Am. Ind. Hyg. Assoc. J.* **1995**, *56*, 443–458. [CrossRef] [PubMed]
42. Bao, S.; Howard, N.; Spielholz, P.; Silverstein, B. Quantifying repetitive hand activity for epidemiological research on musculoskeletal disorders—Part II: Comparison of different methods of measuring force level and repetitiveness. *Ergonomics* **2006**, *49*, 381–392. [CrossRef]
43. Bao, S.; Silverstein, B. Estimation of hand force in ergonomic job evaluations. *Ergonomics* **2005**, *48*, 288–301. [CrossRef]

44. Bao, S.; Spielholz, P.; Howard, N.; Silverstein, B. Quantifying repetitive hand activity for epidemiological research on musculoskeletal disorders—Part I: Individual exposure assessment. *Ergonomics* **2006**, *49*, 361–380. [CrossRef]
45. McAtamney, L.; Nigel Corlett, E. Rula: A survey method for the investigation of work-related upper limb disorders. *Appl. Ergon.* **1993**, *24*, 91–99. [CrossRef]
46. Thomsen, J.F.; Mikkelsen, S.; Andersen, J.H.; Fallentin, N.; Loft, I.P.; Frost, P.; Kaergaard, A.; Bonde, J.P.; Overgaard, E. Risk factors for hand-wrist disorders in repetitive work. *Occup. Environ. Med.* **2007**, *64*, 527–533. [CrossRef]
47. Borg, G.A. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exerc.* **1982**, *14*, 377–381. [CrossRef] [PubMed]
48. Silverstein, B.A.; Fine, L.J.; Armstrong, T.J. Hand wrist cumulative trauma disorders in industry. *Br. J. Ind. Med.* **1986**, *43*, 779–784. [CrossRef] [PubMed]
49. Latinovic, R.; Gulliford, M.C.; Hughes, R.A. Incidence of common compressive neuropathies in primary care. *J. Neurol. Neurosurg. Psychiatry* **2006**, *77*, 263–265. [CrossRef] [PubMed]
50. Ranavolo, A.; Chini, G.; Silvetti, A.; Mari, S.; Serrao, M.; Draicchio, F. Myoelectric manifestation of muscle fatigue in repetitive work detected by means of miniaturized semg sensors. *Int. J. Occup. Saf. Ergon.* **2018**, *24*, 464–474. [CrossRef] [PubMed]
51. Merletti, R.; Parker, P.J. *Electromyography: Physiology, Engineering, and Non-Invasive Applications*; Wiley-IEEE Press: New York, NY, USA, 2004.

## 2.2 From the review to the assessment approach – parameter definition

The systematic review by Seidel et al. 2019b is the basis for considerations used to develop a measurement-based assessment method. According to this work, the most frequently reported risk factors with the most specifications are, 'Posture/movement' (44 of 133 specifications in 7/10 studies) and 'Combined exposures' (62 of 133 specifications in 7/10 studies). This was verified (**Figure 2.** in the manuscript by Seidel et al. 2019b, p. 8). Thus, these two main exposure categories seem to be the most important ones. As more combined exposures were reported, the main risk factor 'Combined exposures' appears to be most relevant according to Seidel and colleagues. Furthermore, the review showed that the relevance – to analyze the combination of risk factors – has increased significantly since the key paper of van Rijn et al. 2009a.

Regarding Seidel's systematic review, the main exposure categories were subdivided into subcategories. The evidence of these subcategories was determined (**Table 5.** in the manuscript by Seidel et al. 2019b, p. 14). Evidence was rated as 'high' in the following 7 of 16 subcategories: "*S2 (Forceful exertion), S4 (Manual load handling), S6 (Repetitiveness), S8 (Hand movements), S10 (Non-neutral posture), S13 (Force and repetition), S14 (Posture and force)*" (Seidel et al. 2019b, p. 13). Thus, these 7 exposure subcategories appear to be the most important ones. Considering the main risk factors and highest evidence of exposure subcategories "*S13 (Force and repetition)*" and "*S14 (Posture and force)*" (Seidel et al. 2019b, p. 13) are the most important ones. Similar evidence ratings by Melhorn et al. 2014 provided additional support for this assumption. More precise, force in combination with another factor (repetition or posture) has the greatest influence on the development of SDEs. Based on Seidel's review and given the identified relevance of the two subcategories, the assessment method to be developed should evaluate either the combination of force and repetition or force and posture. Further intensive visual investigations revealed higher measures of e.g., ORs for S13 than for S14 (**Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10). Thus, S13 appears to be slightly more significant than subcategory S14.

In addition, Seidel and colleagues identified in 2019 only three studies (Fan et al. 2014b; Fan et al. 2009; Nordander et al. 2013) that conducted measurement-based exposure assessments based on sensor or force gauge data. These studies also received the highest score (5 out of 5) for exposure assessment (**Table 3.** in the manuscript by Seidel et al. 2019b, p. 7). Based on these three studies, the following 19 risk factor specifications could be considered for development of an assessment approach: "*#6 Forceful lifting (≥4.5 kg) >0% of time*"; "*#7 Forceful lifting (≥4.5 kg) ≥2 times/min*"; "*#10 wrist angular velocity (5°/s) in [%/(°/s)]*"; "*#16 Wrist flexion (−40.0°) in [%/°]*"; "*#17 Wrist flexion (−20.0°) in [%/°]*"; "*#24 Forearm rotation ≥45° for ≥45% time and duty cycle ≥10% of time*"; "*#25 Forearm pronation ≥45° for ≥40% time and duty cycle ≥10% of time*"; "#26 *Forearm supination ≥45° for ≥5% time*"; "*#29 Frequency of forceful exertions (≥44.1 N or ≥4.5 kg) ≤1 to <5 times/min*"; "*#30 Frequency of forceful exertions (≥44.1 N or ≥4.5 kg) ≥5 times/min*"; "*#31 Duty cycle of forceful exertions (≥44.1 N or ≥4.5 kg) from ≤3 to <15% time*"; "*#32 Duty cycle of forceful exertions (≥44.1 N or ≥4.5 kg) for ≥15% time*"; "*#33 Forearm supination ≥45° and forceful lifting (≥4.5 kg) in [% time]*"; "*#34 Forearm supination ≥45° ≥5% (duty cycle) and forceful lifting (≥4.5 kg) >0% of time*"; "*#35 Forearm supination ≥45° for <5% time and lifting (≥4.5 kg) ≥3% of time*"; "*#36 Forearm supination ≥45° for <5% time and any power grip (≥44.1 N)*"; "*#37 Forearm rotation ≥45° for ≥45% time and any power grip (≥44.1 N)*"; "*#38 Forearm pronation ≥45° for ≥40% time and any power grip (≥44.1 N)*"; "*#39 Forearm pronation ≥45° for ≥40% time and lifting (≥4.5 kg) ≥3% of time*" (**Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10). Furthermore, Nordander et al. 2013 predominantly reported on wrist flexion/extension (**Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10, specifications: "*#10 Wrist angular velocity (5°/s) in [%/(°/s)]*"; "*#16 Wrist flexion (−40.0°) in [%/°]*"; "*#17 Wrist flexion (−20.0°) in [%/°]*"). Whereat, Fan et al. 2009 and Fan et al. 2014b reported on forearm supination/pronation (**Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10, specifications: "*#24 Forearm rotation ≥45° for ≥45% time and duty cycle ≥10% of time*"; "*#25 Forearm pronation ≥45° for ≥40% time and duty cycle ≥10% of time*"; "*#26 Forearm supination ≥45° for ≥5% time*"; "*#33 Forearm supination ≥45° and forceful lifting (≥4.5 kg) in [% time]*"; "*#34 Forearm supination ≥45° ≥5% (duty cycle) and forceful lifting (≥4.5 kg) >0% of time*"; "*#35 Forearm supination ≥45° for <5% time and lifting (≥4.5 kg) ≥3% of time*"; "*#36 Forearm supination ≥45° for <5% time and any power grip (≥44.1 N)*"; "*#37 Forearm rotation ≥45° for ≥45% time and any power grip (≥44.1 N)*"; "*#38 Forearm pronation ≥45° for ≥40% time and any power grip (≥44.1 N)*"; "*#39 Forearm pronation ≥45° for ≥40% time and lifting (≥4.5 kg) ≥3% of time*"). Further visual inspection of **Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10 revealed that wrist flexion/extension and forearm supination/pronation are the two most common degrees of freedom (DoF) examined in all included studies (specifications: "*#13 Frequent wrist bending or twisting on average 2 to 4 h/day*"; "*#14 Frequent wrist bending or twisting on average ≥4 h/day*"; "*#15 Frequent wrist bending ≥4 h/day and forearm rotating on average ≥2 h/day*"; "*#16 Wrist flexion (−40.0°) in [%/°]*"; "*#17 Wrist flexion (−20.0°) in [%/°]*"; "*#18 Wrist extension >1 h/day*"; "*#19 Wrist flexion >1 h/day*"; "*#20 Extreme wrist bending >2 h/day*"; "*#22 Forearm rotating (also twisting, or screwing motion) ≥4 h/day*"; "*#24 Forearm rotation ≥45° for ≥45% time and duty cycle ≥10% of time*"; "*#25 Forearm pronation ≥45° for ≥40% time and duty cycle ≥10% of time*"; "*#26 Forearm supination ≥45° for ≥5% time*"; "*#33 Forearm supination ≥45° and forceful lifting (≥4.5 kg) in [% time]*"; "*#34 Forearm supination ≥45° ≥5% (duty cycle) and forceful lifting (≥4.5 kg) >0% of time*"; "*#35 Forearm supination ≥45° for <5% time and lifting (≥4.5 kg) ≥3% of time*"; "*#36 Forearm supination ≥45° for <5% time and any power grip (≥44.1 N)*"; "*#37 Forearm rotation ≥45° for ≥45% time and any power grip (≥44.1 N)*"; "*#38 Forearm pronation ≥45° for ≥40% time and any power grip (≥44.1 N)*"; "*#39 Forearm pronation ≥45° for ≥40% time and lifting (≥4.5 kg) ≥3% of time*"). As a digression, it can be additionally mentioned here that, for example, the pressure on the ulnar nerve increases through forearm movements. This pathophysiological effect has been extensively studied by the National Research Council (NRC 1999) and supports the assumption that besides flexion/extension of the wrist, forearm supination/pronation might be very important in connection with the development of distal upper extremity disorders. Further in the ideas for approach development, Nordander et al. 2013 dealt with similar content (e.g., specification: "*#10 Wrist angular velocity (5°/s) in [%/(°/s)]*" in **Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10) as Schedlbauer et al. 2014 (a basis for further assessment developments, chapter 1.1.5). Therefore, Nordander's work should be preferably included in the development of the assessment method. Another aspect in favor of Nordander et al. 2013 is the usage of EMG. This is an adequate method for measuring exposures, especially muscle activity (Seidel et al. 2019b). Regarding risk factor specification "*#3 <10% maximum voluntary contraction across a full working day*" and "*#4 10 to 29% maximum voluntary contraction across a full working day*" investigated by Svendsen et al. 2012 and shown in **Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10, it could be assumed that muscle activity and maximum voluntary contraction might be very important and should be considered in the assessment of occupational exposure. Altogether, all these considerations led to the selection of main exposure category 'Combined exposures'. More precisely, it led still to the selection of subcategory S13 – the combination of force and repetition. Additionally, reasonable DoF's such as wrist flexion/extension and forearm supination/pronation and results of Nordander and colleagues published in 2013 should be considered in the assessment approach. Based on this information and the approach by Schedlbauer and colleagues from 2014, further systematic reviews were analyzed. Especially reviews focusing on upper extremity workload assessments (Grooten and Johanssons 2018; Nasrull Abdol Rahman and Syafiqa Abd Razak 2016; Takala et al. 2010) were investigated. In this context, Takala et al. 2010 investigated for instance 30 observational methods in which the following risk factors were assessed: force (n = 25), repetition (n = 19), posture (n = 28), duration (n = 16), vibration (n = 7), movements (n = 6), static action (n = 1) or work activity (n = 1). This study showed additionally that force, repetition, and posture were also most frequently recorded in observational-based assessments. Overall, the ACGIH[1] TLV for HAL[2] method (ACGIH 2001, 2018) was identified in these reviews as the most appropriate approach that provides a very good basis for a measurement-based assessment of physical exposures of the elbow (and hand). In this ACGIH method, the combination of force and repetition is illustrated. It is related to hand/wrist and includes concrete evidence that EMG can be used to assess the force component (ACGIH 2018; Harris et al. 2011). As stated by Seidel's workgroup (Seidel et al. 2019 c; Weber et al. 2019a), it also includes evidence that movement velocities are included alongside frequencies and pauses via a verbally anchored scale (Latko et al. 1997). Additionally, the TLV for HAL method has been used to verify associations with specific elbow diseases like LE (Garg et al. 2014), or diffuse disorders such as forearm or elbow tendonitis (Franzblau et al. 2005; Werner et al. 2005).

To link the kinematic parameters of Nordander et al. 2013 and Schedlbauer et al. 2014 with EMG to TLV for HAL, individual studies were specifically searched by D.H.S. in

[1] American Conference of Governmental Industrial Hygienists.

[2] Threshold Limit Value for Hand Activity Level.

Google Scholar narrative up to including 2019 (potential search terms: e.g., angular velocity, frequency, pauses, upper limb, inertial sensor, EMG). These studies should include information on kinematic parameters such as mean power frequency, angular velocity or kinematic micro-pauses, and EMG, similar to Nordander and colleagues or Schedlbauer's work.

**Chapter summary:** Via the procedure described, using the considerations from chapter 1.1.5, the following parameters are defined, which should be transferred into a measurement-based assessment approach for the elbow region: Combination of risk factors: force and repetition; Degrees of freedom (DoF): wrist flexion/extension; forearm supination/pronation; Kinematic parameters: mean power frequency (MPF), angular velocity (ω), kinematic micro-pauses (MP); Kinetic parameter: EMG; Baseline methods: observational-based assessment approach TLV for HAL (ACGIH 2001, 2018) and the traffic light assessment approach of Schedlbauer et al. 2014.

## 2.3 Publication 2 – Seidel et al. 2021b

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# Assessment of work-related hand and elbow workloads using measurement-based TLV for HAL

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ABSTRACT

Direct-measurement-based methods for assessing workloads of the hand or elbow in the field are rare. Aim of the study was to develop such a method based on the Threshold Limit Value for Hand Activity Level (TLV for HAL). Hence, HAL was quantified using kinematic data (mean power frequencies, angular velocities and micro-pauses) and combined with electromyographic data (root-mean-square values) in order to generate a measurement-based TLV for HAL (mTLV for HAL). The multi-sensor system CUELA including inertial sensors, potentiometers and a 4-channel surface electromyography module was used. For wrist and elbow regions, associations between mTLV for HAL and disorders/complaints (quantified by odds ratios (OR [95%-confidence interval])) were tested exploratively within a cross-sectional field study with 500 participants. Higher workloads were frequently significantly associated with arthrosis of distal joints (9.23 [3.29–25.87]), wrist complaints (2.89 [1.63–5.11]) or elbow complaints (1.99 [1.08–3.67]). The new method could extend previous application possibilities.

## 1. Introduction

Work-related musculoskeletal disorders (MSDs) of the upper extremities may be a consequence of overloading of physiological structures, such as muscles, tendons or ligaments and nearby nerves, caused by work-related physical factors. Awkward postures, repetitive movements, force exertion and hand-arm vibration are well-known risk factors for upper limb MSDs (Bernard, 1997). These include specific disorders such as Carpal Tunnel Syndrome (CTS), Lateral Epicondylitis (LE) and finger joint arthrosis (da Costa and Vieira, 2010; Descatha et al., 2016; Melhorn et al., 2014; Seidel et al., 2019). Tasks involving highly repetitive work combined with high forces may lead to higher risks of musculoskeletal hand and elbow disorders than discrete exposures involving either or both high repetitions and high forces (Garg et al., 2017; Melhorn et al., 2014).

In practice, the above-mentioned risk factors are usually recorded by surveys, observations, or videos. In recent years, however, kinematic measurement methods in combination with electromyographic measurements have increasingly been used for objective recording of work-related risk factors of the hand-arm-system (Hansson et al., 2004b; Nordander et al., 2004). Repetitive wrist and elbow kinematics have been successfully assessed in field studies by calculation of parameters such as the mean power frequency of the power spectra of angular data (MPF), mean angular velocities (ω) and kinematic micro-pauses (MP) based on motion sensors (Barrero et al., 2012; Hansson et al., 2009; Nordander et al., 2013). Technical measurements and definitions of these kinematic parameters had previously been described in principle (Hansson et al., 1996). Generally, the use of sensors or wearables is recommended for upper limb workload assessments, owing to advances of technical devices with respect to their versatility, accuracy, and objectivity (Weber et al., 2018).

The Strain Index (SI) (Moore and Garg, 1995) and rapid upper limb assessment (RULA) (McAtamney and Nigel Corlett, 1993) exist since years as observational-based assessment tools. Recently, these methods were transferred from observational-based to measurement-based[1] methods and were available for objective risk assessments (Peppoloni

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[1] "Measurement-based" is defined in this article as a method that is supported by continuous data recorded by sensors. Data from video analyses are not meant in this case.

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et al., 2016). Besides this, the original and revised Threshold Limit Value for Hand Activity Level (TLV for HAL) approach was established for the assessment of combinations of work-related risk factors (ACGIH, 2001; ACGIH, 2018). This estimates the risk for work-related MSDs by considering HAL based on standardized observation and normalized peak force (NPF). Positive associations were found between the risk identified by the TLV for HAL and CTS (Bonfiglioli et al., 2013; Kapellusch et al., 2014), elbow/forearm/hand/wrist/finger tendonitis (Franzblau et al., 2005; Werner et al., 2005) or LE (Garg et al., 2014). Harris et al. (2011) and ACGIH (2018) proposed the use of electromyography (EMG) or force gauges for NPF determination as measurement-based alternatives to the BORG scale (Borg, 1982). Additionally, HAL estimation has also already been technically adapted. HAL can be determined by several methods such as video-based computer vision algorithms (Akkas et al., 2017, 2018, 2019; Chen et al., 2013; Greene et al., 2017), calculations using hand speed based on pixels and video processing (Akkas et al., 2015), frequency and duty cycle estimation using automated video processing (Akkas et al., 2016) and multimedia video task analysis (Radwin et al., 2015).

However, also workplaces exist where it is not possible to make video recordings because of trade secrets (e.g., industrial prototype construction) or for ethical reasons (e.g., workplaces in health care or handling with patients). At other restricted workplaces (e.g., transistor module assembly) the upper extremities can be hidden by several objects or other body parts. Especially in these cases, further HAL developments are needed to perform objective risk assessments at workplaces where video analyses cannot be used or were limited. For further video independent developments, sensors such as inertial sensors and EMG sensor technology seem to be suitable, since more detailed and further valid information can be recorded on forces or when the arms are twisted. By using only kinematic sensor data, duty cycles cannot be precisely automatically identified. As manual identification of duty cycles is not a practical option within long measurements, an approach that is independent of the determination of duty cycles is required for automated analyses. In addition, in the above-mentioned studies, the TLV for HAL method was previously used for the assessment of hand workload and to our knowledge, there are no attempts so far to include also in this type of analyses a simultaneous assessment of the elbow workload.

We developed an automated measurement-based assessment approach for the wrist and elbow region using the TLV for HAL estimation. This approach assesses the HAL independently from the identification of duty cycles based on MPF, ω and MP for the hands and elbows using kinematic data. The present study aimed to combine these calculated HALs with measurement-based NPF information to deliver an overall assessment. We assumed a measurement-based assessment of hand and elbow workloads employing directly measured combined kinematic and kinetic exposures to be feasible. The new approach was compared with the observational-based method and it was tested in the field by exploring the association between the produced estimations of workload and several upper extremity musculoskeletal outcomes, using the data of the cross-sectional study within the MEGAPHYS[2] project (BAuA, 2019; Klussmann et al., 2017). We expected that higher exposures of combined risk factors were positively associated with work-related upper extremity disorders.

## 2. Materials and methods

### 2.1. Assessment approach – development

This new approach presented here followed the TLV for HAL method (ACGIH, 2018). However, the information on repetition and force were not assessed by observation or video-based computer vision algorithms but estimated with the use of kinematic and electromyographic directly measured sensor data.

#### 2.1.1. Measurement-based representation of hand repetition (repetition score) based on HAL

The original HAL includes a verbally anchored scale (Latko et al., 1997) and considers frequencies, movement velocities and pauses. We utilized these aspects and developed a measurement-based representation of hand repetition following HAL by using the kinematic parameters of MPF, ω and MP for wrist flexion/extension, suggested by Hansson et al. (1996), as suitable representations of hand activity and repetition. The category limits for MPF, ω and MP were set based on literature findings (Table 1). Besides wrist flexion/extension, the forearm supination/pronation is also relevant for the development of distal upper extremity MSDs (e.g., ulnar nerve pressure increases during these forearm movements, NRC, 1999). The ranges and limits of forearm supination/pronation used in previous studies (Barrero et al., 2012; Hansson et al., 2004a) were similar to those for wrist flexion/extension and were added to Table 1. We thus assumed that the repetition score (RepSc, RepScore) can be calculated exactly in the same way for both degrees of freedom (DoF) using equation (1). As the wrist repetition score is based on kinematic parameters of wrist flexion/extension, the elbow repetition score is based on parameters of forearm supination/pronation.

$$RepSc_{Wrist\ or\ Elbow} = MPF\text{-}score_{i\ or\ k} + \omega\text{-}score_{i\ or\ k} + MP\text{-}score_{i\ or\ k} \quad (1)$$

$i$ = wrist flexion/extension; $k$ = forearm supination/pronation; $\{RepSc \in \mathbb{N} \mid 0 \leq RepSc \leq 10\}$

To test the comparability of HAL and repetition score, we performed comparisons of both methods within 50 cycles (mean: 18.0 s ± 15.7 s) of 10 different industrial repetitive work tasks (average cycle time < 30 s according to Silverstein et al., 1986). Kinematic and video data were extracted from the sample data set described in chapter 2.2.1 and 2.2.2. Using a frame-by-frame video analysis, intervals and duty cycles were set manually. HAL was determined using equation (2) (Akkas et al. (2015) p. 3; Radwin et al. (2015) p. 1).

$$HAL = 6.56 \ln D \left[\frac{F^{1.31}}{1 + 3.18F^{1.31}}\right] \quad (2)$$

For each cycle interval, time-weighted RepScore of the wrist was also automatically calculated. As HAL was not normally distributed (Kolmogorov-Smirnov test) the non-parametric Wilcoxon signed-rank test was performed to compare HAL results based on observations and our proposed method using sensors. The test revealed no statistically significant differences between the two methods ($Z$-$value$ = 0.796 (based on negative ranks), $p = 0.426$). Both methods show a high correlation (Spearman's rho: $\rho = 0.847$, $p < 0.0001$). Therefore, we assumed that the wrist HAL can be equated to the wrist RepScore, as expressed by equation (3).

$$RepSc_{Wrist} = HAL_{Wrist} \quad (3)$$

$\{RepSc \in \mathbb{N} \mid 0 \leq RepSc \leq 10\}$; $\{HAL \in \mathbb{R} \mid 0 \leq HAL \leq 10\}$

#### 2.1.2. Combining repetition score and force assessment

Electromyographic data of the forearm flexor/extensor muscles were used to estimate the force component of the TLV for HAL. With the use of the individual maximum voluntary contraction (MVC), continuous EMG data were normalized for each subject on a continuous scale from 0 to 10 (NPF determination). Seidel et al. (2019) found that forceful grip or maximum forceful efforts of the hand, and values below 29% MVC are already associated with an increased risk for LE, medial epicondylitis (ME) or ulnar neuropathy. Therefore, forearm flexor/extensor muscle loading was equally used for wrist and elbow joint.

The kinematic and force parameters were recorded continuously (Section 2.2.2). The NPF and the HAL representation (RepSc) were

[2] Multilevel risk assessment of physical workload.

**Table 1**
Applied classification of kinematic parameters for assessing repetition of the hand and elbow – limits set based on a narrative and a systematic literature review (Seidel et al., 2019).

| Mean power frequency (MPF)[b] 50th percentile [Hz] | | | Angular velocity (ω)[c] 50th percentile [°/s] | | | Micro-pauses[a] (MP)[d] [% time] | | |
|---|---|---|---|---|---|---|---|---|
| MPF | MPF-score | Verbal anchoring[e] | ω | ω-score | Verbal anchoring[e] | MP | MP-score | Verbal anchoring[e] |
| ≤0.17 | 0 | Not frequent | ≤5 | 0 | Extremely slow motion (no exertion) | ≥10 | 0 | Long, regular pauses, hands idle most of time |
| >0.17 to ≤ 0.25 | 1 | Slow, steady | >5 to ≤ 11 | 1 | Very slow motion | <10 to ≥ 5 | 1 | Consistent conspicuous long pauses |
| >0.25 to ≤ 0.32 | 2 | Steady | >11 to ≤ 17 | 2 | Motion | <5 | 2 | Frequent brief pauses, sometimes infrequent pauses |
| >0.32 to ≤ 0.39 | 3 | Rapid, steady | >17 to ≤ 23 | 3 | Medium motion (exertion) | | | |
| >0.39 | 4 | Difficulty keeping up | >23 | 4 | Rapid motion (exertion) | | | |

Limits of kinematic parameters valid for two degrees of freedom (hand: wrist flexion/extension, elbow: forearm supination/pronation).
[a] Continuous time sequence of ≥0.5s with low angular velocity (<1.0°/s) (Hansson et al., 1996); MP is related to the analyzed period of time, such as task or shift. Higher MP values indicated more time on muscular rest and ran contrary to the trend of MPF or ω.
[b] Derived from Arvidsson et al. (2003); Barrero et al. (2012); Hansson et al. (2000); Hansson et al. (2004a,b); Ohlsson et al. (1994); Schedlbauer et al. (2014); Stal et al. (1999).
[c] Derived from Arvidsson et al. (2003); Balogh et al. (2019); Barrero et al. (2012); Hansson et al. (2009); Hansson et al. (1996); Hansson et al. (2004a); Nordander et al. (2013); Ohlsson et al. (1994); Schedlbauer et al. (2014).
[d] Derived from Arvidsson et al. (2003); Hansson et al. (2009); Hansson et al. (2004a); Schedlbauer et al. (2014).
[e] Derived from ACGIH (2018); Latko et al. (1997).

determined on a task basis separately for both DoF, and extrapolations for the whole shift were performed with time weightings. The shift-based results were subsequently inserted into the two linear equations (4) and (5) for TLV and Action Limit (AL) calculation by ACGIH (2018), using the measurement-based RepScore instead of the observational-based HAL.

$$\text{TLV: } NPF_{measurement\text{-}based} = 5.6 - 0.56 \text{ x } RepSc_{Wrist \text{ or } Elbow} \quad (4)$$

$$\text{AL: } NPF_{measurement\text{-}based} = 3.6 - 0.56 \text{ x } RepSc_{Wrist \text{ or } Elbow} \quad (5)$$

This yielded a rated task or shift specific-value for wrist and elbow joints, denoted measurement-based TLV for HAL (mTLV for HAL). It was classified in three TLV for HAL exposure categories (>TLV: high exposure, ≥ AL to ≤ TLV: medium exposure < AL: low exposure) according to Kapellusch et al. (2017).

### 2.2. *Assessment approach – testing in field*

#### 2.2.1. *Study design*

To test the new approach, the association between the new metric and musculoskeletal outcomes of the hand and elbow was assessed. This work was conducted as a pilot study based on the MEGAPYHS data set. Exposure and medical outcome data were collected during the cross-sectional study within MEGAPHYS (BAuA, 2019; Klussmann et al., 2017) from June 2015 to May 2017. Recruitment of workers was done via oral presentation, telephone or email directed to 44 companies in 21 different economic sectors in Germany. Once the participants had voluntarily granted written consent, experienced researchers blinded to subjects' health status collected 198 exposure profiles via interviews, observations, and direct measurements. Therefore, 198 workplaces were examined, most of which occupied several workers. Exposure estimates of measured workers were assigned to other workers in the same company occupying the same job. In total, 808 workers were selected by companies' internal invitations for further medical investigations. Trained physicians blinded to subjects' exposure status completed medical interviews (n = 789) and physical examinations (n = 753), taking into account specific inclusion criteria (i.e., age 19–65 years old, proficient in German language, employment at workplace at least 3 months) as described elsewhere (Klussmann et al., 2017). Ethics committees (University of Technology Darmstadt, Germany, EK 2/2013, EK 12/2015; Eberhard Karls University Tuebingen, Germany, 004/2016BO2) approved MEGAPHYS and the present work. In MEGAPHYS there were different aims for which different data sets were created from the total of 808 participants. One aim was criterion validation including performing association analyses between exposures and medical outcomes of different body regions (e.g., cervical/lumbar spine, upper arms, hips, knees). Within the MEGAPHYS framework 275 subjects were excluded according to the following reasons: no information on tasks of a typical shift; language problems; no medical outcome data; no exposure data; no information on relevant confounders (e.g., age, gender, smoking behavior); and work experience in the job less than 1 year. A comparison of key characteristics (age, gender, BMI, height, education level, job seniority) of included and excluded workers revealed, that workers in the final MEGAPHYS sample (n = 533) were generally similar to the initial 808 workers.

Based on the 533 subjects, we excluded 33 further cases for this study, as no EMG data were available. Due to this low exclusion rate (6.2%) we do not assume any bias here either. The final 500 subjects were assigned to 140 measured exposure profiles. The profiles involved different types of work tasks: vulcanization of rubber tubes including trimming, washing and demolding (n = 15); warehouse logistics including storage and retrieval and packaging of consignments and single goods (n = 31); logistics and picking of containers and single goods (food industry, car construction) including machine control, driving of forklifts or other lifting vehicles (n = 27); portioning of food, cleaning of dishes, rooms and beds including bed transport in hospitals (n = 7); upholstery of car seats and manual assembly individually or at the line, including visual and machine-supported inspection and completion of automotive parts (n = 34); repair and manufacturing processes including grinding/forging and visual inspection (n = 20); road construction, fiber optic cable laying and house construction, including bricklayers' tasks (n = 5); office work (n = 1).

#### 2.2.2. *Technical measurements of physical exposure*

Measurements of relevant tasks at each workplace (0.5 to almost 5 h per worker) were conducted, which were thought to be representative exposures for each job. Kinematics were measured with a sampling rate of 50 Hz by means of the CUELA[3] system (Ellegast et al., 2010). The system consists of sensors (inertial sensors, potentiometer) and a miniature data storage unit and can be attached to the subject's clothing

[3] Computer-assisted recording and long-term analysis of musculoskeletal loads.

(Fig. 1). Kinematic measurement data were synchronized to two video recordings. Therefore, a very fast initial knee movement (full extension to full flexion back to full extension) was performed. Using the CUELA-related software WIDAAN, the maximum knee flexion angle was synchronized manually with video frames of each camera, where the knee was most flexed. Overall, the videos were only used in this approach to document the workplace and environment or as a non-essential supplementary tool to make a task visible. The videos also served testing the results of the proposed method with observational-/video-based HAL assessments. Kinematic and EMG data were finally recorded exclusively by sensors, not by videos.

The ambulatory measuring system is designed for long-term field measurements at the workplace and is of modular design. For the present project, a configuration was employed that permits kinematic measurements of the legs (left, right), back, shoulder-arm-hand-system (left, right) and head. Body angles and their DoF that were acquired by CUELA are specified in Table 2.

Details of the data logger and further sensors, their accuracy (±1°) and data processing can be found elsewhere (Barrero et al., 2012; Glitsch et al., 2007).

The system was synchronized with a 4-channel surface EMG module (BioMed, Germany). In total, 9 Ag/AgCl electrocardiogram electrodes (Ambu® BlueSensor N, Denmark) were attached to the left and right Musculus extensor digitorum and Musculus flexor digitorum superficialis in accordance with the SENIAM[4] standard (Hermens et al., 1999). EMG data (root-mean-square, RMS) were normalized to MVC for each side using the maximum of 3 isometric MVC exercises on each side. Each subject compressed a synchronized force gauge dynamometer PABLO® (Tyromotion, Austria) with maximum effort using a static power grip in a neutral wrist posture and with a 90° flexed elbow similar to Barrero et al. (2012) and Hansson et al. (2009). Raw MVC values were filtered by means of a moving average filter (window size 0.5s), and maximum of all calibration exercises of each hand was taken as 100% MVC named as MVCP [%] similar to Hansson et al. (1997). To eliminate random peak forces and noise and to make the static MVC measurement applicable to the different dynamic exertions during work the following data proceeding was carried out. All peaks >0.6 mV of the RMS signal were identified and exchanged using a linear interpolation. The signal was filtered using a low pass filter with a cut-off frequency of 5.0 Hz. Finally, the mean of a muscular rest interval was taken as 0% (minimum) and the 99.9$^{th}$ percentile of the whole measurement was taken as 100% (maximum). Within the comparison of the static and dynamic calibration, all RMS values were reduced by 25% on average in the analysis. Flexor and extensor MVCP signals were converted to one continuous muscle load data channel using equation (6).

$$MVCP_{stable,\ i} = \frac{\text{Maximum}\left(MVCP_{Extension,\ i},\ MVCP_{Flexion,\ i}\right) + MVCP_{Extension,\ i} + MVCP_{Flexion,\ i}}{3} \tag{6}$$

$i$ = current data point; $\{i \in \mathbb{R} \mid i \geq 0\}$

Equation (6) provides a quite stable MVCP result even though one EMG channel has got measuring artifacts. In the next step the 90$^{th}$ percentiles of each working task were taken as the NPF value. To adapt the scale, the NPF value was divided with 10.

MPF, ω, MP, RepSc, NPF and mTLV for HAL were calculated with use of the updated CUELA-related software. The values were time-weighted averaged to estimate shift exposures by means of a shift editor within the software as described elsewhere (Ditchen et al., 2015).

### 2.2.3. Confounders

Standardized questionnaires (SLESINA (Caffier et al., 1999; Slesina, 1987); COPSOQ[5] (Kristensen, 2002; Nübling et al., 2005)) were applied by interview for collection of information about previous and current occupational activities (e.g., shift work); information on subjective exposure assessments; personal data, demographics and other potential sociodemographic confounders (e.g., age, years on the job) or psychosocial aspects (e.g., job satisfaction). Information on tasks, task rotation and durations were merged to form workplace shift profiles (usually 8 h) and timetables. More details on the collection of confounders are described elsewhere (BAuA, 2019; Klussmann et al., 2017).

### 2.2.4. Medical outcomes

The collection of medical outcomes involved interviews (including standardized anamnesis, questionnaire) and physical examinations. The anamnesis contained medical interviews including the Nordic Questionnaire (Kuorinka et al., 1987) for collection of prevalence's of musculoskeletal complaints, and other information as mentioned above (i.e., gender, height, weight, smoking behavior). Preceding year/month/week and point prevalence of complaints were determined for nine body regions. For this study, we used self-reported complaints of the wrist and elbow regions as dichotomized variables (complaints: yes/no) during the preceding month.

Physical examinations as multistage diagnostics according to Grifka et al. (2001) and with observance of the focus® method (Spallek and Kuhn, 2009), were performed as screenings and clinical examinations (functional diagnostics) for several body regions. Based on the physical examination combined with anamnestic indications for disorders or diseases, tentative diagnoses were assigned according to a list of diagnoses as defined elsewhere (BAuA, 2019; Klussmann et al., 2017; Sluiter et al., 2001). In addition, diagnoses of the left and right-hand sides were collected in a combined fashion for presence or absence in either side. For this study, we selected arthrosis of the distal upper extremity joints [including Heberden's nodes (distal interphalangeal joints), Bouchard's nodes (proximal interphalangeal joints) and thumb basal/wrist/elbow joint swelling/nodes], CTS, LE and ME as outcomes.

Cases were defined as follows (BAuA, 2019; Klussmann et al., 2017): Arthrosis: Intermittent pain in individual joints or local joint stiffness usually occurring after rest period or specific movement related complaints. Pain could be present currently, and limited passive joint mobility with capsule pattern or joint nodes. CTS: Intermittent paresthesias or pain in at least 2 of the fingers I (Pollex), II (Index) or III (Medius) occurring usually at night, as well as pain occurring in palm, wrist or with proximal radiation into the wrist. Symptoms were present currently and at least one of the following tests being pathological (flexion compression test/carpal compression test/Tinel's sign/Phalen's Test/Two-point discrimination test/resisted thumb abduction or motor loss with atrophy of the Musculus abductor pollicis brevis). LE/ME: At least intermittent and activity-dependent pain localized around lateral (LE) or medial epicondylus (ME). Pain was present at the day of physical

[4] Surface EMG for non-invasive assessment of muscles.

[5] Copenhagen Psychosocial Questionnaire.


**Fig. 1.** CUELA measurement system; **A:** dorsal view; **B:** adult during disposal of metal parts, lateral view.

**Table 2**
Body angles and their degrees of freedom measured/calculated using the CUELA system in this study.

| Joint or body region | Degree of freedom (DoF) |
|---|---|
| Head | Sagittal inclination |
| Cervical spine | Flexion/extension |
| Thoracic spine | Sagittal and lateral inclination at Th1 |
| Lumbar spine | Sagittal and lateral inclination at L5 |
| Hip joint | Flexion/extension |
| Knee joint | Flexion/extension |
| Shoulder joint | Flexion/extension, ab-/adduction, inner/outer rotation |
| Elbow | Flexion/extension |
| Forearm | Supination/pronation |
| Wrist | Flexion/extension, radial/ulnar deviation |

examination and local pain occurred on resisted/isometric wrist extension (lateral)/flexion (medial) or during positive Drop-Chair-Test in pronation/during palpation or examination of muscle pattern. All diagnoses were dichotomized (diagnosis: yes/no) using the summarized physician statement for each participant based on the presence of typical anamnestic or clinical/functional observations during physical examination. Detailed information on collection of medical outcomes and case definition are described elsewhere (BAuA, 2019; Klussmann et al., 2017).

#### 2.2.5. Data analysis

Statistical analyses were conducted by means of SPSS v23 (IBM® SPSS®, IBM, Ehningen, Germany). Mean, standard deviation (SD), minimum, maximum and percentiles of age, BMI, job satisfaction, MPF, ω, MP, NPF, RepSc (only minimum, maximum, and percentiles) were estimated.

We performed association analyses using generalized estimating equation (GEE) models (Horton and Lipsitz, 1999) to adjust for company clusters and using a logit link function to produce Odds Ratios (ORs; as measure of association). The model outcome (dependent variable) was hand and elbow complaints and dichotomized diagnoses for CTS, LE, arthrosis of the distal joints (Section 2.2.4) and ME. The model main independent variable was the mTLV for HAL value. The model was adjusted for the following potential confounders for which data were available: age, gender, BMI, smoking, sporting exercise, job satisfaction and comorbidity of other MSDs. The model resulted in ORs for exposed and reference categories including lower and upper 95%-confidence intervals (CI) (significance: $p$-value < 0.05, CI not including 1.00 (du Prel et al., 2009)).

## 3. Results

### 3.1. Sample characteristics

The 500 employees linked to the exposure profiles were mostly male (81.6%), below 55 years old (87.0%) and predominantly overweight or obese (61.4%). A significant proportion of the workers reported being smokers, and on average workers reported being satisfied with their work (Table 3).

### 3.2. Wrist and elbow exposures

Descriptive statistics of MPF (P50), ω (P50), MP (P50), RepSc, NPF and mTLV for HAL values for all participants are presented in Table 4 and Table 5. The distribution of the kinematic parameters indicated that both wrists were exposed more highly to repetition than forearm/elbow structures. The kinematic exposures of the left and right-hand side were similar for both joint regions. The NPF values of the left and right forearm were also similarly distributed. Consequently, the mTLV for HAL also showed higher values for the wrist than for the elbow, with only minor differences between left and right.

Between 1.8% (mTLV for HAL, left elbow) and 25.2% (mTLV for HAL, right wrist) of the study population was considered to be overexposed, depending on the exposure metric under consideration (Category 3, Table 5). The metrics of MPF wrist flexion/extension and ω wrist flexion/extension showed particularly high exposures. Exposures such as ω forearm supination/pronation and MP supination/pronation had the lowest proportion of overexposed workers (Table 4).

### 3.3. Medical outcomes of the wrist and elbow region

In total, 29 cases of CTS (5.8% of the sample), 34 cases of arthrosis of the distal joints (6.8%), 60 cases of LE (12.0%) and 15 cases of ME

**Table 3**
Characteristics of the study population (n = 500).

| Characteristics | n | *Mean* or % | SD | Min | P5 | P25 | P50 | P75 | P95 | Max |
|---|---|---|---|---|---|---|---|---|---|---|
| **Age [years]** | 500 | *41.1* | 11.2 | 18.0 | 23.1 | 32.0 | 41.0 | 50.0 | 59.0 | 65.0 |
| ≥55 | 65 | 13.0% | – | – | – | – | – | – | – | – |
| ≥45 to < 55 | 140 | 28.0% | – | – | – | – | – | – | – | – |
| ≥35 to < 45 | 128 | 25.6% | – | – | – | – | – | – | – | – |
| ≥25 to < 35 | 134 | 26.8% | – | – | – | – | – | – | – | – |
| <25 | 33 | 6.6% | – | – | – | – | – | – | – | – |
| **Gender** | 500 | | – | – | – | – | – | – | – | – |
| Female | 92 | 18.4% | – | – | – | – | – | – | – | – |
| Male | 408 | 81.6% | – | – | – | – | – | – | – | – |
| **BMI [kg/m$^2$]** | 500 | *26.8* | 4.5 | 17.7 | 20.5 | 23.9 | 26.1 | 29.4 | 35.3 | 47.7 |
| Obese I/II/III, ≥ 30 | 102 | 20.4% | – | – | – | – | – | – | – | – |
| Overweight, ≥ 25 to < 30 | 205 | 41.0% | – | – | – | – | – | – | – | – |
| Normal weight, < 25 | 193 | 38.6% | – | – | – | – | – | – | – | – |
| **Sport practice (regularly)** | 500 | | – | – | – | – | – | – | – | – |
| Regular | 154 | 30.8% | – | – | – | – | – | – | – | – |
| Occasional | 130 | 26.0% | – | – | – | – | – | – | – | – |
| Never | 216 | 43.2% | – | – | – | – | – | – | – | – |
| **Smoker** | 500 | | – | – | – | – | – | – | – | – |
| Yes | 239 | 47.8% | – | – | – | – | – | – | – | – |
| No | 261 | 52.2% | – | – | – | – | – | – | – | – |
| **Job satisfaction**[a] | 500 | *62.8* | 11.3 | 9.5 | 42.9 | 57.1 | 64.3 | 66.7 | 76.2 | 100.0 |
| **Work in current job [years]**[b] | 498 | *9.8* | 8.3 | 0.3 | 1.5 | 3.0 | 7.0 | 15.0 | 26.0 | 48.0 |
| **Dominant hand** | 500 | | – | – | – | – | – | – | – | – |
| Right | 434 | 86.8% | – | – | – | – | – | – | – | – |
| Left | 50 | 10.0% | – | – | – | – | – | – | – | – |
| Both sided | 16 | 3.2% | – | – | – | – | – | – | – | – |

P5, 5$^{th}$ percentile;
[a] Job satisfaction: 7 four-level items were measured using the COPSOQ (Kristensen, 2002; Nübling et al., 2005), items were combined and standardized to 100 points (continuously modelled), 0 = no satisfaction, 100.0 = high satisfaction (BAuA, 2019).
[b] 2 cases were missing, but since only subjects with a general work experience of more than 3 months at the workplace were included (general inclusion criterion in MEGAPHYS), it was assumed that the subjects simply forgot to provide this information (at least 3 months experience at current workplace), so these cases were not generally excluded a priori from the data set.

**Table 4**
Wrist and elbow exposure characteristics of the workplaces (n = 500).

| | MPF wrist flex/ext[a] P50 [Hz] | ω wrist flex/ext[a] P50 [°/s] | MP wrist flex/ext[a] P50 [%] | RepSc wrist | MPF forearm sup/pro[b] P50 [Hz] | ω forearm sup/pro[b] P50 [°/s] | MP forearm sup/pro[b] P50 [%] | RepSc elbow | NPF forearm |
|---|---|---|---|---|---|---|---|---|---|
| **Left** | | | | | | | | | |
| Mean | 0.27 | 10.14 | 22.27 | – | 0.18 | 3.59 | 48.16 | – | 1.95 |
| SD | 0.10 | 6.10 | 15.71 | – | 0.08 | 3.85 | 22.44 | – | 0.58 |
| Min | 0.04 | 0.07 | 3.13 | 0 | 0.00 | 0.00 | 9.31 | 0 | 0.45 |
| P25 | 0.20 | 5.14 | 11.90 | 2 | 0.14 | 1.35 | 31.90 | 0 | 1.54 |
| P50 | 0.27 | 9.50 | 17.55 | 3 | 0.19 | 2.46 | 44.91 | 1 | 1.87 |
| P75 | 0.32 | 14.11 | 27.69 | 5 | 0.24 | 4.08 | 57.29 | 1 | 2.30 |
| P90 | 0.43 | 17.72 | 41.28 | 7 | 0.30 | 9.68 | 77.24 | 3 | 2.78 |
| Max | 0.62 | 31.81 | 87.65 | 10 | 0.33 | 18.86 | 100.00 | 6 | 4.40 |
| **Right** | | | | | | | | | |
| Mean | 0.29 | 11.74 | 18.11 | – | 0.20 | 4.36 | 45.96 | – | 2.07 |
| SD | 0.10 | 6.34 | 12.34 | – | 0.10 | 4.24 | 23.19 | – | 0.66 |
| Min | 0.07 | 1.50 | 3.07 | 0 | 0.00 | 0.00 | 9.78 | 0 | 0.52 |
| P25 | 0.22 | 7.13 | 9.29 | 2 | 0.16 | 1.52 | 29.44 | 0 | 1.65 |
| P50 | 0.27 | 10.59 | 16.41 | 3 | 0.21 | 2.90 | 41.52 | 1 | 2.09 |
| P75 | 0.35 | 15.63 | 22.51 | 5 | 0.26 | 6.17 | 56.14 | 2 | 2.51 |
| P90 | 0.43 | 20.30 | 34.63 | 8 | 0.32 | 11.05 | 84.11 | 4 | 2.92 |
| Max | 0.62 | 35.09 | 59.06 | 10 | 0.45 | 20.06 | 100.00 | 7 | 3.65 |

P50, 50$^{th}$ percentile; RepSc, repetition score; degrees of freedom:
[a] Wrist flexion/extension.
[b] Forearm supination/pronation.

(3.0%) were identified according to the criteria applied. Furthermore, 116 subjects reported on hand complaints (23.2%) and 66 reported on elbow complaints (13.2%) during the preceding month (Table 6, Table 7).

### 3.4. *Association analyses*

Tables 6 and 7 show the results of the association analysis between mTLV for HAL and three different musculoskeletal outcomes each for the wrist and elbow, as well as the distribution of cases by mTLV for HAL exposure categories. Overall, the majority of participants was assigned

**Table 5**
Distribution of workplaces across mTLV for HAL exposure categories (n = 500).

| Classification[a] | mTLV for HAL wrist | mTLV for HAL elbow | mTLV for HAL wrist | mTLV for HAL elbow |
|---|---|---|---|---|
| | Left | | Right | |
| Category 3: > TLV | 83 (16.6%) | 9 (1.8%) | 126 (25.2%) | 33 (6.6%) |
| Category 2: ≥ AL to ≤ TLV | 137 (27.4%) | 65 (13.0%) | 176 (35.2%) | 79 (15.8%) |
| Category 1: < AL | 280 (56.0%) | 426 (85.2%) | 198 (39.6%) | 388 (77.6%) |

[a] Classification according to Kapellusch et al. (2017): > TLV: high exposure, ≥ AL to ≤ TLV: medium exposure, < AL: low exposure; AL, Action Limit; TLV, Threshold Limit Value.

to the lowest exposure categories. The lowest exposure categories also contained the most cases of workers with upper extremity MSDs. Owing to the low number of cases and uneven distribution of the subjects across exposure categories, ME was not present in all categories and it was not possible to perform the GEE procedures. ME was therefore excluded from the association analyses.

### 3.4.1. Associations mTLV for HAL wrist and wrist musculoskeletal outcomes

Positive associations between exposure categories and specific musculoskeletal health outcomes were identified for the mTLV for HAL of both wrists (Table 6). The results for mTLV for HAL of the left and right wrist differed only minimally. Overall, the differences between the results of the unadjusted and adjusted analyses were also fairly small.

Wrist load determined by mTLV for HAL exposure categories was positively and significantly associated with arthrosis of the distal joints. The significant ORs of the adjusted analyses (OR 2.76 and 3.06) were slightly higher than those of the unadjusted analyses (OR 2.13 and 2.78). There was no statistically significant association between the exposure categories and CTS. However, the second highest exposure category showed always the largest positive non-significant odds ratios in the analyses for CTS. Wrist complaints were predominantly statistically non-significant and positively associated with the exposure categories. Only the second highest exposure categories of the left wrist showed significant odds ratios (OR 2.71 and 2.89).

### 3.4.2. Associations mTLV for HAL elbow and elbow musculoskeletal outcomes

Positive associations between the mTLV for HAL and specific musculoskeletal health outcomes were also found for the elbow (Table 7). Differences between the left and right-hand side and between unadjusted and adjusted analyses were again for the most part marginal.

Elbow load determined by mTLV for HAL exposure categories was statistically significant positively associated with arthrosis of the distal joints. Large and significant ORs, for the most part greater than 2.0, were found for the second highest and highest exposure categories. Significant results occurred predominantly for the left-hand side. For LE, positive and negative (OR < 1.00) associations were observed but were in all cases non-significant. However, the second highest exposure category showed predominantly the largest non-significant odds ratios in the analyses for LE. Regarding to elbow complaints, the second highest exposure category was in each case positively and predominantly non-significantly, whereas the highest exposure category was always negatively and predominantly non-significantly associated with complaints. Only one significant positive association was found for the right elbow with the second highest exposure category in the unadjusted

**Table 6**
Unadjusted and adjusted associations between mTLV for HAL exposure categories and health outcomes of the wrist.

| mTLV for HAL, wrist | Carpal tunnel syndrome | | | | | Arthrosis of the distal joints | | | | | Wrist complaints in the preceding month[b] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | Cases | OR | 95%-CI | *p*-value | n | Cases | OR | 95%-CI | *p*-value | n | Cases | OR | 95%-CI | *p*-value |
| | UNADJUSTED | | | | | UNADJUSTED | | | | | UNADJUSTED | | | | |
| Left[a] | 500 | 29 | | | | 500 | 34 | | | | 497 | 116 | | | |
| Category 3: > TLV | 83 | 4 | 1.14 | 0.28–4.69 | 0.856 | 83 | 9 | **2.13** | **1.00–4.51** | **0.049** | 82 | 16 | 1.15 | 0.59–2.24 | 0.673 |
| Category 2: ≥ AL to ≤ TLV | 137 | 12 | 1.86 | 0.60–5.73 | 0.279 | 137 | 10 | 1.33 | 0.62–2.83 | 0.463 | 135 | 50 | **2.71** | **1.61–4.54** | **< 0.001** |
| Category 1: < AL (Ref.) | 280 | 13 | 1.00 | – | | 280 | 15 | 1.00 | – | | 280 | 50 | 1.00 | – | |
| Right[a] | 500 | 29 | | | | 500 | 34 | | | | 497 | 116 | | | |
| Category 3: > TLV | 126 | 6 | 1.00 | 0.32–3.19 | 0.996 | 126 | 16 | **2.78** | **1.33–5.80** | **0.006** | 124 | 35 | 1.45 | 0.78–2.69 | 0.235 |
| Category 2: ≥ AL to ≤ TLV | 176 | 13 | 1.53 | 0.50–4.68 | 0.452 | 176 | 8 | 0.94 | 0.40–2.19 | 0.883 | 176 | 40 | 1.12 | 0.63–1.97 | 0.707 |
| Category 1: < AL (Ref.) | 198 | 10 | 1.00 | – | | 198 | 10 | 1.00 | – | | 197 | 41 | 1.00 | – | |
| | ADJUSTED[c] | | | | | ADJUSTED[c] | | | | | ADJUSTED[c] | | | | |
| Left[a] | 500 | 29 | | | | 500 | 34 | | | | 497 | 116 | | | |
| Category 3: > TLV | 83 | 4 | 1.10 | 0.18–6.86 | 0.916 | 83 | 9 | **2.76** | **1.17–6.51** | **0.021** | 82 | 16 | 0.98 | 0.45–2.14 | 0.955 |
| Category 2: ≥ AL to ≤ TLV | 137 | 12 | 1.93 | 0.65–5.67 | 0.234 | 137 | 10 | 1.13 | 0.52–2.43 | 0.757 | 135 | 50 | **2.89** | **1.63–5.11** | **< 0.001** |
| Category 1: < AL (Ref.) | 280 | 13 | 1.00 | – | | 280 | 15 | 1.00 | – | | 280 | 50 | 1.00 | – | |
| Right[a] | 500 | 29 | | | | 500 | 34 | | | | 497 | 116 | | | |
| Category 3: > TLV | 126 | 6 | 0.61 | 0.16–2.37 | 0.478 | 126 | 16 | **3.06** | **1.49–6.28** | **0.002** | 124 | 35 | 1.41 | 0.71–2.81 | 0.326 |
| Category 2: ≥ AL to ≤ TLV | 176 | 13 | 2.11 | 0.62–7.26 | 0.234 | 176 | 8 | 1.17 | 0.50–2.72 | 0.715 | 176 | 40 | 1.18 | 0.63–2.20 | 0.603 |
| Category 1: < AL (Ref.) | 198 | 10 | 1.00 | – | | 198 | 10 | 1.00 | – | | 197 | 41 | 1.00 | – | |

Significant in **bold**, **p < 0.05**; AL, Action Limit; TLV, Threshold Limit Value.
[a] Classification according to Kapellusch et al. (2017): > TLV: high exposure, ≥ AL to ≤ TLV: medium exposure, < AL: low exposure - reference category (Ref.).
[b] Three cases were excluded due to incomplete information on wrist complaints.
[c] Odds ratio (OR) and 95%-CI (95%-confidence interval) adjusted for age (continuous), gender (nominal), BMI (ordinal), smoking (nominal), regular sporting exercise (ordinal), job satisfaction (continuous), comorbidity (number of additional work-related musculoskeletal disorders or complaints, continuous).

**Table 7**
Unadjusted and adjusted associations between mTLV for HAL exposure categories and health outcomes of the elbow.

| mTLV for HAL, elbow | Lateral epicondylitis | | | | | Arthrosis distal joints | | | | | Elbow complaints in the preceding month | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | Cases | OR | 95%-CI | *p*-value | n | Cases | OR | 95%-CI | *p*-value | n | Cases | OR | 95%-CI | *p*-value |
| | UNADJUSTED | | | | | UNADJUSTED | | | | | UNADJUSTED | | | | |
| Left[a] | 500 | 60 | | | | 500 | 34 | | | | 500 | 66 | | | |
| Category 3: > TLV | 9 | 1 | 0.88 | 0.53–1.46 | 0.622 | 9 | 2 | **4.88** | **2.98–7.97** | **< 0.0001** | 9 | 1 | 0.86 | 0.55–1.35 | 0.512 |
| Category 2: ≥ AL to ≤ TLV | 65 | 7 | 0.91 | 0.29–2.89 | 0.872 | 65 | 8 | **2.23** | **1.06–4.67** | **0.034** | 65 | 11 | 1.41 | 0.60–3.31 | 0.433 |
| Category 1: < AL (Ref.) | 426 | 52 | 1.00 | – | | 426 | 24 | 1.00 | – | | 426 | 54 | 1.00 | – | |
| Right[a] | 500 | 60 | | | | 500 | 34 | | | | 500 | 66 | | | |
| Category 3: > TLV | 33 | 1 | 0.22 | 0.04–1.14 | 0.071 | 33 | 3 | 1.70 | 0.84–3.43 | 0.143 | 33 | 2 | 0.47 | 0.08–2.70 | 0.398 |
| Category 2: ≥ AL to ≤ TLV | 79 | 11 | 1.15 | 0.49–2.71 | 0.745 | 79 | 9 | **2.25** | **1.06–4.76** | **0.035** | 79 | 17 | **1.99** | **1.08–3.67** | **0.028** |
| Category 1: < AL (Ref.) | 388 | 48 | 1.00 | – | | 388 | 22 | 1.00 | – | | 388 | 47 | 1.00 | – | |
| | ADJUSTED[b] | | | | | ADJUSTED[b] | | | | | ADJUSTED[b] | | | | |
| Left[a] | 500 | 60 | | | | 500 | 34 | | | | 500 | 66 | | | |
| Category 3: > TLV | 9 | 1 | 1.14 | 0.55–2.33 | 0.728 | 9 | 2 | **9.23** | **3.29–25.87** | **< 0.0001** | 9 | 1 | **0.48** | **0.27–0.86** | **0.013** |
| Category 2: ≥ AL to ≤ TLV | 65 | 7 | 0.77 | 0.22–2.68 | 0.680 | 65 | 8 | 2.10 | 0.87–5.10 | 0.100 | 65 | 11 | 1.29 | 0.49–3.41 | 0.602 |
| Category 1: < AL (Ref.) | 426 | 52 | 1.00 | – | | 426 | 24 | 1.00 | – | | 426 | 54 | 1.00 | – | |
| Right[a] | 500 | 60 | | | | 500 | 34 | | | | 500 | 66 | | | |
| Category 3: > TLV | 33 | 1 | 0.14 | 0.01–1.57 | 0.111 | 33 | 3 | 1.14 | 0.44–2.96 | 0.786 | 33 | 2 | 0.46 | 0.06–3.61 | 0.458 |
| Category 2: ≥ AL to ≤ TLV | 79 | 11 | 1.08 | 0.44–2.68 | 0.862 | 79 | 9 | 1.89 | 0.89–4.05 | 0.099 | 79 | 17 | 1.52 | 0.68–3.42 | 0.306 |
| Category 1: < AL (Ref.) | 388 | 48 | 1.00 | – | | 388 | 22 | 1.00 | – | | 388 | 47 | 1.00 | – | |

Significant in **bold**, **$p < 0.05$**; AL, Action Limit; TLV, Threshold Limit Value.
[a] Classification according to Kapellusch et al. (2017): > TLV: high exposure, ≥ AL to ≤ TLV: medium exposure, < AL: low exposure - reference category (Ref.).
[b] Odds ratio (OR) and 95%-CI (95%-confidence interval) adjusted for age (continuous), gender (nominal), BMI (ordinal), smoking (nominal), regular sporting exercise (ordinal), job satisfaction (continuous), comorbidity (number of additional work-related musculoskeletal disorders or complaints, continuous).

analyses (OR 1.99 [1.08–3.67]). In addition, one significant negative association was identified for the left elbow with the highest exposure category in the adjusted analyses (OR 0.48 [0.27–0.86]).

## 4. Discussion

In the present work, repetitions, and forces of distal upper extremities of employees working at different jobs were assessed by means of a direct-measurement method that simultaneously measured the parameters of the mTLV for HAL. Force assessments were conducted as suggested by ACGIH (2018). For repetition assessments, a score was developed based on MPF, ω and MP translating a verbally anchored scale and the HAL approach to objectively measured data. Repetition and force assessments were merged to form mTLV for HAL following the concept of ACGIH (2018). To our knowledge, it was the first time that both parts of the ACGIH assessment approach were estimated based on direct measurements using sensors.

The 50$^{th}$ percentiles of the kinematic parameters for the wrists (MPF, ω) and elbows (MPF) in this work appeared similar to some specific exposures observed during a repetitive task in the floriculture (Barrero et al., 2012). Especially for forearm supination/pronation angular velocity, our sample was less exposed than those reported by Barrero et al. (2012). In relation to micro-pauses, our sample was less exposed than the sample of Hansson et al. (2009). The median force appeared similar to that reported by Kapellusch et al. (2017), who used observational methods for NPF determination in the TLV for HAL approach. Our work can provide orientation for future measurement-based threshold values.

We tested the feasibility of estimating the exposures of both hands and elbows by measuring simultaneously in a large working population with direct methods the parameters of the mTLV for HAL. We tested whether the resulting exposures related to upper-extremity disorders using a heterogeneous population of workers in several industrial sectors in Germany.

Our results are not easily comparable to previous studies due to methodological differences and distribution of exposures. We found positive associations between mTLV for HAL for wrists and CTS or wrist complaints. Such positive associations were reported by other studies between observational-based TLV for HAL and CTS (Kapellusch et al., 2014) or wrist tendinosis (Harris et al., 2011) as well. Associations in our analyses were frequently not significant and showed only partially significant monotonic associations for wrist complaints as exposures increased. This could be due to methodological differences. On the one hand, observational-based assessments of physical workload could differ generally from automated measurement-based assessments (Ditchen et al., 2015). On the other hand, it is to be assumed that our sample is not as representative as that for example of Bonfiglioli et al. (2013). These authors had access to more CTS cases for example and a more meaningful distribution of cases across exposure categories. The findings concerning LE (positive, non-significant associations) and elbow complaints (positive, significant association) were associated with measurement-based elbow exposures and cannot be compared directly with results of previous studies (e.g., Garg et al., 2014; Werner et al., 2005), who focused only on observational-based wrist exposures. Furthermore, these studies also showed a prospective cohort as study design, which reduces the chances of bias due to the healthy worker effect.

To our knowledge, no studies have investigated the association between arthrosis of the distal joints and TLV for HAL approaches so far. Although, arthrosis refers to the degeneration of cartilage, which is a condition associated to aging, previous studies indicated the relationship between finger joint osteoarthritis and highly repetitive work alone or combined with other factors (Melhorn et al., 2014). Our positive and significant results for arthrosis cannot be compared with results from previous studies. Nevertheless, results of the present study supported our assumptions and should be confirmed in future longitudinal studies.

We found in a recent review that the evidence of the relation of repetition combined with force and upper extremity MSDs is stronger than the evidence of the relation of repetition and force combined with posture with such disorders (Seidel et al., 2019). Melhorn et al. (2014) showed that repetition and force were also more often investigated during studies involving Trigger Digits (some evidence), de Quervain's Disease (some evidence) or CTS (very strong evidence), with less emphasis on the influence of posture. This supports our focus on the physical risk factors repetition and force.

Our mTLV for HAL may support a development from observational, mono-task-based TLV for HAL assessments to measurement-based, multi-task assessment approaches within a whole shift, as previously proposed (Drinkaus et al., 2005; Kapellusch et al., 2017, 2018). Our assessment differs from conventional observational assessments and would allow a differentiated identification of problematic tasks. It contains an independent numerical score (RepSc) and could be a helpful supplement to existing TLV for HAL methods based on observations (e.g., Kapellusch et al., 2014) or video analyses (e.g., Akkas et al., 2015, 2017; Radwin et al., 2015).

An adjustment of the RepSc range starting from 1 would be conceivable, since basic muscle activity is always present. We kept our first approach as simple as possible and used rounded integers for the repetition score. However, since this score is based on continuous data, it would be possible to treat it and the subsequent mTLV for HAL as continuous variables. Therefore, we recommend the modified equation (7), based on Kapellusch et al. (2017) for future continuous mTLV for HAL calculation and their cut points for subsequent assessment.

$$mTLV\ for\ HAL_{Wrist\ or\ Elbow} = \frac{NPF_{measurement-based}}{(10\ -\ RepSc_{Wrist\ or\ Elbow})} \tag{7}$$

$$\{NPF\ \in\ \mathbb{R}\ |\ NPF\ \geq\ 0\}; \{RepSc\ \in\ \mathbb{R}\ |\ 0\ \leq\ RepSc\ <\ 10\}$$

The mTLV for HAL is a first step toward a measurement-based assessment of hand and elbow workload and could support the observational-based and video-based TLV for HAL methods.

### *4.1. Strengths and limitations*

This study had strengths and methodological advantages towards conventional exposure estimations and assessments. For instance, we had access to data of several body regions from a large medical sample and the exposure data set covered a large range of different upper extremity strain intensities. The outcome recording was blinded to subject's exposure status and vice versa, and physicians were specially trained to perform physical examinations. Both measures increase the quality of the data used in this study. The choice of month prevalence as an outcome was expected to result in a lower recall bias compared to a one-year prevalence. The measurement-based approach has advantages compared to video-based computer vision and observational-based HAL assessment. The key advantage is the independence of the duty cycle. With CUELA, we can measure continuously kinetic and kinematic parameters and have no parallax errors, that are present in exposure measurements via normal video cameras (Tian et al., 2002). With the direct approach, it is also possible to measure exposures objectively at workplaces where cameras are not allowed or where the view of workplaces is restricted. The exposure data on task level are not affected by subjective information or any recall bias. The observational-based TLV for HAL approach is intended for evaluations of daily work from 4 to 8 h (ACGIH, 2018). They proposed to use time-weighted averaging for TLV for HAL estimation over all tasks for jobs with multiple tasks. We measured representative tasks in the job, and performed when necessary, shift extrapolations to capture the full job following their approach. Altogether, our approach proved to be feasible to make exposure estimations in large populations. In addition, we followed an explorative approach, and no sample size calculation was previously necessary. However, a first measurement-based assessment approach for hand and elbow workloads based on TLV for HAL and the findings of plausible associations with several health outcomes are strengths of this work.

This study had also some limitations. For instance, cross-sectional data were not ideal for validating this approach because in contrast to a cohort, no causal associations can be derived directly from this cross-sectional study. We found odds ratios below 1.00, especially in the highest exposure categories. Such negative associations may indicate the presence of a healthy worker effect in the current data as mentioned by Chowdhury et al. (2017) and Marras and Karwowski (2006) and imply underestimation of the current workload. In spite of this limitation, our exposure assessment approach was able to differentiate levels of exposure which frequently were associated in the expected direction with several upper extremity outcomes, consistent with longitudinal studies that have used observational-based TLV for HAL methods (Bonfiglioli et al., 2013; Kapellusch et al., 2014). Furthermore, the outcome data were not captured with focus on the hand or elbow joint and for reasons of practicability, measurements could not be conducted over 8 h and shift extrapolations were necessary. The diagnoses were documented independently of the body side, which made the interpretation of associations more difficult. A potential disadvantage of the measurement-based RepScore compared to video-based HAL calculation can be seen in the application of body worn sensors, whereas video recordings are contactless. Last, our study sample cannot be considered to be representative of German workplaces, so the level of exposure while indicative of the exposures of the measured jobs, cannot be extrapolated to other working populations in the country.

## 5. Conclusion

In this study, an approach for a direct-measurement-based assessment for wrist and elbow workloads including repetitions combined with forces was presented. Analyses were conducted of associations between mTLV for HAL values and specific disorders (arthrosis of the distal upper extremity joints, CTS and LE) or non-specific self-reported complaints of the wrist or elbow region (based on a one-month prevalence). The associations were predominantly positive and partially significant. Overall, the metric proved to be feasible to be used in the field with many workers. The mTLV for HAL may be helpful in the development of preventive measures and implements previous recommendations to use more objective measures for better estimating the occurrence of physical risk factors (Seidel et al., 2019). We recommend taking further steps (i.e., testing its test-reliability or performing more profound analyses beyond the validity testing of this study) to understand how this approach compares formally in different contexts to the observational-based approach in large scaled studies, and to better use the potential of continuous data. It would also be desirable to check the gain in accuracy that can be obtained with our measurement approach, in the association estimations between exposures and upper extremity disorders in the context of prospective epidemiological studies. Finally, further research is required for development of more complex measurement-based assessment methods with additional parameters.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References


ACGIH, 2001. Hand Activity Level TLVs and BEIs - Threshold Limit Values for Chemical Substances and Physical Agents. American Conference of Governmental Industrial Hygienists (ACGIH®), Cincinnati, Ohio, pp. 1–18.

ACGIH, 2018. TLVs® and BEIs®: Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. American Conference of Governmental Industrial Hygienists (ACGIH®), Cincinnati, Ohio, pp. 182–213.

Akkas, O., Azari, D.P., Chen, C.-H.E., Hu, Y.H., Ulin, S.S., Armstrong, T.J., Rempel, D., Radwin, R.G., 2015. A hand speed and duty cycle equation for estimating the ACGIH hand activity level rating. Ergonomics 58 (2), 184–194. https://doi.org/10.1080/00140139.2014.966155.

Akkas, O., Bao, S., Harris-Adamson, C., Lin, J.-H., Meyers, A., Rempel, D., Radwin, R.G., 2019. The Speed Calculated Hand Activity Level (HAL) Matches Observer Estimates Better Than the Frequency Calculated HAL. In: Bagnara, S., Tartaglia, R., Albolino, S., Alexander, T., Fujita, Y. (Eds.), Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). IEA 2018. Advances in Intelligent Systems and Computing, vol. 820. Springer, Cham, pp. 547–549. https://doi.org/10.1007/978-3-319-96083-8_71.

Akkas, O., Lee, C.-H., Hu, Y.H., Yen, T.Y., Radwin, R.G., 2016. Measuring elemental time and duty cycle using automated video processing. Ergonomics 59 (11), 1514–1525. https://doi.org/10.1080/00140139.2016.1146347.

Akkas, O., Hu, Y.H., Lee, C.-H., Bao, S., Harris-Adamson, C., Lin, J.-H., Meyers, A., Rempel, D., Radwin, R.G., 2018. How do computer vision upper extremity exposure measures compare against manual measures? Proc. Hum. Factors Ergon. Soc. Annu. Meet. 62 (1), 960–961. https://doi.org/10.1177/1541931218621221.

Akkas, O., Lee, C.H., Hu, Y.H., Harris Adamson, C., Rempel, D., Radwin, R.G., 2017. Measuring exertion time, duty cycle and hand activity level for industrial tasks using computer vision. Ergonomics 60 (12), 1730–1738. https://doi.org/10.1080/00140139.2017.1346208.

Arvidsson, I., Åkesson, I., Hansson, G.Å., 2003. Wrist movements among females in a repetitive, non-forceful work. Appl. Ergon. 34 (4), 309–316. https://doi.org/10.1016/s0003-6870(03)00042-5.

Balogh, I., Arvidsson, I., Björk, J., Hansson, G.-Å., Ohlsson, K., Skerfving, S., Nordander, C., 2019. Work-related neck and upper limb disorders – quantitative exposure–response relationships adjusted for personal characteristics and psychosocial conditions. BMC Muscoskel. Disord. 20 (139/1), 1–19. https://doi.org/10.1186/s12891-019-2491-6.

Barrero, L.H., Pulido, J.A., Berrio, S., Monroy, M., Quintana, L.A., Ceballos, C., Hoehne-Hueckstaedt, U., Ellegast, R., 2012. Physical workloads of the upper-extremity among workers of the Colombian flower industry. Am. J. Ind. Med. 55 (10), 926–939. https://doi.org/10.1002/ajim.22102.

BAuA, 2019. MEGAPHYS - Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz [MEGAPHYS - multilevel risk assessment of physical workloads]. Gemeinsamer Abschlussbericht der BAuA und der DGUV. Band 1. Dortmund/Berlin/Dresden: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), pp. 1–987.

Bernard, B.P., 1997. Musculoskeletal Disorders and Work Place Factors. A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back. U.S. Department of Health and Human Services, National Institute of Occupational Safety and Health (NIOSH), Cincinnati, OH, USA, 1–590.

Bonfiglioli, R., Mattioli, S., Armstrong, T.J., Graziosi, F., Marinelli, F., Farioli, A., Violante, F.S., 2013. Validation of the ACGIH TLV for hand activity level in the OCTOPUS cohort: a two-year longitudinal study of carpal tunnel syndrome. Scand. J. Work. Environ. Health 39 (2), 155–163. https://doi.org/10.5271/sjweh.3312.

Borg, G.A., 1982. Psychophysical bases of perceived exertion. Med. Sci. Sports Exerc. 14 (5), 377–381. https://doi.org/10.1249/00005768-198205000-00012.

Caffier, G., Steinberg, U., Liebers, F., 1999. Praxisorientiertes Methodeninventar zur Belastungsbeurteilung im Zusammenhang mit arbeitsbedingten Muskel-Skelett-Erkrankungen [Practice-oriented inventory of methods for exposure assessment in relation with work-related musculoskeletal disorders]. Wirtschaftsverl. NW 1999. (Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: Forschung, Fb 850). Bremerhaven.

Chen, C.-H., Hu, Y.H., Yen, T.Y., Radwin, R.G., 2013. Automated video exposure assessment of repetitive hand activity level for a load transfer task. Hum. Factors 55 (2), 298–308. https://doi.org/10.1177/0018720812458121.

Chowdhury, R., Shah, D., Payal, A.R., 2017. Healthy worker effect phenomenon: revisited with emphasis on statistical methods - a review. Indian J. Occup. Environ. Med. 21 (1), 2–8. https://doi.org/10.4103/ijoem.IJOEM_53_16.

da Costa, B.R., Vieira, E.R., 2010. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. Am. J. Ind. Med. 53 (3), 285–323. https://doi.org/10.1002/ajim.20750.

Descatha, A., Albo, F., Leclerc, A., Carton, M., Godeau, D., Roquelaure, Y., Petit, A., Aublet-Cuvelier, A., 2016. Lateral epicondylitis and physical exposure at work? A review of prospective studies and meta-analysis. Arthritis Care Res. 68 (11), 1681–1687. https://doi.org/10.1002/acr.22874.

Ditchen, D.M., Ellegast, R.P., Gawliczek, T., Hartmann, B., Rieger, M.A., 2015. Occupational kneeling and squatting: development and validation of an assessment method combining measurements and diaries. Int. Arch. Occup. Environ. Health 88 (2), 153–165. https://doi.org/10.1007/s00420-014-0946-5.

Drinkaus, P., Sesek, R., Bloswick, D.S., Mann, C., Bernard, T., 2005. Job level risk assessment using task level ACGIH hand activity level TLV scores: a pilot study. Int. J. Occup. Saf. Ergon. 11 (3), 263–281. https://doi.org/10.1080/10803548.2005.11076648.

du Prel, J.B., Hommel, G., Röhrig, B., Blettner, M., 2009. Confidence interval or P-value? Part 4 of a series on evaluation of scientific publications. Dtsch Arztebl Int 106 (19), 335–339. https://doi.org/10.3238/arztebl.2009.0335.

Ellegast, R.P., Hermanns, I., Schiefer, C., 2010. Feldmesssystem CUELA zur Langzeiterfassung und -analyse von Bewegungen an Arbeitsplätzen [Ambulatory measurement system CUELA for long-term motion analysis at workplaces]. Z. Arb. Wiss. 64 (2), 101–110.

Franzblau, A., Armstrong, T.J., Werner, R.A., Ulin, S.S., 2005. A cross-sectional assessment of the ACGIH TLV for hand activity level. J. Occup. Rehabil. 15 (1), 57–67. https://doi.org/10.1007/s10926-005-0874-z.

Garg, A., Kapellusch, J.M., Hegmann, K.T., Thiese, M.S., Merryweather, A.S., Wang, Y.C., Malloy, E.J., 2014. The strain Index and TLV for HAL: risk of lateral epicondylitis in a prospective cohort. Am. J. Ind. Med. 57 (3), 286–302. https://doi.org/10.1002/ajim.22279.

Garg, A., Moore, J.S., Kapellusch, J.M., 2017. The Revised Strain Index: an improved upper extremity exposure assessment model. Ergonomics 60 (7), 912–922. https://doi.org/10.1080/00140139.2016.1237678.

Glitsch, U., Jürgen Ottersbach, H., Ellegast, R., Schaub, K., Franz, G., Jaeger, M., 2007. Physical workload of flight attendants when pushing and pulling trolleys aboard aircraft. Int. J. Ind. Ergon. 37, 845–854. https://doi.org/10.1016/j.ergon.2007.07.004.

Greene, R.L., Azari, D.P., Hu, Y.H., Radwin, R.G., 2017. Visualizing stressful aspects of repetitive motion tasks and opportunities for ergonomic improvements using computer vision. Appl. Ergon. 65, 461–472. https://doi.org/10.1016/j.apergo.2017.02.020.

Grifka, J., Bär, H.-F., Peters, T., 2001. Mehrstufendiagnostik von Muskel-Skelett-Erkrankungen in der arbeitsmedizinischen Praxis [Multi-level diagnostics of musculoskeletal disorders in occupational medicine practice]. Bremerhaven: Wirtschaftsverlag NW Verlag für neue Wissenschaft GmbH. Sonderschrift Band 62, 1–48.

Hansson, G.-Å., Asterland, P., Skerfving, S., 1997. Acquisition and analysis of whole-day electromyographic field recordings. In: Hermens, H., Hägg, G., Freriks, B. (Eds.), European Applications of Surface Electromyography. Second General SENIAM (Surface EMG for Non Invasive Assessment of Muscles) Workshop. Roessingh Research and Development b.v, Enschede, The Netherlands, pp. 19–27.

Hansson, G.-Å., Balogh, I., Ohlsson, K., Granqvist, L., Nordander, C., Arvidsson, I., Åkesson, I., Unge, J., Rittner, R., Strömberg, U., Skerfving, S., 2009. Physical workload in various types of work: Part I. Wrist and forearm. Int. J. Ind. Ergon. 39 (1), 221–233. https://doi.org/10.1016/j.ergon.2008.04.003.

Hansson, G.-Å., Balogh, I., Ohlsson, K., Palsson, B., Rylander, L., Skerfving, S., 2000. Impact of physical exposure on neck and upper limb disorders in female workers. Appl. Ergon. 31 (3), 301–310. https://doi.org/10.1016/S0003-6870(99)00047-2.

Hansson, G.-Å., Balogh, I., Ohlsson, K., Rylander, L., Skerfving, S., 1996. Goniometer measurement and computer analysis of wrist angles and movements applied to occupational repetitive work. J. Electromyogr. Kinesiol. 6 (1), 23–35.

Hansson, G.-Å., Balogh, I., Ohlsson, K., Skerfving, S., 2004a. Measurements of wrist and forearm positions and movements: effect of, and compensation for, goniometer crosstalk. J. Electromyogr. Kinesiol. 14 (3), 355–367. https://doi.org/10.1016/j.jelekin.2003.10.001.

Hansson, G.-Å., Ohlsson, K., Balogh, I., Nordander, C., Skerfving, S., 2004b. Exposure-response relation for wrist/hand disorders. In: Premus (Ed.), Premus 2004, 5th International Scientific Conference on Prevention of Workrelated Musculoskeletal Disorders. Zürich, Switzerland, pp. 477–478.

Harris, C., Eisen, E.A., Goldberg, R., Krause, N., Rempel, D., 2011. 1st place, PREMUS best paper competition: workplace and individual factors in wrist tendinosis among blue-collar workers-the San Francisco study. Scand. J. Work. Environ. Health 37 (2), 85–98. https://doi.org/10.5271/sjweh.3147.

Hermens, H.J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C., Hägg, G., 1999. SENIAM 8. European Recommendations for Surface ElectroMyoGraphy. Results of the SENIAM Project. Enschede. Roessingh Research and Development b.v, the Netherlands.

Horton, N., Lipsitz, S., 1999. Review of software to fit generalized estimating equation regression models. Am. Statistician 53, 160–169. https://doi.org/10.2307/2685737.

Kapellusch, J.M., Bao, S.S., Silverstein, B.A., Merryweather, A.S., Thiese, M.S., Hegmann, K.T., Garg, A., 2017. Risk assessments using the Strain Index and the TLV for HAL, Part I: task and multi-task job exposure classifications. J. Occup. Environ. Hyg. 14 (12), 1011–1019. https://doi.org/10.1080/15459624.2017.1366037.

Kapellusch, J.M., Gerr, F.E., Malloy, E.J., Garg, A., Harris-Adamson, C., Bao, S.S., Burt, S. E., Dale, A.M., Eisen, E.A., Evanoff, B.A., Hegmann, K.T., Silverstein, B.A., Theise, M. S., Rempel, D.M., 2014. Exposure-response relationships for the ACGIH threshold limit value for hand-activity level: results from a pooled data study of carpal tunnel syndrome. Scand. J. Work. Environ. Health 40 (6), 610–620. https://doi.org/10.5271/sjweh.3456.

Kapellusch, J.M., Silverstein, B.A., Bao, S.S., Thiese, M.S., Merryweather, A.S., Hegmann, K.T., Garg, A., 2018. Risk assessments using the Strain Index and the TLV for HAL, Part II: multi-task jobs and prevalence of CTS. J. Occup. Environ. Hyg. 15 (2), 157–166. https://doi.org/10.1080/15459624.2017.1401709.
Klussmann, A., Liebers, F., Brandstädt, F., Schust, M., Serafin, P., Schäfer, A., Gebhardt, H., Hartmann, B., Steinberg, U., 2017. Validation of newly developed and redesigned key indicator methods for assessment of different working conditions with physical workloads based on mixed-methods design: a study protocol. BMJ Open 7 (8/e015412), 1–12. https://doi.org/10.1136/bmjopen-2016-015412.
Kristensen, T.S., 2002. A new tool for assessing psychosocial factors at work. The Copenhagen Psychosocial Questionnaire. TUTB Newsletter 19 (20), 45–47.
Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sorensen, F., Andersson, G., Jorgensen, K., 1987. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl. Ergon. 18 (3), 233–237.
Latko, W.A., Armstrong, T.J., Foulke, J.A., Herrin, G.D., Rabourn, R.A., Ulin, S.S., 1997. Development and evaluation of an observational method for assessing repetition in hand tasks. Am. Ind. Hyg. Assoc. J. 58 (4), 278–285. https://doi.org/10.1080/15428119791012793.
Marras, W.S., Karwowski, W., 2006. Fundamentals and Assessment Tools for Occupational Ergonomics. The Occupational Ergonomics Handbook, 2 ed. CRC Press, Taylor & Francis Group, Boca Raton, London, New York, pp. 1–1024.
McAtamney, L., Nigel Corlett, E.R.U.L.A., 1993. A survey method for the investigation of work-related upper limb disorders. Appl. Ergon. 24 (2), 91–99. https://doi.org/10.1016/0003-6870(93)90080-s.
Melhorn, J.M., Talmage, J.B., Ackerman III, W.E., Hyman, M.H., 2014. AMA Guides to the Evaluation of Disease and Injury Causation, second ed. American Medical Association, Chicago, Illinois, pp. 1–792.
Moore, J.S., Garg, A., 1995. The Strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am. Ind. Hyg. Assoc. J. 56 (5), 443–458. https://doi.org/10.1080/15428119591016863.
Nordander, C., Balogh, I., Mathiassen, S.E., Ohlsson, K., Unge, J., Skerfving, S., Hansson, G.-Å., 2004. Precision of measurements of physical workload during standardised manual handling. Part I: surface electromyography of m. trapezius, m. infraspinatus and the forearm extensors. J. Electromyogr. Kinesiol. 14 (4), 443–454. https://doi.org/10.1016/j.jelekin.2003.12.003.
Nordander, C., Ohlsson, K., Åkesson, I., Arvidsson, I., Balogh, I., Hansson, G.-Å., Stromberg, U., Rittner, R., Skerfving, S., 2013. Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands - a synthesis of group-level data on exposure and response obtained using uniform methods of data collection. Appl. Ergon. 44 (2), 241–253. https://doi.org/10.1016/j.apergo.2012.07.009.
NRC, 1999. In: Work-Related Musculoskeletal Disorders: Report, Workshop Summary, and Workshop Papers. Steering Committee for the Workshop on Work-Related Musculoskeletal Injuries: the Research Base. National Research Council (NRC): National Academies Press (US), Washington, DC, pp. 1–240.
Nübling, M., Stößel, U., Hasselhorn, H.-M., Michaelis, M., Hofmann, F., 2005. Methoden zur Erfassung psychischer Belastungen - Erprobung eines Messinstrumentes (COPSOQ) [Methods for recording of psychological exposures - testing of a measuring instrument (COPSOQ)]. Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: Forschungsbericht, Fb 1058. Bremerhaven. Wirtschaftsverlag NW Verlag für neue Wissenschaft GmbH, pp. 1–144.
Ohlsson, K., Hansson, G.-Å., Balogh, I., Stromberg, U., Pålsson, B., Nordander, C., Rylander, L., Skerfving, S., 1994. Disorders of the neck and upper limbs in women in the fish processing industry. Occup. Environ. Med. 51 (12), 826–832. https://doi.org/10.1136/oem.51.12.826.
Peppoloni, L., Filippeschi, A., Ruffaldi, E., Avizzano, C.A., 2016. A novel wearable system for the online assessment of risk for biomechanical load in repetitive efforts. Int. J. Ind. Ergon. 52, 1–11. https://doi.org/10.1016/j.ergon.2015.07.002.
Radwin, R.G., Azari, D.P., Lindstrom, M.J., Ulin, S.S., Armstrong, T.J., Rempel, D., 2015. A frequency-duty cycle equation for the ACGIH hand activity level. Ergonomics 58 (2), 173–183. https://doi.org/10.1080/00140139.2014.966154.
Schedlbauer, G., Glitsch, U., Hoehne-Hückstädt, U.M., 2014. Komplexe Analyse von Muskel-Skelett-Belastungen der oberen Extremität – Fallbeispiel Physiotherapie [Complex analysis of musculoskeletal loads of the upper extremity - case study physiotherapy]. DGUV Report 2/2014: 5. Fachgespräch Ergonomie 2013. Deutsche Gesetzliche Unfallversicherung e. V. (DGUV), pp. 63–76.
Seidel, D.H., Ditchen, D.M., Hoehne-Hückstädt, U.M., Rieger, M.A., Steinhilber, B., 2019. Quantitative measures of physical risk factors associated with work-related musculoskeletal disorders of the elbow: a systematic review. Int. J. Environ. Res. Publ. Health 16 (130), 1–23. https://doi.org/10.3390/ijerph16010130.
Silverstein, B.A., Fine, L.J., Armstrong, T.J., 1986. Hand wrist cumulative trauma disorders in industry. Br. J. Ind. Med. 43 (11), 779–784.
Slesina, W., 1987. Fragebogen zur subjektiven Einschätzung der Belastungen am Arbeitsplatz (FEBA) [Questionnaire for subjective estimation of work-related exposures (FEBA)]. Instrumente zur Erfassung psychischer Belastungen. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Berlin.
Sluiter, J.K., Rest, K.M., Frings-Dresen, M.H.W., 2001. Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. Scand. J. Work. Environ. Health 27 (Suppl. 1), 1–102. https://doi.org/10.5271/sjweh.637.
Spallek, M., Kuhn, W., 2009. Funktionsorientierte körperliche Untersuchungssystematik: Die fokus-Methode zur Beurteilung des Bewegungsapparates in der Arbeits- und Allgemeinmedizin [Functional-oriented physical examination systematic: The focus method for assessing the musculoskeletal system in occupational and general medicine]. Ecomed, Heidelberg.
Stal, M., Hansson, G.-Å., Moritz, U., 1999. Wrist positions and movements as possible risk factors during machine milking. Appl. Ergon. 30 (6), 527–533.
Tian, Z.Z., Kyte, M.D., Messer, C.J., 2002. Parallax error in video-image systems. J. Transport. Eng. 128, 218–223. https://doi.org/10.1061/(ASCE)0733-947X(2002)128:3(218).
Weber, B., Douwes, M., Forsman, M., Könemann, R., Heinrich, K., Enquist, H., Pinder, A., Punakallio, A., Uusitalo, A., Ditchen, D., Takala, E.-P., Draicchio, F., Desbrosses, K., Wichtl, M., Strebl, M., Wærsted, M., Gupta, N., Lechner, N., Alvarez Bayona, T., Hoehne-Hückstädt, U., Mathiassen, S.E., Holtermann, A., Veiersted, K.B., 2018. Assessing Arm Elevation at Work with Technical Assessment Systems: Partnership for European Research in Occupational Safety and Health. PEROSH, pp. 1–49.
Werner, R.A., Franzblau, A., Gell, N., Hartigan, A., Ebersole, M., Armstrong, T., 2005. Predictors of persistent elbow tendonitis among auto assembly workers. J. Occup. Rehabil. 15 (3), 393–400. https://doi.org/10.1007/s10926-005-5945-6.

## 2.4 More detailed information related to publication 2

Additional and more detailed information which are important for transparency in this thesis are briefly indicated below and are included in supplementary material (chapter 8.2.1, p. 188ff) or were already published elsewhere and will not be duplicated in this thesis. The information for companies, subjects, the exact consent form, Original CUELA measurement protocol template in German for exposure recording/ documentation, and documentation forms for workplace or task schedules used for this thesis have been published elsewhere (DGUV 2020; Weber et al. 2020a). As mentioned in subchapter 2.2.1. Study design in the manuscript by Seidel et al. 2021b, p. 3, the workgroup of Seidel followed in 2021 a rigorous extended inclusion and exclusion proceeding to identify suitable datasets. A flowchart describing the detailed exclusion of 275 data sets was already published elsewhere (DGUV 2020; Weber et al. 2020a). **Table 3.** (p. 188) and **Table 4.** (p. 189) presented the sample baseline-characteristics (n = 500) in more detail.

The final attachment of all sensors, measuring devices including EMG electrodes application and fixation of electrodes with elastic tape (KintexTM®) and the system in motion is shown in Seidel et al. 2019c.

The developed GEE model for an association analysis e.g., concerning LE – as presented in this thesis and used in Seidel et al. 2021b – is shown in detail in **Figure 1.** (p. 190). The presented script code also includes ideas, e.g., for a fourth mTLV for HAL exposure category. However, this idea was rejected in favor of better comparability between observational-based and measurement-based HAL assessments.

The tables (**Table 5.** to **Table 10.**, pp. 191-196) show the detailed results of all univariate and multivariate (adjusted) association analyses of each combination of mTLV for HAL and medical outcomes at the elbow region. Consideration of confounders revealed a similar pattern in many univariate and adjusted analyses. Age, comorbidity (**Table 5.** to **Table 10.**, pp. 191-196), and, in some analyses, smoking, female sex or occasional sport practice (**Table 9.** to **Table 10.**, pp. 195-196) represented significant risk factors for developing specific disorders or receiving complaints in the elbow region.

RepScore verification and comparability testing with HAL are presented in more detail in chapter 8.2.2 (p. 197ff).

By using multilevel correlation-analytical investigations, the measurement-based assessment method presented here should originally be modified which was planned at the beginning of the doctorate. To fulfill this purpose, the threshold values should be fine-tuned based on employee data on subjective perception of load considering CUELA and EMG measurements as well as complaints and medical examination findings. However, a more extensive modification of the mTLV for HAL approach beyond a modification as for instance presented in equation (7) in Seidel et al. 2021b would go beyond the appropriate scope of this thesis. For this reason, this very comprehensive modification of the mTLV for HAL has not been presented here but could be a very interesting future research.

## 2.5 Publication 3 – Seidel et al. 2021a

Seidel DH, Ellegast RP, Rieger MA, Steinhilber B und Weber B (2021) Messdatenbasierte Gefährdungsbeurteilung. Kategorisierung messtechnischer Methoden zur Beurteilung physischer Belastungen der oberen Extremität [Measurement-based risk assessment. Categorization of measurement methods for assessing physical workloads of the upper extremity]. Zentralbl Arbeitsmed Arbeitsschutz Ergon 71(4): 192-199. doi: 10.1007/s40664-021-00424-y.

Measurement-based risk assessment. Categorization of measurement methods for assessing physical workloads of the upper extremity – English translation of the published manuscript [Messdatenbasierte Gefährdungsbeurteilung. Kategorisierung messtechnischer Methoden zur Beurteilung physischer Belastungen der oberen Extremität]

The following chapter is the English translation of the publication; the original publication can be found in the supplementary material in chapter 8.3 on page 202ff.

Zentralblatt für Arbeitsmedizin, Arbeitsschutz und Ergonomie

# Measurement-based risk assessment

## Categorization of measurement methods for assessing physical workloads of the upper extremity

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**Abstract**

**Background.** Observational-based methods for risk assessment of physical workloads of the upper extremity can be influenced by subjective experiences of the investigators. In addition, it is difficult to quantify biomechanical workloads, of e.g., time courses of joint angles, angular velocities, or forces by observations. For objective and precise quantification of exposures in the context of specific risk assessments, technical measurement-based methods are therefore particularly suitable, although the choice of the appropriate method can be challenging. **Objectives.** This article is intended to support occupational safety experts to identify the appropriate measurement-based method for an existing exposure situation from the different range of methods. **Methods.** Based on a literature review, measurement methods for the upper extremity were classified according to their complexity based on an established category system. In addition, application examples are presented for all categories. **Results.** This article provides an overview and classification of different recording and assessment methods of work-related musculoskeletal loads, which are divided into three categories from simple to complex. **Discussion.** Simplified sensor technology in combination with specific assessment approaches might support the objective risk assessment of physical workload in the future.

**Keywords**

Quantification of work-related exposure · Objective assessment approach · Measurement system category · Sensor · Shoulder-Elbow-Hand-area

**In the risk assessment of physical load, a distinction can be made between observational-based and measurement-based methods. Measurement-based methods are characterized by objectivity and accuracy and are becoming increasingly less expensive and more practicable. This article provides an overview of potential measurement-based methods and supports occupational safety specialists in selecting suitable methods for the respective assessment situation.**

The performance of risk assessment of physical load is a central component of German occupational safety and health guidelines, regulations, laws, and legal ordinances. Employers are obliged (Occupational Safety and Health Act [3], § 5 I-III) to record and evaluate the relevant hazards at workplaces, work areas or executed tasks, to derive safeguards and to check their effectiveness as part of the risk assessment. Risk assessment contributes to prevention of work-related musculoskeletal load, which has been agreed as an important objective by the Joint German Occupational Safety and Health

Strategy (GDA) of Federal Government, federal states, and agencies of the social accident insurance.

To improve prevention and occupational safety and health, the European Agency for Safety and Health at Work (EU-OSHA) attracts attention to the promotion of prevention measures and risk assessments related to work-related musculoskeletal disorders (MSDs) in the current campaign “Healthy Workplaces Lighten the Load” [12]. By 2022, EU-OSHA aims to provide an overview of appropriate methods and assessment tools.

Between 20 to 57 % of all work-related MSDs affect the hand-arm-shoulder region [24]. Abnormal loads on the upper extremities are thus a frequent cause of illness-related absenteeism. For risk assessments, it is necessary to identify corresponding risk factors in advance to select suitable methods for exposure assessment. In addition to highly repetitive or forceful work and awkward postures, combinations of force exertion and movement behavior have already been quantitatively described as work-related risk factors of the upper extremity [25].

For risk assessment of physical load, a 5-step level-model was already proposed in 2010 [11], which was the basis for the procedure in the MEGAPHYS (Multilevel risk assessment of physical workload) project [6, 9] and can be applied at the upper extremity.

The levels can be divided into observational-based (coarse screening, specific screening, expert screening) and measurement-based methods (occupational measurement, laboratory measurement/ simulation).

The advantage of observational-based methods is primarily in their ease and practicality of use, especially when additional assessment of the workplace environment, conditions, or organization is required [6, 9]. They are advantageous for initial exposure estimations. However, some limitations are also described in the literature. Observational-based methods can be influenced by subjective experiences [13]. This means that there may be significant differences in assessment between different observers. Other influencing factors are e.g., angle of view (occlusion), daily form or memory [13, 16, 17, 23]. In this context, Holtermann et al. [17] also remark that experienced observers are needed, which is costly per observed unit of working time and usually leads to short assessment sequences or limited sample sizes. Observations can also lead to ethical complications, e.g., in nursing activities [17].

For coarse recordings, observational-based methods seem to be sufficient, but for more extensive investigations, complementary technical methods with higher reliability are advantageous [13, 23].

For example, Lin et al. [18] indicate that in recent years, technical measurement systems have become more practical and accurate, enabling longer operating times, and can store or process more data than before. These methods are objective, have an elevated level of detail, and enable accurate quantification of exposures. Likewise, technical methods are used to create objective exposure registers [10] and to analyze complex workplaces with rapidly changing or parallel types of loads [15]. Technical measurement-based methods are also recommended for risk assessments to evaluate interventions [23]. Technical measurement-based methods for recording physical workload are not liable to subjective bias, are generally applicable even in concealed or confined workplaces, and exhibit high validity and reliability [16]. Limitations to date have been higher time and cost expenditures compared to observational-based methods (often due to complex instrumentation and evaluation), usage primarily by experts, and potential interference with the workflow [14]. However, advances in technology are making objective and accurate systems increasingly practical and affordable [13, 18], and they are already recommended internationally for risk assessment [16]. This offers good conditions for other user groups and future advance and new developments of measurement-based methods or assessment approaches also in the context of the risk assessment of physical loads to be conducted in this country, e.g., in the area of the upper extremity. So far, it has been exceedingly difficult in the working environment to select the appropriate measurement-based method for the respective purposes.

The aim of this work is therefore to create a clear categorization using currently available methods for technical measurement-based risk assessment of physical workload in the area of the upper extremity. Examples should clarify the areas of application and support occupational safety specialists in prospective selection of suitable measurement-based methods.

**Measurement methods for quantifying the load**

Numerous methods are available for the objective quantification of work-related musculoskeletal loads of the upper extremity.

**Camera-based methods** as a basis for automated motion analysis with passive or active reflective markers are predominantly related to special stationary laboratory environments. Accordingly, such methods are only suitable for mobile use to a limited extent and thus, depending on the framework conditions, are not very practicable for a practical risk assessment on site, e.g., at non-stationary workplaces. Nowadays, video-based pattern detection (not marker-based) in combination with biomechanical modeling are also used for quantifications [1]. If the work processes and work content permit, video-based methods can often be used in practice at industrial workplaces without any problems, since all that is required as hardware is a video camera, smartphone, or tablet. However, special video analysis software is additionally required here to assess the loads at the workplace. In addition, the assessment approaches available to date are often only related to specific movement patterns. Although data acquisition is possible in principle, subsequent evaluation therefore requires increased effort, e.g., through additional programming. The use of cameras is also problematic at workplaces where video recording is not permitted because of data protection, ethical or operational reasons. Personal worn **motion sensors** are therefore not only suitable for such workplaces, but also for use at non-stationary workplaces. The spectrum ranges from the use of individual acceleration sensors to the use of inertial sensors as multi-sensor systems synchronized with other sensors, e.g., for recording forces or physiological processes.

**Category system**

In the literature, measurement-based methods for recording and assessing occupational physical activity and specific physical workloads are classified into a category system that provides a differentiation using 3 measurement system categories [8, 16, 17, 29]. In the following, this category system is used as basis for a corresponding classification of measurement-based systems for recording and assessing work-related load on the upper extremities.

Category 1

These include measurement methods with 1–2 sensor units that represent the load of a specific localization (e.g., wrist, elbow). Such methods are usually based on the use of motion, posture, or position sensors such as accelerometers or goniometers.

In the past, these sensors were often wired and costly, and their handling required specialized knowledge of sensor attachment and data analysis. Today, technical optimizations have resulted in suitable systems for recording work movements that are less expensive and more user-friendly. For example, they are often wireless and intelligent algorithms avoid errors during attachment or data analysis [29].

Category 2

Measurement methods with ≥ 2 sensor units can be used to monitor loads in a localization area (chain of localizations, e.g., shoulder-elbow-hand area). The sensor units can be incorporated into smart textiles or attached individually to the body. In addition to sensor technology for motion capture (e.g., inertial sensors), electromyography (EMG), near-infrared spectroscopy (NIRS), or hand-arm vibration (HAV) capture sensor technology can be used, for example. There exist numerous wearables including inertial sensors, dynamometers, and surface EMG that can be used as a basis for biomechanical data collection at work and subsequent risk assessment [22].

Category 3

In these complex measurement methods, numerous sensors are combined to observe the load of several chains of localizations or on the entire body. These include multi-sensor systems, which are usually based on inertial sensors, but can also be combined with other measurement techniques (e.g., Computer-assisted recording and long-term analysis of musculoskeletal loads (CUELA), Xsens, [28]).

**Method overview and application examples**

A basic overview of the 3 categories of measurement systems is shown in **Fig. 1**. Examples of the respective measurement system category for recording and assessing work-related loads on the upper extremities are summarized in **Fig. 2**, with categories 1 and 2 appearing particularly significant for use in the workplace due to their high practicability. Examples of such sensor systems and possible assessment approaches that can be derived from the literature are shown in **Fig. 3**.

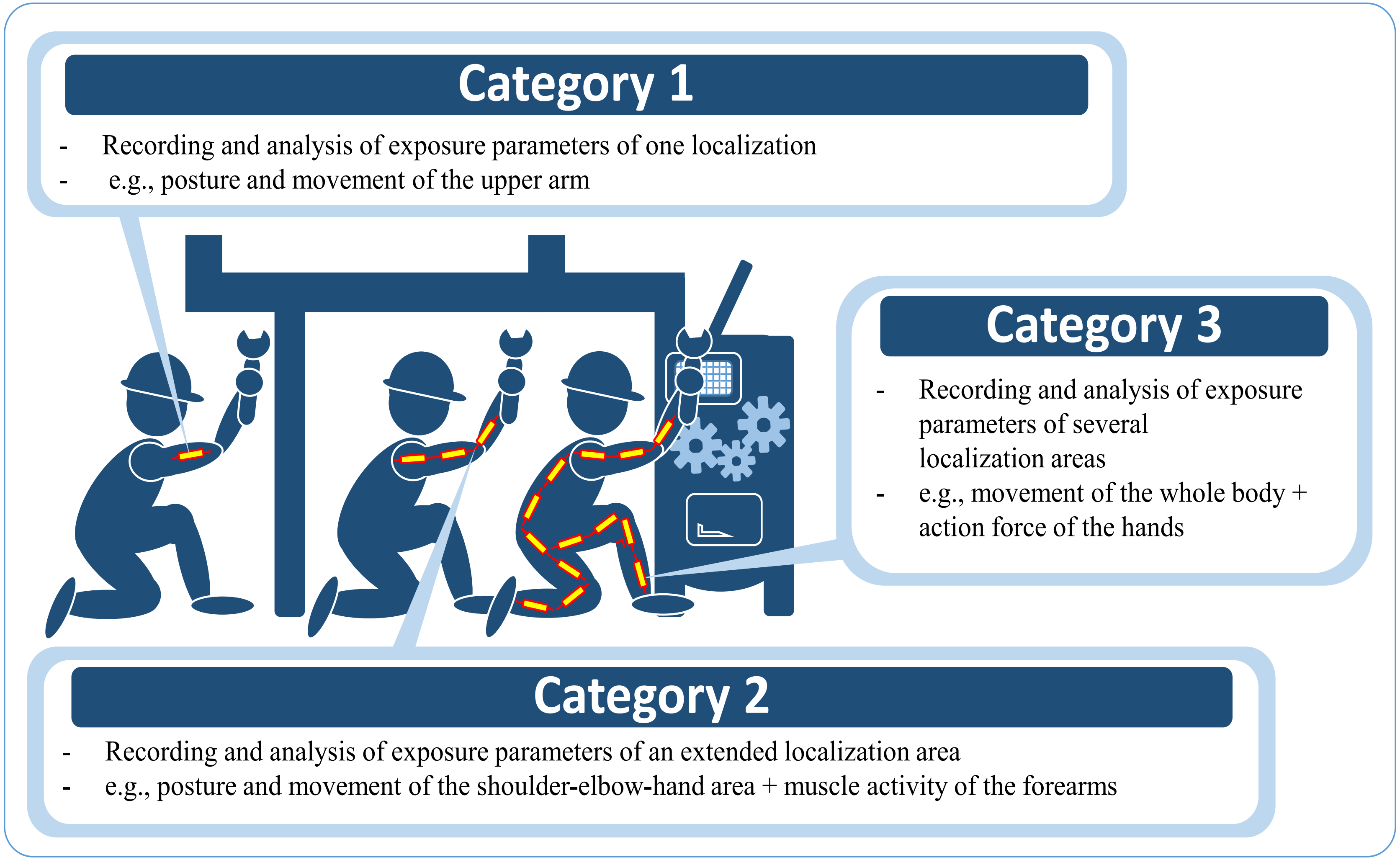


**Fig. 1** ▲ Categorization of measurement systems for recording and assessing work-related loads on the upper extremities based on the classifications of physical activity measurements. (According to [8, 1, 17, 29])

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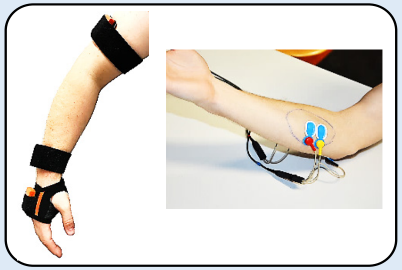
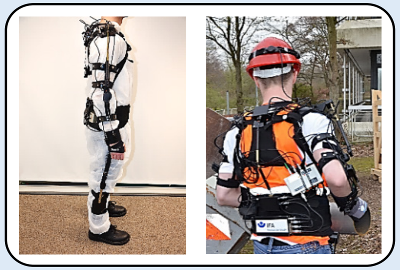
| Measurement system category | Category 1<br>1-2 Sensor units,<br>1 localization of the body | Category 2<br>≥ 2 Sensor units,<br>2-3 localizations of the body | | Category 3<br>Complex measurement-based methods,<br>several localizations of the body |
|---|---|---|---|---|
| **Examples for sensors** [a] | <br>left: wearable;<br>right: individual sensors | <br>smart textile | <br>left: several sensors/ wearables/ IMU;<br>right: surface electromyography (EMG) | <br>Multi-sensor system + further measurement technology; left: CUELA, right: CUELA & EMG |
| **Assessment of risk factors:** Muscle activity | - | - | -/+ | -/+ |
| **Assessment of risk factors:** Repetition | + | o/+ | + | + |
| **Assessment of risk factors:** Posture | + | + | + | + |
| **Assessment of risk factors:** Combination of force requirements & movement behavior | - | - | o | o/+ |
| **Expertise for sensor attachment** | low | low-medium | medium/high | high |
| **Possible number of subjects** | many | various | various | few |
| **Time/cost per subject** | low | low | moderate | high |
| **Potential user groups** [b] | OM: **o**, OA: **+**, S: **+** | OM: **+**, OA: **+**, S: **+** | OM: **-/o**, OA: **o/+**, S: **+** | OM: **-**, OA: **o**, S: **+** |
| **Examples for specific applications** | **ErgoArmMeter [30];**<br>ErgoArmMeter as iOS application in combination with accelerometers and gyroscopes integrated in iPhone or iPod Touch for analysis and percentile formation of angles & angular velocities + values in relation to recommended limits of an 8 h day | **Angle measurements [7];**<br>Sensors integrated into sweater to detect and display flexion angle in elbow joint, assessment by static model for angle detection based on machine learning & neural network | **Quantification of exposure-response relationships [4];**<br>Accelerometer, electro goniometer to record upper arm & wrist movements & wrist postures + percentile determination, assessment of exposure-response relationship via exponential function and estimation of different prevalence's<br><br>**Quantification of force applications [9];**<br>4-channel surface EMG module for recording and assessing muscular loads on the forearms by quantifying strain + classifying them into risk classes | **Complex exposure recording and assessment of combined risk factors [9, 26];**<br>CUELA multi-sensor measurement system + 4-channel surface EMG module for recording and assessment of force, repetition & combination, and non-recommended postures/movements of different localizations + classification into risk categories |

**+** recommended, **o** partially recommended/ conditionally suitable, **-** not recommended; inertial measurement unit-applications = IMU; [a] Further examples of operational wearables according to Walmsley et al. [28] among other Xsens, ADPM Opal, Shimmer, InvenSense MPU9150 chip, BioKin WMS, YEI Technology, CAPTIV Motion, L-P Research Motion Sensor B2, Noraxon Myomotion, ArduMuV3 chip or MSULS.
[b] User groups: occupational health and safety professionals with minor technical measurement experience = OM; occupational health and safety professionals with advanced technical measurement experience = OA; Scientist (with measurement expertise) = S

**Fig. 2** ▲Examples of mobile, body-worn measurement methods (categories 1–3) for exposure determination of the upper extremity. The estimation of required expertise for application of the sensors, possible number of subjects, time/cost per subject and the recommendation regarding the user groups are based on the PEROSH classification (Partnership for European Research in Occupational Safety and Health). (According to [4, 7, 9, 16, 17, 26, 28, 29, 30])

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**Category 1**

| Localization | Wrist (forearm if applicable) | Elbow joint | Upper arm |
|---|---|---|---|
| **Repetition** | **S:** Electro goniometer;<br>**O:** Wrist angular velocity (ω) in °/s;<br>**A:** mathematical function for prevalence estimation of carpal tunnel syndrome; [4] | **S:** Accelerometer, gyroscope, goniometer/inertial sensor;<br>**O:** Repetitions score as a sum of kinematic single parameter assessments (frequency, angular velocity, and micro-pauses) based on forearm supination/pronation;<br>**A:** Classification into 4 risk categories; [9, 26] | **S:** Electro goniometer;<br>**O:** Upper arm angular velocity (ω) in °/s;<br>**A:** mathematical function for prevalence estimation of rotator cuff syndrome; [4] |
| **Posture** | **S:** Electro goniometer;<br>**O:** Wrist flexion/extension in °;<br>**A:** Exposure-response relationship of hand/elbow complaints; [20] | **S:** Accelerometer, gyroscope, goniometer;<br>**O:** Forearm supination/pronation in °;<br>**A:** Time proportion of task spent in sustained posture according to German industrial and European standard; [5] | **S:** iPhone 5s, 6/iPod Touch;<br>**O:** Upper arm angle in °, Time proportion >30°/ >60°/>90° in % (>60° ≙ overhead work);<br>**A:** ErgoArmMeter App; values compared with recommended thresholds of an 8h workday [30]<br>Value: > 30°; 46 % time — Threshold: [50%] |

**Category 2**

| Localization | Hand/forearm | Forearm/elbow | Elbow/upper arm |
|---|---|---|---|
| **Repetition** | **S:** Accelerometer, gyroscope, goniometer/inertial sensors;<br>**O:** Repetitions score of the wrist and elbow joint as a sum of kinematic single parameter assessments (frequency, angular velocity, and micro-pauses) based on wrist flexion/extension and forearm supination/pronation;<br>**A:** Classification into 4 risk categories; [9, 26] | | **S:** Xsens MTx inertial sensors;<br>**O:** Flexion/extension elbow, supination/pronation forearm, abduction/adduction + inner/outer rotation shoulder, angle in ° + angular velocity in °/s;<br>**A:** Time proportion movement frequencies/velocities, angle-angular velocity graphs + identification of irregular movement patterns; [2] |
| **Muscular activity** | **S:** Miotec 4-channel Miotool 400 system;<br>**O:** Square mean (root mean square, RMS) + median frequency trendlines over time in s;<br>**A:** Muscle activity & fatigue of muscles for wrist movements; [19] | **S:** CUELA surface EMG module;<br>**O:** Strain on the finger flexor and extensor muscles in % + electromyographic micro pauses in %;<br>**A:** Classification into 4 risk categories; [9] | **S:** Miotec 4-channel Miotool 400 system;<br>**O:** Square mean (root mean square, RMS) + median frequency trendlines over time in s;<br>**A:** Muscle activity & fatigue of muscles for forearm twisting & elbow bending; [19] |
| **Posture** | **S:** Xsens MVN Biomech™;<br>**O:** Wrist radial/ulnar deviation, flexion/extension, angle in °;<br>**A:** Deviations angle from neutral gripping positions; [19] | **S:** Smart textile;<br>**O:** Elbow flexion/extension in °;<br>**A:** Angle assessment by static angle detection model based on machine learning & deep neural network; [7] | **S:** CAPTIV Motion IMUs + electro goniometer;<br>**O:** Joint angles of the upper extremity in °;<br>**A:** RULA assessments + time proportions; [27] |
| **Combinations** | **S:** CUELA-accelerometer, gyroscope, goniometer/inertial sensors;<br>**O:** mTLV for HAL for wrist and elbow joint (repetitions scores in each case as a sum of kinematic single parameter assessments (frequency, angular velocity, and micro-pauses) + normalized peak force (NPF));<br>**A:** mTLV for HAL, classification into 3 exposure categories; [26] | | **S:** CUELA-accelerometer, gyroscope, goniometer/ inertial sensors;<br>**O:** Time proportion of non-recommended elbow/upper arm postures/movements;<br>**A:** Classification into 4 risk categories; [9] |
| | **S:** Inertial sensors + EMG;<br>**O:** Upper arm/elbow/wrist flexion/extension, forearm supination/pronation; wrist abduction in °;<br>6 Multiplicators (Intensity, duration, effort, posture, speed, duration of day);<br>**A:** Rapid Upper Limb Assessment (RULA) point values and Strain Index (SI) point values; [21]<br>SI: 7; RULA: 2 | | |

**S:** = Sensors (commercial/non-commercial); **O:** = Output parameter; **A:** = Assessment approach; mTLV for HAL = measurement-based Threshold Limit Value for Hand Activity Level

**Fig. 3** ▲Examples of measurement technology, output parameters and underlying assessment approaches for devices of measurement system categories 1 and 2. (According to [2, 4, 5, 7, 9, 19–21, 26, 27, 30])

6

## Application scenarios from the working environment

**Scenario a)** After restructuring on the assembly line, complaints in the shoulder area occur frequently in assemblers of tailgate cable harnesses. Since the cable harnesses are predominantly assembled above shoulder height, forced body postures and problematic joint loads arise. The company's ergonomics expert is commissioned to identify particularly high shoulder loads during assembly to be able to develop possible improvement measures in the work process. Since awkward upper arm postures (e.g., arm elevations of more than 60°) are suspected as the cause of incorrect loads in the shoulder region after activity observation and orienting assessment, a simple category 1 system, such as the use of a smartphone in combination with an appropriate application, is suitable for quantifying the load in this case (**Fig. 3**, Category 1, Posture, Upper arm). The low-cost application provides objective parameters that are independent of workplaces and partial tasks, such as percentiles of angular distributions, percentage shift proportion of awkward arm postures, or median angular velocity, which cannot be precisely quantified by observations. Based on data on cumulative duration of arm elevations exceeding 60°, as well as the duration of uninterrupted arm elevations exceeding 60° during a typical work shift, peak loads can be identified more accurately than by observing circumscribed durations. The objective parameters and comparison of angle data with recommended shift limit values enable the design of measures to reduce the average angular velocity, which cannot be objectively assessed by observations. Based on the shift load profiles, measures to reduce the shoulder load can then be derived, if necessary, e.g., through job or workplace rotations.

**Scenario b)** In a large retail grocery store, employees report on complaints in the area of wrists and elbows, especially during cashier tasks, but less so when restocking shelves with new products. Based on task observation, it is suspected that high frequency bending of the wrists and elbows as well as twisting of forearms in combination with the weights of goods during tasks at the checkout line can lead to typical complaints and disorders in the extended localization area (wrist/elbow). To quantify the difference in load between the two workplaces, the loads in the hand-arm area should be compared in each case by an occupational safety and health specialist. For easy handling, in addition to a commercially available scale for recording product weights, a category 2 smart textile equipped with inertial sensors, for example, is suitable. Against the background of data from the literature, objective load profiles can be generated from the results obtained, such as angle-time trajectories, number and weights of goods moved, and assessment of the extent of repetition. These results can be the basis for solid adjustments of the checkout counter desk to enable ergonomic tasks.

**Scenario c)** The management of a company specializing in the construction of concrete pavers is considering the purchase of a new, cost-intensive machine to largely replace the manual stone setting process. The management hopes the machine will provide an economic benefit by saving time and reducing work absenteeism due to illness. Employees had complained more frequently of complaints in several localizations (arms, shoulders, neck, back, knees). Therefore, a scientific project is planned in cooperation with a university to compare paving with and without machine assistance. Considering the time factor, the effects on the musculoskeletal system are to be precisely quantified for both working conditions. Since the expected effects on the movement patterns are complex and involve the whole body, the accuracy and level of detail of the output parameters must be very high. Therefore, a Category 3 multi-sensor system with surface EMG and HAV acquisition sensors and multiple deposited assessment approaches is appropriate for this project for load assessment in multiple localizations. The extensive measurement technology can be used to quantify complex movements, postures, force applications and possible loads caused by machine-induced vibrations. Based on the exposure data determined during paving with and without machine assistance, shift load profiles can be created in each case, into which, for example, loads on the intervertebral discs, awkward body postures and peak loads due to repetitions and high forces can be integrated. The determined exposure difference is to be evaluated in combination with the temporal observation and can provide the basis for the purchase decision.

## Discussion and perspective

The method overview and application examples in this article are intended to provide the occupational safety specialist with an up-to-date view of measurement-based recording methods and possible parameters from the literature that are used to assess loads. A measurement system categorization recommended in the literature for recording and assessing physical activity [8, 16, 17, 29] was extended and applied to the upper extremity.

This procedure and the elaborated overview provide an orientation for the possible applications of a measurement-based risk assessment of work-related physical loads of the upper extremity. In addition, the elaborated recommendations regarding different user groups can serve as an assistance as to which type of measurement technology might be most appropriate for the respective assessment situation.

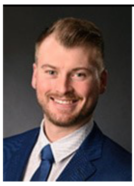
As the complexity of the measurement systems increases, so do the demands for expertise required to attach the sensors and assess the data, and thus the time and costs involved. Data protection must also be adhered when recording exposures with wearable technology. In addition to further development of assessment approaches, the definition and provision of practicable commercial sensor technology or rather corresponding measurement systems is also desirable. In this context, the focused technical measurement-based analysis of individual parameters and selected localizations is also conceivable. A more specific set-up and an easy-to-use measurement technology would enable a significant reduction of effort and complexity in prospective operational measurements. Thus, software-supported, faster, and objective evaluations are also possible, and depending on the objective, the analyses can easily be repeated or extended. In addition to scientists, occupational safety specialists could also collect measurement data. To avoid possible misinterpretation of data and associated incorrect risk assessments, it is generally recommended to obtain precise information about the possibilities and limits of the respective method. However, this applies not only to technical measurement methods, but also to all other risk assessment approaches.

For exposure recording and assessment, commercially available sensors with output parameters and assessment approaches are already available for the localizations hand/upper arm (repetition, posture), hand/forearm (force, posture) and elbow/upper arm (repetition, force, posture) as a basis for use in measurement-based risk assessment of physical load (**Fig. 3**). In perspective, however, it is recommended to further develop assessment approaches that are currently based on data collected with non-commercially available sensor technology and to transfer them to the use of measurement data from the application of commercially available sensor technology. For example, Walmsley et al. [28] present 13 commercial wearable sensors that are appropriate for such a transfer. Thus, the assessments developed for MEGAPHYS (e.g., repetition score (RepScore) [9, 26]) and approaches based on them (e.g., measurement-based Threshold Limit Value for Hand Activity Level (mTLV for HAL) [26]) will be available to occupational safety specialists and can support the measurement-based risk assessment of physical loads. The assessment approaches for measurement-based analyses of work-related musculoskeletal loads developed and validated in the MEGAPHYS project can be used as a basis for the assessment of localization-related loads with measurement systems of categories 1–3. Interfaces to corresponding commercial measurement technology are currently being defined and implemented at the IFA to facilitate access to the methodology for occupational safety specialists. Against this background, it is recommended to adapt that the level model of risk assessment from 2010 [11]. In this context, category 1 systems could complement specific screening by simple handling. The use of category 2 systems could extend the expert screening level by detailed exposure recording. In the future, simple measurement-based approaches can also support the investigators at the screening level by providing objective analyses and thus enable a new standard in the risk assessment of physical loads.

## Conclusion for practice

- **A classification of commercial and non-commercial measurement technology and objective assessment methods is now available for the measurement-based risk assessment of physical loads on the upper extremity.**
- **The assignment of the technical measurement-based approaches of categories 1 to 3 was based, among other things, on different user groups.**
- **The use of measurement-based risk assessments is recommended as a supplement to the previous procedure.**
- **The further development of sensor technology including software for the assessment of exposure data is to be supported to enable occupational safety specialists to perform a measurement-based risk assessment in the future or to give them access to measurement data.**

## Correspondence address



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## Adherence to ethical guidelines

**Conflict of Interest.** D.H. Seidel, R.P. Ellegast, M.A. Rieger, B. Steinhilber, and B. Weber declare no conflict of interest.

No studies on humans or animals were performed by the authors for this article. For the studies referenced, the ethical guidelines stated therein apply in each case.



## Literature

1. Akkas O, Azari DP, Chen C-HE et al (2015) A hand speed and duty cycle equation for estimating the ACGIH hand activity level rating. Ergonomics 58:184–194
2. Álvarez D, Alvarez JC, González RC et al (2016) Upper limb joint angle measurement in occupational health. Comput Methods Biomech Biomed Engin 19:159–170
3. ArbSchG (1996) Law on the execution of occupational safety and heatlth measures to improve the safety and health of employees at work. Occupational Safety and Health Act (ArbSchG) of August 7, 1996 (BGBl. I p. 1246), as last amended by Article 427 of the Ordinance of August 31, 2015 (BGBl. I p. 1474). Federal Ministry of Justice and Consumer Protection, Federal Office of Justice, pp. 1–11
4. Balogh I, Arvidsson I, Björk J et al (2019) Work-related neck and upper limb disorders—quantitative exposure–response relationships adjusted for personal characteristics and psychosocial conditions. BMC Musculoskelet Disord 20(139):1–19
5. Barrero LH, Pulido JA, Berrio S et al (2012) Physical workloads of the upper-extremity among workers of the colombian flower industry. Am J Ind Med 55:926–939
6. BAuA (2019) MEGAPHYS – Multilevel risk assessment of physical workload. Joint final report of the BAuA and the DGUV. Federal Institute for Occupational Safety and Health (BAuA). Volume 1, Dortmund/Berlin/Dresden, pp. 1–987
7. Bobin M, Amroun H, Coquillart S et al (2017) DNN based approach for the assessment of elbow flexion with smart textile sensor. In: SMC 2017—IEEE international conference on systems, man, and cybernetics Banff (hal-01677679v2)
8. Boudet G, Chausse P, Thivel D et al (2019) How to measure sedentary behavior at work? Front. Public Health 7:1–11
9. DGUV (2020) MEGAPHYS: Multilevel risk assessment of physical workload (DGUV Report 3/2020). Final report on the cooperation project between BAuA and DGUV, Volume 2. German Social Accident Insurance (DGUV), Berlin, pp. 1–984
10. Ditchen D, Ellegast RP, Rehme G (2010) GonKatast – A measured value register of occupational knee stress (IFA-Report 1/2010). Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), Sankt Augustin, pp. 1–137
11. Ellegast RP (2010) Quantification of physical workload at the workplace. Zbl Arbeitsmed 60:386–389
12. Eu-Osha (2020) Healthy Workplaces Lighten the Load! Guide to the campaign. European Agency for Safety and Health at Work (EU-OSHA), Eu-Osha, Luxemburg, pp. 1–36

13. Forsman M (2016) Ergonomic risk assessments—a need for reliable and attractive methods. In: Järvelin-Pasanen S (Hrsg) NES2016—Ergonomics in theory and practice—48th Annual Conference of Nordic Ergonomics and Human Factors Society. University Eastern Finland, Kuopio. Report and Studies in Health Sciences, S 28–32

14. Grooten W, Johanssons E (2018) Observational methods for assessing ergonomic risks for work-related musculoskeletal disorders. A scoping review. Rev Cienc Salud 16(especial):8–38

15. Hartmann B, Spallek M, Ellegast R (2013) Work-related musculoskeletal disorders. Causes – Prevention – Ergonomics – Rehabilitation. ecomed MEDIZIN, Zwickau, pp. 1–440

16. Holtermann A, Mathiassen SE, Pinder A et al (2017) Assessing sedentary behaviour at work with technical assessment systems—final report. Partnership for European Research in Occupational Safety and Health (PEROSH), S 1–53

17. Holtermann A, Schellewald V, Mathiassen SE et al (2017) A practical guidance for assessments of sedentary behavior at work: a PEROSH initiative. Appl Ergon 63:41–52

18. Lin J-H, Kirlik A, Xu X (2018) New technologies in human factors and ergonomics research and practice. Appl Ergon 66:179–181

19. Merino G, Da Silva L, Mattos D et al (2019) Ergonomic evaluation of the musculoskeletal risks in a banana harvesting activity through qualitative and quantitative measures, with emphasis on motion capture (Xsens) and EMG. Int J Ind Ergon 69:80–89

20. Nordander C, Ohlsson K, Åkesson I et al (2013) Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands—a synthesis of group-level data on exposure and response obtained using uniform methods of data collection. Appl Ergon 44:241–253

21. Peppoloni L, Filippeschi A, Ruffaldi E et al (2016) A novel wearable system for the online assessment of risk for biomechanical load in repetitive efforts. Int J Ind Ergon 52:1–11

22. Ranavolo A, Draicchio F, Varrecchia T et al (2018) Wearable monitoring devices for biomechanical risk assessment at work: current status and future challenges—a systematic review. Int J Environ Res Public Health 15:1–26

23. Rhén IM, Forsman M (2020) Inter- and intra-rater reliability of the OCRA checklist method in video-recorded manual work tasks. Appl Ergon 84:103025

24. Schneider E, Irastorza X, Copsey S (2010) OSH in figures: work-related musculoskeletal disorders in the EU—facts and figures. In: European Agency for Safety and Health at Work (EU-OSHA) (Hrsg) European risk observatory report. Publications Office of the European Union, Luxembourg, S 1–184

25. Seidel DH, Ditchen DM, Hoehne-Hückstädt UM et al (2019) Quantitative measures of physical risk factors associated with work-related musculoskeletal disorders of the elbow: a systematic review. Int J Environ Res Public Health 16:1–23

26. Seidel DH, Heinrich K, Hermanns-Truxius I et al (2021) Assessment of work-related hand and elbow workloads using measurement-based TLV for HAL. Appl Ergon 92:103310

27. Vignais N, Bernard F, Touvenot G et al (2017) Physical risk factors identification based on body sensor network combined to videotaping. Appl Ergon 65:410–417

28. Walmsley CP, Williams SA, Grisbrook T et al (2018) Measurement of upper limb range of motion using wearable sensors: a systematic review. Sports Med Open 4(53):1–22

29. Weber B, Douwes M, Forsman M et al (2018) Assessing arm elevation at work with technical assessment systems. Partnership for European Research in Occupational Safety and Health (PEROSH), S 1–49

30. Yang L, Grooten WJA, Forsman M (2017) An iPhone application for upper arm posture and movement measurements. Appl Ergon 65:492–500

## 2.6 More detailed information related to publication 3

Potential measurement systems and measurement-based assessment methods were identified and extracted from a variety of sources to create a methods overview. Some measurement-based assessment approaches e.g., those of Barrero et al. 2012 or Nordander et al. 2013 were identified during title and abstract screening in the systematic review by Seidel et al. 2019b. Other measurement-based assessment approaches were developed in Seidel's work group. These methods were already published and presented nationally (Heinrich et al. 2019) and internationally (Heinrich et al. 2018; Weber et al. 2019b; Weber et al. 2019c; Weber et al. 2018b). Other methods such as those reported by Balogh et al. 2019 were identified through the procedure of mTLV for HAL assessment approach development (Seidel et al. 2019c; Seidel et al. 2021b; Seidel et al. 2019d). By performing several manual narrative searches in Google Scholar[1], D.H.S. identified further additional relevant and recent measurement-based assessment methods for the upper extremity, such as the work of Álvarez et al. 2016, Bobin et al. 2017, Merino et al. 2019, Peppoloni et al. 2016, Vignais et al. 2017 and Yang et al. 2017. With the compilation of several measurement-based methods and assessment approaches for the upper extremity (Seidel et al. 2021a), the mTLV for HAL method including RepScore and NPF assessment, was classified and presented together with other possible methods for objective upper extremity risk assessment to occupational safety specialists or occupational safety and health officers.

[1] 1st search: date: 28th Mai 2020; search string: biomechanical occupational work "risk assessment" "upper" direct" measurement -gait -spine -trunk; results: n = 637 | 2nd search: date: 28th Mai 2020, search string: "inertial" "risk assessment" hand elbow "upper" limb work results: n = 178 results | 3rd search: date 28th Mai 2020; search string: inertial wearable "risk assessment" hand elbow upper limb work; time restriction: since 2018; results: n = 121.

# 3 Discussion

## 3.1 Systematic review

### *3.1.1 Summary*

Seidel et al. 2019b identified 10 relevant peer-reviewed articles from a total of 524 references, published between 2007 and 2017. The methodological quality of these 10 articles ranged from medium to high, with all studies achieving the highest possible outcome assessment score. The exposure assessment score ranged from the lowest possible values to the maximum score. Across these 10 studies (5 cross-sectional; 3 cohort; 1 triple and 1 case-referent study), a total of 133 risk factor specifications were found. Forty-four were significant (**Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10) and 89 were not significant (**Table S6.** in the manuscript by Seidel et al. 2019b, pp. SF 60-65). Risk factor specifications were also assigned to 5 main exposure categories (Force, Repetition, Posture/Movement, Vibration, Combined Exposure). Additionally, 16 exposure sub-categories were defined similar to Melhorn et al. 2014. Results from subsequent evidence assessment of these sub-categories ranged from very low to high evidence as mentioned by Seidel's workgroup in 2019. The review identified three studies (Fan et al. 2014b; Fan et al. 2009; Nordander et al. 2013) that can be treated as important examples for determination and assessment of quantitative occupational risk factors. Worthy of note is their use of sensor technology such as electro goniometers, force gauges, or EMG (Seidel et al. 2019b). In summary, this review provides a solid foundation for assessment method developments. It indicates that exposure recording devices have evolved over the last decade. Thus, the review is an important finding on the topic of prevention of work-related diseases of the elbow region.

### *3.1.2 Research questions*

The 5 main and 16 exposure sub-categories were described in detail in **Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10, **Table S6.** in the manuscript by Seidel et al. 2019b, pp. SF 60-65, and **Figure 2.** in the manuscript by Seidel et al. 2019b, p. 8. All identified 133 quantitative risk factor specifications (involving e.g., wrist angular velocity [°/s], forearm supination/pronation/rotation over 45° for more than 40 %/45 % of time combined with additionally power grip) were detailly summarized in **Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10, **Table S5.** in the manuscript by Seidel et al. 2019b, pp. SF 50-59 and **Table S6.** in the manuscript by Seidel et al. 2019b, pp. SF 60-65. The comprehensive presentation of these results as body text, figures, tables, and supplementary files successfully answered research question Q. 1[1]. To answer Q. 2[2], associations between exposures and disorders were first tabulated and classified by exposure main and sub-categories. The tables on associations (**Table 4.** in the manuscript by Seidel et al. 2019b, pp. 9-10, **Table S5.** in the manuscript by Seidel et al. 2019b, pp. SF 50-59, **Table S6.** in the manuscript by Seidel et al. 2019b, pp. SF 60-65) each included a specific number (marked with '#') and an exact risk factor description involving quantitative information, a reference, a specific outcome (LE, ME, UN, Radial tunnel syndrome, Pronator teres syndrome), gender (male, female) when possible, a measure (OR, HR, IRR, PR) with 95%-CI, and the type of adjustment for reported analyses. Additional study information, such as design, population/sample, type of exposure and outcome assessment, and additional declarations, were reviewed and provided (**Table S5.** in the manuscript by Seidel et al. 2019b, pp. SF 50-59) to completely represent the extent of associations.

### *3.1.3 Limitations*

Limitations have been discussed in detail in Seidel's review in 2019. Among others, the following limitations were pointed out: neglect of psychosocial influences, different types of risk factor descriptions, non-feasibility of meta-analysis due to heterogeneity of study designs, rigorous exclusion of studies, time-restricted searching (2007 – 2017), difficulty in comparison and handling of different measures (IRR, PR, OR, HR), possible bias due to recall/publication or information bias, may be no generalizability of the results probably due to less included studies or EMG which could be distorted by e.g., crosstalk or subcutaneous adipose tissue that affects electrode-skin impedances (Seidel et al. 2019b). Although some factors limited the results of the review, some of them have been processed in the following research steps. Especially, e.g., recall bias were tried to consider in mTLV for HAL association analyses adjustments.

[1] Q. 1: What specific quantitative work-related risk factors and exposures can be identified in current literature for the elbow region?

[2] Q. 2: How and to what extent can the associations between such risk factors and specific elbow disorders be quantitatively described?

### *3.1.4 Current state of science*

The extent of association (chapter 3.1.2) is very similar to that recently reported by Curti et al. 2021. Curti's workgroup examined associations between elbow-specific disorders (LE, ME, olecranon bursitis) and quantitative occupational exposures. At a minimum, diagnoses were based on physical examinations (plus imaging techniques, if available). For exposure assessment, only studies with observations involving video analysis and/or direct measurements were included. Since Seidel et al. 2019b and Curti et al. 2021 examined very similar content, a comparison of both is certainly possible. Curti and colleagues identified 5 studies, while Seidel's group included 10. In both reviews, the study by Fan et al. 2014b was identified. This study was rated with high (Seidel et al. 2019b) and medium (Curti et al. 2021) quality (13 vs. 11 points). This could be justified e.g., due to quality assessments by different researchers. The overall quality assessment of Seidel's review included 18 items, whereas Curti's group used 17 items. Cutoffs for high, medium, and low study quality were very similar in Seidel's and Curti's research (≥ 12 vs. 13-17; 6 < 12 vs. 8-12; ≤ 6 vs. 3-7). Thus, the highest threshold is also similar to ≥ 13 of 20 points as reported by Descatha et al. 2016 in a meta-analysis of LE and work-related physical exposures. Curti's and Seidel's reviews had both a maximum outcome assessment score of 3. Similar to Descatha et al. 2016, Seidel's group included self-reported exposures. Such exposures were methodologically excluded in Curti's research. Additionally, Curti' group included three further studies (Barrero et al. 2012; Fan et al. 2014a; Garg et al. 2014). These studies were identified by Seidel's group as well but were excluded (**Table S4.** in the manuscript by Seidel et al. 2019b, pp. SF 9-49). The reason for this was the lack of a quantitative measure between risk factors and at least one SDE. Nevertheless, because these three studies provided relevant information related to assessment methods, Barrero's and Garg's research were used and considered in the assessment approach development and discussion by Seidel et al. 2021b. Chiang et al. 1993 was included in Curti's review. Descatha's group included the study by Leclerc et al. 2001. However, because these two studies from 1993 and 2001 were included and discussed in the key paper of van Rijn et al. 2009a, they were not included again in Seidel's continuing review in 2019. Descatha's group identified three further studies (Descatha et al. 2013; Fan et al. 2014b; Herquelot et al. 2013b). They were also included and discussed by Seidel and colleagues as 3 of 10 studies. Seidel's group identified more relevant studies which were not listed by Curti et al. 2021 and Descatha et al. 2016. Curti et al. 2021 found limited overall evidence between exposures and LE, with insufficient evidence for ME. In contrast, some evidence related to LE, ME, and UN in individual exposure sub-categories was very high in Seidel's review. Descatha's review supported the association between biomechanical exposures at wrists and/or elbows and the incidence of LE. Contrary, Bretschneider et al. 2021 demonstrated a nonsignificant association between repetition and LE in a meta-analysis, although only two studies were pooled here in a forest plot. Overall, Seidel et al. 2019b is a good supplement to previous systematic reviews that provide qualitative (Bernard 1997; da Costa and Vieira 2010; van Rijn et al. 2009a) or semiquantitative (Melhorn et al. 2014; van Rijn et al. 2009a) work-related information on risk factors in the elbow joint.

It should be noted that Seidel's review was processed and cited at least 22 times (17$^{th}$ October 2021) in e.g., a meta-analysis (Bretschneider et al. 2021), systematic reviews (Curti et al. 2021; Girgis and Duarte 2020), other reviews (Stegink-Jansen et al. 2021), in two cohort studies reporting on hairdresser workload associated with self-reported haircuts/week (Aavang Petersen et al. 2021), a case report about nerve injuries at elbows associated with laptop use at flexible workplaces (Kuijer et al. 2020), ultrasonographic analyses of muscles such as extensor carpi radialis brevis (Kajita et al. 2020), assessments of risk factors in oil refinery jobs (Esmailzadeh et al. 2020), in the mTLV for HAL assessment approach (Seidel et al. 2021b), in an accuracy comparison between e.g., inertial sensors and systems for optical recording for angular velocity of the wrist (Yang et al. 2021), in an article providing an algorithm development and Adjusted Rapid Upper Limb Assessment (AdRULA) using wearables (Santos et al. 2020), in LE conditions and current management strategies (Duncan et al. 2019), in a guideline summary (Leschinger et al. 2021), in the measurement-based risk assessment overview of the upper extremity (Seidel et al. 2021a), in an occupational disease book (Grosser 2020) and several conference contributions. It shows that Seidel's review from 2019 has filled international research gaps and is very important for current research.

## 3.2 Assessment approach

### *3.2.1 Summary*

**From the review to the assessment approach – parameter definition**

As described in chapter 2.2, force combined with repetition was identified as the most significant exposure sub-category (S13) in Seidel et al. 2019b. Similarly, wrist flexion/extension and forearm supination/pronation were the most important and examined DoF among all 10 studies. Furthermore, it was possible to define MPF, ω, and MP as relevant kinematic parameters. One important kinetic parameter (EMG) was identified as well. By analyzing systematic reviews on observational-based assessments (Grooten and Johanssons 2018; Nasrull Abdol Rahman and Syafiqa Abd Razak 2016; Takala et al. 2010), the TLV for HAL (ACGIH 2001, 2018) was identified as the most appropriate method for an assessment approach development. TLV for HAL, combined with the traffic light assessment of Schedlbauer et al. 2014, should be transferred to an assessment method for occupational physical exposures in the elbow region.

**Assessment approach mTLV for HAL development and testing**

The results in chapter 2.1 and considerations described in chapter 2.2 were used to develop a measurement-based approach (chapter 2.3), which assesses the combination of force and repetition of the distal upper limb (Seidel et al. 2019c; Seidel et al. 2019d). As mentioned by Seidel et al. 2021b, a repetition score was developed. It represented a sum of individual scores of MPF, ω and MP, and included the verbally anchored Latko-scale, which was transferred to objective measurement-based data. Further analyses using the MEGAPHYS data set were performed. It could be verified that the repetition score was equivalent with original HAL assessment (chapter 2.3, 8.2.2 for more details). Moreover, according to Seidel's research in 2021, the RepScore was further combined with NPF using EMG as proposed by e.g., ACGIH 2018 or Harris et al. 2011. Following, the new mTLV for HAL was formed, considering ACGIH 2018. This new approach was applied to wrist flexion/extension and forearm supination/pronation. By further use of GEE models, mTLV for HAL was contrasted as 3-level exposure category assessment to arthrosis of the distal joints, LE, CTS, and nonspecific wrist/elbow joint complaints. Significant and non-significant ORs obtained by association analyses for 500 participants showed that the mTLV for HAL could be positively associated with some diseases or complaints. Therefore, the new method expands existing TLV for HAL application opportunities. It can be excellently used in practice to objectively assess work-related musculoskeletal load in the elbow (and hand) region and to take preventive measures.

### *3.2.2 Research questions and generated hypotheses*

**From the review to the assessment approach – parameter definition**

Besides the most relevant risk factor (force combined with repetition), three kinematic measurement parameters MPF, ω, MP and one kinetic parameter named muscle activity (recorded by EMG) were derived from literature. These are appropriate measurement parameters, which contributed to answering research question Q. 3[3] in the affirmative.

In the literature, the Strain Index (SI, Moore and Garg 1995), the TLV for HAL (ACGIH 2001, 2018) and individual assessment approaches of single kinematic or kinetic parameters (e.g., Arvidsson et al. 2003, Balogh et al. 2019, Barrero et al. 2012, Hansson et al. 2009, Nordander et al. 2013, Ohlsson et al. 1994, Schedlbauer et al. 2014 or Stål et al. 1999) were identified as suitable methods for an assessment approach development in the elbow region. The revised Strain Index by Garg et al. 2017 appears to provide a potential assessment basis. Furthermore, Peppoloni et al. 2016 have transformed the SI and RULA (McAtamney and Nigel Corlett 1993) into measurement-based methods. Additionally, the SI assesses the combination of force, repetition, and posture. However, this triple combination was not the most relevant one in this presented research (chapter 2.2). Furthermore, TLV for HAL has been associated with elbow diseases (Franzblau et al. 2005; Garg et al. 2014; Werner et al. 2005). In addition, there was evidence that force can be assessed using EMG (ACGIH 2018; Harris et al. 2011). Therefore, the focus in this thesis was more on the TLV for HAL approach to assess combined exposures. In addition, there exist further duty cycle-dependent video-based approaches for objective quantification of specific exposures using TLV for HAL (e.g., Akkas et al. 2019, Akkas et al. 2016, Chen et al. 2013, Greene et al. 2017, or Radwin et al. 2015). All these assessments led to establishment of hypothesis H. 1 for further research.

[3] Q. 3: Can appropriate measurement parameters (e.g., kinematics, muscular load) be derived for the identified risk factors?

**H. 1 Suitable assessment approaches can be derived from literature as a basis for developing a measurement-based assessment method for work-related physical exposures at the elbow region.**

**Assessment approach mTLV for HAL development and testing**

The identified kinematic/kinetic parameters have already been used in several studies (chapter 3.2.2) in different ways to validly estimate work-related loads. Therefore, the parameters seemed very suitable for a development. As described in chapter 2.3, including subchapters, the range of these kinematic parameters was enlarged. Compared with Schedlbauer et al. 2014, 5 instead of 3 gradings were now classified for MPF, 5 instead of 3 for ω, and 3 instead of 2 for MP (**Table 1** in the manuscript by Seidel et al. 2021b, p. 3). The extended grading was justified and defined based on evidence. Thresholds for RepScore were based on limits of relevant articles identified by systematic (Seidel et al. 2019b) and narrative searches as described in this thesis. By transforming the continuous EMG data into a NPF score from 0 to 10 (Subchapter 2.2.2. in the manuscript by Seidel et al. 2021b, pp. 3-4), the muscle activity data could be fully utilized. The NPF and RepScore were merged into mTLV for HAL, fully covering the risk factors of force combined repetition related to the elbow region which answered Q. 4[4].

At the time the association analyses were performed in Seidel et al. 2021b, D.H.S. assumed that there was excellent expertise in Seidel's workgroup to process quantitative measurement-based data. This was already demonstrated by splendid previous research (e.g., Ditchen et al. 2013, Ellegast et al. 2009, Glitsch et al. 2007, Kiermayer et al. 2011, Kraemer et al. 2018, Luger et al. 2019 and Steinhilber et al. 2017). In addition, the shift editor for reconstructed working shifts by Ditchen et al. 2015, supervised by Prof. Dr. M. A. Rieger, provided a good baseline for determining shift exposures as used in this thesis. This editor has been optimized and improved as described elsewhere in more detail (Weber et al. 2020a). The update made it possible to quantitatively represent shift exposures for e.g., the elbow region, based on different tasks. Finally, this editor was successfully used for the mTLV for HAL at 140 measured shift exposure profiles including different types of work tasks (Seidel et al. 2021b). Thus, another hypothesis (H. 2) could be generated for future research.

[4] Q. 4: To what extent can quantitative criteria for the assessment of work-related elbow load be defined?

## H. 2 It is possible to use measurement-based data from a field study to make quantitative statements about combined elbow loads during the entire work shift for different tasks.

In Seidel et al. 2021b, ORs were calculated using GEE models. Furthermore, some significant results were found for elbow joint complaints in the preceding month (**Table 7** in the manuscript by Seidel et al. 2021b, p. 8). However, not all the highest exposure categories were significantly different from lower ones – especially when considering both sides of the body. Thus, research question Q. 5[5] can currently only be answered with 'no'. This could be due to subjective data on complaints. On the one hand, the information on self-reported complaints in a cross-sectional study could have been distorted by e.g., recall bias as indicated by Aavang Petersen et al. 2021, although a month prevalence instead of an annual prevalence was already chosen to reduce recall bias. Schmier and Halpern 2004 reported on patient recall and recall bias and mentioned that patients tend to remember the location of pain more accurately than the intensity or frequency of pain. On the second hand, it is also possible that answers were modified out of e.g., fear of losing the job or because complaints may be interpreted as personal weaknesses and the participants do not want to admit this. Further research is required here.

To answer Q. 6[6], the following explanation should be applied. By using the assessment approach as developed in this thesis (chapter 2.2, 2.3), several load profiles can be distinguished. For example, two load profiles refers to repetitions either of wrists (DoF: wrist flexion/extension) or elbows (DoF: forearm pronation/supination). Here, the RepScore was developed, which evaluates as a sum score the individual kinematic parameters for these DoF. In this context, it would also be possible to form sub load profiles. For example, each individual kinematic parameter could be assessed independently of the others (MPF-score, ω-score, MP-score, **Table 1** in the manuscript by Seidel et al. 2021b, p. 3) if only certain parts of the repetition are to be considered. The measurement-based NPF was used to estimate muscular activity of forearm muscles and thus represents another possible load profile with respect to force. With mTLV for HAL,

[5] Q. 5: Can significant differences in the prevalence of complaints be described in workplaces with high exposure versus workplaces with low exposure?

[6] Q. 6: To what extent can different load profiles be differentiated with respect to total load and assessed with consideration of different load levels for structures in the elbow region (surface electromyography, complaints, examination findings)?

it is possible to represent a total loading profile, including force combined with repetition, of the distal upper extremity (wrist, forearm, and elbow). The assessment approach of Seidel's group was validated in 2021 in a field study, using results from association analyses with arthrosis of the distal joints, LE, CTS, and wrist/elbow joint complaints. By using three differentiated exposure categories of mTLV for HAL (**Table 5** to **Table 7** in the manuscript by Seidel et al. 2021b, pp. 7-8 and **Table 5.** to **Table 10.**, pp. 191-196), it is also possible to represent three different levels of exposure related to total distal upper extremity workload. Unfortunately, it is not possible to draw conclusions from total upper extremity load profile to total load of the entire body. Further investigations and in-depth models are required here, which would go beyond the scope of this work. Therefore, research question Q. 6 can only be answered partially and not completely now.

### *3.2.3 Limitations*

Limitations related to mTLV for HAL have already been discussed in detail in Seidel et al. 2021b. Among others, the following limitations were pointed out: cross-sectional data were may be limited for validations; healthy worker effect could have influenced association analyses and was may be related with underestimation of exposure; outcome data (e.g., diagnoses) were not recorded for both sides and not with focus on hand/elbow region; measurements over 8 hours were not possible and extrapolations were required; no contactless measurements were possible due to body worn sensors and there was no representative sample of German workplaces (extrapolation to further populations of employee is not possible) as mentioned by Seidel's group in 2021. As discussed in chapter 3.2.2, recall bias may have affected data on elbow (and wrist) joint complaints.

### *3.2.4 Current state of science*

Recently, Arvidsson et al. 2021 published a paper on workload measurements using wearable technology and associated action levels related to movement velocities, postures, and muscular loads. Here, thresholds were suggested to protect workers from e.g., nerve entrapments or upper extremity tendon disorders. For example, Arvidsson's group reported a daily median angular velocity threshold of 20°/s for the wrist. In Seidel et al. 2021b several thresholds were defined for this kinematic parameter to classify exposures more precisely. The threshold value of Arvidsson's work is assigned to ω-score classification 3 in Seidel's research from 2021. This confirms on the one hand that angular velocity (ω) is a very important parameter when work-related repetitive load should be assessed. This was also similarly confirmed by Yang et al. 2021. Furthermore, this confirms the findings and derivations from the systematic review by Seidel et al. 2019b. Additionally, the thresholds of both – Seidel's and Arvidsson's research from 2021 – are in similar range, which supports the classification used e.g., in the RepScore development. In Arvidsson et al. 2021, the action level thresholds were determined for only one load (parameter) at a time. Whereas in Seidel et al. 2021b, three kinematic parameters could be assessed simultaneously. This could lead to minimal differences between the thresholds. Arvidsson's group further indicated in 2021 that it is more relevant to define action levels for combined exposures. These authors explicitly further refer to the TLV for HAL approach. This confirms that it was very important to develop the mTLV for HAL to fill an international research gap in the measurement-based and wearable/sensor-supported assessment of work-related load in the elbow (and hand) region. Since Arvidsson and colleagues, themselves reported that the proposed action levels are open for discussion and revision, the mTLV for HAL provides a good evidence-based groundwork to justify prospective action level adjustments. It would also be conceivable to add and discuss the parameters MPF and MP to threshold values of the action level. Moreover, the mTLV for HAL as an important supplement to previous TLV for HAL improvements and the duty cycle independence as both previously mentioned by Seidel et al. 2021b, makes the mTLV for HAL even more objective and universally applicable. Due to the developed RepScore combined with measurement-based NPF, the combination of sensor-based kinematic data of hand/elbow joints and EMG data could be shown for the first time within the TLV for HAL method. Furthermore, the observational-based approach was fully technically mapped and extended to the elbow region, which has not been studied before. This created new assessment possibilities.

As suspected by Seidel et al. 2019b, several new assessment methods, e.g., for the upper extremity, have indeed been developed in recent years. For example, to assess force, posture, and repetition, especially in the wrist region, the SI has been further developed. It was already applied as Composite or Cumulative Strain Index as recommended by Kapellusch 2019. In addition, the Variable Revised Strain Index algorithm was developed to quantify the intensity of strain/postural change during execution (Mitterlehner and

Kapellusch 2019). In addition to SI, the RULA approach was also presented as a measurement-based assessment method by Peppoloni et al. 2016. Humadi et al. 2021 and Vignais et al. 2017 also demonstrated an inertial sensor-based RULA assessment approach. Using wearable technology, Santos et al. 2020 modified the observation-based method and developed the AdRULA. Other motion tracking methods based on inertial sensors have been discussed by Filippeschi et al. 2017, whereas Hindle et al. 2021 presented besides inertial-based movement recoding further information on e.g., 2-/3-dimensional optical motion capturing, or sensor fusions. Incidentally, similar sensor fusions were also performed when assembling the equipment for data acquisition used in Seidel et al. 2021b. Furthermore, Weber and colleagues reported on new and further developed assessment approaches for the hand, elbow, and shoulder regions (Weber et al. 2019b; Weber et al. 2018b). In this context, the work of PEROSH (Weber et al. 2018a) on shoulder loading assessments should also be mentioned. Similarly, time proportions of non-recommended postures/movements of the upper arms, elbows, or wrists – also known as Kinematic Assessment Index (Heinrich et al. 2019; Weber et al. 2019b) – have been reported by MEGAPHYS scientists (Weber et al. 2020a). In addition, dose of shoulder moments and time proportion of micro-pauses in EMG were provided as assessment approaches by these scientists. Recently, EMG was also used e.g., by Luger et al. 2020 to quantify motor variability and neuromuscular responses during a repeated screwing task. Furthermore, Bauters et al. 2018 developed an automatic work cycle classification based on video data. The list of new and further developed assessment methods, e.g., in the upper extremity area, can probably be continued arbitrarily. All listed methods show that the assessment approaches differ in parts or completely due to developed methods and applied technology. Thus, each method, as well as the mTLV for HAL approach, acquires its reason for existence and allows objective assessment of different work-related exposures. To introduce the developed mTLV for HAL approach to occupational safety specialists or occupational safety and health officers for objective risk assessment of physical exposures, the new method was classified and briefly compared with some other assessments for upper extremity regions as mentioned by Seidel et al. 2021a.

## 3.3 Categorization of measurement-based methods for the upper extremity

### *3.3.1 Summary*

As mentioned by Seidel et al. 2021a, in addition to more advanced camera-based methods or systems using active or passive markers, sensor technology has been further developed. Furthermore, according to these authors, body-worn motion sensors such as single accelerometers, inertial sensors, or multi-sensor systems are particularly suitable for exposure assessments. Owing the scope of various available sensors and associated measurement-based assessment approaches that have been evolved, particularly following the early research of D.H.S. (chapter 1.1.5), it was necessary to categorize potential sensor technology and available measurement-based methods. For this purpose, a 3-level categorization of measurement systems (Boudet et al. 2019; Holtermann et al. 2017a; Holtermann et al. 2017b; Weber et al. 2018a) was selected as proposed by Seidel's workgroup in 2021. It was transferred and applied to the upper extremity area. This new categorization classifying to the number of sensor units and localizations/localization areas or the whole body is very important for usage in the working environment in Germany. The occupational safety specialists or occupational safety and health officers are thus supported to adequately select the appropriate sensor unit and assessment method for the respective assessment situation. The mTLV for HAL was classified in this context and is thus presented as additional possible assessment approach. The work of Seidel et al. 2021a is a kind of recommendation, provides an orientation for different measurement-based methods and is intended to reduce subjective influences in prospective risk assessments of physical exposures, especially at the upper extremity. It should encourage occupational safety specialists or occupational safety and health officers to perform prospective measurement-based and objective risk assessments.

### *3.3.2 Research questions*

**Fig. 2** and **Fig. 3** in the manuscript by Seidel et al. 2021a, pp. 195-196 provide examples of currently available mobile body-worn sensors in combination with possible assessment approaches in addition to the approach by Seidel et al. 2021b. All these are related to repetition, posture, muscular activity, or combinations thereof. Furthermore, these can be used in the regions of wrist (if applicable forearm), elbow joint, or upper arm. Furthermore, the following methods were briefly categorized by Seidel and colleagues in 2021: Mathematical functions for prevalence estimation of CTS/rotator cuff syndrome (Balogh et al. 2019); exposure-response relationships of hand/elbow complaints (Nordander et al. 2013); risk category classifications of individual kinematic parameters, non-recommended postures/movements (Weber et al. 2020a); time spent in sustained posture according to e.g., European standard (Barrero et al. 2012); ErgoArmMeter (Yang et al. 2017); identification of irregular movement patterns, time proportions of kinematic parameters with e.g., angle-time or velocity-time graphs (Álvarez et al. 2016); activity and fatigue estimation for different upper extremity muscles (Merino et al. 2019); angular deviations from neutral grip positions (Merino et al. 2019); angle assessments based on machine learning and a deep neural network (Bobin et al. 2017); RULA or SI as measurement-based assessment methods (Peppoloni et al. 2016; Vignais et al. 2017). At this point, chapter 3.2.4 should also be mentioned, in which several other new measurement-based assessment approaches for the elbow region and upper limb were discussed. All these studies and assessment methods listed in this context within this thesis thus answer research question Q. 7[7]. The list of further objective assessments is likely to be constantly expanded due to rapid increase in new technical developments and new possibilities. Several validated measurement-based methods (e.g., RepScore, mTLV for HAL) are already publicly accessible e.g., for occupational safety specialists or occupational safety and health officers. Other methods such as RULA or SI (Peppoloni et al. 2016; Vignais et al. 2017) or muscle activity and motor variability assessments using EMG supported RMS calculations (Luger et al. 2020) have already been tested on real or experimental workplaces and were validated and published including the methodology used. In addition, specific sensors, individual accelerometers/goniometers, commercial/non-commercial sensor technology, and HAV acquisition sensor technology, NIRS and some inertial sensors or multi-sensor systems are also available. Filippeschi et al. 2017, Walmsley et al. 2018 and Hindle et al. 2021 provided excellent reviews related to various hardware/sensors, respectively. These publications can be important if the interest in certain sensors is very high. Overall, the procedures and methods mentioned in this thesis define a good scope of measurement-based assessments for usage in the working environment. Thus, Q. 8[8] can be answered successfully.

[7] Q. 7: What other objective, measurement-based assessment methods exist besides the approach developed here?
[8] Q. 8: To what extent are the methods available for usage in the working environment?

### *3.3.3 Limitations*

Due to lack of material, time, and human resources, publication 3 could not be conducted as a systematic review or meta-analysis. Therefore, this publication does not claim to be a fully comprehensive presentation of all currently available measurement-based methods for upper extremity exposure assessment. Due to publisher's guidelines on maximum number of references, only a few methods could be presented to raise awareness of this topic among occupational safety specialists or occupational safety and health officers. The authors are aware that this specific selection of methods leads to biases, such as influence of attrition, reporting, or publication bias. Publication 3 is further limited because, e.g., Seidel et al. 2019b identified additional exposure main and subcategories that could not be explicitly included in this publication.

### *3.3.4 Current state of science*

By transferring a classification to the area of the upper extremity, the work of Seidel et al. 2021a offers a good supplement to current international classifications, e.g., for recording sedentary behavior at the workplace (Boudet et al. 2019). The parameters in **Fig. 2** in the manuscript by Seidel et al. 2021a, p. 195 are similar to those defined as relevant by PEROSH (Holtermann et al. 2017a; Holtermann et al. 2017b; Weber et al. 2018a). In the presented work, there are also parallels (e.g., in user groups, definition of sensor units/categories, body localizations, expertise for attachment of sensors) to the 3-level categorization of upper extremities, spine, and lower extremities as recommended by Ellegast et al. 2022. According to Ellegast’s workgroup, the mTLV for HAL could be classified to measurement category no. 3, which is in line with the categorization presented in **Fig. 2** in the manuscript by Seidel et al. 2021a, p. 195. Thus, this work in the present thesis is in line with international research on classification methods.

## 3.4 Conclusion and perspectives

This thesis presented a holistic approach. Besides a preparation of a systematic review, an extraction of quantitative information was addressed. Consequently, measurement-based parameters were derived and transferred into an evidence-based assessment approach for the elbow region. In addition, the new developed mTLV for HAL approach was tested for the first time in a pilot study, was related to other upper extremity exposure assessments and was shown to occupational safety specialists or occupational safety and health officers for objective risk assessments. Only by addressing these topics, it was possible to successfully answer the main research question[9] with 'yes' and fill three research gaps.

In addition to previous systematic reviews reporting on qualitative and semiquantitative information, there is now a systematic review available describing purely quantitative risk factor specifications in the elbow region (Seidel et al. 2019b).

Second, the developed repetition score and measurement-based NPF can used as independent assessments (Seidel et al. 2019a; Weber et al. 2020a). With the newly developed mTLV for HAL (Seidel et al. 2021b), an evidence-based tool was created to preventively (perhaps retrospectively) assess physical workload. More specifically, force combined with repetition in the elbows (and hands) can be assessed without subjective influences. Thus, a very good duty cycle independent supplement to previous video-based and observational-based TLV for HAL assessments has been provided.

Third, this thesis presented an overview of measurement-based assessment methods for risk assessment of physical exposures of the upper extremity. Commercially and non-commercially sensor technology was shown to occupational safety specialists or occupational safety and health officers and the mTLV for HAL approach was classified. Advantages of measurement-based risk assessments were highlighted to occupational safety specialists or occupational safety and health officers. This could perhaps even objectify and revolutionize the risk assessment of physical workload especially in the distal upper extremity. Possibly, this could form the basis for new standards in risk assessments of physical workload (Seidel et al. 2021a).

This thesis should increase general confidence in objective measurement-based data. Furthermore, e.g., scientists, physicians, occupational safety specialists or occupational safety and health officers should be encouraged by this thesis to measure exposures objectively. The usage of objective risk assessments for physical workload is recommended. This will increase transparency in usage in the working environment and reduce subjective influences or biases. It would also be desirable if future decisions were

[9] Is it possible to develop a measurement-based assessment method for the elbow region using a systematic literature review and measurement-based occupational-scientific analyses in the field and to present this assessment approach together with other methods to occupational safety specialists or occupational safety and health officers for objective risk assessment?

increasingly supported by evidence-based, quantifiable information on risk factors such as those presented in Seidel's systematic review in 2019. Besides the review, the mTLV for HAL (Seidel et al. 2021b) and categorization of assessment methods (Seidel et al. 2021a), provide an important basis for primary, secondary, and tertiary prevention measures. Thus, this underscores their importance to occupational science or medicine, and related fields. The present research could likely contribute to reduced work-related absenteeism due to upper limb MSDs. Furthermore, this research could help to reduce costs for e.g., treatments or absenteeism. Future research could include among others: systematic investigations including dose-response relationships between specific work-related elbow disorders and occupational exposures; profound testing of test reliability or conducting intensive validity testing's regarding the mTLV for HAL in large-scaled, epidemiological studies; further developments of the mTLV for HAL involving RepScore and NPF adjustments; supporting the classification of measurement-based methods through prospective systematic reviews or meta-analyses.

# 4 Summaries

## 4.1 Abstract

Work-related musculoskeletal disorders and elbow complaints occur annually and relatively frequently among employees. Consequently, employees may be absent from work and companies may suffer from loss of gross value added or have other high costs. To protect employees from overload, evidence-based, transparent, and objective risk assessments of physical workload, e.g., in the elbow region, are very important. The aim of this work was therefore to develop an objective, evidence- and measurement-based assessment approach for the elbow region, based on the findings of a systematic literature review and occupational scientific investigations in the field. Furthermore, this new approach is presented as an example in addition to other methods to usage in the working environment. To establish objective assessments in the future, it was necessary to investigate three research topics.

First, a systematic review of quantitative information was required because previous systematic reviews have mostly described qualitative or semiquantitative risk factors in the elbow. Following the PRISMA guideline, the MEDLINE, EMBASE, and Cochrane Work databases were screened from 2007 to 2017. From a total of 524 articles, 10 relevant articles were identified. These were assessed for methodological quality and the way exposures and outcomes were recorded. The review of studies identified 5 main exposure categories (Force, Repetition, Posture/movement, Vibration, Combined exposures) and 16 subcategories. Evidence of subcategories were estimated using the GRADE method and ranged from very low to high. A total of 133 quantitative risk factor specifications were identified that were associated with lateral/medial epicondylitis, radial tunnel syndrome, pronator teres syndrome or ulnar neuropathy.

Second, further research identified the combination of force and repetition as the most important subcategory related to elbow exposures. In addition, wrist flexion/extension and forearm supination/pronation were identified as the most important degrees of freedom. Furthermore, three kinematic parameters (mean power frequency, angular velocity, kinematic micro-pauses) and one kinetic parameter (electromyography) were extracted as an important basis for the development of an assessment approach. These kinematic parameters were computed into the repetition score, considering the verbally anchored Latko-scale, and were merged with normalized peak force. In this process, the

mTLV for HAL method was developed. It can estimate combined loads (force and repetition) in the wrist and elbow region. A pilot study demonstrated that the repetition score was indistinguishable from conventional HAL assessment. In addition, association analyses based on GEE models revealed that the mTLV for HAL can partially be significantly associated with carpal tunnel syndrome, arthrosis of the distal joints, lateral epicondylitis, and complaints in the hand and elbow joints/regions. The validation and analysis of 500 data sets of individual subjects showed that the mTLV for HAL can be used very well in practice. Furthermore, this method is a very good duty cycle independent supplement to previous observational- and video-based TLV for HAL assessment approaches.

Third, it is sometimes difficult for occupational safety specialists or occupational safety and health officers to select the appropriate sensor technology in combination with the appropriate assessment method for the respective risk assessment situation. Therefore, a categorization of measurement-based assessment methods for the upper extremity region was particularly required. For this purpose, an internationally accepted 3-level categorization was applied to this area. This allowed both – sensor technologies and measurement-based methods – to be presented to occupational safety specialists or occupational safety and health officers. The mTLV for HAL assessment approach was also classified and contrasted with other selected methods.

This work is intended to encourage scientific, medical, and occupational safety and health professionals to process evidence-based quantitative information and measure exposures. The use of measurement-based assessment methods is also recommended, especially for the elbow region. Thus, this work provides a good basis for primary, secondary, and tertiary prevention measures.

## 4.2 Deutsche Zusammenfassung

**Titel:** Entwicklung eines Bewertungsverfahrens für arbeitsbedingte muskuloskelettale Belastungen in der Region des Ellenbogens auf Basis einer systematischen Literaturrecherche und messtechnischer arbeitswissenschaftlicher Analysen

Arbeitsbedingte Muskel-Skelett-Erkrankungen und Beschwerden am Ellenbogen treten jährlich und vergleichsweise häufig bei Arbeitnehmenden auf. In der Folge kann es bei Beschäftigten z. B. zu Arbeitsausfällen und bei Firmen zu

Bruttowertschöpfungsverlusten oder anderen hohen Kosten kommen. Um Arbeitnehmende vor Überlastungen zu schützen, sind evidenzbasierte, transparente und objektive Gefährdungsbeurteilungen von physischen Belastungen z. B. im Ellenbogenbereich sehr wichtig. Ziel dieser Arbeit war daher die Entwicklung eines objektiven, evidenz- und messdatenbasierten Bewertungsverfahrens für den Ellenbogenbereich, basierend auf den Erkenntnissen einer systematischen Literaturrecherche und arbeitswissenschaftlichen Untersuchungen im Feld. Darüber hinaus wird dieses neue Verfahren exemplarisch in Ergänzung zu anderen Methoden der betrieblichen Praxis vorgestellt. Um in Zukunft objektive Beurteilungen zu etablieren, war es notwendig, drei Forschungsthemen zu untersuchen.

Erstens, wurde zuerst eine systematische Übersicht über quantitative Informationen benötigt, da bisherige systematische Übersichtsarbeiten meist qualitative oder semiquantitative Risikofaktoren im Ellenbogen beschrieben haben. In Anlehnung an die PRISMA-Richtlinie wurden die Datenbanken *MEDLINE*, *EMBASE* und *Cochrane Work* von 2007 bis 2017 durchsucht. Von insgesamt 524 Artikeln wurden 10 relevante Artikel identifiziert. Diese wurden hinsichtlich der methodischen Qualität und der Art der Erfassung von Expositionen und Outcomes bewertet. Die Untersuchung der Studien identifizierte 5 Hauptexpositionskategorien (Kraft, Repetition, Haltung/Bewegung, Vibration, kombinierte Expositionen) und 16 Unterkategorien. Die Evidenz der Unterkategorien wurde mit Hilfe der GRADE-Methode geschätzt und reichte von sehr niedrig bis hoch. Insgesamt wurden 133 quantitative Risikofaktorspezifikationen identifiziert, die mit lateraler/medialer Epikondylitis, ulnarer Neuropathie, Radial Tunnel Syndrom oder Pronator teres Syndrom assoziiert wurden.

Zweitens wurde in weiteren Untersuchungen die Kombination aus Kraft und Repetition als wichtigste Unterkategorie für Expositionen identifiziert. Außerdem wurden Handgelenksflexion/-extension und Unterarm Supination/Pronation als die wichtigsten Freiheitsgrade ermittelt. Weiterhin wurden drei kinematische Parameter (Mittenfrequenz, Winkelgeschwindigkeit, kinematische Mikropausen) und ein kinetischer Parameter (Elektromyographie) als wichtige Grundlage für die Entwicklung eines Bewertungsverfahrens herausgearbeitet. Diese kinematischen Parameter wurden unter Berücksichtigung der verbal verankerten Latko-Skala in einem Repetitionsscore verrechnet und mit normalisierten Kraftspitzen zusammengeführt. Dabei wurde das *mTLV for HAL*-Verfahren entwickelt. Dieses kann die kombinierten Belastungen aus Kraft und Repetition im Bereich des Handgelenks und Ellenbogens abschätzen. In einer Pilotstudie konnte gezeigt werden, dass der Repetitionsscore nicht von der konventionellen HAL-Bewertung zu unterscheiden ist. Darüber hinaus ergaben Zusammenhangsanalysen auf Basis von GEE-Modellen, dass der *mTLV for HAL* mit Karpaltunnelsyndrom, Arthrose der distalen Gelenke, lateraler Epikondylitis und Beschwerden in den Hand- und Ellenbogengelenken/ -regionen teilweise signifikant assoziiert werden kann. Die Validierung und Analyse von 500 Datensätzen zu einzelnen Probanden zeigte, dass der *mTLV for HAL* sehr gut in der Praxis eingesetzt werden kann. Darüber hinaus ist diese Methode eine sehr gute Arbeitszyklus-unabhängige Ergänzung zu bisherigen beobachtungs- und videobasierten *TLV for HAL*-Bewertungsansätzen.

Drittens ist es für Fachkräfte für Arbeitssicherheit oder Arbeitsschutzbeauftrage manchmal schwierig, die geeignete Sensorik in Verbindung mit der geeigneten Beurteilungsmethode für die jeweilige Gefährdungsbeurteilungssituation auszuwählen. Daher wurde insbesondere eine Kategorisierung von messdatenbasierten Bewertungsmethoden für den Bereich der oberen Extremitäten benötigt. Zu diesem Zweck wurde eine international anerkannte 3-stufige Kategorisierung auf diesen Bereich übertragen. Damit konnten sowohl Sensortechnologien als auch messdatenbasierte Methoden den Fachkräften für Arbeitssicherheit oder Arbeitsschutzbeauftragen vorgestellt werden. Der *mTLV for HAL*-Bewertungsansatz wurde ebenfalls klassifiziert und anderen ausgewählten Methoden dabei gegenübergestellt.

Die vorliegende Arbeit soll Fachleute aus der Wissenschaft, Medizin und des Arbeitsschutzes dazu anregen, evidenzbasierte quantitative Informationen zu verarbeiten und Expositionen zu messen. Auch die Anwendung von messtechnischen Beurteilungsmethoden wird empfohlen, insbesondere für den Bereich des Ellenbogens. Damit bietet diese Arbeit eine gute Grundlage für Maßnahmen der Primär-, Sekundär- und Tertiärprävention.

# 5 References

Aavang Petersen J, Brauer C, Thygesen LC, Flachs EM, Bach Lund C and Froelund Thomsen J (2021) Risk of pain in the neck and shoulders and job change among hairdressers: a combined questionnaire and register-based Danish prospective cohort study. Int Arch Occup Environ Health: 1-11. doi: 10.1007/s00420-021-01753-4.

ACGIH (2001) Hand activity level TLVs and BEIs - Threshold limit values for chemical substances and physical agents: 1-18. American Conference of Governmental Industrial Hygienists (ACGIH®): Cincinnati, Ohio.

ACGIH (2018) TLVs® and BEIs®: based on the documentation of the threshold limit values for chemical substances and physical agents & biological exposure indices: 182-213. American Conference of Governmental Industrial Hygienists (ACGIH®): Cincinnati, Ohio.

Acosta Batlle J, Cerezal L, López Parra MD, Alba B, Resano S and Blázquez Sánchez J (2019) The elbow: review of anatomy and common collateral ligament complex pathology using MRI. Insights Imaging 10(43): 1-25. doi: 10.1186/s13244-019-0725-7.

Ahmad Z, Siddiqui N, Malik SS, Abdus-Samee M, Tytherleigh-Strong G and Rushton N (2013) Lateral epicondylitis: a review of pathology and management. Bone Joint J 95-B(9): 1158-1164. doi: 10.1302/0301-620x.95b9.29285.

Akkas O, Azari DP, Chen C-HE, Hu YH, Ulin SS, Armstrong TJ, Rempel D and Radwin RG (2015) A hand speed – duty cycle equation for estimating the ACGIH hand activity level rating. Ergonomics 58(2): 184-194. doi: 10.1080/00140139.2014.966155.

Akkas O, Bao S, Harris-Adamson C, Lin J-H, Meyers A, Rempel D and Radwin RG (2019) The Speed Calculated Hand Activity Level (HAL) Matches Observer Estimates Better Than the Frequency Calculated HAL. 547-549. In: Bagnara, S, Tartaglia, R, Albolino, S, Alexander, T and Fujita, Y, (eds). Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). IEA 2018. Advances in Intelligent Systems and Computing; Cham. vol 820. Springer. doi: 10.1007/978-3-319-96083-8_71.

Akkas O, Hu YH, Lee C-H, Bao S, Harris-Adamson C, Lin J-H, Meyers A, Rempel D and Radwin RG (2018) How Do Computer Vision Upper Extremity Exposure Measures Compare Against Manual Measures? Proc Hum Factors Ergon Soc Annu Meet 62(1): 960-961. doi: 10.1177/1541931218621221.

Akkas O, Lee C-H, Hu YH, Yen TY and Radwin RG (2016) Measuring elemental time and duty cycle using automated video processing. Ergonomics 59(11): 1514-1525. doi: 10.1080/00140139.2016.1146347.

Akkas O, Lee CH, Hu YH, Harris Adamson C, Rempel D and Radwin RG (2017) Measuring exertion time, duty cycle and hand activity level for industrial tasks using computer vision. Ergonomics 60(12): 1730-1738. doi: 10.1080/00140139.2017.1346208.

Álvarez D, Alvarez JC, González RC and López AM (2016) Upper limb joint angle measurement in occupational health. Comput Methods Biomech Biomed Engin 19(2): 159-170. doi: 10.1080/10255842.2014.997718.

## REFERENCES


AMR 13.2 (2014) Tätigkeiten mit wesentlich erhöhten körperlichen Belastungen mit Gesundheitsgefährdungen für das Muskel-Skelett-System [Tasks with significantly increased physical loads with health risks for the musculoskeletal system] – Bek. d. BMAS v. 17.11.2014 – IIIb1-36628-15/9 – GMBl Nr. 76-77, 23. Dezember 2014, S. 1571: 1-9. BAuA.

Anderson N, Adams D, Bonauto D, Howard N and Silverstein B (2015) Work-Related Musculoskeletal Disorders of the Back, Upper Extremity, and Knee in Washington State, 2002-2010: 1-333. SHARP Program, Washington State Department of Labor and Industries: Washington.

ARBMEDVV (2008) Verordnung zur arbeitsmedizinischen Vorsorge (ArbMedVV) [Ordinance on Preventive Occupational Health Care (ArbMedVV)]. "Verordnung zur arbeitsmedizinischen Vorsorge vom 18. Dezember 2008 (BGBl. I S. 2768) [Occupational Health Care Ordinance of 18 December 2008 (Federal Law Gazette I, p. 2768)], die zuletzt durch Artikel 3 Absatz 1 der Verordnung vom 15. November 2016 (BGBl. I S. 2549) geändert worden ist": 1-11. BMAS, BfJ.

ArbSchG (1996) Gesetz über die Durchführung von Maßnahmen des Arbeitsschutzes zur Verbesserung der Sicherheit und des Gesundheitsschutzes der Beschäftigten bei der Arbeit (Arbeitsschutzgesetz ArbSchG) [Act on the Implementation of Measures of Occupational Safety and Health to Encourage Improvements in the Safety and Health Protection of Workers at Work (Occupational Safety and Health Act ArbSchG)]. "Arbeitsschutzgesetz vom 7. August 1996 (BGBl. I S. 1246), das zuletzt durch Artikel 427 der Verordnung vom 31. August 2015 (BGBl. I S. 1474) geändert worden ist: 1-11. BMJV, BJ.

Arvidsson I, Åkesson I and Hansson GÅ (2003) Wrist movements among females in a repetitive, non-forceful work. Appl Ergon 34(4): 309-316. doi: 10.1016/s0003-6870(03)00042-5.

Arvidsson I, Dahlqvist C, Enquist H and Nordander C (2021) Action Levels for the Prevention of Work-Related Musculoskeletal Disorders in the Neck and Upper Extremities: A Proposal. Ann Work Expo Health: 1-7. doi: 10.1093/annweh/wxab012.

Aumüller G, Aust G, Doll A, Engele J, Kirsch J, Mense S, Reißig D, Salvetter J, Schmidt W, Schmitz F, Schulte E, Spanel-Borowski K, Wolff W, Wurzinger LJ und Zilch H-G (2007) Duale Reihe Anatomie [Dual series anatomy]: 1-1344. Georg Thieme Verlag: Stuttgart.

Balogh I, Arvidsson I, Björk J, Hansson G-Å, Ohlsson K, Skerfving S and Nordander C (2019) Work-related neck and upper limb disorders – quantitative exposure–response relationships adjusted for personal characteristics and psychosocial conditions. BMC Musculoskelet Disord 20:139(1): 1-19. doi: 10.1186/s12891-019-2491-6.

Bao S, Howard N, Spielholz P and Silverstein B (2006a) Quantifying repetitive hand activity for epidemiological research on musculoskeletal disorders – Part II: comparison of different methods of measuring force level and repetitiveness. Ergonomics 49(4): 381-392. doi: 10.1080/00140130600555938.

Bao S and Silverstein B (2005) Estimation of hand force in ergonomic job evaluations. Ergonomics 48(3): 288-301. doi: 10.1080/0014013042000327724.

Bao S, Spielholz P, Howard N and Silverstein B (2006b) Quantifying repetitive hand activity for epidemiological research on musculoskeletal disorders – Part I:

individual exposure assessment. Ergonomics 49(4): 361-380. doi: 10.1080/00140130500520214.

Barrero LH, Pulido JA, Berrio S, Monroy M, Quintana LA, Ceballos C, Hoehne-Hueckstaedt U and Ellegast R (2012) Physical Workloads of the Upper-Extremity Among Workers of the Colombian Flower Industry. Am J Ind Med 55(10): 926-939. doi: 10.1002/ajim.22102.

BAuA (2019a) Gefährdungsfaktoren: Ein Ratgeber [Hazard factors: A guidebook]: 1-382. BAuA: Dortmund. URL: www.baua.de/gefaehrdungsfaktoren [Zugriff: 22.10.2019].

BAuA (2019b) MEGAPHYS - Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz [MEGAPHYS - Multilevel risk assessment of physical workload]. Gemeinsamer Abschlussbericht der BAuA und der DGUV. Band 1: 1-987. BAuA: Dortmund/Berlin/Dresden. doi: 10.21934/baua:bericht20190821.

Bauters K, Cottyn J, Claeys D, Slembrouck M, Veelaert P and van Landeghem H (2018) Automated work cycle classification and performance measurement for manual work stations. Robot Comput Integr Manuf 51: 139-157. doi: 10.1016/j.rcim.2017.12.001.

Bernard BP (1997) Musculoskeletal Disorders and Work Place Factors – A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity and Low Back: 1-590. U.S. Department of Health and Human Services, National Institute of Occupational Safety and Health (NIOSH): Cincinnati, OH, USA.

BETRSICHV (2015) Verordnung über Sicherheit und Gesundheitsschutz bei der Verwendung von Arbeitsmitteln (Betriebssicherheitsverordnung - BetrSichV) [Ordinance on safety and health protection in the use of work equipment (Ordinance on company safety and health - BetrSichV)]. "Betriebssicherheitsverordnung vom 3. Februar 2015 (BGBl. I S. 49), die zuletzt durch Artikel 5 Absatz 7 der Verordnung vom 18. Oktober 2017 (BGBl. I S. 3584) geändert worden ist": 1-104. Antiphon Verlag: Frankfurt am Main.

BMAS und BAuA (2010) Sicherheit und Gesundheit bei der Arbeit 2008. Unfallverhütungsbericht Arbeit [Safety and health at work 2008. Accident prevention report work]: 1-172. BMAS, BAuA: Dortmund/Berlin/Dresden.

BMAS und BAuA (2011) Sicherheit und Gesundheit bei der Arbeit 2009. Unfallverhütungsbericht Arbeit [Safety and health at work 2009. Accident prevention report work]: 1-259. BMAS, BAuA: Dortmund/Berlin/Dresden.

BMAS und BAuA (2012) Sicherheit und Gesundheit bei der Arbeit 2010. Unfallverhütungsbericht Arbeit [Safety and health at work 2010. Accident prevention report work]: 1-194. BMAS, BAuA: Dortmund/Berlin/Dresden.

BMAS und BAuA (2013) Sicherheit und Gesundheit bei der Arbeit 2011. Unfallverhütungsbericht Arbeit [Safety and health at work 2011. Accident prevention report work]: 1-193. BMAS, BAuA: Dortmund/Berlin/Dresden.

BMAS und BAuA (2014a) Sicherheit und Gesundheit bei der Arbeit 2012. Unfallverhütungsbericht Arbeit [Safety and health at work 2012. Accident prevention report work]: 1-195. BMAS, BAuA: Dortmund/Berlin/Dresden.

**REFERENCES**


BMAS und BAuA (2014b) Sicherheit und Gesundheit bei der Arbeit 2013. Unfallverhütungsbericht Arbeit [Safety and health at work 2013. Accident prevention report work]: 1-339. BMAS, BAuA: Dortmund/Berlin/Dresden.

BMAS und BAuA (2016a) Sicherheit und Gesundheit bei der Arbeit 2014. Unfallverhütungsbericht Arbeit [Safety and health at work 2014. Accident prevention report work]: 1-185. BMAS, BAuA, Druck & Verlag Kettler GmbH, Bönen: Dortmund/Berlin/Dresden.

BMAS und BAuA (2016b) Sicherheit und Gesundheit bei der Arbeit 2015. Unfallverhütungsbericht Arbeit [Safety and health at work 2015. Accident prevention report work]: 1-191. BMAS, BAuA, Druck & Verlag Kettler GmbH, Bönen: Dortmund/Berlin/Dresden.

BMAS und BAuA (2017) Sicherheit und Gesundheit bei der Arbeit - Berichtsjahr 2016. Unfallverhütungsbericht Arbeit [Safety and health at work - Reporting year 2016. Accident prevention report work]: 1-189. BMAS, BAuA, Druck & Verlag Kettler GmbH, Bönen: Dortmund/Berlin/Dresden.

BMAS und BAuA (2018) Sicherheit und Gesundheit bei der Arbeit - Berichtsjahr 2017. Unfallverhütungsbericht Arbeit [Safety and health at work - Reporting year 2017. Accident prevention report work]: 1-286. BMAS, BAuA, Druck & Verlag Kettler GmbH, Bönen: Dortmund/Berlin/Dresden.

BMAS und BAuA (2020) Sicherheit und Gesundheit bei der Arbeit - Berichtsjahr 2018. Unfallverhütungsbericht Arbeit. [Safety and health at work - Reporting year 2018. Accident prevention report work]: 1-189. BMAS, BAuA, Druck & Verlag Kettler GmbH, Bönen: Dortmund/Berlin/Dresden.

Bobin M, Amroun H, Coquillart S, Bimbard F and Ammi M (2017) DNN based Approach for the Assessment of Elbow Flexion with Smart Textile Sensor: 1-7. In: SMC 2017 - IEEE International Conference on Systems, Man, and Cybernetics. Oct 2017; Banff, Canada. hal-01677679v2. vol. 1. doi: 10.1109/SMC.2017.8122934.

Bonfiglioli R, Mattioli S, Armstrong TJ, Graziosi F, Marinelli F, Farioli A and Violante FS (2013) Validation of the ACGIH TLV for hand activity level in the OCTOPUS cohort: a two-year longitudinal study of carpal tunnel syndrome. Scand J Work Environ Health 39(2): 155-163. doi: 10.5271/sjweh.3312.

Borg GA (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14(5): 377-381. doi: 10.1249/00005768-198205000-00012.

Boschman JS, van der Molen HF, Sluiter JK and Frings-Dresen MH (2011) Occupational demands and health effects for bricklayers and construction supervisors: A systematic review. Am J Ind Med 54(1): 55-77. doi: 10.1002/ajim.20899.

Boudet G, Chausse P, Thivel D, Rousset S, Mermillod M, Baker JS, Parreira LM, Esquirol Y, Duclos M and Dutheil F (2019) How to Measure Sedentary Behavior at Work? Front Public Health 7(167): 1-11. doi: 10.3389/fpubh.2019.00167.

Bretschneider SF, Los FS, Eygendaal D, Kuijer PPFM and van der Molen HF (2021) Work-relatedness of lateral epicondylitis: Systematic review including meta-analysis and GRADE work-relatedness of lateral epicondylitis. Am J Ind Med: 1-10. doi: 10.1002/ajim.23303.

Caffier G, Steinberg U und Liebers F (1999) Praxisorientiertes Methodeninventar zur Belastungsbeurteilung im Zusammenhang mit arbeitsbedingten Muskel-Skelett-Erkrankungen [Practice-oriented method inventory for load assessment in association with work-related musculoskeletal disorders]: 1-102. Schriftenreihe der BAuA (Hrsg.), Forschung, Fb 850. Wirtschaftsverlag NW, Bremerhaven: Dortmund, Berlin.

Chen C-H, Hu YH, Yen TY and Radwin RG (2013) Automated video exposure assessment of repetitive hand activity level for a load transfer task. Hum Factors 55(2): 298-308. doi: 10.1177/0018720812458121.

Chiang HC, Ko YC, Chen SS, Yu HS, Wu TN and Chang PY (1993) Prevalence of shoulder and upper-limb disorders among workers in the fish-processing industry. Scand J Work Environ Health 19(2): 126-131. doi: 10.5271/sjweh.1496.

Chowdhury R, Shah D and Payal AR (2017) Healthy Worker Effect Phenomenon: Revisited with Emphasis on Statistical Methods - A Review. Indian J Occup Environ Med 21(1): 2-8. doi: 10.4103/ijoem.IJOEM_53_16.

Cinque ME, Schickendantz M and Frangiamore S (2020) Review of Anatomy of the Medial Ulnar Collateral Ligament Complex of the Elbow. Curr Rev Musculoskelet Med 13(1): 96-102. doi: 10.1007/s12178-020-09609-z.

Curti S, Mattioli S, Bonfiglioli R, Farioli A and Violante FS (2021) Elbow tendinopathy and occupational biomechanical overload: A systematic review with best-evidence synthesis. J Occup Health 63: e12186. doi: 10.1002/1348-9585.12186.

da Costa BR and Vieira ER (2010) Risk Factors for Work-Related Musculoskeletal Disorders: A Systematic Review of Recent Longitudinal Studies. Am J Ind Med 53(3): 285-323. doi: 10.1002/ajim.20750.

Dale AM, Harris-Adamson C, Rempel D, Gerr F, Hegmann K, Silverstein B, Burt S, Garg A, Kapellusch J, Merlino L, Thiese MS, Eisen EA and Evanoff B (2013) Prevalence and incidence of carpal tunnel syndrome in US working populations: pooled analysis of six prospective studies. Scand J Work Environ Health 39(5): 495-505. doi: 10.5271/sjweh.3351.

Degen RM, Conti MS, Camp CL, Altchek DW, Dines JS and Werner BC (2018) Epidemiology and Disease Burden of Lateral Epicondylitis in the USA: Analysis of 85, 318 Patients. HSS J 14(1): 9-14. doi: 10.1007/s11420-017-9559-3.

Descatha A, Albo F, Leclerc A, Carton M, Godeau D, Roquelaure Y, Petit A and Aublet-Cuvelier A (2016) Lateral Epicondylitis and Physical Exposure at Work? A Review of Prospective Studies and Meta-Analysis. Arthritis Care Res (Hoboken) 68(11): 1681-1687. doi: 10.1002/acr.22874.

Descatha A, Dale AM, Jaegers L, Herquelot E and Evanoff B (2013) Self-reported physical exposure association with medial and lateral epicondylitis incidence in a large longitudinal study. Occup Environ Med 70(9): 670-673. doi: 10.1136/oemed-2012-101341.

Descatha A, Leclerc A, Chastang J-F and Roquelaure Y (2004) Incidence of ulnar nerve entrapment at the elbow in repetitive work. Scand J Work Environ Health J 30(3): 234-240. doi: 10.5271/sjweh.784.

Descatha A, Petit A and Roquelaure Y (2018) 1632c Criteria for work-related upper extremity musculoskeletal disorders in france. Occup Environ Med 75(Suppl 2): A255. doi: 10.1136/oemed-2018-ICOHabstracts.729.

DFG (2019) Guidelines for Safeguarding Good Research Practice: Code of Conduct: 1-26. DFG: Bonn.

**REFERENCES**


DGUV (2013) DGUV Vorschrift 1. Unfallverhütungsvorschrift Grundsätze der Prävention [DGUV regulation 1. Accident prevention regulation principles of prevention]: 1-32. DGUV: Berlin.

DGUV (2020) DGUV Report 3/2020. MEGAPHYS - Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz [DGUV Report 3/2020. MEGAPHYS - Multilevel risk assessment of physical workload]. Gemeinsamer Abschlussbericht der BAuA und der DGUV. Band 2: 1-984. DGUV: Berlin.

DIMDI (2018) Internationale statistische Klassifikation der Krankheiten und verwandter Gesundheitsprobleme [International statistical classification of diseases and related health problems], 10. Revision – German Modification: 1-806. DIMDI: Köln.

Ditchen D, Ellegast RP und Rehme G (2010) GonKatast - Ein Messwertkataster zu beruflichen Kniebelastungen [GonKatast - A measured value register of occupational knee stress] (IFA-Report 1/2010): 1-137. IFA: Sankt Augustin.

Ditchen D, Gebhardt H, Hartmann B, Hermanns I, Jäger M, Jordan C, Klußmann A, Schaub K, Schust M, Sinn-Behrendt A, Weber B, Brandstädt F, Bruder R, Brütting M, Glitsch U, Hoehne-Hückstädt U, Kern G, Lang K, Lietz R, Liebers F, Post M, Rieger MA, Schäfer A, Seidel D, Serafin P und Steinberg U (2017) DGUV Report 2/2017. Gefährdungsbeurteilung physischer Belastungen – neue Ansätze im Projekt MEGAPHYS [DGUV Report 2/2017. Risk assessment of physical loads – New approaches in the MEGAPHYS project]. 87-92. In: Ellegast, R (Ed.). 6. DGUV Fachgespräch Ergonomie – Zusammenfassung der Vorträge vom 2. und 3. November 2016; Sankt Augustin. DGUV.

Ditchen DM, Ellegast RP, Gawliczek T, Hartmann B and Rieger MA (2015) Occupational kneeling and squatting: development and validation of an assessment method combining measurements and diaries. Int Arch Occup Environ Health 88(2): 153-165. doi: 10.1007/s00420-014-0946-5.

Ditchen DM, Ellegast RP, Hartmann B and Rieger MA (2013) Validity of self-reports of knee-straining activities at work: a field study with 6-month follow-up. Int Arch Occup Environ Health 86(2): 233-243. doi: 10.1007/s00420-012-0758-4.

Drinkaus P, Sesek R, Bloswick DS, Mann C and Bernard T (2005) Job Level Risk Assessment Using Task Level ACGIH Hand Activity Level TLV Scores: A Pilot Study. Int J Occup Saf Ergon 11(3): 263-281. doi: 10.1080/10803548.2005.11076648.

du Prel JB, Hommel G, Röhrig B and Blettner M (2009) Confidence Interval or P-Value?. Part 4 of a Series on Evaluation of Scientific Publications. Dtsch Arztebl Int 106(19): 335-339. doi: 10.3238/arztebl.2009.0335.

Duncan J, Duncan R, Bansal S, Davenport D and Hacker A (2019) Lateral epicondylitis: the condition and current management strategies. Br J Hosp Med (Lond) 80(11): 647-651. doi: 10.12968/hmed.2019.80.11.647.

Ellegast R, Weber B, Schiefer C, Heinrich K and Hermanns-Truxius I (2022) Measurement of Work-Related Physical Workloads - Proposal for a Body Region-Related Categorization System. 139-147. In: Black NL, Neumann WP and Noy I (eds). Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021). IEA 2021. Lecture Notes in Networks and Systems; Cham. Springer International Publishing. doi: 10.1007/978-3-030-74614-8_16.

**REFERENCES**

Ellegast RP, Hermanns I and Schiefer C (2009) Workload Assessment in Field Using the Ambulatory CUELA System: 221-226. In: Duffy VG (ed). Digital Human Modeling. ICDHM 2009. Lecture Notes in Computer Science. vol 5620. Springer: Berlin, Heidelberg.

Ellegast RP, Hermanns I und Schiefer C (2010) Feldmesssystem CUELA zur Langzeiterfassung und -analyse von Bewegungen an Arbeitsplätzen [Ambulatory measurment system CUELA for long-term motion analysis at workplaces]. Zent Arbeitswissenschaft 64(2): 101-110.

Esmailzadeh A, Yazdani Rad S, Jahadi naeini M, Moradi R and Mousavi S (2020) Assessment of Effective Risk Factors Leading to Musculoskeletal Disorders in Jobs of a Central Repair Workshop in an Oil Refinery using Relative Stress Index. Arch Hyg Sci 9(3): 205-213. doi: 10.29252/ArchHygSci.9.3.205.

EU-OSHA (2020) Gesunde Arbeitsplätze - entlasten Dich! Leitfaden zur Kampagne [Healthy Workplaces Lighten the Load]: 1-36. EU-OSHA: Luxemburg. URL https://osha.europa.eu/de/publications/campaign-guide/view [Zugriff 14.11.2021].

Fan ZJ, Bao S, Silverstein BA, Howard NL, Smith CK and Bonauto DK (2014a) Predicting work-related incidence of lateral and medial epicondylitis using the strain index. Am J Ind Med 57(12): 1319-1330. doi: 10.1002/ajim.22383.

Fan ZJ, Silverstein BA, Bao S, Bonauto DK, Howard NL and Smith CK (2014b) The association between combination of hand force and forearm posture and incidence of lateral epicondylitis in a working population. Hum Factors 56(1): 151-165. doi: 10.1177/0018720813492327.

Fan ZJ, Silverstein BA, Bao S, Bonauto DK, Howard NL, Spielholz PO, Smith CK, Polissar NL and Viikari-Juntura E (2009) Quantitative exposure-response relations between physical workload and prevalence of lateral epicondylitis in a working population. Am J Ind Med 52(6): 479-490. doi: 10.1002/ajim.20700.

Filippeschi A, Schmitz N, Miezal M, Bleser G, Ruffaldi E and Stricker D (2017) Survey of Motion Tracking Methods Based on Inertial Sensors: A Focus on Upper Limb Human Motion. Sensors (Basel) 17(1257): 1-40. doi: 10.3390/s17061257.

Forsman M (2016) Ergonomic risk assessments – a need for reliable and attractive methods. 28-32. In: Järvelin-Pasanen, S (ed). NES2016 - Ergonomics in theory and practice - 48th Annual Conference of Nordic Ergonomics and Human Factors Society. August 14-17, 2016; Kuopio, Finland. University Eastern Finland. Report and Studies in Health Sciences.

Franzblau A, Armstrong TJ, Werner RA and Ulin SS (2005) A Cross-Sectional Assessment of the ACGIH TLV for Hand Activity Level. J Occup Rehabil 15(1): 57-67. doi: 10.1007/s10926-005-0874-z.

Garg A, Kapellusch JM, Hegmann KT, Thiese MS, Merryweather AS, Wang YC and Malloy EJ (2014) The Strain Index and TLV for HAL: Risk of Lateral Epicondylitis in a Prospective Cohort. Am J Ind Med 57(3): 286-302. doi: 10.1002/ajim.22279.

Garg A, Moore JS and Kapellusch JM (2017) The Revised Strain Index: an improved upper extremity exposure assessment model. Ergonomics 60(7): 912-922. doi: 10.1080/00140139.2016.1237678.

**REFERENCES**


Giavarina D (2015) Understanding Bland Altman analysis. Biochem Med (Zagreb) 25(2): 141-151. doi: 10.11613/BM.2015.015.

Girgis B and Duarte JA (2020) Efficacy of physical therapy interventions for chronic lateral elbow tendinopathy: a systematic review. Phys Ther Rev 25(1): 42-59. doi: 10.1080/10833196.2019.1695355.

Glitsch U, Jürgen Ottersbach H, Ellegast R, Schaub K, Franz G and Jaeger M (2007) Physical workload of flight attendants when pushing and pulling trolleys aboard aircraft. Int J Ind Ergon 37: 845-854. doi: 10.1016/j.ergon.2007.07.004.

Greene RL, Azari DP, Hu YH and Radwin RG (2017) Visualizing stressful aspects of repetitive motion tasks and opportunities for ergonomic improvements using computer vision. Appl Ergon 65: 461-472. doi: 10.1016/j.apergo.2017.02.020.

Grifka J, Bär H-F und Peters T (2001) Mehrstufendiagnostik von Muskel-Skelett-Erkrankungen in der arbeitsmedizinischen Praxis [Multi-stage diagnostics of musculoskeletal disorders in occupational medicine practice]: 1-48. Wirtschaftsverl. NW, Verlag für Neue Wiss., Sonderschrift Band S62: Bremerhaven.

Grooten W and Johanssons E (2018) Observational Methods for Assessing Ergonomic Risks for Work-Related musculoskeletal disorders. A Scoping Review. Rev Cienc Salud 16(especial): 8-38. doi: 10.12804/revistas.urosario.edu.co/revsalud/a.6840.

Grosser V (2020) Kapitel 20 - Berufskrankheiten [Chapter 20 - Occupational diseases]: 359-402. In: Orthopädisch-unfallchirurgische Begutachtung (Dritte Ausgabe). Urban & Fischer: München.

Hansson G-Å, Asterland P and Skerfving S (1997) Acquisition and analysis of whole-day electromyographic field recordings' In European Applications of Surface Electromyography. Second general SENIAM (Surface EMG for Non Invasive Assessment of Muscles) workshop: 19-27. Roessingh Research and Development b.v.: Enschede, The Netherlands.

Hansson G-Å, Balogh I, Ohlsson K, Granqvist L, Nordander C, Arvidsson I, Åkesson I, Unge J, Rittner R, Strömberg U and Skerfving S (2009) Physical workload in various types of work: Part I. Wrist and forearm. Int J Ind Ergon 39(1): 221-233. doi: 10.1016/j.ergon.2008.04.003.

Hansson G-Å, Balogh I, Ohlsson K, Palsson B, Rylander L and Skerfving S (2000) Impact of physical exposure on neck and upper limb disorders in female workers. Appl Ergon 31(3): 301-310. doi: 10.1016/S0003-6870(99)00047-2.

Hansson G-Å, Balogh I, Ohlsson K, Rylander L and Skerfving S (1996) Goniometer Measurement and Computer Analysis of Wrist Angles and Movements Applied to Occupational Repetitive Work. J Electromyogr Kinesiol 6(1): 23-35.

Hansson G-Å, Balogh I, Ohlsson K and Skerfving S (2004a) Measurements of wrist and forearm positions and movements: effect of, and compensation for, goniometer crosstalk. J Electromyogr Kinesiol 14(3): 355-367. doi: 10.1016/j.jelekin.2003.10.001.

Hansson G-Å, Ohlsson K, Balogh I, Nordander C and Skerfving S (2004b) Exposure-response relation for wrist/hand disorders. 477-478. In: PREMUS (ed). PREMUS 2004, 5th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders. 2004/07/11; Zürich, Switzerland. PREMUS.

**REFERENCES**


Harris C, Eisen EA, Goldberg R, Krause N and Rempel D (2011) 1st place, PREMUS best paper competition: workplace and individual factors in wrist tendinosis among blue-collar workers – the San Francisco study. Scand J Work Environ Health 37(2): 85-98. doi: 10.5271/sjweh.3147.

Hartmann B (2014) Häufigkeiten, Beschwerden und Risikofaktoren arbeitsbezogener Muskel-Skelett-Erkrankungen (MSE). Basisinformationen für das Projekt MEGAPHYS (unveröffentlichter Bericht Arbeitspaket 1.3) [Frequencies, complaints and risk factors of work-related musculoskeletal disorders (MSDs). Basic information for the MEGAPHYS project (unpublished report work package 1.3)]: 1-119. ArbMedErgo: Hamburg.

Hartmann B, Spallek M und Ellegast R (2013) Arbeitsbezogene Muskel-Skelett-Erkrankungen. Ursachen - Prävention - Ergonomie – Rehabilitation [Work-related musculoskeletal disorders. Causes - Prevention - Ergonomics - Rehabilitation]: 1-440. ecomed MEDIZIN: Zwickau.

Hayden JA, Cote P and Bombardier C (2006) Evaluation of the quality of prognosis studies in systematic reviews. Ann Intern Med 144(6): 427-437. doi: 10.7326/0003-4819-144-6-200603210-00010.

Hayden JA, van der Windt DA, Cartwright JL, Cote P and Bombardier C (2013) Assessing bias in studies of prognostic factors. Ann Intern Med 158(4): 280-286. doi: 10.7326/0003-4819-158-4-201302190-00009.

Heinrich K, Ditchen D, Ellegast R, Hermanns I, Jaeger M, Seidel D, Sinn-Behrendt A and Weber B (2018) The assessment of physical workload using technical measurements within the MEGAPHYS project. In: 20th Congress International Ergonomics Association; Florence, Italy. IEA.

Heinrich K, Weber B, Hermanns I, Seidel D, Hoehne-Hückstädt U, Ditchen D und Ellegast R (2019) Entwicklung messwertbasierter biomechanischer Belastungsindikatoren für das Handgelenk [Development of measurement-based biomechanical load indicators for the wrist]. 34-35. In: DGAUM (Ed). 59. Wissenschaftliche Jahrestagung der Deutschen Gesellschaft für Arbeitsmedizin und Umweltmedizin (DGAUM); Erfurt. DGAUM.

Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G, Disselhorst-Klug C and Hägg G (1999) SENIAM 8. European Recommendations for Surface ElectroMyoGraphy. Results of the SENIAM project: 1-122. Roessingh Research and Development b.v.: Enschede, the Netherlands.

Herquelot E, Bodin J, Roquelaure Y, Ha C, Leclerc A, Goldberg M, Zins M and Descatha A (2013a) Work-related risk factors for lateral epicondylitis and other cause of elbow pain in the working population. Am J Ind Med 56(4): 400-409. doi: 10.1002/ajim.22140.

Herquelot E, Gueguen A, Roquelaure Y, Bodin J, Serazin C, Ha C, Leclerc A, Goldberg M, Zins M and Descatha A (2013b) Work-related risk factors for incidence of lateral epicondylitis in a large working population. Scand J Work Environ Health 39(6): 578-588. doi: 10.5271/sjweh.3380.

Hindle BR, Keogh JWL and Lorimer AV (2021) Inertial-Based Human Motion Capture: A Technical Summary of Current Processing Methodologies for Spatiotemporal and Kinematic Measures. Appl Bionics Biomech 2021: 1-14. doi: 10.1155/2021/6628320.

**REFERENCES**


Holtermann A, Mathiassen SE, Pinder A, Punakallio A, Veiersted B, Weber B, Ditchen D, Takala E-P, Draicchio F, Enquist H, Desbrosses K, Sanz MPG, Villar M, Malińska M, Wichtl M, Strebl M, Forsman M, Gupta N, Hendriksen P, Lusa S, Tokarski T, Schellewald V and Ellegast R (2017a) Assessing Sedentary Behaviour at Work with Technical Assessment Systems – Final Report: 1-53. PEROSH.

Holtermann A, Schellewald V, Mathiassen SE, Gupta N, Pinder A, Punakallio A, Veiersted KB, Weber B, Takala E-P, Draicchio F, Enquist H, Desbrosses K, Sanz MPG, Malinska M, Villar M, Wichtl M, Strebl M, Forsman M, Lusa S, Tokarski T, Hendriksen P and Ellegast R (2017b) A practical guidance for assessments of sedentary behavior at work: A PEROSH initiative. Appl Ergon 63: 41-52. doi: 10.1016/j.apergo.2017.03.012.

Horton N and Lipsitz S (1999) Review of Software to Fit Generalized Estimating Equation Regression Models. Am Stat 53: 160-169. doi: 10.2307/2685737.

Howard J, Piacentino J, MacMahon K and Schulte P (2017) Using systematic review in occupational safety and health. Am J Ind Med 60(11): 921-929. doi: 10.1002/ajim.22771.

HSE (2017) Work-related Musculoskeletal Disorders (WRMSDs) Statistics in Great Britain 1-22. HSE: URL: www.hse.gov.uk/statistics/causdis/musculoskeletal/msd.pdf [access 18.05.2018].

Huguet A, Hayden JA, Stinson J, McGrath PJ, Chambers CT, Tougas ME and Wozney L (2013) Judging the quality of evidence in reviews of prognostic factor research: adapting the GRADE framework. Syst Rev 2(71): 1-12. doi: 10.1186/2046-4053-2-71.

Hulkkonen S, Lampainen K, Auvinen J, Miettunen J, Karppinen J and Ryhänen J (2020) Incidence and operations of median, ulnar and radial entrapment neuropathies in Finland: a nationwide register study. J Hand Surg Eur Vol 45(3): 226-230. doi: 10.1177/1753193419886741.

Humadi A, Nazarahari M, Ahmad R and Rouhani H (2021) Instrumented Ergonomic Risk Assessment Using Wearable Inertial Measurement Units: Impact of Joint Angle Convention. IEEE Access 9: 7293-7305. doi: 10.1109/ACCESS.2020.3048645.

Kajita Y, Iwahori Y, Harada Y, Takahashi R and Deie M (2020) Ultrasonographic analysis of the extensor carpi radialis brevis in asymptomatic individuals. J Orthop Sci 25(6): 999-1002. doi: 10.1016/j.jos.2019.12.003.

Kapellusch J (2019) The revised strain index: a physical exposure quantification tool for detailed assessment and design of distal upper limb work: 70. In: PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders; Bologna, Italia. PREMUS.

Kapellusch JM, Bao SS, Silverstein BA, Merryweather AS, Thiese MS, Hegmann KT and Garg A (2017) Risk assessments using the Strain Index and the TLV for HAL, Part I: Task and multi-task job exposure classifications. J Occup Environ Hyg 14(12): 1011-1019. doi: 10.1080/15459624.2017.1366037.

Kapellusch JM, Gerr FE, Malloy EJ, Garg A, Harris-Adamson C, Bao SS, Burt SE, Dale AM, Eisen EA, Evanoff BA, Hegmann KT, Silverstein BA, Theise MS and Rempel DM (2014) Exposure-response relationships for the ACGIH threshold limit value for hand-activity level: results from a pooled data study of carpal tunnel syndrome. Scand J Work Environ Health 40(6): 610-620. doi: 10.5271/sjweh.3456.

Kapellusch JM, Silverstein BA, Bao SS, Thiese MS, Merryweather AS, Hegmann KT and Garg A (2018) Risk assessments using the Strain Index and the TLV for HAL, Part II: Multi-task jobs and prevalence of CTS. J Occup Environ Hyg 15(2): 157-166. doi: 10.1080/15459624.2017.1401709.

Kiermayer C, Hoehne-Hückstädt UM, Brielmeier M, Brütting M, Ellegast R and Schmidt J (2011) Musculoskeletal load in and highly repetitive actions of animal facility washroom employees. J Am Assoc Lab Anim Sci 50(5): 665-674.

Klussmann A, Liebers F, Brandstädt F, Schust M, Serafin P, Schäfer A, Gebhardt H, Hartmann B and Steinberg U (2017) Validation of newly developed and redesigned key indicator methods for assessment of different working conditions with physical workloads based on mixed-methods design: a study protocol. BMJ Open 7(8): e015412 (015411-015412). doi: 10.1136/bmjopen-2016-015412.

Kraemer B, Seibt R, Stoffels A-K, Rothmund R, Brucker SY, Rieger MA and Steinhilber B (2018) An ergonomic field study to evaluate the effects of a rotatable handle piece on muscular stress and fatigue as well as subjective ratings of usability, wrist posture and precision during laparoscopic surgery: an explorative pilot study. Int Arch Occup Environ Health 91(8): 1021-1029. doi: 10.1007/s00420-018-1344-1.

Kristensen TS (2002) A new tool for assessing psychosocial factors at work. The Copenhagen Psychosocial Questionnaire. TUTB Newsletter 19(20): 45-47.

Kuijer PPFM, van der Pas J and van der Molen HF (2020) Work Disabling Nerve Injury at Both Elbows Due to Laptop Use at Flexible Workplaces inside an Office: Case-Report of a Bilateral Ulnar Neuropathy. Int J Environ Res Public Health 17(9529): 1-8. doi: 10.3390/ijerph17249529.

Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sorensen F, Andersson G and Jorgensen K (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon 18(3): 233-237.

Lai WC, Erickson BJ, Mlynarek RA and Wang D (2018) Chronic lateral epicondylitis: challenges and solutions. Open Access J Sports Med 9: 243-251. doi: 10.2147/OAJSM.S160974.

Latinovic R, Gulliford MC and Hughes RA (2006) Incidence of common compressive neuropathies in primary care. J Neurol Neurosurg Psychiatry 77(2): 263-265. doi: 10.1136/jnnp.2005.066696.

Latko WA, Armstrong TJ, Foulke JA, Herrin GD, Rabourn RA and Ulin SS (1997) Development and Evaluation of an Observational Method for Assessing Repetition in Hand Tasks. Am Ind Hyg Assoc J 58(4): 278-285. doi: 10.1080/15428119791012793.

Leclerc A, Landre MF, Chastang JF, Niedhammer I and Roquelaure Y (2001) Upper-limb disorders in repetitive work. Scand J Work Environ Health 27(4): 268-278.

Leschinger T, Tischer T, Doepfer AK, Glanzmann M, Hackl M, Lehmann L, Müller L, Reuter S, Siebenlist S, Theermann R, Wörtler K und Banerjee M (2021) Epicondylopathia humeri radialis (Epicondylitis radialis) – Diagnostik und Therapie unter Berücksichtigung der aktuellen S2k-Leitlinie [Epicondylopathia humeri radialis (Epicondylitis radialis) - Diagnosis and therapy considering the current S2k guideline]. Z Orthop Unfall (EFirst): doi: 10.1055/a-1340-0931.

## REFERENCES


Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J and Moher D (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol 62(10): e1-34. doi: 10.1016/j.jclinepi.2009.06.006.

Lietz J, Kozak A and Nienhaus A (2018) Prevalence and occupational risk factors of musculoskeletal diseases and pain among dental professionals in Western countries: A systematic literature review and meta-analysis. PLoS One 13(12): e0208628. doi: 10.1371/journal.pone.0208628.

Lin J-H, Kirlik A and Xu X (2018) New technologies in human factors and ergonomics research and practice. Appl Ergon 66: 179-181. doi: 10.1016/j.apergo.2017.08.012.

Longo A, Meulenbroek R, Haid T and Federolf P (2018) Postural reconfiguration and cycle-to-cycle variability in patients with work-related musculoskeletal disorders compared to healthy controls and in relation to pain emerging during a repetitive movement task. Clin Biomech (Bristol, Avon) 54: 103-110. doi: 10.1016/j.clinbiomech.2018.03.004.

Luger T, Seibt R, Rieger MA and Steinhilber B (2019) The Role of Motor Learning on Measures of Physical Requirements and Motor Variability During Repetitive Screwing. Int J Environ Res Public Health 16(7): doi: 10.3390/ijerph16071231.

Luger T, Seibt R, Rieger MA and Steinhilber B (2020) Sex differences in muscle activity and motor variability in response to a non-fatiguing repetitive screwing task. Biol Sex Differ 11(1): 6. doi: 10.1186/s13293-020-0282-2.

Luopajarvi T, Kuorinka I, Virolainen M and Holmberg M (1979) Prevalence of tenosynovitis and other injuries of the upper extremities in repetitive work. Scand J Work Environ Health 5 suppl 3: 48-55.

Marras WS and Karwowski W (2006) Fundamentals and Assessment Tools for Occupational Ergonomics: 1-1024. In: The Occupational Ergonomics Handbook. 2nd ed. CRC Press, Taylor & Francis Group: Boca Raton, London, New York.

Mattioli S, Zanardi F, Baldasseroni A, Schaafsma F, Cooke RM, Mancini G, Fierro M, Santangelo C, Farioli A, Fucksia S, Curti S, Violante FS and Verbeek J (2010) Search strings for the study of putative occupational determinants of disease. Occup Environ Med 67(7): 436-443. doi: 10.1136/oem.2008.044727.

McAtamney L and Nigel Corlett E (1993) RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon 24(2): 91-99. doi: 10.1016/0003-6870(93)90080-s.

Melhorn JM, Talmage JB, Ackerman III WE and Hyman MH (2014) AMA Guides to the Evaluation of Disease and Injury Causation: 1-792. In: Melhorn, JM, Talmage, JB, Ackerman III, WE and Hyman, MH (eds). American Medical Association: Chicago, Illinois.

Merino G, da Silva L, Mattos D, Guimarães B and Merino E (2019) Ergonomic evaluation of the musculoskeletal risks in a banana harvesting activity through qualitative and quantitative measures, with emphasis on motion capture (Xsens) and EMG. Int J Ind Ergon 69: 80-89. doi: 10.1016/j.ergon.2018.10.004.

**REFERENCES**


Merletti R and Parker PJ (2004) Electromyography: physiology, engineering, and non-invasive applications: 1-477. Wiley-IEEE Press: New York (NY). doi: 10.1002/0471678384.

Mitterlehner L and Kapellusch J (2019) How to improve the revised strain index to enable the quantification of forces that change during physical exertion: 71. In: PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders; Bologna, Italia. PREMUS.

Moher D, Liberati A, Tetzlaff J and Altman DG (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 6(7): e1000097. doi: 10.1371/journal.pmed.1000097.

Mondelli M, Giannini F, Ballerini M, Ginanneschi F and Martorelli E (2005) Incidence of ulnar neuropathy at the elbow in the province of Siena (Italy). J Neurol Sci 234(1-2): 5-10. doi: 10.1016/j.jns.2005.02.010.

Mondelli M, Grippo A, Mariani M, Baldasseroni A, Ansuini R, Ballerini M, Bandinelli C, Graziani M, Luongo F, Mancini R, Manescalchi P, Pellegrini S, Sgarrella C and Giannini F (2006) Carpal tunnel syndrome and ulnar neuropathy at the elbow in floor cleaners. Neurophysiol Clin 36(4): 245-253. doi: 10.1016/j.neucli.2006.08.013.

Moore JS and Garg A (1995) The Strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am Ind Hyg Assoc J 56(5): 443-458. doi: 10.1080/15428119591016863.

Naam NH and Nemani S (2012) Radial tunnel syndrome. Orthop Clin North Am 43(4): 529-536. doi: 10.1016/j.ocl.2012.07.022.

Nakashian MN, Ireland D and Kane PM (2020) Cubital Tunnel Syndrome: Current Concepts. Curr Rev Musculoskelet Med 13(4): 520-524. doi: 10.1007/s12178-020-09650-y.

Nasrull Abdol Rahman M and Syafiqa Abd Razak N (2016) Review on Pen and Paper Based Observational Methods for Assessing Work-related Upper Limb Disorders. Indian J Sci Technol 9(S1): 1-11. doi: 10.17485/ijst/2016/v9iS1/106822.

Nordander C, Balogh I, Mathiassen SE, Ohlsson K, Unge J, Skerfving S and Hansson G-Å (2004) Precision of measurements of physical workload during standardised manual handling. Part I: surface electromyography of m. trapezius, m. infraspinatus and the forearm extensors. J Electromyogr Kinesiol 14(4): 443-454. doi: 10.1016/j.jelekin.2003.12.003.

Nordander C, Ohlsson K, Åkesson I, Arvidsson I, Balogh I, Hansson G-Å, Stromberg U, Rittner R and Skerfving S (2013) Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands - A synthesis of group-level data on exposure and response obtained using uniform methods of data collection. Appl Ergon 44(2): 241-253. doi: 10.1016/j.apergo.2012.07.009.

Nordander C, Ohlsson K, Akesson I, Arvidsson I, Balogh I, Hansson GA, Stromberg U, Rittner R and Skerfving S (2009) Risk of musculoskeletal disorders among females and males in repetitive/constrained work. Ergonomics 52(10): 1226-1239. doi: 10.1080/00140130903056071.

NRC (1999) Work-Related Musculoskeletal Disorders: Report, Workshop Summary, and Workshop Papers. Steering Committee for the Workshop on Work-Related

Musculoskeletal Injuries: The Research Base, National Research Council (NRC): 1-240. National Academies Press (US): Washington, DC.

Nübling M, Stößel U, Hasselhorn H-M, Michaelis M und Hofmann F (2005) Methoden zur Erfassung psychischer Belastungen - Erprobung eines Messinstrumentes (COPSOQ) [Methods for the assessment of mental work load – Testing of a measuring procedure (COPSOQ)]: 1-141. Schriftenreihe der BAuA (Hrsg.), Forschungsbericht, Fb 1058. Wirtschaftsverlag NW, Bremerhaven: Dortmund, Berlin, Dresden.

Ochsmann E (2018) 1632d Work-related upper extremity msds in germany. Occup Environ Med 75(Suppl 2): A255. doi: 10.1136/oemed-2018-ICOHabstracts.730.

Ohlsson K, Hansson G-Å, Balogh I, Stromberg U, Pålsson B, Nordander C, Rylander L and Skerfving S (1994) Disorders of the neck and upper limbs in women in the fish processing industry. Occup Environ Med 51(12): 826-832. doi: 10.1136/oem.51.12.826.

Padula RS, Comper MLC, Sparer EH and Dennerlein JT (2017) Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review. Appl Ergon 58: 386-397. doi: 10.1016/j.apergo.2016.07.018.

Peppoloni L, Filippeschi A, Ruffaldi E and Avizzano CA (2016) A novel wearable system for the online assessment of risk for biomechanical load in repetitive efforts. Int J Ind Ergon 52: 1-11. doi: 10.1016/j.ergon.2015.07.002.

PEROSH (2014) PEROSH - OSH Evidence Clearinghouse of Systematic Reviews: 1-27. PEROSH: URL: http://www.perosh.eu/wp-content/uploads/2013/06/PEROSH-Clearinghouse-Methods_Last-update-June-2014.pdf [access 09.05.2016].

Plantard P, Shum HPH, Le Pierres A-S and Multon F (2017) Validation of an ergonomic assessment method using Kinect data in real workplace conditions. Appl Ergon 65: 562-569. doi: 10.1016/j.apergo.2016.10.015.

Pope and Plante (1886) Tennis elbow-cap. The Lancet 128(3301): 1083. doi: 10.1016/S0140-6736(00)49587-5.

Radwin RG, Azari DP, Lindstrom MJ, Ulin SS, Armstrong TJ and Rempel D (2015) A frequency-duty cycle equation for the ACGIH hand activity level. Ergonomics 58(2): 173-183. doi: 10.1080/00140139.2014.966154.

Ranavolo A, Chini G, Silvetti A, Mari S, Serrao M and Draicchio F (2018a) Myoelectric manifestation of muscle fatigue in repetitive work detected by means of miniaturized sEMG sensors. Int J Occup Saf Ergon 24(3): 464-474. doi: 10.1080/10803548.2017.1357867.

Ranavolo A, Draicchio F, Varrecchia T, Silvetti A and Iavicoli S (2018b) Wearable Monitoring Devices for Biomechanical Risk Assessment at Work: Current Status and Future Challenges—A Systematic Review. Int J Environ Res Public Health 15(9): 1-26. doi: 10.3390/ijerph15092001.

Rhén IM and Forsman M (2020) Inter- and intra-rater reliability of the OCRA checklist method in video-recorded manual work tasks. Appl Ergon 84: 103025. doi: 10.1016/j.apergo.2019.103025.

Roquelaure Y, Raimbeau G, Dano C, Martin YH, Pelier-Cady MC, Mechali S, Benetti F, Mariel J, Fanello S and Penneau-Fontbonne D (2000) Occupational risk factors for radial tunnel syndrome in industrial workers. Scand J Work Environ Health 26(6): 507-513.

Sanders TL, Maradit Kremers H, Bryan AJ, Ransom JE and Morrey BF (2016) Health Care Utilization and Direct Medical Costs of Tennis Elbow: A Population-Based Study. Sports Health 8(4): 355-358. doi: 10.1177/1941738116650389.

Sanderson S, Tatt ID and Higgins JP (2007) Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: a systematic review and annotated bibliography. Int J Epidemiol 36(3): 666-676. doi: 10.1093/ije/dym018.

Santos S, Folgado D, Rodrigues J, Mollaei N, Fujão C and Gamboa H (2020) Explaining the Ergonomic Assessment of Human Movement in Industrial Contexts: 79-88. In: Proceedings of the 13th International Joint Conference on Biomedical Engineering Systems and Technologies - Vol 4: BIOSIGNALS. SCITEPRESS – Science and Technology Publications. doi: 10.5220/0008953800790088.

Schaafsma F, Hulshof C, Verbeek J, Bos J, Dyserinck H and van Dijk F (2006) Developing search strategies in Medline on the occupational origin of diseases. Am J Ind Med 49(2): 127-137. doi: 10.1002/ajim.20235.

Schedlbauer G, Glitsch U und Hoehne-Hückstädt UM (2014) DGUV Report 2/2014. Komplexe Analyse von Muskel-Skelett-Belastungen der oberen Extremität – Fallbeispiel Physiotherapie [DGUV Report 2/2014. Complex analysis of musculoskeletal loads on the upper extremity – case report physiotherapy]: 63-76. In: Fietz, T, Freiberg, S und Zieschang, H (Hrsg.). 5. DGUV Fachgespräch Ergonomie - Zusammenfassung der Vorträge vom 26. und 27. November 2013; Dresden. DGUV.

Schiebelsberger EM (2009) Ludwig Hirt (1844-1907) – Ein Pionier der Arbeitsmedizin [Ludwig Hirt (1844-1907) – A pioneer of occupational medicine]: 1-101. Medizinische Dissertationsschrift, Universität Regensburg.

Schiefer C, Kraus T, Ellegast RP and Ochsmann E (2015) A technical support tool for joint range of motion determination in functional diagnostics - an inter-rater study. J Occup Med Toxicol 10(16): 1-13. doi: 10.1186/s12995-015-0058-5.

Schmier JK and Halpern MT (2004) Patient recall and recall bias of health state and health status. Expert Rev Pharmacoecon Outcomes Res 4(2): 159-163. doi: 10.1586/14737167.4.2.159.

Schneider E, Irastorza X and Copsey S (2010) OSH in figures: Work-related musculoskeletal disorders in the EU - Facts and figures. In: European Risk Observatory Report, EU-OSHA (ed): 1-182. Publications Office of the European Union: Luxembourg.

Schust M, Liebers F, Seidel DH, Heinrich K und Weber B (2020) Teil D.2. Vergleich der Belastungsbewertungen des Speziellen Screenings und der Messtechnischen Analyse [Part D.2. Comparison of the load assessments of the special screening and the measurement-based analysis]. In: DGUV Report 3/2020. MEGAPHYS: Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Abschlussbericht zum Kooperationsprojekt von BAuA und DGUV - Band 2: 883-952. DGUV: Berlin.

Seidel D, Weber B, Heinrich K, Hermanns I, Hoehne-Hückstädt U, Ditchen D, Jäger M, Barrero L und Ellegast R (2019a) Messtechnische Analyse: Neue und weiterentwickelte Ansätze zur Abbildung und Bewertung der Belastung und Ergebnisse der Validierung [Measurement-based analysis: New and further developed approaches for illustration and assessment of the load and results of validation]: 22-23. In: 36th International Congress for Occupational Safety and

Health (A+A) Safety – Health – Ergonomics; Düsseldorf, Germany. A+A, Basi, European Agency for Safety and Health at Work, issa, Messe Düsseldorf.

Seidel DH, D'Souza SF, Alt WW and Wachowsky M (2015) Comparison of an inertial sensor based motion measurement system with a 3D-reflex marker based motion capture system. Gait Posture 42: S75. doi: 10.1016/j.gaitpost.2015.06.139.

Seidel DH, Ditchen DM, Hoehne-Hückstädt U, Rieger MA und Steinhilber B (2017) Arbeitsbezogene Risikofaktoren für muskuloskelettale Beschwerden und Erkrankungen des Ellenbogens – Systematisches Review als Grundlage zur Entwicklung eines Bewertungsverfahrens [Work-related risk factors for musculoskeletal complaints and diseases of the elbow – Systematic review as a basis for the development of an assessment approach]: 25. In: Klussmann, A und Hartmann, B (Hrsg.). aser:info, Schriftenreihe des Instituts ASER e.V., Forum Arbeitsphysiologie: 21. Symposium Arbeitsmedizin und Arbeitswissenschaft für Nachwuchswissenschaftler; Bad Münder. vol. 9. ASER e.V.

Seidel DH, Ditchen DM, Hoehne-Hückstädt UM, Rieger MA and Steinhilber B (2019b) Quantitative Measures of Physical Risk Factors Associated with Work-Related Musculoskeletal Disorders of the Elbow: A Systematic Review. Int J Environ Res Public Health 16(130): 1-23. doi: 10.3390/ijerph16010130.

Seidel DH, Ellegast RP, Rieger MA, Steinhilber B und Weber B (2021a) Messdatenbasierte Gefährdungsbeurteilung. Kategorisierung messtechnischer Methoden zur Beurteilung physischer Belastungen der oberen Extremität [Measurement-based risk assessment. Categorization of measurement methods for assessing physical workloads of the upper extremity]. Zentralbl Arbeitsmed Arbeitsschutz Ergon 71(4): 192-199. doi: 10.1007/s40664-021-00424-y.

Seidel DH, Heinrich K, Hermanns-Truxius I, Ellegast R, Barrero LH, Rieger MA, Steinhilber B und Weber B (2019c) DGUV Report 2/2020. Messdatenbasierte Bewertung arbeitsbedingter Hand- und Ellenbogenbelastungen [DGUV Report 2/2020. Measurement-based assessment of work-related hand and elbow loads]: 41-46. In: 7. DGUV Fachgespräch Ergonomie – Zusammenfassung der Vorträge vom 25. und 26. November 2019; Dresden, Deutschland. DGUV.

Seidel DH, Heinrich K, Hermanns-Truxius I, Ellegast RP, Barrero LH, Rieger MA, Steinhilber B and Weber B (2021b) Assessment of work-related hand and elbow workloads using measurement-based TLV for HAL. Appl Ergon 92(103310): 1-11. doi: 10.1016/j.apergo.2020.103310.

Seidel DH, Hermanns I, Heinrich K, Ellegast R, Rieger MA, Barrero LH, Weber B and Steinhilber B (2019d) Extension of a kinematic and force measurement-based tlv approach to assess workloads of the elbow joint – a field feasibility study: 120. In: PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders; Bologna, Italia. PREMUS.

Shiri R and Viikari-Juntura E (2011) Lateral and medial epicondylitis: role of occupational factors. Best Pract Res Clin Rheumatol 25(1): 43-57. doi: 10.1016/j.berh.2011.01.013.

Silverstein BA, Fine LJ and Armstrong TJ (1986) Hand wrist cumulative trauma disorders in industry. Br J Ind Med 43(11): 779-784. doi: 10.1136/oem.43.11.779.

Silverstein BA, Viikari-Juntura E and Kalat J (2002) Use of a prevention index to identify industries at high risk for work-related musculoskeletal disorders of the neck, back, and upper extremity in Washington state, 1990 – 1998. Am J Ind Med 41(3): 149-169. doi: doi.org/10.1002/ajim.10054.

Slesina W (1987) Fragebogen zur subjektiven Einschätzung der Belastungen am Arbeitsplatz (FEBA) [Questionnaire for the subjective assessment of loads at the workplace (FEBA)]: 127-128. In: Richter G (Ed.). Instrumente zur Erfassung und Bewertung psychischer Belastungen: Aktualisierung der Toolbox Version 1.0 (2010). BAuA: Dortmund/Berlin/Dresden.

Sluiter JK, Rest KM and Frings-Dresen MHW (2001) Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. Scand J Work Environ Health 27 Suppl 1: 1-102. doi: 10.5271/sjweh.637.

Sobotta J (2004) Atlas der Anatomie des Menschen/Sobotta [Atlas of human anatomy/Sobotta]: 1-828. Putz R und Pabst R (Hrsg.). Urban und Fischer, Elsevier GmbH: München, Jena.

Spahn G, Lipfert J-U, Schmidt A, Maurer C, Dein W, Hartmann B, Hofmann GO und Schiele R (2016) Fall-Kontrolle-Studie zur Bestimmung von Risikofaktoren der lateralen Epikondylitis [Risc factors for the lateral epicondylitis – results from a case-control study]. Arbeitsmed Sozialmed Umweltmed 51: 360-368.

Spallek M und Kuhn W (2009) Funktionsorientierte körperliche Untersuchungssystematik: Die fokus-Methode zur Beurteilung des Bewegungsapparates in der Arbeits- und Allgemeinmedizin [Function-oriented physical examination systematic: The fokus method for the assessment of the musculoskeletal system in occupational and general medicine]: 1-120. Ecomed: Heidelberg.

Stål M, Hansson G-Å and Moritz U (1999) Wrist positions and movements as possible risk factors during machine milking. Appl Ergon 30(6): 527-533. doi: 10.1016/S0003-6870(99)00015-0.

Stegink-Jansen CW, Bynum JG, Lambropoulos AL, Patterson RM and Cowan AC (2021) Lateral epicondylosis: A literature review to link pathology and tendon function to tissue-level treatment and ergonomic interventions. J Hand Ther 34(2): 263-297. doi: 10.1016/j.jht.2021.05.005.

Steinhilber B, Reiff F, Seibt R, Rieger MA, Martus P, Kraemer B and Rothmund R (2017) Ergonomic Benefits From a Laparoscopic Instrument With Rotatable Handle Piece Depend on the Area of the Operating Field and Working Height. Hum Factors 59(7): 1048-1065. doi: 10.1177/0018720817712597.

Sulsky SI, Carlton L, Bochmann F, Ellegast R, Glitsch U, Hartmann B, Pallapies D, Seidel D and Sun Y (2012) Epidemiological evidence for work load as a risk factor for osteoarthritis of the hip: a systematic review. PLoS One 7(2, e31521): 1-13. doi: 10.1371/journal.pone.0031521.

Svendsen SW, Johnsen B, Fuglsang-Frederiksen A and Frost P (2012) Ulnar neuropathy and ulnar neuropathy-like symptoms in relation to biomechanical exposures assessed by a job exposure matrix: a triple case-referent study. Occup Environ Med 69(11): 773-780. doi: 10.1136/oemed-2011-100499.

Svernlov B, Larsson M, Rehn K and Adolfsson L (2009) Conservative treatment of the cubital tunnel syndrome. J Hand Surg Eur Vol 34(2): 201-207. doi: 10.1177/1753193408098480.

**REFERENCES**


Takala E-P, Pehkonen I, Forsman M, Hansson G-Å, Mathiassen SE, Neumann WP, Sjøgaard G, Veiersted KB, Westgaard RH and Winkel J (2010) Systematic evaluation of observational methods assessing biomechanical exposures at work. Scand J Work Environ Health 36(1): 3-24. doi: 10.5271/sjweh.2876.

Tang JB (2020) Radial tunnel syndrome: definition, distinction and treatments. J Hand Surg Eur Vol 45(8): 882-889. doi: 10.1177/1753193420953990.

Thomsen JF, Mikkelsen S, Andersen JH, Fallentin N, Loft IP, Frost P, Kaergaard A, Bonde JP and Overgaard E (2007) Risk factors for hand-wrist disorders in repetitive work. Occup Environ Med 64(8): 527-533. doi: 10.1136/oem.2005.021170.

Tian ZZ, Kyte MD and Messer CJ (2002) Parallax Error in Video-Image Systems. J Transp Eng 128: 218-223. doi: 10.1061/(ASCE)0733-947X(2002)128:3(218).

van der Molen HF, Foresti C, Daams JG, Frings-Dresen MHW and Kuijer P (2017) Work-related risk factors for specific shoulder disorders: a systematic review and meta-analysis. Occup Environ Med 74(10): 745-755. doi: 10.1136/oemed-2017-104339.

van Rijn RM, Huisstede BM, Koes BW and Burdorf A (2009a) Associations between work-related factors and specific disorders at the elbow: a systematic literature review. Rheumatology (Oxford) 48(5): 528-536. doi: 10.1093/rheumatology/kep013.

van Rijn RM, Huisstede BM, Koes BW and Burdorf A (2009b) Associations between work-related factors and the carpal tunnel syndrome — a systematic review. Scand J Work Environ Health 35(1): 19-36. doi: 10.5271/sjweh.1306.

van Rijn RM, Huisstede BM, Koes BW and Burdorf A (2010) Associations between work-related factors and specific disorders of the shoulder — a systematic review of the literature. Scand J Work Environ Health 36(3): 189-201. doi: 10.5271/sjweh.2895.

van Tulder M, Furlan A, Bombardier C and Bouter L (2003) Updated method guidelines for systematic reviews in the cochrane collaboration back review group. Spine (Phila Pa 1976) 28(12): 1290-1299. doi: 10.1097/01.Brs.0000065484.95996.Af.

Verbeek J, Salmi J, Pasternack I, Jauhiainen M, Laamanen I, Schaafsma F, Hulshof C and van Dijk F (2005) A search strategy for occupational health intervention studies. Occup Environ Med 62(10): 682-687. doi: 10.1136/oem.2004.019117.

Viera AJ and Garrett JM (2005) Understanding interobserver agreement: the kappa statistic. Fam Med 37(5): 360-363.

Vignais N, Bernard F, Touvenot G and Sagot J-C (2017) Physical risk factors identification based on body sensor network combined to videotaping. Appl Ergon 65: 410-417. doi: 10.1016/j.apergo.2017.05.003.

Violante F (2018) 1632a Work-related upper extremity musculoskeletal disorders in italy. Occup Environ Med 75(Suppl 2): A255. doi: 10.1136/oemed-2018-ICOHabstracts.727.

Walker-Bone K, Palmer KT, Reading I, Coggon D and Cooper C (2012) Occupation and epicondylitis: a population-based study. Rheumatology (Oxford) 51(2): 305-310. doi: 10.1093/rheumatology/ker228.

Walmsley CP, Williams SA, Grisbrook T, Elliott C, Imms C and Campbell A (2018) Measurement of Upper Limb Range of Motion Using Wearable Sensors: A

Systematic Review. Sports Med Open 4(53): 1-22. doi: 10.1186/s40798-018-0167-7.

Watts AC and Edwards DS (2020) Elbow and forearm: 280-284. In: Brennan PA, Standring SM and Wiseman SM (eds). Gray's Surgical Anatomy. Elsevier Health Sciences: Poland.

Weber B, Brütting M, Ditchen D, Eul M, Glitsch U, Heinrich K, Hermanns-Truxius I, Hoehne-Hückstädt U, Lietz R, Post M, Seidel D und Ellegast R (2019a) DGUV Report 2/2020. Ergebnisse des Kooperationsprojektes MEGAPHYS [DGUV Report 2/2020. Results of the MEGAPHYS cooperation project]: 29-33. In: 7. DGUV Fachgespräch Ergonomie – Zusammenfassung der Vorträge vom 25. und 26. November 2019; Dresden, Deutschland. DGUV.

Weber B, Douwes M, Forsman M, Könemann R, Heinrich K, Enquist H, Pinder A, Punakallio A, Uusitalo A, Ditchen D, Takala E-P, Draicchio F, Desbrosses K, Wichtl M, Strebl M, Wærsted M, Gupta N, Lechner N, Alvarez Bayona T, Hoehne-Hückstädt U, Mathiassen SE, Holtermann A and Veiersted KB (2018a) Assessing Arm Elevation at Work with Technical Assessment Systems: 1-49. PEROSH: doi: 10.23775/20181201.

Weber B, Heinrich K, Hermanns-Truxius I, Seidel DH und Ellegast R (2021) Messwertbasierte Gefährdungsbeurteilung der distalen oberen Extremität [Measurement-based risk assessment of the distal upper extremity]: A.1.9: 1-3. In: Jäger M (Ed.). Arbeit HUMAINE gestalten. 67. Frühjahrskongress der Gesellschaft für Arbeitswissenschaft. 03. - 05.03.2021. Institut für Arbeitswissenschaft, GfA/GfA-Press: Dortmund/Bochum.

Weber B, Heinrich K, Seidel D, Hermanns I, Hoehne-Hückstädt U, Ditchen D, Barrero LH and Ellegast R (2019b) Biomechanical wrist load indicators using technically measured data: 72. In: PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders; Bologna, Italia. PREMUS.

Weber B, Heinrich K, Seidel D, Hermanns I, Hoehne-Hückstädt U, Ditchen D, Jäger M, Barrero L and Ellegast R (2019c) Method level 'technical field measurement': Updated and new approaches for exposure assessment: 87. In: PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders; Bologna, Italia. PREMUS.

Weber B, Heinrich K, Seidel DH, Hermanns-Truxius I, Hoehne-Hückstädt U, Ditchen D, Jäger M, Barrero LH and Ellegast R (2022) Overview of Measurement-Based Assessment Approaches from the MEGAPHYS Project. 206-212. In: Black NL, Neumann WP and Noy I (eds). Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021). IEA 2021. Lecture Notes in Networks and Systems; Cham. vol. 223. Springer. doi: 10.1007/978-3-030-74614-8_25.

Weber B, Hoehne-Hückstädt U, Ditchen D, Seidel D, Hermanns I and Ellegast R (2018b) 1631e Update on german risk assessment tools for upper limb msds. Occup Environ Med 75(Suppl 2): A259. doi: 10.1136/oemed-2018-ICOHabstracts.741.

Weber B, Seidel DH, Brütting M, Ditchen D, Eul M, Glitsch U, Heinrich K, Hermanns-Truxius I, Hoehne-Hückstädt U, Lietz R, Post M, Barrero LH und Ellegast R (2020a) Teil B. Weiterentwicklung und Evaluierung von Ansätzen zur Gefährdungsanalyse bei physischen Belastungen für die Methodenebene

Messtechnische Analyse im Feld [Part B. Further development and evaluation of approaches to risk assessment for physical load for the method level measurement-based analysis in the field]. In: DGUV Report 3/2020. MEGAPHYS: Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Abschlussbericht zum Kooperationsprojekt von BAuA und DGUV - Band 2: 269-410. DGUV: Berlin.

Weber B, Seidel DH, Hermanns-Truxius I, Heinrich K, Sinn-Behrendt A, Oberle M und Bruder R (2020b) Teil D.3. Vergleich der Belastungsbewertungen des Experten-Screenings und der Messtechnischen Analyse [Part D.3. Comparison of the load assessments of the expert screening and measurement-based analysis]. In: DGUV Report 3/2020. MEGAPHYS: Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Abschlussbericht zum Kooperationsprojekt von BAuA und DGUV - Band 2: 953-979. DGUV: Berlin.

Webster BS and Snook SH (1994) The cost of compensable upper extremity cumulative trauma disorders. J Occup Med 36(7): 713-717.

Werner RA, Franzblau A, Gell N, Hartigan A, Ebersole M and Armstrong T (2005) Predictors of Persistent Elbow Tendonitis Among Auto Assembly Workers. J Occup Rehabil 15(3): 393-400. doi: 10.1007/s10926-005-5945-6.

WMA (2013) World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA 310(20): 2191-2194. doi: 10.1001/jama.2013.281053.

Wong WC, Cheung CS and Hart GJ (2008) Development of a quality assessment tool for systematic reviews of observational studies (QATSO) of HIV prevalence in men having sex with men and associated risk behaviours. Emerg Themes Epidemiol 5(23): 1-4. doi: 10.1186/1742-7622-5-23.

Wouda FJ, Giuberti M, Bellusci G and Veltink PH (2016) Estimation of Full-Body Poses Using Only Five Inertial Sensors: An Eager or Lazy Learning Approach? Sensors (Basel) 16(2138): 1-17. doi: 10.3390/s16122138.

Yang L, Grooten WJA and Forsman M (2017) An iPhone application for upper arm posture and movement measurements. Appl Ergon 65: 492-500. doi: 10.1016/j.apergo.2017.02.012.

Yang L, Manivasagam K and Forsman M (2021) Comparison of Accuracy of Inertial Measurement Units, Goniometer and Optical Tracking System for Wrist Velocity Assessment. 868-873. In: Black NL, Neumann WP and Noy I (eds). Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021). IEA 2021. Lecture Notes in Networks and Systems; Cham. vol. 223. Springer International Publishing. doi: 10.1007/978-3-030-74611-7_118.

Zbogar D, Eng JJ, Miller WC, Krassioukov AV and Verrier MC (2017) Movement repetitions in physical and occupational therapy during spinal cord injury rehabilitation. Spinal Cord 55(2): 172-179. doi: 10.1038/sc.2016.129.

# 6 Statements on own contribution

## 6.1 Dissertation

This thesis was supervised by Prof. Dr. Monika A. Rieger and PD Dr. Benjamin Steinhilber. Besides published articles, I, David Henry Seidel, declare that I have written all other parts of the thesis independently by myself and without external help. No sources or auxiliaries other than those specifically mentioned were used in this dissertation. Verbatim quotations as well as content adopted posts, ideas, thoughts, tables, or figures from other works are indicated by citations. I am aware that a thesis that is not written by myself will be considered as cheating and will have corresponding consequences. Furthermore, this thesis has not been submitted to, accepted, or rejected by any other institution. This thesis has not been submitted in the same or a similar form in another language or in another doctoral procedure, neither in Germany nor in foreign countries. No doctorate or corresponding procedure for examination has been applied at any other university to date. In addition, I am aware that false or incomplete information may result in the faculty initiating proceedings to withdraw any academic degree that may have been awarded. There are no criminal proceedings against me. Furthermore, I hereby declare that I have not previously completed a doctorate in the chosen subject 'Medicine – Clinical' and that this thesis is not based on a failed doctoral procedure. The explanations of the own contribution to the three main publications are shown in the next chapters.

## 6.2 Publication 1 – Seidel et al. 2019b

In addition to Prof. Dr. Monika A. Rieger and PD Dr. Benjamin Steinhilber, Dr. Ulrike M. Hoehne-Hückstädt, Dr. Dirk M. Ditchen and David H. Seidel, were predominantly involved in brainstorming, design, and conceptualization of publication 1. The methods were mainly selected and defined by David H. Seidel and finalized with Prof. Dr. Monika A. Rieger, PD Dr. Benjamin Steinhilber and Dr. Dirk M. Ditchen. After profound conversations about general search strategies and procedures for data interpretation of systematic reviews and meta-analyses with Annette Nold, Angelika Hauke, and Dr. Dorothea Koppisch, David H. Seidel independently performed the literature search in MEDLINE and Cochrane Work, independently transferred the results to databases and made them available. Bernd Göbel-Jouaux and David H. Seidel jointly performed the technical processing of the literature search in EMBASE, whereby David H. Seidel independently determined the search strategy for EMBASE in advance. David H. Seidel extracted the data from all searches and compiled them into a database. PD Dr. Benjamin Steinhilber and David H. Seidel independently screened, assessed, and excluded the identified articles by title and abstract in equal parts and blinded from each other. Both authors reviewed and evaluated the jointly selected/included full texts separately and blinded form each other according to a priori defined criteria, created by PD Dr. Benjamin Steinhilber and predominantly by David H. Seidel. In case of ambiguities in the assessment, Dr. Dirk M. Ditchen was contacted. David H. Seidel converted the screening results into a final study pool. David H. Seidel is responsible for all references and data accuracy. Under the guidance of Dr. Dirk M. Ditchen and Dr. Ulrike M. Hoehne-Hückstädt, David H. Seidel performed most of the data analysis independently. David H. Seidel, PD Dr. Benjamin Steinhilber, and Dr. Dirk M. Ditchen were equally involved in data interpretation, with Dr. Ulrike M. Hoehne-Hückstädt assisted with the interpretation. David H. Seidel wrote the article draft independently. David H. Seidel independently prepared **Table 1.** (in the manuscript by Seidel et al. 2019b, p. 4), **Table 2.** (in the manuscript by Seidel et al. 2019b, p. 5), **Table 3.** (in the manuscript by Seidel et al. 2019b, p. 7), **Table 4.** (in the manuscript by Seidel et al. 2019b, pp. 9-10), **Table 5.** (in the manuscript by Seidel et al. 2019b, p. 14), **Figure 1.** (in the manuscript by Seidel et al. 2019b, p. 3) and **Figure 2.** (in the manuscript by Seidel et al. 2019b, p. 8), and the entire Supplementary Material including **Table S1.** (in the manuscript by Seidel et al. 2019b, pp. SF 2-4), **Table S2.** (in the manuscript by Seidel et al. 2019b, pp. SF 5-6), **Table S3.** (in the manuscript by Seidel et al. 2019b, p. SF 8), **Table S4.** (in the manuscript by Seidel et al. 2019b, p. SF 9-49), **Table S5.** (in the manuscript by Seidel et al. 2019b, p. SF 50-59) and **Table S6.** (in the manuscript by Seidel et al. 2019b, p. SF 60-65) and modified them as necessary after consultation with all coauthors. Prof. Dr. Monika A. Rieger, PD Dr. Benjamin Steinhilber, Dr. Dirk M. Ditchen, and Dr. Ulrike M. Hoehne-Hückstädt provided similar critical comments on the manuscript. Based on the critical comments and in consultation with PD Dr. Benjamin Steinhilber and Dr. Dirk M. Ditchen, David H. Seidel revised the manuscript. PD Dr. Benjamin Steinhilber predominantly supervised publication 1, although Prof. Dr. Monika A. Rieger, Dr. Dirk M. Ditchen, and Dr. Ulrike M. Hoehne-Hückstädt were additionally involved in the supervision. Dr. Sonia D'souza, Anna-Regine Pavely, and Alexander D. Pavely reviewed the manuscript in English and suggested some linguistic changes. Lisa Peterson performed the final linguistic proofreading and suggested only a few modifications. All authors are responsible for all aspects of the article. All authors equally approved the final version. David H. Seidel submitted the content via the publisher's input mask without assistance, uploaded it, and corresponded with the editors after consulting with the co-authors. In addition, David H. Seidel coordinated internal review loops as needed and ensured that the article was finally published. All authors have given their consent for publication and usage in this dissertation. All authors finally acknowledged that David H. Seidel performed most of the activities for this publication.

## 6.3 Publication 2 – Seidel et al. 2021b

The derivation of the parameters from the systematic review (chapter 2.2) was performed independently by David H. Seidel. In addition, the selection of parameters for development of a measurement-based assessment approach was described by David H. Seidel without further assistance. All parameters were discussed several times with the co-authors Prof. Dr. Monika A. Rieger, PD Dr. Benjamin Steinhilber, Prof. Dr. Rolf P. Ellegast, Dr. Kai Heinrich, and Dr. Britta Weber before and during the preparation of publication 2. After discussions about the relevance of the content, these authors agreed on the derived parameters of chapter 2.2. The concept and design of publication 2 was jointly determined by David H. Seidel, Prof. Dr. Monika A. Rieger, PD Dr. Benjamin Steinhilber, Prof. Dr. Rolf P. Ellegast, Dr. Kai Heinrich, and Dr. Britta Weber, with all these authors were additionally involved in similar parts of the idea generation. All authors were involved in the selection of methods, with David H. Seidel taking the largest part. Furthermore, David H. Seidel was a member of the MEGAPHYS project, which is why he was allowed to use project's data for his dissertation. Related to data recording, David H. Seidel was largely responsible for subject recruitment. David H. Seidel performed a very large amount of kinematic and kinetic data recording using CUELA measuring instruments, EMG, PABLO force grip, different video cameras and further equipment at 135 workplaces at 44 German companies (Weber et al. 2020a). Dipl. Ing. Ingo Hermanns-Truxius and Dr. Britta Weber were also involved in acquisition in reduced parts. Other staff members of department 4 at IFA, in particular Mark Brütting, Rainer Lietz, Markus Post, Dr. Frank Emrich, and Michaela Eul assisted David H. Seidel as additional persons during the data collection, as the data could not be collected alone e.g., for security reasons. David H. Seidel, Dr. Kai Heinrich, Dipl. Ing. Ingo Hermanns-Truxius, Prof. Dr. Lope H. Barrero and Dr. Britta Weber extracted the data, with David H. Seidel handling most of the extraction. David H. Seidel, along with Dipl. Ing. Ingo Hermanns-Truxius, did both most of the data processing and analysis in publication 2 (including video processing/cutting, interval setting, data analysis with WIDAAN), with Dipl. Ing. Ingo Hermanns-Truxius programmed the data processing and analysis software WIDAAN used in this article. Kevin Habetz and Michaela Eul assisted in data analysis for MEGAPHYS and thus indirectly influenced the data quality in this publication 2. Dipl. Ing. Ingo Hermanns-Truxius, Prof. Dr. Lope H. Barrero and Dr. Britta Weber – together with David H. Seidel – are responsible for the accuracy of the data, with David H. Seidel taking major part of the responsibility. Under the direction of Dr. Britta Weber and especially under the direction of Prof. Dr. Lope H. Barrero, David H. Seidel performed all association analyses independently using self-written SPSS scripts by David H. Seidel. David H. Seidel, Dr. Kai Heinrich, Prof. Dr. Lope H. Barrero and especially Dipl. Ing. Ingo Hermanns-Truxius and Dr. Britta Weber checked the data for plausibility. All authors were involved in downstream data analysis and interpretation, with David H. Seidel being the major contributor in each case. David H. Seidel prepared most of the draft manuscript including **Table 1** (in the manuscript by Seidel et al. 2021b, p. 3), **Table 2** (in the manuscript by Seidel et al. 2021b, p. 5), **Table 3** (in the manuscript by Seidel et al. 2021b, p. 6), **Table 4** (in the manuscript by Seidel et al. 2021b, p. 6), **Table 5** (in the manuscript by Seidel et al. 2021b, p. 7), **Table 6** (in the manuscript by Seidel et al. 2021b, p. 7), **Table 7** (in the manuscript by Seidel et al. 2021b, p. 8) and **Fig. 1.** (in the manuscript by Seidel et al. 2021b, p. 5) with Dr. Kai Heinrich, Prof. Dr. Rolf P. Ellegast, Prof. Dr. Lope H. Barrero, and Dr. Britta Weber also contributed to a somewhat reduced extent to manuscript draft preparation. David H. Seidel, Prof. Dr. Rolf P. Ellegast, Prof. Dr. Lope H. Barrero, Dr. Kai Heinrich, Dipl. Ing. Ingo Hermanns-Truxius, and Dr. Britta Weber wrote the manuscript, with David H. Seidel doing most of typing. Prof. Dr. Monika A. Rieger, PD Dr. Benjamin Steinhilber, Prof. Dr. Rolf P. Ellegast, Prof. Dr. Lope H. Barrero, Dr. Kai Heinrich, Dipl. Ing. Ingo Hermanns-Truxius, and especially Dr. Britta Weber commented critically on the manuscript. David H. Seidel independently performed the revision based on critical co-author comments. Supervision was provided by Prof. Dr. Monika A. Rieger, PD Dr. Benjamin Steinhilber, Prof. Dr. Rolf P. Ellegast, Prof. Dr. Lope H. Barrero, and Dr. Britta Weber, with Dr. Britta Weber followed by Prof. Dr. Rolf P. Ellegast providing most of the supervision. Prof. Dr. Lope H. Barrero conducted biometric supervision of publication 2. David H. Seidel prepared and performed independently the comparison between RepScore and HAL in terms of content and statistics after bilaterally brainstorming and discussions with Dr. Jörg Rissler, Dipl. Ing. Ingo Hermanns-Truxius, and Dr. Britta Weber, with Dr. Jörg Rissler providing quality assurance of the statistical procedure. Dr. Sonia D'souza and Marc Prior suggested few comments on the manuscript during proof reading. All authors are responsible for all aspects of the article. All authors equally approved the final version. David H. Seidel submitted the content via the publisher's input mask without assistance, uploaded it, and corresponded with the editors after consulting with the co-authors. In addition, David H. Seidel coordinated internal review loops as needed and ensured that the article was finally published. All authors have given their consent for publication and usage in this dissertation. All authors finally acknowledged that David H. Seidel performed most of the activities for this publication.

## 6.4 Publication 3 – Seidel et al. 2021a

David H. Seidel, Prof. Dr. Rolf P. Ellegast and Dr. Britta Weber conceived and designed the publication 3 in similar proportions and were jointly involved in similar parts in the idea generation. David H. Seidel, Prof. Dr. Rolf P. Ellegast, and Dr. Britta Weber selected the methods, extracted, analyzed, and interpreted the information, with David H. Seidel always performed most of the tasks. David H. Seidel performed the additional literature search in Google Scholar for measurement-based assessment methods without external assistance. Furthermore, David H. Seidel is responsible for accuracy of all information. David H. Seidel independently prepared the German language draft manuscript. David H. Seidel prepared the draft of **Fig. 1** (in the manuscript by Seidel et al. 2021a, p. 195), **Fig. 2** (in the manuscript by Seidel et al. 2021a, p. 195) and **Fig. 3** (in the manuscript by Seidel et al. 2021a, p. 196) Figures/manuscript were than adjusted based consensus discussions between David H. Seidel, Prof. Dr. Rolf P. Ellegast, and Dr. Britta Weber.

## STATEMENTS ON OWN CONTRIBUTION – CHAPTER 6.4

David H. Seidel had the largest contribution to preparation of figures and manuscript writing. Prof. Dr. Monika A. Rieger, PD Dr. Benjamin Steinhilber, Prof. Dr. Rolf P. Ellegast, and most importantly, Dr. Britta Weber provided critical comments on the manuscript. David H. Seidel, Prof. Dr. Rolf P. Ellegast, and Dr. Britta Weber performed the revision, with David H. Seidel doing a major part of the revision. Prof. Dr. Rolf P. Ellegast and Dr. Britta Weber performed the supervision, with Dr. Britta Weber doing the main part. All authors are responsible for all aspects of the article. All authors equally approved the final version. David H. Seidel submitted the content via the publisher's input mask without assistance, uploaded it, and corresponded with the editors after consulting with the co-authors. In addition, David H. Seidel coordinated internal review loops as needed and ensured that the article was finally published. All authors have given their consent for publication and usage in this dissertation. All authors finally acknowledged that David H. Seidel performed most of the activities for this publication. Translation of publication 3 (chapter 2.5) into English was performed by David H. Seidel without further assistance.

| | |
|---|---|
| David Henry Seidel | Place, Date |

# 7 List of publications

Parts of this dissertation have already been published as shown in **Table 2.**.

**Table 2.** List of dissertation-related publications (Date 26th September 2021).

| | |
|---|---|
| ***Journal articles – 2019 until 2021*** | |
| Publication 1: Seidel et al. 2019b | **Seidel DH**, Ditchen DM, Hoehne-Hückstädt UM, Rieger MA and Steinhilber B (2019) Quantitative Measures of Physical Risk Factors Associated with Work-Related Musculoskeletal Disorders of the Elbow: A Systematic Review. Int J Environ Res Public Health 16(130): 1-23. doi: 10.3390/ijerph16010130. |
| Publication 2: Seidel et al. 2021b | **Seidel DH**, Heinrich K, Hermanns-Truxius I, Ellegast RP, Barrero LH, Rieger MA, Steinhilber B and Weber B (2021) Assessment of work-related hand and elbow workloads using measurement-based TLV for HAL. Appl Ergon 92: 103310 (1-11). doi: 10.1016/j.apergo.2020.103310. |
| Publication 3: Seidel et al. 2021a | **Seidel DH**, Ellegast RP, Rieger MA, Steinhilber B und Weber B (2021) Messdatenbasierte Gefährdungsbeurteilung. Kategorisierung messtechnischer Methoden zur Beurteilung physischer Belastungen der oberen Extremität [Measurement-based risk assessment. Categorization of measurement methods for assessing physical workloads of the upper extremity]. Zentralbl Arbeitsmed Arbeitsschutz Ergon 71(4): 192-199. doi: 10.1007/s40664-021-00424-y. |
| ***Congress and conference contributions – 2017 until 2019*** | |
| Contribution 1: Seidel et al. 2017 | **Seidel DH**, Ditchen DM, Hoehne-Hückstädt U, Rieger MA und Steinhilber B (2017) Arbeitsbezogene Risikofaktoren für muskuloskelettale Beschwerden und Erkrankungen des Ellenbogens – Systematisches Review als Grundlage zur Entwicklung eines Bewertungsverfahrens [Work-related risk factors for musculoskeletal complaints and diseases of the elbow – Systematic review as a basis for the development of an assessment approach]: 25. In: Klussmann, A und Hartmann, B (Hrsg.). aser:info, Schriftenreihe des Instituts ASER e.V., Forum Arbeitsphysiologie: 21. Symposium Arbeitsmedizin und Arbeitswissenschaft für Nachwuchswissenschaftler. Bad Münder. vol 9. ASER e.V. |
| Contribution 2: Seidel et al. 2019d | **Seidel DH**, Hermanns I, Heinrich K, Ellegast R, Rieger MA, Barrero LH, Weber B and Steinhilber B (2019) Extension of a kinematic and force measurement-based tlv approach to assess workloads of the elbow joint – a field feasibility study: 120. In: PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders. Bologna, Italia. PREMUS. |
| Contribution 3: Seidel et al. 2019c | **Seidel DH**, Heinrich K, Hermanns-Truxius I, Ellegast R, Barrero LH, Rieger MA, Steinhilber B und Weber B (2019) DGUV Report 2/2020. Messdatenbasierte Bewertung arbeitsbedingter Hand- und Ellenbogenbelastungen [DGUV Report 2/2020. Measurement-based assessment of work-related hand and elbow loads]: 41-46. In: Freiberg S und Zieschang H (Edn). 7. DGUV Fachgespräch Ergonomie – Zusammenfassung der Vorträge vom 25. und 26. November 2019. Dresden, Deutschland. DGUV. |

# 8 Supplementary material

## 8.1 Publication 1 – Seidel et al. 2019b – Supplementary Material

*Review – Supplementary Files (SF)*

# Quantitative Measures of Physical Risk Factors Associated with Work-Related Musculoskeletal Disorders of the Elbow: A Systematic Review

**David H. Seidel, Dirk M. Ditchen, Ulrike M. Hoehne-Hückstädt, Monika A. Rieger and Benjamin Steinhilber**

*File I – Table S1: PRISMA checklist adopted from Moher et al. [12] and modified*

**Table S1.** PRISMA checklist adopted from Moher et al. [12] and modified.

| Section/topic | Item No. | Checklist item | Section | Page |
|---|---|---|---|---|
| **TITLE** | | | | |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. | Title page | 1 |
| **ABSTRACT** | | | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | Abstract | 1 |
| **INTRODUCTION** | | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | Introduction | 1, 2 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). | Methods | 4 |
| **METHODS** | | | | |
| Protocol and registration | 5 | Indicate whether a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | not exist | - |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | Methods | 1 to 4 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | Methods & Supplementary Files | 2, SF 5 to SF 8 |

| | | | | |
|---|---|---|---|---|
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | Supplementary Files | SF 5 to SF 8 |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | Methods & Supplementary Files | 2, 3, SF 9 to SF 50 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | Methods | 2 to 4 |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | Methods, Supplementary Files | 2 to 4, SF 5 to SF 8 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | Methods | 5 |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | Methods | 5 |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | Methods | 5 |
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | Methods, Results | 5, 14 to 15 |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | not exist | - |
| **RESULTS** | | | | |
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | Results | 3 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | Supplementary Files | SF 50 to SF 59 |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | (grouped) Results | 5, 14 to 15 |

| | | | | |
|---|---|---|---|---|
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | Results, Supplementary Files | 6 to 14, SF 9 to SF 65 |
| Synthesis of results | 21 | Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency. | Results, Supplementary Files | 6 to 14, SF 9 to SF 65 |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | Results | 14, 15 |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | not exist | - |
| **DISCUSSION** | | | | |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | Discussion | 16 to 19 |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | Discussion | 19, 20 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | Discussion | 21 |
| **FUNDING** | | | | |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | Discussion | 22 |

*File II – Table S2: MEDLINE search strategy – 03th February 2017*

**Table S2.** MEDLINE search strategy – 03th February 2017.

| No. | Searches | Reference/ Comment | Results |
|---|---|---|---|
| I | (elbow [MH] OR upper limb [MH] OR upper extremit*[MH] elbow joint [MeSH Terms] OR cubital joint OR articulatio cubiti) | | 18738 |
| II | (musculoskeletal disorders OR pain OR injury OR cumulative trauma disorders) | [4] | 2535768 |
| III | **#1 AND #2** | | **13842** |
| IV | (epicondylitis OR (epicondylitides, lateral humeral[MeSH Terms]) OR (epicondylitis, lateral humeral[MeSH Terms]) OR (humeral epicondylitides, lateral[MeSH Terms]) OR (tennis* AND elbow) OR (golf* AND elbow) OR cubital tunnel syndrome OR radial tunnel syndrome OR ulnar nerve entrapment OR median nerve entrapment OR pronator teres syndrome OR tenosynovitis OR tendovaginitis OR radial nerve entrapment) | [6] | 17373 |
| V | #3 OR #4 | | 30227 |
| VI | (((((((("Elbow/abnormalities"[MeSH] OR "Elbow/diagnosis"[MeSH] OR "Elbow/etiology"[MeSH] OR "Elbow/injuries"[MeSH] OR "Elbow/pathology"[MeSH] OR "Elbow/physiopathology"[MeSH] ))) OR (( "Elbow Joint/abnormalities"[MeSH] OR "Elbow Joint/diagnosis"[MeSH] OR "Elbow Joint/etiology"[MeSH] OR "Elbow Joint/injuries"[MeSH] OR "Elbow Joint/pathology"[MeSH] OR "Elbow Joint/physiopathology"[MeSH] ))) OR (( "Tennis Elbow/diagnosis"[MeSH] OR "Tennis Elbow/epidemiology"[MeSH] OR "Tennis Elbow/etiology"[MeSH] OR "Tennis Elbow/mortality"[MeSH] OR "Tennis Elbow/pathology"[MeSH] OR "Tennis Elbow/physiopathology"[MeSH] ))) OR (( "Elbow Tendinopathy/diagnosis"[MeSH] OR "Elbow Tendinopathy/epidemiology"[MeSH] OR "Elbow Tendinopathy/etiology"[MeSH] OR "Elbow Tendinopathy/mortality"[MeSH] OR "Elbow Tendinopathy/pathology"[MeSH] OR "Elbow Tendinopathy/physiopathology"[MeSH] ))) OR (( "Cubital Tunnel Syndrome/diagnosis"[MeSH] OR "Cubital Tunnel Syndrome/epidemiology"[MeSH] OR "Cubital Tunnel Syndrome/etiology"[MeSH] OR "Cubital Tunnel Syndrome/pathology"[MeSH] OR "Cubital Tunnel Syndrome/physiopathology"[MeSH])))) | | 8987 |
| VII | **#5 OR #6** | | 32111 |
| VIII | ((((((epicondylitides, lateral humeral[MeSH Terms]) OR epicondylitis, lateral humeral[MeSH Terms]) OR humeral epicondylitides, lateral[MeSH Terms]) OR humeral epicondylitis, lateral[MeSH Terms]) OR lateral humeral epicondylitides[MeSH Terms]) OR lateral humeral epicondylitis[MeSH Terms]) | | 1438 |

| | | | |
|---|---|---|---|
| IX | (((((((carpal tunnel syndrome[MeSH Terms]) OR carpal tunnel syndromes[MeSH Terms]) OR compression neuropathy, carpal tunnel[MeSH Terms]) OR entrapment neuropathy, carpal tunnel[MeSH Terms]) OR median neuropathy, carpal tunnel[MeSH Terms]) OR syndrome, carpal tunnel[MeSH Terms]) OR syndromes, carpal tunnel[MeSH Terms]) | | 7605 |
| X | ((rotator cuff[MeSH Terms]) OR cuff, rotator[MeSH Terms]) | | 5148 |
| XI | **#8 AND #9** | | 51 |
| XII | **#8 AND #10** | | 10 |
| XIII | **#7 NOT #9 NOT #10** | | 23920 |
| XIV | **#13 OR #11 OR #12** | | 23981 |
| XV | (occupational diseases [MH] OR occupational exposure [MH] OR occupational exposure* [TW] OR "occupational health" OR "occupational medicine" OR work-related OR working environment [TW] OR at work [TW] OR work environment [TW] OR occupations [MH] OR work [MH] OR workplace* [TW] OR workload OR occupation* OR worke* OR work place* [TW] OR work site* [TW] OR job* [TW] OR occupational groups [MH] OR employment OR worksite* OR industry OR risk factor* OR occupational risk [TW]) | [13] (p. 437) added: OR risk factor* OR occupational risk [TW] OSH-Terms | 2164104 |
| XVI | **#14 AND #15** | | 1904 |
| XVII | ("2007/09/01"[Date - Publication] : "2017/02/01"[Date - Publication]) | | 8875059 |
| XVIII | **#16 AND #17** | | 848 |
| XIX | (("Humans"[MeSH Terms]) AND "Adult"[MeSH Terms]) | | 6159838 |
| XX | **#18 AND #19** | | 490 |
| XXI | (((TH[SH] OR (Case Reports[Publication Type]) OR child [MH] OR child* [OT] OR child* [Title]))) | no therapies / case reports | 8244510 |
| XXII | **#20 NOT #21** | | 159 |
| XXIII | Filters: Abstract; Full text; German; English | | 141 |

*File III – MEDLINE search string – 03th February 2017*

((((((((((((((((((((((elbow [MH] OR upper limb [MH] OR upper extremit*[MH] elbow joint [MeSH Terms] OR cubital joint OR articulatio cubiti))) AND ((musculoskeletal disorders OR pain OR injury OR cumulative trauma disorders)))) OR ((epicondylitis OR (epicondylitides, lateral humeral[MeSH Terms]) OR (epicondylitis, lateral humeral[MeSH Terms]) OR (humeral epicondylitides, lateral[MeSH Terms]) OR (tennis* AND elbow) OR (golf* AND elbow) OR cubital tunnel syndrome OR radial tunnel syndrome OR ulnar nerve entrapment OR median nerve entrapment OR pronator teres syndrome OR tenosynovitis OR tendovaginitis OR radial nerve entrapment)))) OR ((((((((("Elbow/abnormalities"[MeSH] OR "Elbow/diagnosis"[MeSH] OR "Elbow/etiology"[MeSH] OR "Elbow/injuries"[MeSH] OR "Elbow/pathology"[MeSH] OR "Elbow/physiopathology"[MeSH] ))) OR (( "Elbow Joint/abnormalities"[MeSH] OR "Elbow Joint/diagnosis"[MeSH] OR "Elbow Joint/etiology"[MeSH] OR "Elbow Joint/injuries"[MeSH] OR "Elbow Joint/pathology"[MeSH] OR "Elbow Joint/physiopathology"[MeSH] ))) OR (( "Tennis Elbow/diagnosis"[MeSH] OR "Tennis Elbow/epidemiology"[MeSH] OR "Tennis Elbow/etiology"[MeSH] OR "Tennis Elbow/mortality"[MeSH] OR "Tennis Elbow/pathology"[MeSH] OR "Tennis Elbow/physiopathology"[MeSH] ))) OR (( "Elbow Tendinopathy/diagnosis"[MeSH] OR "Elbow Tendinopathy/epidemiology"[MeSH] OR "Elbow Tendinopathy/etiology"[MeSH] OR "Elbow Tendinopathy/mortality"[MeSH] OR "Elbow Tendinopathy/pathology"[MeSH] OR "Elbow Tendinopathy/physiopathology"[MeSH]))) OR (( "Cubital Tunnel Syndrome/diagnosis"[MeSH] OR "Cubital Tunnel Syndrome/epidemiology"[MeSH] OR "Cubital Tunnel Syndrome/etiology"[MeSH] OR "Cubital Tunnel Syndrome/pathology"[MeSH] OR "Cubital Tunnel Syndrome/physiopathology"[MeSH]))))))) NOT ((((((((carpal tunnel syndrome[MeSH Terms]) OR carpal tunnel syndromes[MeSH Terms]) OR compression neuropathy, carpal tunnel[MeSH Terms]) OR entrapment neuropathy, carpal tunnel[MeSH Terms]) OR median neuropathy, carpal tunnel[MeSH Terms]) OR syndrome, carpal tunnel[MeSH Terms]) OR syndromes, carpal tunnel[MeSH Terms]))) NOT (((rotator cuff[MeSH Terms]) OR cuff, rotator[MeSH Terms])))) OR (((((((((epicondylitides, lateral humeral[MeSH Terms]) OR epicondylitis, lateral humeral[MeSH Terms]) OR humeral epicondylitides, lateral[MeSH Terms]) OR humeral epicondylitis, lateral[MeSH Terms]) OR lateral humeral epicondylitides[MeSH Terms]) OR lateral humeral epicondylitis[MeSH Terms]))) AND ((((((((carpal tunnel syndrome[MeSH Terms]) OR carpal tunnel syndromes[MeSH Terms]) OR compression neuropathy, carpal tunnel[MeSH Terms]) OR entrapment neuropathy, carpal tunnel[MeSH Terms]) OR median neuropathy, carpal tunnel[MeSH Terms]) OR syndrome, carpal tunnel[MeSH Terms]) OR syndromes, carpal tunnel[MeSH Terms])))) OR (((((((((epicondylitides, lateral humeral[MeSH Terms]) OR epicondylitis, lateral humeral[MeSH Terms]) OR humeral epicondylitides, lateral[MeSH Terms]) OR humeral epicondylitis, lateral[MeSH Terms]) OR lateral humeral epicondylitides[MeSH Terms]) OR lateral humeral epicondylitis[MeSH Terms]))) AND (((rotator cuff[MeSH Terms]) OR cuff, rotator[MeSH Terms]))))) AND ((occupational diseases [MH] OR occupational exposure [MH] OR occupational exposure* [TW] OR “occupational health” OR “occupational medicine” OR work-related OR working environment [TW] OR at work [TW] OR work environment [TW] OR occupations [MH] OR work [MH] OR workplace* [TW] OR workload OR occupation* OR worke* OR work place* [TW] OR work site* [TW] OR job* [TW] OR occupational groups [MH] OR employment OR worksite* OR industry OR risk factor* OR occupational risk [TW])))) AND ("2007/09/01"[Date - Publication] : "2017/02/01"[Date - Publication]))) AND ((("Humans"[MeSH Terms]) AND "Adult"[MeSH Terms])))) NOT ((((TH[SH] OR (Case Reports[Publication Type]) OR child [MH] OR child* [OT] OR child* [Title]))))) AND ( ( hasabstract[text] AND full text[sb] ) AND ( English[lang] OR German[lang])))

*File IV – Table S3: EMBASE search strategy – 08th February 2017*

**Table S3.** EMBASE search strategy – 08th February 2017.

| EMBASE ENTERED 10:12:09 ON 08 FEB 2017 | | RESULTS |
|---|---|---|
| **=> s elbow disease+nt/ct** | | |
| L1 | ELBOW DISEASE+NT/CT (5 TERMS) | 5945 |
| **=> s elbow injury/ct** | | |
| L2 | ELBOW INJURY/CT | 1704 |
| **=> s L1 or L2** | | |
| L3 | L1 OR L2 | 7302 |
| **=> s occupation?/ct** | | |
| L4 | OCCUPATION?/CT | 271962 |
| **=> s work?/ct** | | |
| L5 | WORK?/CT | 247856 |
| **=> s L4 or L5** | | |
| L6 | L4 OR L5 | 477782 |
| **=> s L3 and L6** | | |
| L7 | L3 AND L6 | 443 |
| **=> s risk factor?** | | |
| | RISK | 2845952 |
| | FACTOR? | 4438575 |
| L8 | RISK FACTOR? | 1005760 |
| | (RISK(W)FACTOR?) | |
| **=> s L3 and L8** | | |
| L9 | L3 AND L8 | 323 |
| **=> s L7 or L9** | | |
| L10 | L7 OR L9 | 667 |
| **=> s 20070901-20170207/pd** | | |
| L11 | 20070901-20170207/PD | 11441788 |
| | (20070901-20170207/PD) | |
| **=> s L10 and L11** | | |
| L12 | L10 AND L11 | 321 |
| **=> s L12 not case report/ct** | | |
| | CASE REPORT/CT | 2171856 |
| L13 | L12 NOT CASE REPORT/CT | 295 |
| **=> s L13 not child?/ti,ct** | | |
| | CHILD?/TI | 796065 |
| | CHILD?/CT | 1842185 |
| L14 | L13 NOT CHILD?/TI,CT | 264 |
| **=> s L14 and en/la** | | |
| | EN/LA | 26116521 |
| L15 | L14 AND EN/LA | 249 |
| **=> s L15 and ab/fa** | | |
| | AB/FA | 21970944 |
| L16 | L15 AND AB/FA | 226 |

*File V – Cochrane Work search strategy – 06th January 2017*

Cochrane Work (available from: http://work.cochrane.org/cochrane-reviews-about-occupational-safety-and-health, accessed 06th January 2017) were scanned manually via title and abstract by D.H.S., because computer-based search including e. g. MeSH terms, other key words, or search strings were not supported by Cochrane Work in January 2017.

*File VI – Table S4: Documentation of all included and excluded studies*

**Table S4.** Documentation of all included and excluded studies.

| Identification | | | Scanning title & abstract | | | | | | Scanning full-text | | | | After scanning title & abstract, full-text, discussions about eligibility | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Reference | Source | Reviewer D.H.S no = 0; yes = 1 | Reviewer B.S. no = 0; yes = 1 | Inclusion/ Exclusion after scanning abstracts,<br>both no = 0;<br>DHS yes & BS no = 1;<br>DHS no & BS yes = 2;<br>both yes = 3 | | | Exclusion; after scanning title & abstract<br>(incl./excl. = 1) = 0<br>discussion necessary (incl./excl. = 2) = 1<br>discussion necessary (incl./excl. = 3) = 1<br>inclusion for scanning full-text (incl./excl. = 3) = 2 | After first discussion<br>exclusion = 0<br>discussion necessary = 1<br>inclusion = 2 | After Scanning full-text<br>exclusion = 0<br>inclusion = 1 | After Scanning full-text and after first discussion<br>exclusion; because abstract is missing = 0<br>exclusion; after scanning title & abstract (no; no) = 1<br>exclusion; abstract (yes, no), full-text (no) = 2<br>discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract = 3<br>discussion necessary = 4<br>inclusion for scanning full-text = 5 | | Exclusion / inclusion after initial full-text scanning<br>no = 0; yes = 1 | | Exclusion / inclusion after checking for eligibility and last discussions<br>final rating<br>no = 0; yes = 1 | | Reasons for exclusion of single studies a) to e) ( see chapter 'Inclusion criteria' in 'Materials and Methods) |
| 1 | Aasmoe, L., et al. (2008). "Musculoskeletal symptoms among seafood production workers in North Norway." Occup Med (Lond) 58(1): 64-70. | EMBASE_08_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e |
| 2 | Abledu, J. K., Offei, E. B., & Abledu, G. K. (2014). Predictors of Work-Related Musculoskeletal Disorders among Commercial Minibus Drivers in Accra Metropolis, Ghana. Advances in Epidemiology, 2014. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 3 | Abgarov, Alisa, et al. "Understanding trends and risk factors of swimming-related injuries in varsity swimmers." Clinical Kinesiology: Journal of the American Kinesiotherapy Association, vol. 66, no. 2, 2012, p. 24+. Academic OneFile, Accessed 21 Feb. 2017. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 4 | Abrams, G. D., et al. (2012). "Risk factors for development of heterotopic ossification of the elbow after fracture fixation." J Shoulder Elbow Surg 21(11): 1550-1554. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Aghilinejad, M., et al. (2012). "Work-related musculoskeletal complaints among workers of Iranian aluminum industries." Arch Environ Occup Health 67(2): 98-102. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 6 | Ahmed, S. (2013). Risk factors of tennis elbow patients attended at two selected organizations in Dhaka (Doctoral dissertation, Department of Physiotherapy, Bangladesh Health Professions Institute, CRP). | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | yes | 1 | no | 0 | b |
| 7 | Aitchison, L. P., et al. (2016). "The ergonomics of laparoscopic surgery: a quantitative study of the time and motion of laparoscopic surgeons in live surgical environments." Surg Endosc 30(11): 5068-5076. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 8 | Alnaser, M. Z. (2007). Occupational musculoskeletal injuries in the health care environment and its impact on occupational therapy practitioners: a systematic review. Work, 29(2), 89-100. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | e |
| 9 | Alperovitch-Najenson, D., et al. (2010). "Upper body quadrant pain in bus drivers." Arch Environ Occup Health 65(4): 218-223. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 10 | Alqahtani, S. M., et al. (2016). "Adult Reconstructive Surgery: A High-Risk Profession for Work-Related Injuries." J Arthroplasty 31(6): 1194-1198. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 11 | Alrowayeh, H. N., et al. (2010). "Prevalence, characteristics, and impacts of work-related musculoskeletal disorders: a survey among physical therapists in the State of Kuwait." BMC Musculoskelet Disord 11: 116. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 12 | Altinisik, J., et al. (2015). "The BstUI and DpnII Variants of the COL5A1 Gene Are Associated With Tennis Elbow." Am J Sports Med 43(7): 1784-1789. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 13 | Andersen, J. H., Haahr, J. P., & Frost, P. (2007). Risk factors for more severe regional musculoskeletal symptoms: A two-year prospective study of a general working population. Arthritis & Rheumatology, 56(4), 1355-1364. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | d |
| 14 | Andersen, J. H., et al. (2011). "Risk factors for neck and upper extremity disorders among computers users and the effect of interventions: an overview of systematic reviews." PLoS One 6(5): e19691. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 15 | Andersen, J. H., et al. (2012). "Computer use and ulnar neuropathy: results from a case-referent study." Work 41 Suppl 1: 2434-2437. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | results in abstract, but not in full-text, exclusion after discussion of content |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | Andersen, L. L., et al. (2010). "Effect of physical exercise interventions on musculoskeletal pain in all body regions among office workers: a one-year randomized controlled trial." Man Ther 15(1): 100-104. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 17 | Anderson, A. M., Meador, K. A., McClure, L. R., Makrozahopoulos, D., Brooks, D. J., & Mirka, G. A. (2007). A biomechanical analysis of anterior load carriage. Ergonomics, 50(12), 2104-2117. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 18 | Anderson, M. W. and B. A. Alford (2010). "Overhead throwing injuries of the shoulder and elbow." Radiol Clin North Am 48(6): 1137-1154. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 19 | Lindegård Andersson, A. (2007). Working technique during computer work Associations with biomechanical and psychological strain, neck and upper extremity musculoskeletal symptoms. Inst of Medicine. Dept of Public Health and Community Medicine. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 20 | Andrade, D. M. and A. Barbosa-Branco (2015). "Synovitis and tenosynovitis in Brazil: analysis of sickness benefit claims." Rev Bras Epidemiol 18(1): 194-207. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c |
| 21 | Aragon, V. J., et al. (2012). "Trunk-rotation flexibility in collegiate softball players with or without a history of shoulder or elbow injury." J Athl Train 47(5): 507-513. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c |
| 22 | Arcury, T. A., et al. (2016). "The effects of work organization on the health of immigrant manual workers: A longitudinal analysis." Arch Environ Occup Health 71(2): 66-73. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c |
| 23 | Aroui, H., et al. (2016). "Musculoskeletal disorders of the hand and wrist and population attributable fraction of risk of exposure to biomechanical constraints." Ann Phys Rehabil Med 59s: e113-e114. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 24 | Artati, S. P., Van der Smagt, P., Krüger, D. I. N., & Baena, J. M. B. Calculation of Human Arm Stiffness using a Biomechanical Model. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d, e |
| 25 | Arvidsson, I., et al. (2008). "Follow-up study of musculoskeletal disorders 20 months after the introduction of a mouse-based computer system." Scand J Work Environ Health 34(5): 374-380. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 26 | Auerbach, J. D., et al. (2011). "Musculoskeletal disorders among spine surgeons: results of a survey of the Scoliosis Research Society membership." Spine (Phila Pa 1976) 36(26): E1715-1721. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c |
| 27 | Bagher, O. M., et al. (2011). "Pattern of rheumatic diseases in two outpatient clinics in Iran: similarities with some different features." Indian J Med Sci 65(1): 7-17. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d |
| 28 | Baker SR, Patel RH, Lelkes V, Castro A 3rd, Sarmast U, Whang J. Non-spinal musculoskeletal malpractice suits against radiologists in the USA--rates, anatomic locations, and payments in a survey of 8,265 radiologists. Emerg Radiol. 2014 Feb;21(1):29-34. doi: 10.1007/s10140-013-1154-4. PubMed PMID: 23996223. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c |
| 29 | Balogh I, Ohlsson K, Nordander C, Björk J, Hansson GÅ. The importance of work organization on workload and musculoskeletal health--Grocery store work as a model. Appl Ergon. 2016 Mar;53 Pt A:143-51. doi: 10.1016/j.apergo.2015.09.004. PubMed PMID: 26464034. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | Bandinelli, F., et al. (2015). "Ultrasonographic wrist and hand abnormalities in early psoriatic arthritis patients: correlation with clinical, dermatological, serological and genetic indices." Clin Exp Rheumatol 33(3): 330-335. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c |
| 31 | Bao, S., et al. (2011). "Comparison of two different methods for performing combination analysis of force and posture risk factors in an epidemiological study." Scand J Work Environ Health 37(6): 512-524. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 32 | Bao, S. S., et al. (2016). "Impact of Work Organizational Factors on Carpal Tunnel Syndrome and Epicondylitis." J Occup Environ Med 58(8): 760-764. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | d |
| 33 | Barrero, L. H., et al. (2012). "Physical workloads of the upper-extremity among workers of the Colombian flower industry." Am J Ind Med 55(10): 926-939. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 34 | Bepko, J. and K. Mansalis (2016). "Common Occupational Disorders: Asthma, COPD, Dermatitis, and Musculoskeletal Disorders." Am Fam Physician 93(12): 1000-1006. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 35 | Bethapudi, S., et al. (2013). "Elbow injuries at the London 2012 Summer Olympic Games: demographics and pictorial imaging review." AJR Am J Roentgenol 201(3): 535-549. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 36 | Bheeshma, B., Manoj Deepak, M., Prabhu Thangaraju, Venkatachalam, K. 2015. Prospective Study of the Evaluation of Autologous Blood Transfusion in the Treatment of Lateral Epicondylitis. Research Journal of Pharmaceutical, Biological and Chemical Sciences. 6(2) Page No. 970-974 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 37 | Bigorre, N., et al. (2011). "Lateral epicondylitis treatment by extensor carpi radialis fasciotomy and radial nerve decompression: is outcome influenced by the occupational disease compensation aspect?" Orthop Traumatol Surg Res 97(2): 159-163. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 38 | Bonfiglioli, R., et al. (2015). "Occupational mononeuropathies in industry." Handb Clin Neurol 131: 411-426. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e |
| 39 | Bongartz, T., et al. (2015). "Dual-energy CT for the diagnosis of gout: an accuracy and diagnostic yield study." Ann Rheum Dis 74(6): 1072-1077. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 40 | Bonneterre, V., et al. (2010). "Programmed health surveillance and detection of emerging diseases in occupational health: contribution of the French national occupational disease surveillance and prevention network (RNV3P)." Occup Environ Med 67(3): 178-186. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 41 | Boocock, M. G., et al. (2009). "A framework for the classification and diagnosis of work-related upper extremity conditions: systematic review." Semin Arthritis Rheum 38(4): 296-311. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 42 | Bosch, T., Mathiassen, S. E., Visser, B., Looze, M. D., & Dieën, J. V. (2011). The effect of work pace on workload, motor variability and fatigue during simulated light assembly work. Ergonomics, 54(2), 154-168. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | Boschman, J. S., van der Molen, H. F., Sluiter, J. K., & Frings-Dresen, M. H. (2011). Occupational demands and health effects for bricklayers and construction supervisors: A systematic review. American journal of industrial medicine, 54(1), 55-77. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | e |
| 44 | Boschman, J. S., et al. (2012). "Musculoskeletal disorders among construction workers: a one-year follow-up study." BMC Musculoskelet Disord 13: 196. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 45 | Briskin, S. M. (2012). "Injuries and medical issues in softball." Curr Sports Med Rep 11(5): 265-271. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 46 | Bruce JR, Hess R, Joyner P, Andrews JR. How much valgus instability can be expected with ulnar collateral ligament (UCL) injuries? A review of 273 baseball players with UCL injuries. J Shoulder Elbow Surg. 2014 Oct;23(10):1521-6. doi: 10.1016/j.jse.2014.05.015. PubMed PMID: 25220199. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 47 | Buchanan, K. A., et al. (2016). "Proximal forearm extensor muscle strain is reduced when driving nails using a shock-controlled hammer." Clin Biomech (Bristol, Avon) 38: 22-28. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 48 | Bugajska, J., et al. (2013). "Psychological factors at work and musculoskeletal disorders: a one year prospective study." Rheumatol Int 33(12): 2975-2983. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 49 | Bunata R, Icenogle K. Cerebral palsy of the elbow and forearm. J Hand Surg Am. 2014 Jul;39(7):1425-32. doi: 0.1016/j.jhsa.2013.12.017. Review. PubMed PMID: 24969499. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 50 | Burnett, D. R., & Campbell-Kyureghyan, N. H. (2010). Quantification of scan-specific ergonomic risk-factors in medical sonography. International Journal of Industrial Ergonomics, 40(3), 306-314. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 51 | Burton, A. K., Kendall, N. A., Pearce, B. G., Birrell, L. N., & Bainbridge, L. C. (2009). Management of work-relevant upper limb disorders: a review. Occupational medicine, 59(1), 44-52. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 52 | Burton, A. K. (2008). Work-relevant upper limb disorders: their characterisation, causation and management. Occupational Health at Work, 5(4), 13-18. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 53 | Cai J, Zhou Y, Chen S, Sun Y, Yuanming O, Ruan H, Fan C. Ulnar neuritis after open elbow arthrolysis combined with ulnar nerve subcutaneous transposition for post-traumatic elbow stiffness: outcome and risk factors. J Shoulder Elbow Surg. 2016 Jun;25(6):1027-33. doi: 10.1016/j.jse.2016.01.013. PubMed PMID: 27039670. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 54 | Cabral, P., et al. (2013). "Correlation of morphologic and pathologic features of the various tendon groups around the ankle: MR imaging investigation." Skeletal Radiol 42(10): 1393-1402. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55 | Cai J, Wang W, Yan H, Sun Y, Chen W, Chen S, Fan C. Complications of Open Elbow Arthrolysis in Post-Traumatic Elbow Stiffness: A Systematic Review. PLoS One. 2015 Sep 18;10(9):e0138547. doi: 10.1371/journal.pone.0138547. Review. PubMed PMID: 26383106; PubMed Central PMCID: PMC4575202. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 56 | Cantley, L. F., Taiwo, O. A., Galusha, D., Barbour, R., Slade, M. D., Tessier-Sherman, B., & Cullen, M. R. (2014). Effect of systematic ergonomic hazard identification and control implementation on musculoskeletal disorder and injury risk. Scandinavian journal of work, environment & health, 40(1), 57. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 57 | Carter GT, Weiss MD. Diagnosis and Treatment of Work-Related Proximal Median and Radial Nerve Entrapment. Phys Med Rehabil Clin N Am. 2015 Aug;26(3):539-49. doi: 10.1016/j.pmr.2015.04.001. Review. PubMed PMID: 26231964. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 58 | Cartwright, M. S., et al. (2016). "Examining the association between musculoskeletal injuries and carpal tunnel syndrome in manual laborers." Muscle Nerve 54(1): 31-35. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 59 | Chahal, J., et al. (2010). "Generalized ligamentous laxity as a predisposing factor for primary traumatic anterior shoulder dislocation." J Shoulder Elbow Surg 19(8): 1238-1242. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 60 | Chalmers PN, Sgroi T, Riff AJ, Lesniak M, Sayegh ET, Verma NN, Cole BJ, Romeo AA. Correlates With History of Injury in Youth and Adolescent Pitchers. Arthroscopy. 2015 Jul;31(7):1349-57. doi: 10.1016/j.arthro.2015.03.017. PubMed PMID: 25953122. | EMBASE_08_02_2017_Double | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 61 | Chang, C. W., et al. (2008). "Increased carrying angle is a risk factor for nontraumatic ulnar neuropathy at the elbow." Clin Orthop Relat Res 466(9): 2190-2195. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | exclusion after discussion of content, diagnostic study |
| 62 | Chang, J. H., et al. (2012). "Prevalence of musculoskeletal disorders and ergonomic assessments of cleaners." Am J Ind Med 55(7): 593-604. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 63 | Chassé M, Fergusson DA, Chen Y. Body mass index and the risk of injury in adults: a cross-sectional study. Int J Obes (Lond). 2014 Nov;38(11):1403-9. doi: 10.1038/ijo.2014.28. PubMed PMID: 24525959. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 64 | Chau, Leo, and Richard Wells. "Biomechanical loading on the hand, wrist, and forearm when holding a tablet computer." IIE Transactions on Occupational Ergonomics and Human Factors 3.2 (2015): 105-114. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 65 | Cherniack M, Brammer AJ, Lundstrom R, et al. The effect of different warming methods on sensory nerve conduction velocity in shipyard workers occupationally exposed to hand-arm vibration. International archives of occupational and environmental health 2008;81(8):1045-58. doi: 10.1007/s00420-007-0299-4 [published Online First: 2008/01/16] | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | Castillo-Lozano R., Casuso-Holgado M.J. , A comparison musculoskeletal injuries among junior and senior paddle-tennis players, Science & Sports, Volume 30, Issue 5, October 2015, Pages 268-274, ISSN 0765-1597, http://dx.doi.org/10.1016/j.scispo.2015.03.005. (http://www.sciencedirect.com/science/article/pii/S0765159715000684) | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 67 | Chelsea Hopkins, Sai-Chuen Fu, Eldrich Chua, Xiaorui Hu, Christer Rolf, Ville M. Mattila, Ling Qin, Patrick Shu-Hang Yung, Kai-Ming Chan, Critical review on the socio-economic impact of tendinopathy, Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology, Volume 4, April 2016, Pages 9-20, ISSN 2214-6873, http://dx.doi.org/10.1016/j.asmart.2016.01.002. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 68 | Chimenti RL, Van Dillen LR, Prather H, Hunt D, Chimenti PC, Khoo-Summers L. Underutilization of worker's compensation insurance among professional orchestral musicians. Med Probl Perform Art. 2013 Mar;28(1):54-60. PubMed PMID: 23462905. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 69 | Cho, C. Y., et al. (2012). "Musculoskeletal symptoms and associated risk factors among office workers with high workload computer use." J Manipulative Physiol Ther 35(7): 534-540. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 70 | Choi, S. D., Yuan, L., & Borchardt, J. G. (2014, September). Critical analyses of work-related musculoskeletal disorders and practical solutions in construction. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 58, No. 1, pp. 1633-1637). SAGE Publications. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 71 | Choung, S. D., et al. (2016). "Comparison of muscle activity of wrist extensors and kinematics of wrist joint during wrist extension in automobile assembly line workers with and without lateral epicondylitis." Work 55(1): 241-247. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 72 | Chu, P. C., et al. (2013). "The impact of occupational health service network and reporting system in Taiwan." Int J Occup Environ Health 19(4): 352-362. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 73 | Chung KC, Lark ME. Upper Extremity Injuries in Tennis Players: Diagnosis, Treatment, and Management. Hand Clin. 2017 Feb;33(1):175-186. doi: 10.1016/j.hcl.2016.08.009. Review. PubMed PMID: 27886833; PubMed Central PMCID: PMC5125509. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 74 | Chung, W. M., et al. (2012). "Musculoskeletal injuries in elite able-bodied and wheelchair foil fencers--a pilot study." Clin J Sport Med 22(3): 278-280. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 75 | Chung, Y. C., et al. (2013). "Risk of musculoskeletal disorder among Taiwanese nurses cohort: a nationwide population-based study." BMC Musculoskelet Disord 14: 144. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 76 | Claessen FM, Braun Y, van Leeuwen WF, Dyer GS, van den Bekerom MP, Ring D. What Factors are Associated With a Surgical Site Infection After Operative Treatment of an Elbow Fracture? Clin Orthop Relat Res. 2016 Feb;474(2):562-70. doi: 10.1007/s11999-015-4523-3. PubMed PMID: 26304043; PubMed Central PMCID: PMC4709303. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77 | Clavet, H., et al. (2008). "Joint contracture following prolonged stay in the intensive care unit." Cmaj 178(6): 691-697. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 78 | Clement, N. D. and D. E. Porter (2013). "Forearm deformity in patients with hereditary multiple exostoses: factors associated with range of motion and radial head dislocation." J Bone Joint Surg Am 95(17): 1586-1592. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 79 | Cohn CS, Lockhart E, McCullough JJ. The use of autologous platelet-rich plasma in the orthopedic setting. Transfusion. 2015 Jul;55(7):1812-20. doi: 10.1111/trf.13005. PubMed PMID: 25646697. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 80 | Colantoni, A., Marucci, A., Monarca, D., Pagniello, B., Cecchini, M., & Bedini, R. (2012). The risk of musculoskeletal disorders due to repetitive movements of upper limbs for workers employed to vegetable grafting. Journal of Food, Agriculture & Environment, 10(3&4), 14-18. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | d |
| 81 | Collins, R. M., Janse Van Rensburg, D. C. & Patricios, J. S. Common work-related musculoskeletal strains and injuries. S Afr Fam Pract 2011;53(3):240-246 | EMBASE_08_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 82 | Conte SA, Hodgins JL, ElAttrache NS, Patterson-Flynn N, Ahmad CS. Media perceptions of Tommy John surgery. Phys Sportsmed. 2015 Nov;43(4):375-80. doi: 10.1080/00913847.2015.1077098. PubMed PMID: 26307904. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 83 | Coombes, B. K., et al. (2010). "Efficacy and safety of corticosteroid injections and other injections for management of tendinopathy: a systematic review of randomised controlled trials." Lancet 376(9754): 1751-1767. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a, c, e |
| 84 | Crawford, J. O., Laiou, E., Spurgeon, A., & McMillan, G. (2008). Musculoskeletal disorders within the telecommunications sector—a systematic review. International Journal of Industrial Ergonomics, 38(1), 56-72. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 85 | Creuzé, A. 2014). Interest of botulinum toxin in tendinopathies: Review of literature. Annals of Physical and Rehabilitation Medicine Volume 57, n° S1 page e269 (mai 2014) Doi : 10.1016/j.rehab.2014.03.975 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 86 | Cudlip, A. C., et al. (2015). "Effects of sitting and standing on upper extremity physical exposures in materials handling tasks." Ergonomics 58(10): 1637-1646. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 87 | Cunha-Miranda, L., et al. (2010). "Prevalence of rheumatic occupational diseases - PROUD study." Acta Reumatol Port 35(2): 215-226. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 88 | Curti S, Sauni R, Spreeuwers D, De Schryver A, Valenty M, Rivière S, Mattioli S. Interventions to increase the reporting of occupational diseases by physicians. Cochrane Database of Systematic Reviews 2015, Issue 3. Art. No.: CD010305. DOI: 10.1002/14651858.CD010305.pub2. | CochraneWork_06_01_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 89 | Curwin, S., et al. (2013). "The Healthy LifeWorks project: The effect of a comprehensive workplace wellness program on the prevalence and severity of musculoskeletal disorders in a Canadian government department." J Occup Environ Med 55(6): 628-633. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | Dabholkar, Ajit, Sinan Tejani, and Sujata Yardi. "Common Musculoskeletal Injuries in Rock Climbers." Indian Journal of Public Health Research & Development 5.4 (2014): 184-189. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 91 | da Costa, B. R. and E. R. Vieira (2010). "Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies." Am J Ind Med 53(3): 285-323. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | systematic review, no single study |
| 92 | da Costa, J. T., et al. (2015). "Incidence and prevalence of upper-limb work related musculoskeletal disorders: A systematic review." Work 51(4): 635-644. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 93 | Dahlquist M, Leisz MC, Finkelstein M. The club-level road cyclist: injury, pain, and performance. Clin J Sport Med. 2015 Mar;25(2):88-94. doi: 10.1097/JSM.0000000000000111. PubMed PMID: 24915174. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 94 | Daruwalla JH, Daly CA, Seiler JG 3rd. Medial Elbow Injuries in the Throwing Athlete. Hand Clin. 2017 Feb;33(1):47-62. doi: 10.1016/j.hcl.2016.08.013. Review. PubMed PMID: 27886839. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 95 | Darwish, M. A. and S. Z. Al-Zuhair (2013). "Musculoskeletal Pain Disorders among Secondary School Saudi Female Teachers." Pain Res Treat 2013: 878570. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 96 | Das, B., Ghosh, T., & Gangopadhyay, S. (2012). Assessment of ergonomic and occupational health-related problems among female prawn seed collectors of Sunderbans, West Bengal, India. International Journal of Occupational Safety and Ergonomics, 18(4), 531-540. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 97 | Das De, S., et al. (2013). "Contribution of kinesophobia and catastrophic thinking to upper-extremity-specific disability." J Bone Joint Surg Am 95(1): 76-81. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 98 | Davis WT, Fletcher SA, Guillamondegui OD. Musculoskeletal occupational injury among surgeons: effects for patients, providers, and institutions. J Surg Res. 2014 Jun 15;189(2):207-212.e6. doi: 10.1016/j.jss.2014.03.013. PubMed PMID: 24721601. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 99 | Day, C. S., et al. (2010). "Effects of workers' compensation on the diagnosis and surgical treatment of patients with hand and wrist disorders." J Bone Joint Surg Am 92(13): 2294-2299. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 100 | de Haan, J., Schep, N.W.L., Eygendaal, D., Kleinrensink, G-J., Tuinebreijer, W.E., den Hartog, D. (2011).Stability of the Elbow Joint: Relevant Anatomy and Clinical Implications of In Vitro Biomechanical Studies. The Open Orthopaedics Journal, 2011, Volume 5 | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 101 | Delleman, N. J., & Dul, J. (2007). International standards on working postures and movements ISO 11226 and EN 1005-4. Ergonomics, 50(11), 1809-1819. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 102 | Dempsey, P. G., Mathiassen, S. E., Jackson, J. A., & O'Brien, N. V. (2010). Influence of three principles of pacing on the temporal organisation of work during cyclic assembly and disassembly tasks. Ergonomics, 53(11), 1347-1358. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 103 | Denbeigh, K., et al. (2013). "Wrist postures and forces in tree planters during three tree unloading conditions." Ergonomics 56(10): 1599-1607. | PubMed_03 _02_2017 | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 104 | Dennerlein, J. T., & Johnson, P. W. (2006). Different computer tasks affect the exposure of the upper extremity to biomechanical risk factors. Ergonomics, 49(1), 45-61. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 105 | Dennerlein, J. T., Kingma, I., Visser, B., & van Dieën, J. H. (2007). The contribution of the wrist, elbow and shoulder joints to single-finger tapping. Journal of biomechanics, 40(13), 3013-3022. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | b, d, e |
| 106 | Degen RM, Cancienne JM, Camp CL, Altchek DW, Dines JS, Werner BC. Three or more preoperative injections is the most significant risk factor for revision surgery after operative treatment of lateral epicondylitis: an analysis of 3863 patients. J Shoulder Elbow Surg. 2017 Jan 13. pii: S1058-2746(16)30567-5. doi: 10.1016/j.jse.2016.10.022. [Epub ahead of print] PubMed PMID: 28094190. | EMBASE_0 8_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 107 | Descatha, A., Roquelaure, Y., Evanoff, B. et al. Int Arch Occup Environ Health (2007) 81: 1. doi:10.1007/s00420-007-0180-5 | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, d, e |
| 108 | Descatha, A., et al.Do Symptoms And Physical Examination Findings Predict Elbow Pain And Functional Outcomes In A Working Population? J Occup Environ Med. 2014 November; 56(11): e131–e132. doi:10.1097/JOM.0000000000000293 | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 109 | Descatha, A., et al. (2016). "Lateral Epicondylitis and Physical Exposure at Work? A Review of Prospective Studies and Meta-Analysis." Arthritis Care Res (Hoboken) 68(11): 1681-1687. | EMBASE_0 8_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | meta-analysis, no single study |
| 110 | Descatha, Alexis; Despreaux, Thomas; Calfee, Ryan P.; Evanoff, Bradley; and Saint-Lary, Olivier,"Progressive elbow pain." BMJ.353,. i1391. (2016). http://digitalcommons.wustl.edu/open_access_pubs/4881 | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 111 | Descatha, Alexis; Dale, Ann Marie; Silverstein, Barbara A.; Roquelaure, Yves; and Rempel, David, "Lateral epicondylitis: new evidence for work relatedness".Joint Bone Spine, 82, 1, 5-7. 2015. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 112 | Descatha, A., et al. (2013). "Self-reported physical exposure association with medial and lateral epicondylitis incidence in a large longitudinal study." Occup Environ Med 70(9): 670-673. | PubMed_03 _02_2017/ EMBASE_0 8_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 113 | De Smedt, T., de Jong, A., Van Leemput, W., Lieven, D., & Van Glabbeek, F. (2007). Lateral epicondylitis in tennis: update on aetiology, biomechanics and treatment. British journal of sports medicine, 41(11), 816-819. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 114 | Diesselhorst, M. M., et al. (2013). "Survey of upper extremity injuries among martial arts participants." Hand Surg 18(2): 151-157. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 115 | Dick, F. D., et al. (2011). "Workplace management of upper limb disorders: a systematic review." Occup Med (Lond) 61(1): 19-25. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 116 | Dick, R. B., Lowe, B., Ming-Lun, L., & Krieg, E. F. (2015). Further Trends in Work-Related Musculoskeletal Disorders-A Comparison of Risk factors for Symptoms Using Quality of Work Life Data From the 2002, 2006 and 2010 General Social Survey. Journal of Occupational and Environmental Medicine / American College of Occupational and Environmental Medicine, 57(8), 910–928. http://doi.org/10.1097/JOM.0000000000000501 | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 117 | Di Domizio, J., & Keir, P. J. (2010). Forearm posture and grip effects during push and pull tasks. Ergonomics, 53(3), 336-343. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 118 | DiFiori, J. P., et al. (2014). Overuse Injuries and Burnout in Youth Sports: A Position Statement from the American Medical Society for Sports Medicine. Clin J Sport Med 2014;24:3–20) | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 119 | Dion, S., et al. (2017). "Are Passive Physical Modalities Effective for the Management of Common Soft Tissue Injuries of the Elbow?: A Systematic Review by the Ontario Protocol for Traffic Injury Management (OPTIMa) Collaboration." Clin J Pain 33(1): 71-86. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 120 | Dohn, P., et al. (2012). "Adult post-traumatic radioulnar synostosis." Orthop Traumatol Surg Res 98(6): 709-714. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 121 | Doke, P. P., et al. (2011). "A clinico-epidemiological study of Chikungunya outbreak in Maharashtra State, India." Indian J Public Health 55(4): 313-316. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 122 | Douglas, K., et al. (2012). "Incidence and risk factors of heterotopic ossification following major elbow trauma." Orthopedics 35(6): e815-822. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 123 | Dozono, K., et al. (2015). "Peripheral Neuropathies in Nonparetic Upper Extremities of Stroke Patients Induced by Excessive Use of a Walking Device." J Stroke Cerebrovasc Dis 24(8): 1841-1847. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 124 | Draicchio F, Trebbi M, Mari S, Forzano F, Serrao M, Sicklinger A, Silvetti A, Iavicoli S, Ranavolo A. Biomechanical evaluation of supermarket cashiers before and after a redesign of the checkout counter. Ergonomics. 2012;55(6):650-69. doi: 10.1080/00140139.2012.659762. PubMed PMID: 22455556. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 125 | Dryson, E. W. and C. B. Walls (2001). "The distribution of occupations in two populations with upper limb pain." Int J Occup Environ Health 7(3): 201-205. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 126 | East, J. M., Whittenmore, K., Polan, M., Lenehan, B. 2013.A fractured referral system-an audit of accident and emergency referrals to orthopedic fracture clinics at the University Hospital Limerick (UHL). Irish Journal of Medical Science 182:S57-S58 · March 2013 | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 127 | Edouard P, Depiesse F, Branco P, Alonso JM. Analyses of Helsinki 2012 European Athletics Championships injury and illness surveillance to discuss elite athletes risk factors. Clin J Sport Med. 2014 Sep;24(5):409-15.doi: 0.1097/JSM.0000000000000052. PubMed PMID: 24326930. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 128 | Eijckelhof, B. H. W., Huysmans, M. A., Garza, J. B., Blatter, B. M., Van Dieën, J. H., Dennerlein, J. T., & Van Der Beek, A. J. (2013). The effects of workplace stressors on muscle activity in the neck-shoulder and forearm muscles during computer work: A systematic review and meta-analysis. European Journal of Applied Physiology, 113(12), 2897-2912. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | systematic review, no single study |
| 129 | El-Bestar, S. F., et al. (2011). "Neck-upper extremity musculoskeletal disorders among workers in the telecommunications company at Mansoura City." Int J Occup Saf Ergon 17(2): 195-205. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 130 | El-Sayed, A. M., et al. (2010). "Household food insecurity and symptoms of neurologic disorder in Ethiopia: an observational analysis." BMC Public Health 10: 802. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 131 | Eltayeb, S., Staal, J. B., Hassan, A., & De Bie, R. A. (2009). Work related risk factors for neck, shoulder and arms complaints: a cohort study among Dutch computer office workers. Journal of occupational rehabilitation, 19(4), 315-322. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 132 | Emery, K. and J. N. Cote (2012). "Repetitive arm motion-induced fatigue affects shoulder but not endpoint position sense." Exp Brain Res 216(4): 553-564. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | d |
| 133 | Erhan, B., et al. (2013). "Elbow problems in paraplegic spinal cord injured patients: frequency and related risk factors--a preliminary controlled study." Spinal Cord 51(5): 406-408. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 134 | Evans, Kevin D., and Carolyn Sommerich. "The feasibility of using an HCU system for investigating ergonomic injury among autoworkers." Journal of Diagnostic Medical Sonography 25.2 (2009): 80-87. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 135 | Evans, P. J., et al. (2009). "Prevention and treatment of elbow stiffness." J Hand Surg Am 34(4): 769-778. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 136 | Faber, A., Sell, L., Hansen, J. V., Burr, H., Lund, T., Holtermann, A., & Søgaard, K. (2012). Does muscle strength predict future musculoskeletal disorders and sickness absence?. Occupational medicine, 62(1), 41-46. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 137 | Fan, Z. J., et al. (2014). "Predicting work-related incidence of lateral and medial epicondylitis using the strain index." Am J Ind Med 57(12): 1319-1330. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 138 | Fan, Z. J., et al. (2014). "The association between combination of hand force and forearm posture and incidence of lateral epicondylitis in a working population." Hum Factors 56(1): 151-165. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 139 | Fan, Z. J., et al. (2009). "Quantitative exposure-response relations between physical workload and prevalence of lateral epicondylitis in a working population." Am J Ind Med 52(6): 479-490. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 140 | Fearon, A., Scott, A., Ezzat, A., Kennedy, C., Levesque, L., Kahan, K., ... & Hoens, A. (2016). Engaging physiotherapists in effective knowledge translation–Treating tendinopathy effectively. Manual Therapy, 25, e9-e10. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 141 | Feathers, D. J., et al. (2013). "Alternative computer mouse designs: performance, posture, and subjective evaluations for college students aged 18-25." Work 44 Suppl 1: S115-122. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 142 | Fedorczyk, J. M. (2012). "Tendinopathies of the elbow, wrist, and hand: histopathology and clinical considerations." J Hand Ther 25(2): 191-200; quiz 201. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 143 | Feleus, A., et al. (2008). "Incidence of non-traumatic complaints of arm, neck and shoulder in general practice." Man Ther 13(5): 426-433. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 144 | Fernandez-Carnero, J., et al. (2008). "Bilateral myofascial trigger points in the forearm muscles in patients with chronic unilateral lateral epicondylalgia: a blinded, controlled study." Clin J Pain 24(9): 802-807. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 145 | Fernandez-Carnero, J., et al. (2009). "Widespread mechanical pain hypersensitivity as sign of central sensitization in unilateral epicondylalgia: a blinded, controlled study." Clin J Pain 25(7): 555-561. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 146 | Fernandez-de-Las-Penas, C., et al. (2010). "Specific mechanical pain hypersensitivity over peripheral nerve trunks in women with either unilateral epicondylalgia or carpal tunnel syndrome." J Orthop Sports Phys Ther 40(11): 751-760. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 147 | Fethke NB, Merlino L, Gerr F. Effect of ergonomics training on agreement between expert and nonexpert ratings of the potential for musculoskeletal harm in manufacturing tasks. J Occup Environ Med. 2013 Dec;55(12 Suppl):S82-5. doi: 10.1097/JOM.0000000000000038. PubMed PMID: 24284748. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 148 | Fieseler, G., et al. (2015). "Range of motion and isometric strength of shoulder joints of team handball athletes during the playing season, Part II: changes after midseason." J Shoulder Elbow Surg 24(3): 391-398. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 149 | Finestone HM, Yanni MM, Dalzell CJ. Patients' recall of diagnostic and treatment information improves with use of the Pain Explanation and Treatment Diagram in an outpatient chronic pain clinic. Pain Res Manag. 2015 May-Jun;20(3):145-51. PubMed PMID: 25831077; PubMed Central PMCID: PMC4447158. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150 | Fleisig, G. S. and J. R. Andrews (2012). "Prevention of elbow injuries in youth baseball pitchers." Sports Health 4(5): 419-424. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 151 | Flouzat-Lachaniette, C. H., et al. (2012). "The natural progression of adult elbow osteonecrosis related to corticosteroid treatment." Clin Orthop Relat Res 470(12): 3478-3482. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 152 | Font YM, Castro-Santana LE, Nieves-Plaza M, Maldonado M, Mayor AM, Vilá LM. Factors associated with regional rheumatic pain disorders in a population of Puerto Ricans with diabetes mellitus. Clin Rheumatol. 2014 Jul;33(7):995-1000. doi: 10.1007/s10067-013-2474-1. PubMed PMID: 24522480; PubMed Central PMCID: PMC4302737. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 153 | Forcella, L., Bonfiglioli, R., Cutilli, P. et al. Analysis of occupational stress in a high fashion clothing factory with upper limb biomechanical overload Int Arch Occup Environ Health (2012) 85: 527. doi:10.1007/s00420-011-0702-z | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | b, d |
| 154 | Forman, J. L., Lopez-Valdes, F. J., Duprey, S., Bose, D., De Dios, E. D. P., Subit, D., ... & Segui-Gomez, M. (2015). The tolerance of the human body to automobile collision impact–a systematic review of injury biomechanics research, 1990–2009. Accident Analysis & Prevention, 80, 7-17. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 155 | Foruria AM, Augustin S, Morrey BF, Sánchez-Sotelo J. Heterotopic ossification after surgery for fractures and fracture-dislocations involving the proximal aspect of the radius or ulna. J Bone Joint Surg Am. 2013 May 15;95(10):e66. doi: 10.2106/JBJS.K.01533. PubMed PMID: 23677367. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 156 | Fotiadis DG, Fotiadou EG, Kokaridas DG, Mylonas AC. Prevalence of musculoskeletal disorders in professional symphony orchestra musicians in Greece: a pilot study concerning age, gender, and instrument-specific results. Med Probl Perform Art. 2013 Jun;28(2):91-5. PubMed PMID: 23752283. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 157 | Franceschi, F., et al. (2014). "Obesity as a risk factor for tendinopathy: a systematic review." Int J Endocrinol 2014: 670262. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 158 | Fraysse, F., et al. (2016). "Practices and risks associated with operation of tie-down lashings in the vehicle transport industry." Ergonomics 59(12): 1661-1672. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 159 | Frazao, P., et al. (2010). "Risks associated with tendinitis: effects from demographic, socioeconomic, and psychological status among Brazilian workers." Am J Ind Med 53(1): 72-79. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 160 | Fronek, J., et al. (2015). "Shoulder functional performance status of Minor League professional baseball pitchers." J Shoulder Elbow Surg 24(1): 17-23. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 161 | Frost R, MacPherson H, O'Meara S. A critical scoping review of external uses of comfrey (Symphytum spp.). Complement Ther Med. 2013 Dec;21(6):724-45. doi: 10.1016/j.ctim.2013.09.009. Review. PubMed PMID: 24280482. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 162 | Furushima K, Itoh Y, Iwabu S. What are the Risk Factors for Failure after Conservative Treatment of Ulnar Collateral Ligament Injuries of the Elbow in Baseball Players? Orthopaedic Journal of Sports Medicine. 2013;1(4 Suppl):2325967113S00015. doi:10.1177/2325967113S00015. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 163 | Furushima, K., et al. (2014). "Classification of Olecranon Stress Fractures in Baseball Players." Am J Sports Med 42(6): 1343-1351. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 164 | Furuya, S., et al. (2012). "Individual differences in the biomechanical effect of loudness and tempo on upper-limb movements during repetitive piano keystrokes." Hum Mov Sci 31(1): 26-39. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | d, e |
| 165 | Gallagher, S., & Heberger, J. R. (2013). Examining the Interaction of Force and Repetition on Musculoskeletal Disorder Risk A Systematic Literature Review. Human Factors: The Journal of the Human Factors and Ergonomics Society, 55(1), 108-124. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 166 | Gallo, R., & Mazzetto, F. (2013). Ergonomic analysis for the assessment of the risk of work-related musculoskeletal disorder in forestry operations. Journal of Agricultural Engineering, 44(2s). | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 167 | Ganiyu, S. O., Olabode, J. A., Stanley, M. M., & Muhammad, I. (2015). Patterns of occurrence of work-related musculoskeletal disorders and its correlation with ergonomic hazards among health care professionals. Nigerian Journal of Experimental and Clinical Biosciences, 3(1), 18. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 168 | Gardner, B. T., et al. (2016). "Functional Measures Developed for Clinical Populations Identified Impairment Among Active Workers with Upper Extremity Disorders." J Occup Rehabil 26(1): 84-94. | added by Seidel | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 169 | Garg, A., et al. (2012). "The WISTAH hand study: a prospective cohort study of distal upper extremity musculoskeletal disorders." BMC Musculoskelet Disord 13: 90. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | e |
| 170 | Garg, A., et al. (2014). "The strain index and TLV for HAL: risk of lateral epicondylitis in a prospective cohort." Am J Ind Med 57(3): 286-302. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 171 | Gaspar, Ana Teresa, and Filipe Antunes. "Type I complex regional pain syndrome." Acta Médica Portuguesa 24.6 (2011): 1031-40. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 172 | Gates, D. H., et al. (2016). "Range of Motion Requirements for Upper-Limb Activities of Daily Living." Am J Occup Ther 70(1): 7001350010p7001350011-7001350010p7001350010. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |

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| 173 | Gerr, F., Fethke, N. B., Merlino, L., Anton, D., Rosecrance, J., Jones, M. P., ... & Meyers, A. R. (2014). A prospective study of musculoskeletal outcomes among manufacturing workers: I. Effects of physical risk factors. Human factors, 56(1), 112-130. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 174 | Gold, J. E., et al. (2009). "Specific and non-specific upper extremity musculoskeletal disorder syndromes in automobile manufacturing workers." Am J Ind Med 52(2): 124-132. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 175 | González-Moreno P, Sanabria RS, Hernández-Sánchez R, et al A6.12 Lateral Epicondyle Tendon Lesions Treatment with Platelet Growth Factors Annals of the Rheumatic Diseases 2013;72:A46. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 176 | Grantham, W. J., et al. (2015). "The curveball as a risk factor for injury: a systematic review." Sports Health 7(1): 19-26. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 177 | Green, H. J., et al. (2015). "Cellular properties of extensor carpi radialis brevis and trapezius muscles in healthy males and females." Can J Physiol Pharmacol 93(11): 953-966. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 178 | Grieve, J. R., & Dickerson, C. R. (2008). Overhead work: Identification of evidence-based exposure guidelines. Occupational Ergonomics, 8(1), 53-66. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 179 | Gross, D. P. and M. C. Battie (2010). "Recovery expectations predict recovery in workers with back pain but not other musculoskeletal conditions." J Spinal Disord Tech 23(7): 451-456. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 180 | Grzywacz, J. G., et al. (2012). "Work organization and musculoskeletal health: clinical findings from immigrant Latino poultry processing and other manual workers." J Occup Environ Med 54(8): 995-1001. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | d |
| 181 | Guillin, R., et al. (2012). "Imaging of snapping phenomena." Br J Radiol 85(1018): 1343-1353. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 182 | Gupta, A., et al. (2014). "Ergonomics in dentistry." Int J Clin Pediatr Dent 7(1): 30-34. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 183 | Ha, C., et al. (2009). "The French Musculoskeletal Disorders Surveillance Program: Pays de la Loire network." Occup Environ Med 66(7): 471-479. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 184 | Hagberg, M., Vilhemsson, R., Tornqvist, E. W., & Toomingas, A. (2007). Incidence of self-reported reduced productivity owing to musculoskeletal symptoms: association with workplace and individual factors among computer users. Ergonomics, 50(11), 1820-1834. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | d |
| 185 | Hansson, G. Å., Balogh, I., Ohlsson, K., Granqvist, L., Nordander, C., Arvidsson, I., ... & Skerfving, S. (2010). Physical workload in various types of work: Part II. Neck, shoulder and upper arm. International Journal of Industrial Ergonomics, 40(3), 267-281. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d |
| 186 | Harber, P., Lin, B. 2011. Lexical Analysis Of Abstracts Demonstrates Occupational Health Perspective. DOI: 10.1164/ajrccm-conference.2011.183.1_MeetingAbstracts.A4775 Conference: American | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thoracic Society 2011 International Conference, May 13-18, 2011 Denver Colorado | | | | | | | | | | | | | | | | | |
| 187 | Harrington, J. M., et al. (1998). "Surveillance case definitions for work related upper limb pain syndromes." Occup Environ Med 55(4): 264-271. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 188 | Heales, L. J., Bergin, M. J., Vicenzino, B., & Hodges, P. W. (2016). Forearm muscle activity in lateral epicondylalgia: a systematic review with quantitative analysis. Sports Medicine, 46(12), 1833-1845. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 189 | Healy, K. A., et al. (2011). "Hand problems among endourologists." J Endourol 25(12): 1915-1920. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 190 | Hegmann, K. T., et al. (2014). "Impacts of differences in epidemiological case definitions on prevalence for upper-extremity musculoskeletal disorders." Hum Factors 56(1): 191-202. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 191 | Helliwell, P. S., et al. (2003). "Towards epidemiological criteria for soft-tissue disorders of the arm." Occup Med (Lond) 53(5): 313-319. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 192 | Herquelot, E., et al. (2013). "Work-related risk factors for lateral epicondylitis and other cause of elbow pain in the working population." Am J Ind Med 56(4): 400-409. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 193 | Herquelot, E., et al. (2013). "Work-related risk factors for incidence of lateral epicondylitis in a large working population." Scand J Work Environ Health 39(6): 578-588. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 194 | Hibberd, E. E., et al. (2015). "Optimal management of ulnar collateral ligament injury in baseball pitchers." Open Access J Sports Med 6: 343-352. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 195 | Hoe VCW, Urquhart DM, Kelsall HL, Sim MR. Ergonomic design and training for preventing work-related musculoskeletal disorders of the upper limb and neck in adults. Cochrane Database of Systematic Reviews 2012, Issue 8. Art. No.: CD008570. DOI: 10.1002/14651858.CD008570.pub2 | CochraneWork_06_01_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, d, e |
| 196 | Holtermann, A., Blangsted, A. K., Christensen, H., Hansen, K., & Søgaard, K. (2009). What characterizes cleaners sustaining good musculoskeletal health after years with physically heavy work?. International archives of occupational and environmental health, 82(8), 1015. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 197 | Hong CC, Nashi N, Hey HW, Chee YH, Murphy D. Clinically relevant heterotopic ossification after elbow fracture surgery: a risk factors study. Orthop Traumatol Surg Res. 2015 Apr;101(2):209-13. doi: 10.1016/j.otsr.2014.10.021. PubMed PMID: 25701160. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 198 | Hoozemans MJ, Knelange EB, Frings-Dresen MH, Veeger HE, Kuijer PP. Are pushing and pulling work-related risk factors for upper extremity symptoms? A systematic review of observational studies. Occup Environ Med. 2014 Nov;71(11):788-95. doi: 10.1136/oemed-2013-101837. Review. PubMed PMID: 25035115. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after | 3 | no | 0 | no | 0 | e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | scanning title & abstract | | | | | | |
| 199 | Hou WH, Chi CC, Lo HLD, Kuo KN, Chuang HY. Vocational rehabilitation for enhancing return-to-work in workers with traumatic upper limb injuries. Cochrane Database of Systematic Reviews 2013, Issue 10. Art. No.: CD010002. DOI: 10.1002/14651858.CD010002.pub2 | CochraneWork_06_01_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 200 | House R, Krajnak K, Jiang D. Factors affecting finger and hand pain in workers with HAVS. Occupational medicine (Oxford, England) 2016;66(4):292-5. doi: 10.1093/occmed/kqw022 [published Online First: 2016/03/02] | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 201 | House R, Wills M, Liss G, et al. The effect of hand-arm vibration syndrome on quality of life. Occupational medicine (Oxford, England) 2014;64(2):133-5. doi: 10.1093/occmed/kqt167 [published Online First: 2014/02/04] | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 202 | Horn, S., et al. (2009). "Self-reported anabolic-androgenic steroids use and musculoskeletal injuries: findings from the center for the study of retired athletes health survey of retired NFL players." Am J Phys Med Rehabil 88(3): 192-200. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 203 | Hsu, J. W., et al. (2009). "The emerging role of elbow arthroscopy in chronic use injuries and fracture care." Hand Clin 25(3): 305-321. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 204 | Hsu, D. J., Chang, J. H., Wu, J. D., Chen, C. Y., & Yang, Y. H. (2011). Prevalence of musculoskeletal disorders and job exposure in Taiwan oyster shuckers. American journal of industrial medicine, 54(11), 885-893. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | d |
| 205 | Huang CY, Cho CY (2011). The effects of dual task on posture and muscle activity of upper trunk in touch and non-touch typists. Proceedings of the 16th International Congress of the WCPT. Amsterdam, Holland: World Confederation for Physical Therapy. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 206 | Huang, Q., et al. (2015). "The arthropathic and functional impairment features of adult Kashin-Beck disease patients in Aba Tibetan area in China." Osteoarthritis Cartilage 23(4): 601-606. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 207 | Huysmans, M. A., IJmker, S., Blatter, B. M., Knol, D. L., van Mechelen, W., Bongers, P. M., & van der Beek, A. J. (2012). The relative contribution of work exposure, leisure time exposure, and individual characteristics in the onset of arm–wrist–hand and neck–shoulder symptoms among office workers. International archives of occupational and environmental health, 85(6), 651-666. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | d, e |
| 208 | Ihm, J. (2008). "Proximal wrist extensor tendinopathy." Curr Rev Musculoskelet Med 1(1): 48-52. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 209 | İLÇE, Arzu. "STUDY ON WORK-RELATED MUSCULOSKELETAL DISORDERS IN INTENSIVE CARE UNIT NURSES." Anatolian Journal of Clinical Investigation 8.2 (2014). | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 210 | Inbaraj LR, Haebar OJ, Saj F, Dawson S, Paul P, Prabhakar AK, Mohan VR, Alex RG. Prevalence of musculoskeletal disorders among brick kiln workers in rural Southern India. Indian J Occup Environ Med. 2013 May;17(2):71-5. doi: 10.4103/0019-5278.123170. PubMed PMID: 24421594; PubMed Central PMCID: PMC3877450. | EMBASE_08_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 211 | Jacobs, J. W. and J. W. Bijlsma (2011). "Glucocorticoids in rheumatology: indications and routes of administration." Clin Exp Rheumatol 29(5 Suppl 68): S81-84. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 212 | Jain, N. B., et al. (2011). "Prevalence of and factors associated with posterior tibial tendon pathology on sonographic assessment." Pm r 3(11): 998-1004. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 213 | James M. Paci, MD, Christopher Michael Jones, MD, Jie Yang, PhD, Jiawen Zhu, MS, David Komatsu, PhD, Arturo Flores, MS, ATC, David Van Dyke, M.S., S.C.C.C., C.S. Predictive Value Of Preseason Screening In Collegiate Baseball Pitchers. Orthopaedic Journal of Sports Medicine Vol 3, Issue 7_suppl2 First published date: July-17-2015 10.1177/2325967115S00148 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 214 | Janga, D. and O. Akinfenwa (2012). "Work-related repetitive strain injuries amongst practitioners of obstetric and gynaecological ultrasound worldwide." Arch Gynecol Obstet 286(2): 353-356. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 1 | 1 | discussion necessary; DHS exclusion after scanning full-text, BS inclusion after scanning title & abstract | 3 | no | 0 | no | 0 | e |
| 215 | Jensen, A., et al. (2008). "Locomotor diseases among male long-haul truck drivers and other professional drivers." Int Arch Occup Environ Health 81(7): 821-827. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 0 | 0 | exclusion; abstract (yes, no), full-text (no) | 2 | no | 0 | no | 0 | c, e |
| 216 | John D. Collins, Leonard W. O'Sullivan, Musculoskeletal disorder prevalence and psychosocial risk exposures by age and gender in a cohort of office based employees in two academic institutions, International Journal of Industrial Ergonomics, Volume 46, March 2015, Pages 85-97, ISSN 0169-8141, http://dx.doi.org/10.1016/j.ergon.2014.12.013. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 217 | Johnston, V. (2007). Biological pathways between occupational stress and work-related musculoskeletal disorders of the neck and upper extremity. Physical Therapy Reviews, 12(4), 335-345. | added by Seidel | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 218 | Jonathan Dickens, Kevin F. Wilson, Scott Tintle, Reed Heckert, Benjamin K. Potter, Outcomes and Risk Factors for Poor Functional Outcomes in Open Elbow Fractures, The Journal of Hand Surgery, Volume 37, Issue 8, 2012, Page 33, ISSN 0363-5023, http://dx.doi.org/10.1016/S0363-5023(12)60044-6. (http://www.sciencedirect.com/science/article/pii/S0363502312600446) | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 219 | Jones, K. J., et al. (2013). "Functional outcomes following revision ulnar collateral ligament reconstruction in Major League Baseball pitchers." J Shoulder Elbow Surg 22(5): 642-646. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 220 | Jones, T., & Kumar, S. (2007). Assessment of physical demands and comparison of multiple exposure definitions in a repetitive sawmill job: board edger operator. Ergonomics, 50(5), 676-693. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 221 | Ju, Y. Y., et al. (2011). "Work-related musculoskeletal disorders in athletic trainer." J Occup Rehabil 21(2): 190-198. | PubMed_03_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e |
| 222 | Juratli, S. M., et al. (2010). "A population-based study of ulnar neuropathy at the elbow in Washington State workers' compensation." Am J Ind Med 53(12): 1242-1251. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 223 | Kaerlev, L., et al. (2008). "Hospital contacts for injuries and musculoskeletal diseases among seamen and fishermen: a population-based cohort study." BMC Musculoskelet Disord 9: 8. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 224 | Kaliniene G, Ustinaviciene R, Skemiene L, Vaiciulis V, Vasilavicius P. Associations between musculoskeletal pain and work-related factors among public service sector computer workers in Kaunas County, Lithuania. BMC Musculoskelet Disord. 2016 Oct 7;17(1):420. PubMed PMID: 27717347; PubMed Central PMCID: PMC5055679. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | e |
| 225 | Kameyama, M., et al. (2009). "The presence of limited joint mobility is significantly associated with multiple digit involvement by stenosing flexor tenosynovitis in diabetics." J Rheumatol 36(8): 1686-1690. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 226 | Kamper, S. J., et al. (2010). "Treatment-based subgroups of low back pain: a guide to appraisal of research studies and a summary of current evidence." Best Pract Res Clin Rheumatol 24(2): 181-191. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 227 | Kane, S. F., et al. (2014). "Evaluation of elbow pain in adults." Am Fam Physician 89(8): 649-657. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 228 | Kelley, Brian P., and Kevin C. Chung. "Soft-Tissue Coverage for Elbow Trauma." Hand clinics 31.4 (2015): 693-703. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 229 | Kennedy, C. A., Amick III, B. C., Dennerlein, J. T., Brewer, S., Catli, S., Williams, R., ... & Franzblau, A. (2010). Systematic review of the role of occupational health and safety interventions in the prevention of upper extremity musculoskeletal symptoms, signs, disorders, injuries, claims and lost time. Journal of occupational rehabilitation, 20(2), 127-162. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 230 | Kim, C. Y., et al. (2014). "Effect of Treatment Table Height on Shoulder Muscles during Ultrasound Therapy Work." J Phys Ther Sci 26(10): 1615-1617. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 231 | Kim, T. H., et al. (2013). "Joint laxity negatively correlates with lumbar disc degeneration in young adults." Spine (Phila Pa 1976) 38(24): E1541-1547. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 232 | Kachooei AR, Claessen FM, Chase SM, Verheij KK, van Dijk CN, Ring D. Factors associated with removal of a radial head prosthesis placed for acute trauma. Injury. 2016 Jun;47(6):1253-7. doi: 10.1016/j.injury.2016.02.023. PubMed PMID: 26975795. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 233 | Kaila-Kangas L, Haukka E, Miranda H, Kivekäs T, Ahola K, Luukkonen R, Shiri R, Kääriä S, Heliövaara M, Leino-Arjas P. Common mental and musculoskeletal disorders as predictors of disability retirement among Finns. J Affect Disord. 2014 Aug;165:38-44. doi: 10.1016/j.jad.2014.04.036. PubMed PMID: 24882175. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 234 | Kebede Deyyas W, Tafese A. Environmental and organizational factors associated with elbow/forearm and hand/wrist disorder among sewing machine operators of garment industry in Ethiopia. J Environ Public Health. 2014;2014:732731. doi: 10.1155/2014/732731. PubMed PMID: 25298780; PubMed Central PMCID: PMC4178914. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 235 | Klussmann, A., et al. (2010). "The Key Indicator Method for Manual Handling Operations (KIM-MHO) - evaluation of a new method for the assessment of working conditions within a cross-sectional study." BMC Musculoskelet Disord 11: 272. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 236 | Knobloch K. Drug-Induced Tendon Disorders. Adv Exp Med Biol. 2016;920:229-38. doi: 10.1007/978-3-319-33943-6_22. PubMed PMID: 27535265. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 237 | Kobayashi, T., et al. (2014). "Prevalence of and risk factors for shoulder osteoarthritis in Japanese middle-aged and elderly populations." J Shoulder Elbow Surg 23(5): 613-619. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 238 | Koh, K. H., et al. (2013). "Surgical treatment of elbow stiffness caused by post-traumatic heterotopic ossification." J Shoulder Elbow Surg 22(8): 1128-1134. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 239 | Kotani, K., Barrero, L. H., Lee, D. L., & Dennerlein, J. T. (2007). Effect of horizontal position of the computer keyboard on upper extremity posture and muscular load during computer work. Ergonomics, 50(9), 1419-1432. | added by Seidel | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 240 | Krabben, A., et al. (2014). "MRI-detected subclinical joint inflammation is associated with radiographic progression." Ann Rheum Dis 73(11): 2034-2037. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 241 | Kreiswirth, E. M., et al. (2014). "Incidence of injury among male Brazilian jiujitsu fighters at the World Jiu-Jitsu No-Gi Championship 2009." J Athl Train 49(1): 89-94. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 242 | Krogue JD, Aleem AW, Osei DA, Goldfarb CA, Calfee RP. Predictors of surgical revision after in situ decompression of the ulnar nerve. J Shoulder Elbow Surg. 2015 Apr;24(4):634-9. doi: 10.1016/j.jse.2014.12.015. Erratum in: J Shoulder Elbow Surg. 2015 Jun;24(6):994. PubMed PMID: 25660241. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 243 | Krüger, M. and E. Bischof-Leger (2008). "[Frequency of biceps tendon tenosynovitis from crutches: a sonographical observation]." Z Rheumatol 67(1): 62, 64-67. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 244 | Kryger, A. I., et al. (2007). "The role of physical examinations in studies of musculoskeletal disorders of the elbow." Occup Environ Med 64(11): 776-781. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 245 | Kumar, A. R., et al. (2009). "Lessons from the modern battlefield: successful upper extremity injury reconstruction in the subacute period." J Trauma 67(4): 752-757. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 246 | Kumar MS, Goud BR, Joseph B. A study of occupational health and safety measures in the Laundry Department of a private tertiary care teaching hospital, Bengaluru. Indian J Occup Environ Med. 2014 Jan;18(1):13-20. doi: 10.4103/0019-5278.134951. PubMed PMID: 25006311; PubMed Central PMCID: PMC4083516. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, d, e |

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| 247 | Laffont, I., Julia, M., Tiffreau, V., Yelnik, A., Herisson, C., & Pelissier, J. (2010). Aging and sequelae of poliomyelitis. Annals of physical and rehabilitation medicine, 53(1), 24-33. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 248 | Langer, D., et al. (2015). "Stenosing flexor tenosynovitis: Validity of standard assessment tools of daily functioning and quality of life." J Hand Ther 28(4): 384-387; quiz 388. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 249 | Larkin, M. E., et al. (2014). "Musculoskeletal complications in type 1 diabetes." Diabetes Care 37(7): 1863-1869. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 250 | Lauren H. Redler, Joshua S. Dines, Elbow Trauma in the Athlete, Hand Clinics, Volume 31, Issue 4, November 2015, Pages 663-681, ISSN 0749-0712, http://dx.doi.org/10.1016/j.hcl.2015.07.002. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 251 | Lee, J. T., et al. (2008). "Long term results of radial tunnel release--the effect of co-existing tennis elbow, multiple compression syndromes and workers' compensation." J Plast Reconstr Aesthet Surg 61(9): 1095-1099. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 252 | Lee, S. Y., et al. (2016). "The Potential Risk Factors Relevant to Lateral Epicondylitis by Wrist Coupling Posture." PLoS One 11(5): e0155379. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 253 | Levanon, Y., et al. (2010). "Validity and reliability of upper extremity three-dimensional kinematics during a typing task." Gait Posture 32(4): 469-474. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | b, c, d, e |
| 254 | Lewis, Thomas L., Nicholas A. Ferran, and Benjamin WT Gooding. "Current concepts in shoulder and elbow fractures and dislocations." Surgery (Oxford) 34.3 (2016): 122-128 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 255 | Lindenhovius, A., et al. (2012). "Radiographic arthrosis after elbow trauma: interobserver reliability." J Hand Surg Am 37(4): 755-759. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 256 | Lo, J. and J. A. Ashton-Miller (2008). "Effect of upper and lower extremity control strategies on predicted injury risk during simulated forward falls: a study in healthy young adults." J Biomech Eng 130(4): 041015. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | b |
| 257 | Lo, M. Y. and M. R. Safran (2007). "Surgical treatment of lateral epicondylitis: a systematic review." Clin Orthop Relat Res 463: 98-106. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 258 | Lombardi DA, Smith GS, Courtney TK, Brennan MJ, Kim JY, Perry MJ. Work-related falls from ladders--a follow-back study of US emergency department cases. Scand J Work Environ Health. 2011 Nov;37(6):525-32. doi: 10.5271/sjweh.3174. PubMed PMID: 21670941. | EMBASE_08_02_2017_Double | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 259 | Lopez, V. G. (2011). "[Evaluation of the Sentinel Surveillance Program in Occupational Health in Navarra (1998-2007)]." An Sist Sanit Navar 34(3): 419-430. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 260 | Lund, H., et al. (2008). "Movement detection impaired in patients with knee osteoarthritis compared to healthy controls: a cross-sectional case-control study." J Musculoskelet Neuronal Interact 8(4): 391-400. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 261 | Lutsky, K., et al. (2016). "Hand Dominance and Common Hand Conditions." Orthopedics 39(3): e444-448. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 262 | MacKenzie, M. S. and J. Berkowitz (2010). "Do procedural skills workshops during family practice residency work?" Can Fam Physician 56(8): e296-301. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 263 | MacIver, H., Smyth, G., & Bird, H. A. (2007). Occupational disorders: non-specific forearm pain. Best Practice & Research Clinical Rheumatology, 21(2), 349-365. | added by Seidel | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e |
| 264 | Maffulli, N., Longo, U. G., Gougoulias, N., Caine, D., & Denaro, V. (2010). Sport injuries: a review of outcomes. British medical bulletin, ldq026. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 265 | Mallows, A., Debenham, J., Walker, T., & Littlewood, C. (2016). Association of psychological variables and outcome in tendinopathy: a systematic review. British Journal of Sports Medicine, bjsports-2016. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 266 | Marks, W., et al. (2014). "Humeral fracture in arm wrestling: bone morphology as a permanent risk factor. Indications for safety measures in arm wrestling." J Sports Med Phys Fitness 54(1): 88-92. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 267 | Marras, W. S., Cutlip, R. G., Burt, S. E., & Waters, T. R. (2009). National occupational research agenda (NORA) future directions in occupational musculoskeletal disorder health research. Applied ergonomics, 40(1), 15-22. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 268 | Martimo K-P, Shiri R, Miranda H, Ketola R, Varonen H, Viikari-Juntura E. Self-reported productivity loss among workers with upper extremity disorders. Scand J Work Environ Health. 2009;35(4):301–308. | EMBASE_08_02_2017_Double | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 269 | Martimo K-P, Shiri R, Miranda H, Ketola R, Varonen H, Viikari-Juntura E. Effectiveness of an ergonomic intervention on the productivity of workers with upper-extremity disorders – a randomized controlled trial. Scand J Work Environ Health. 2010;36(1):25–33 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 270 | Martin, B. D., et al. (2008). "Complications related to simple dislocations of the elbow." Hand Clin 24(1): 9-25. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 271 | Marwa Amer; Tarek Shafshak; Mowaffak Saad. 2014.Upper limb neuro musculoskeletal complications in patients using walking aids. PM&R. Vol. 6, Iss. 8S2, 2014 S159 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 272 | Matzon, J. L., et al. (2016). "Risk Factors for Ulnar Nerve Instability Resulting in Transposition in Patients With Cubital Tunnel Syndrome." J Hand Surg Am 41(2): 180-183. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 273 | Mattioli, S., et al. (2015). "Upper-extremity and neck disorders associated with keyboard and mouse use." Handb Clin Neurol 131: 427-433. | added by Seidel | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 274 | Mautner BK, Blazuk J. Overuse throwing injuries in skeletally immature athletes--diagnosis, treatment, and prevention. Curr Sports Med Rep. 2015 May-Jun;14(3):209-14. doi: 10.1249/JSR.0000000000000155. PubMed PMID: 25968854. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 275 | McMahon, P. J., et al. (2013). "Anterior shoulder dislocation increases the propensity for recurrence: a cadaveric study of the number of dislocations and type of capsulolabral lesion." J Shoulder Elbow Surg 22(8): 1046-1052. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 276 | Menta, R., Randhawa, K., Côté, P., Wong, J. J., Yu, H., Sutton, D., ... & Brown, C. (2015). The effectiveness of exercise for the management of musculoskeletal disorders and injuries of the elbow, forearm, wrist, and hand: a systematic review by the Ontario Protocol for Traffic Injury Management (OPTIMa) collaboration. Journal of manipulative and physiological therapeutics, 38(7), 507-520. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 277 | Michienzi, A. E., et al. (2015). "Lateral Epicondylitis and Tobacco Use: A Case-Control Study." Iowa Orthop J 35: 114-118. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 278 | Mischke C, Verbeek JH, Job J, Morata TC, Alvesalo-Kuusi A, Neuvonen K, Clarke S, Pedlow RI. Occupational safety and health enforcement tools for preventing occupational diseases and injuries. Cochrane Database of Systematic Reviews 2013, Issue 8. Art. No.: CD010183. DOI: 10.1002/14651858.CD010183.pub2. | CochraneWork_06_01_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 279 | Modi CS, Wasserstein D, Mayne IP, Henry PD, Mahomed N, Veillette CJ. The frequency and risk factors for subsequent surgery after a simple elbow dislocation. Injury. 2015;46(6):1156-60. doi: 10.1016/j.injury.2015.02.009. PubMed PMID: 25796345. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 280 | Mohammadi, Ghorbanali. (2012). RISK FACTORS FOR THE PREVALENCE OF THE UPPER LIMB AND NECK WORK-RELATED MUSCULOSKELETAL DISORDERS AMONG POULTRY SLAUGHTER WORKERS. J. Musculoskelet. Res., 15, 1250005 (2012) [8 pages] | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 281 | Mohan, G. M., Prasad, P. S. S., & Sudarmathi, V. (2008). Simplified procedure to analyse work posture of foundry men through the rapid upper limb assessment. International Journal of Environment and Health, 2(2), 225-238. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 282 | Mondam, S., Shaik, R., Prakash, J., Fook, J. L., & Nekkanti, S. (2016). Surveillance of Musculoskeletal Symptoms and Anthropometric Variables among Four International Cricket Teams Competed in ACC Premier League Malaysia 2014. Asian Journal of Pharmaceutical Research and Health Care, 8(2), 47-51. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 283 | Mondelli, M., Aretini, A., Ciaramitaro, P. , Mattioli, S. 2014. Anthropometric, lifestyle and occupational risk factors for ulnar neuropathy at the elbow: Study design. onference: 4th Annual Meeting of the, Volume: 19 | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 284 | Moore, J. S. (2002). "Biomechanical models for the pathogenesis of specific distal upper extremity disorders." Am J Ind Med 41(5): 353-369. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 285 | Mora, D. C., et al. (2016). "Prevalence of musculoskeletal disorders among immigrant Latino farmworkers and non-farmworkers in North Carolina." Arch Environ Occup Health 71(3): 136-143. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 286 | Müezzinoğlu, Arif. "Role of Occupational Physician in Mining Accidents." Turkish Thoracic J 16.Suppl 1 (2015): 21-24. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 287 | Mullick, A. A., et al. (2013). "Stretch reflex spatial threshold measure discriminates between spasticity and rigidity." Clin Neurophysiol 124(4): 740-751. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 288 | Mulimani P, Hoe VCW, Hayes MJ, Idiculla JJ, Abas ABL, Karanth L. Ergonomic interventions for preventing musculoskeletal disorders in dental care practitioners. Cochrane Database of Systematic Reviews 2014, Issue 8. Art. No.: CD011261. DOI:10.1002/14651858.CD011261. | CochraneWork_06_01_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 289 | Murtaugh, Bryan, and Joseph M. Ihm. "Eccentric training for the treatment of tendinopathies." Current sports medicine reports 12.3 (2013): 175-182. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 290 | Myers, J. B., et al. (2013). "Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study." J Shoulder Elbow Surg 22(9): 1154-1159. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 291 | Nandi, S., Maschke, S., Evans, P. J., & Lawton, J. N. (2009). The stiff elbow. Hand, 4(4), 368-379. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 292 | Nainzadeh, N. K., et al. (2011). "Ulnar neuropathy at the elbow in computer keyboard operators." Work 39(2): 93-101. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 293 | Nilsson, P., et al. (2012). "Lateral epicondylalgia. A quantitative and qualitative analysis of interdisciplinary cooperation and treatment choice in the Swedish health care system." Scand J Caring Sci 26(1): 28-37. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 294 | Nilsson, P., et al. (2012). "Lateral epicondylalgia: a structured programme better than corticosteroids and NSAID." Scand J Occup Ther 19(5): 404-410. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 295 | Nimura, A., et al. (2014). "Joint capsule attachment to the extensor carpi radialis brevis origin: an anatomical study with possible implications regarding the etiology of lateral epicondylitis." J Hand Surg Am 39(2): 219-225. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 296 | Noonan TJ, Thigpen CA, Bailey LB, Wyland DJ, Kissenberth M, Hawkins RJ, Shanley E. Humeral Torsion as a Risk Factor for Shoulder and Elbow Injury in Professional Baseball Pitchers. Am J Sports Med. 2016 Sep;44(9):2214-9. doi: 10.1177/0363546516648438. PubMed PMID: 27281279. | EMBASE_08_02_2017_Double | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 297 | Nourissat G, Ciais G, Coudane H. Arthroscopy and obesity. Orthop TraumatolSurg Res. 2015 Dec;101(8 Suppl):S351-2. doi: 10.1016/j.otsr.2015.09.001. Review. PubMed PMID: 26552647. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 298 | Nordander, C., et al. (2009). "Risk of musculoskeletal disorders among females and males in repetitive/constrained work." Ergonomics 52(10): 1226-1239. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 299 | Nordander, C., et al. (2013). "Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands - A synthesis of group-level data on exposure and response obtained using uniform methods of data collection." Appl Ergon 44(2): 241-253. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 300 | Occhionero, V., et al. (2014). "Upper limb musculoskeletal disorders in healthcare personnel." Ergonomics 57(8): 1166-1191. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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| 301 | Odell, D., Barr, A., Goldberg, R., Chung, J., & Rempel, D. (2007). Evaluation of a dynamic arm support for seated and standing tasks: a laboratory study of electromyography and subjective feedback. Ergonomics, 50(4), 520-535. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, d, e |
| 302 | Oh, J. H., et al. (2011). "The prevalence of shoulder osteoarthritis in the elderly Korean population: association with risk factors and function." J Shoulder Elbow Surg 20(5): 756-763. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 303 | Oh, S., et al. (2013). "Causes of hand tingling in visual display terminal workers." Ann Rehabil Med 37(2): 221-228. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 304 | Olaussen M, Holmedal O, Lindbaek M, Brage S, Solvang H. Treating lateral epicondylitis with corticosteroid injections or non-electrotherapeutical physiotherapy: a systematic review. BMJ Open. 2013 Oct 29;3(10):e003564. doi: 10.1136/bmjopen-2013-003564. PubMed PMID: 24171937; PubMed Central PMCID: PMC3816235. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 305 | Oliveira Dantas FF, de Lima KC. The relationship between physical load and musculoskeletal complaints among Brazilian dentists. Appl Ergon. 2015 Mar;47:93-8. doi: 10.1016/j.apergo.2014.09.003. PubMed PMID: 25479978. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d, e |
| 306 | Oliveira, C. R., et al. (2008). "Peripheral neuropathy and neurological disorders in an unselected Brazilian population-based cohort of IBD patients." Inflamm Bowel Dis 14(3): 389-395. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 307 | Oliveira, A. B., Silva, L. C., & Coury, H. J. (2011). How do low/high height and weight variation affect upper limb movements during manual material handling of industrial boxes?. Brazilian Journal of Physical Therapy, 15(6), 494-502. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 308 | Omrane, A., Kammoun, S., Bouzgarrou, L., Rassas, I., Allagui, I., Kraiem, A., ... & Chaari, N. (2015). Musculoskeletal disorders of the upper limbs: A scourge among nursing staff. Annals of Physical and Rehabilitation Medicine, 58, e36. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 309 | Omejec, G. and S. Podnar (2016). "What causes ulnar neuropathy at the elbow?" Clin Neurophysiol 127(1): 919-924. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 310 | Ophir, A., et al. (2014). "An uncommon pattern of polyneuropathy induced by lifetime exposures to drift containing organophosphate pesticides." Neurotoxicology 45: 338-346. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 311 | Osborne, A., Blake, C., Fullen, B. M., Meredith, D., Phelan, J., McNamara, J., & Cunningham, C. (2012). Prevalence of musculoskeletal disorders among farmers: a systematic review. American journal of industrial medicine, 55(2), 143-158. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 312 | O'Shaughnessy, M. A., et al. (2016). "A Rare Diagnosis: Recognizing and Managing Fungal Tenosynovitis of the Hand and Upper Extremity." J Hand Surg Am. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 313 | Oshlag BL, Ray TR. Elbow Injuries in the Young Throwing Athlete. Curr Sports Med Rep. 2016 Sep-Oct;15(5):325-9. doi: 10.1249/JSR.0000000000000300. PubMed PMID: 27618241. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 314 | Otoshi, K., et al. (2015). "Chronic hyperglycemia increases the risk of lateral epicondylitis: the Locomotive Syndrome and Health Outcome in Aizu Cohort Study (LOHAS)." Springerplus 4: 407. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 315 | Özdolap, S., et al. (2013). "Upper limb tendinitis and entrapment neuropathy in coal miners." Am J Ind Med 56(5): 569-575. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 316 | Padula, R. S., Comper, M. L. C., Sparer, E. H., & Dennerlein, J. T. (2017). Job rotation designed to prevent musculoskeletal disorders and control risk in manufacturing industries: A systematic review. Applied Ergonomics, 58, 386-397. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 317 | Palmer, K. T. (2008). "Diagnosing soft tissue rheumatic disorders of the upper limb in epidemiological studies of vibration-exposed populations." Int Arch Occup Environ Health 81(5): 575-593. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 318 | Palmer, K. T., et al. (2012). "Optimising case definitions of upper limb disorder for aetiological research and prevention: a review." Occup Environ Med 69(1): 71-78. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 319 | Pandy, R. (2013). "Prevalence of upper limb disorders among female librarians." Occup Med (Lond) 63(6): 432-434. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 320 | Pansard, E., et al. (2013). "Reliability and validity assessment of a glenoid bone loss measurement using the Bernageau profile view in chronic anterior shoulder instability." J Shoulder Elbow Surg 22(9): 1193-1198. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 321 | Pensri, P., et al. (2009). "Prevalence of self-reported musculoskeletal symptoms in salespersons." Occup Med (Lond) 59(7): 499-501. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 322 | Peters, J. A., Zwerver, J., Diercks, R. L., Elferink-Gemser, M. T., & van den Akker-Scheek, I. (2016). Preventive interventions for tendinopathy: A systematic review. Journal of Science and Medicine in Sport, 19(3), 205-211. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 323 | Papa, J. A. (2012). "Two cases of work-related lateral epicondylopathy treated with Graston Technique(R) and conservative rehabilitation." J Can Chiropr Assoc 56(3): 192-200. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 324 | Parida, R., & Ray, P. K. (2012). Study and analysis of occupational risk factors for ergonomic design of construction worksystems. Work, 41(Supplement 1), 3788-3794. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e, d |
| 325 | Parihar JK, Jain VK, Chaturvedi P, Kaushik J, Jain G, Parihar AK. Computer and visual display terminals (VDT) vision syndrome (CVDTS). Med J Armed Forces India. 2016 Jul;72(3):270-6. doi: 10.1016/j.mjafi.2016.03.016. Review. PubMed PMID: 27546968; PubMed Central PMCID: PMC4982978. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 326 | Park, J. H., et al. (2009). "Effects of vocalization on elbow motion during reaching in persons with hemiparetic stroke." NeuroRehabilitation 25(2): 123-128. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 327 | Park, J. K., & Jang, S. H. (2010). Association between upper extremity musculoskeletal disorders and psychosocial factors at work: a review on the Job DCS Model's perspective. Safety and health at work, 1(1), 37-42. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 328 | Ratri Parida, Pradip Kumar Ray, Biomechanical Modelling of Manual Material Handling Tasks: A Comprehensive Review, Procedia Manufacturing, Volume 3, 2015, Pages 4598-4605, ISSN 2351-9789, | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | http://dx.doi.org/10.1016/j.promfg.2015.07.539. (http://www.sciencedirect.com/science/article/pii/S2351978915005405) | | | | | | | | | | | | | | | | |
| 329 | PANEL, EXPERT. "Selected Issues in Injury and Illness Prevention andtheTeamPhysician: AConsensusStatement." Medicine & Science in Sports & Exercise 500 (2007): 2059. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 330 | Pasternak, B., Jr., et al. (2012). "Analysis of kinematic, kinetic and electromyographic patterns during root canal preparation with rotary and manual instruments." J Appl Oral Sci 20(1): 57-63. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d, e |
| 331 | Petit Le Manac'h A, Roquelaure Y, Ha C, Bodin J, Meyer G, Bigot F, Veaudor M, Descatha A, Goldberg M, Imbernon E. Risk factors for de Quervain's disease in a French working population. Scand J Work Environ Health. 2011 Sep;37(5):394-401. doi: 10.5271/sjweh.3160. PubMed PMID: 21431276. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 332 | Pieber, K., et al. (2012). "Acute injuries and overuse syndromes in sport climbing and bouldering in Austria: a descriptive epidemiological study." Wien Klin Wochenschr 124(11-12): 357-362. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 333 | Pienimaki, T., et al. (2011). "Widespread pain in chronic epicondylitis." Eur J Pain 15(9): 921-927. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 334 | Pienimaki, T. T., et al. (2008). "Three-phase bone scintigraphy in chronic epicondylitis." Arch Phys Med Rehabil 89(11): 2180-2184. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 335 | Piper, S., et al. (2016). "The effectiveness of soft-tissue therapy for the management of musculoskeletal disorders and injuries of the upper and lower extremities: A systematic review by the Ontario Protocol for Traffic Injury management (OPTIMa) collaboration." Man Ther 21: 18-34. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 336 | Ploumis A, Belbasis L, Ntzani E, Tsekeris P, Xenakis T. Radiotherapy for prevention of heterotopic ossification of the elbow: a systematic review of the literature. J Shoulder Elbow Surg. 2013 Nov;22(11):1580-8. doi: 10.1016/j.jse.2013.07.045. Review. PubMed PMID: 24138821. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 337 | Prodromo J, Rackley J, Mulcahey MK. A review of important medical and surgicalconsiderations for obese patients undergoing arthroscopic surgery. PhysSportsmed. 2016 Sep;44(3):231-9. doi: 10.1080/00913847.2016.1221750. Review.PubMed PMID: 27578242. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 338 | Polster, J. M., et al. (2016). "Throwing-related injuries of the subscapularis in professional baseball players." Skeletal Radiol 45(1): 41-47. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 339 | Poulsen, T. R., et al. (2014). "Health of Danish seafarers and fishermen 1970-2010: What have register-based studies found?" Scand J Public Health 42(6): 534-545. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 340 | Pullopdissakul, S., et al. (2013). "Upper extremities musculoskeletal disorders: prevalence and associated ergonomic factors in an electronic assembly factory." Int J Occup Med Environ Health 26(5): 751-761. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 341 | Qin, J., et al. (2014). "Upper extremity kinematic and kinetic adaptations during a fatiguing repetitive task." J Electromyogr Kinesiol 24(3): 404-411. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 342 | Rafie, F., Zamani Jam, A., Shahravan, A., Raoof, M., & Eskandarizadeh, A. (2015). Prevalence of upper extremity musculoskeletal disorders in dentists: symptoms and risk factors. Journal of environmental and public health, 2015. | added by Seidel | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 343 | Raghunathan, R., Maiti, J., & Samanta, B. (2014). Application of the Cube Model for Biomechanical Exposure Assessment of Combined Manual Material Handling Tasks in a Manufacturing Plant in India. IIE Transactions on Occupational Ergonomics and Human Factors, 2(1), 39-51. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 344 | Rahman, M. N. A., & Razak, N. S. A. (2016). Review on Pen and Paper Based Observational Methods for Assessing Work-related Upper Limb Disorders. Indian Journal of Science and Technology, 9(S1). | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 345 | Rajabally, Y. A. and M. Narasimhan (2011). "Electrophysiological entrapment syndromes in chronic inflammatory demyelinating polyneuropathy." Muscle Nerve 44(3): 444-447. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 346 | Rajen N. Naidoo, Syed Atiqul Haq, Occupational use syndromes, Best Practice & Research Clinical Rheumatology, Volume 22, Issue 4, August 2008, Pages 677-691, ISSN 1521-6942, http://dx.doi.org/10.1016/j.berh.2008.04.001. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 347 | Ramponi, D. R. and J. A. Kaufmann (2012). "Elbow injuries and fractures." Adv Emerg Nurs J 34(2): 99-109; quiz 110-101. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 348 | Ratzlaff, C. R., Gillies, J. H., & Koehoorn, M. W. (2007). Work-related repetitive strain injury and leisure-time physical activity. Arthritis Care & Research, 57(3), 495-500. | added by Seidel | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e |
| 349 | Rautiainen R, Lehtola MM, Day LM, Schonstein E, Suutarinen J, Salminen S, Verbeek JH. Interventions for preventing injuries in the agricultural industry. Cochrane Database of Systematic Reviews 2008, Issue 1. Art. No.: CD006398. DOI: 10.1002/14651858.CD006398.pub2. | CochraneWork_06_01_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 350 | Pradip Kumar Ray, Ratri Parida, Sagar Sarkar, Ergonomic Analysis of Construction Jobs in India: A Biomechanical Modelling Approach, Procedia Manufacturing, Volume 3, 2015, Pages 4606-4612, ISSN 2351-9789, http://dx.doi.org/10.1016/j.promfg.2015.07.542. (http://www.sciencedirect.com/science/article/pii/S2351978915005430) | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 351 | Rechardt M, Shiri R, Lindholm H, et al. Associations of metabolic factors and adipokines with pain in incipient upper extremity soft tissue disorders: a cross-sectional study.BMJOpen2013;3:e003036. doi:10.1136/bmjopen-2013-003036 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 352 | Rechardt, M., et al. (2011). "Soluble IL-1RII and IL-18 are associated with incipient upper extremity soft tissue disorders." Cytokine 54(2): 149-153. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 353 | Rechardt, M., et al. (2014). "Adipokines as predictors of recovery from upper extremity soft tissue disorders." Rheumatology (Oxford) 53(12): 2238-2242. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 354 | Rhyou IH, Lim KS, Kim KC, Lee JH, Ahn KB, Moon SC. Drop sign of the elbow joint after surgical stabilization of an unstable simple posterolateral dislocation: natural course and contributing factors. J Shoulder Elbow Surg. 2015 Jul;24(7):1081-9. doi: 10.1016/j.jse.2015.01.018. PubMed PMID: 25825136. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 355 | Ring, D. (2008). "Displaced, unstable fractures of the radial head: fixation vs. replacement--what is the evidence?" Injury 39(12): 1329-1337. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 356 | Riviere, S., et al. (2014). "Underreporting of musculoskeletal disorders in 10 regions in France in 2009." Am J Ind Med 57(10): 1174-1180. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 357 | Roquelaure, Y., et al. (2009). "Risk factors for upper-extremity musculoskeletal disorders in the working population." Arthritis Rheum 61(10): 1425-1434. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 358 | Roquelaure, Y., LeManach, A. P., Ha, C., Poisnel, C., Bodin, J., Descatha, A., & Imbernon, E. (2012). Working in temporary employment and exposure to musculoskeletal constraints. Occupational medicine, kqs004. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | e |
| 359 | Roscher, Patrick (2012).Three-Dimensional Biomechanical Model of Wrist Dynamics during Tasks of Daily LivingMarquette University, Biomedical Engineering | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 360 | Rose, N. E., et al. (2013). "Denervation of the lateral humeral epicondyle for treatment of chronic lateral epicondylitis." J Hand Surg Am 38(2): 344-349. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d, e |
| 361 | Rosenbaum, D. A., et al. (2013). "Prevalence of epicondylitis, rotator cuff syndrome, and low back pain in Latino poultry workers and manual laborers." Am J Ind Med 56(2): 226-234. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 362 | Rosenbaum, D. A., et al. (2014). "Employer differences in upper-body musculoskeletal disorders and pain among immigrant Latino poultry processing workers." J Agromedicine 19(4): 384-394. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 363 | Rosenzweig, Lee E., and Joshua S. Dines. "Conservative and Surgical Management of Tennis Elbow." Techniques in Shoulder & Elbow Surgery 15.1 (2014): 28-35. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 364 | Ross, M. W., et al. (2012). "Occupational health and safety among commercial sex workers." Scand J Work Environ Health 38(2): 105-119. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 365 | Rossi, J., et al. (2014). "Potential effects of racket grip size on lateral epicondilalgy risks." Scand J Med Sci Sports 24(6): e462-470. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d |
| 366 | Sadeghian, F., Sadeghian, A., Raei, M., & Kasaeian, A. (2012). Musculoskeletal disorders among oil field workers: influences of health beliefs, mental health and somatisation tendency. Journal of Medical Sciences, 12(4), 114. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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| 367 | Salazar D, Golz A, Israel H, Marra G. Heterotopic ossification of the elbow treated with surgical resection: risk factors, bony ankylosis, and complications. Clin Orthop Relat Res. 2014 Jul;472(7):2269-75. doi: 10.1007/s11999-014-3591-0.PubMed PMID: 24711127; PubMed Central PMCID: PMC4048438. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 368 | Saltzman BM, Chalmers PN, Mascarenhas R, Cole BJ, Romeo AA. Upper extremity physeal injury in young baseball pitchers. Phys Sportsmed. 2014 Sep;42(3):100-11. doi: 10.3810/psm.2014.09.2081. Review. PubMed PMID: 25295772. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d, e |
| 369 | Saito, M., et al. (2014). "Relationship Between Tightness of the Hip Joint and Elbow Pain in Adolescent Baseball Players." Orthop J Sports Med 2(5): 2325967114532424. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d, e |
| 370 | Salles, J. I., et al. (2015). "BMP4 and FGF3 haplotypes increase the risk of tendinopathy in volleyball athletes." J Sci Med Sport 18(2): 150-155. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d, e |
| 371 | Sandell, C., Frykman, M., Chesky, K., & Fjellman-Wiklund, A. (2009). Playing-related musculoskeletal disorders and stress-related health problems among percussionists. Med Probl Perform Art, 24(4), 175-180. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 372 | Sandoughi M, Zakeri Z, Tehrani Banihashemi A, Davatchi F, Narouie B, Shikhzadeh A, Mohammadi M, Jahantigh M, Shakiba M, Moulaei NA, Yousefi S, Rezazehi B, Shirzaei Sani E, Emamdadi A, Hoseynian M, Masoodian S, Shahbakhsh S. Prevalence of musculoskeletal disorders in southeastern Iran: a WHO-ILAR COPCORD study (stage 1, urban study). Int J Rheum Dis. 2013 Oct;16(5):509-17. doi: 10.1111/1756-185X.12110. PubMed PMID: 24164837. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 373 | Santos, J., Baptista, J. S., Monteiro, P. R. R., Miguel, A. S., Santos, R., & Vaz, M. A. (2016). The influence of task design on upper limb muscles fatigue during low-load repetitive work: A systematic review. International Journal of Industrial Ergonomics, 52, 78-91. | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 374 | Sato, J., et al. (2016). "Clinical and ultrasound features in patients with intersection syndrome or de Quervain's disease." J Hand Surg Eur Vol 41(2): 220-225. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 375 | Saupe, N., et al. (2009). "Pain and other side effects after MR arthrography: prospective evaluation in 1085 patients." Radiology 250(3): 830-838. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 376 | Sauni R, Virtema P, Paakkonen R, et al. Quality of life (EQ-5D) and hand-arm vibration syndrome. International archives of occupational and environmental health 2010;83(2):209-16. doi: 10.1007/s00420-009-0441-6 [published Online First: 2009/07/14] | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d |
| 377 | Schaafsma FG, Mahmud N, Reneman MF, Fassier JB, Jungbauer FHW . Pre-employment examinations for preventing injury, disease and sick leave in workers. Cochrane Database of Systematic Reviews 2016, Issue 1. Art. No.: CD008881. DOI:10.1002/14651858.CD008881.pub2. | CochraneWork_06_01_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 378 | Schaefer, P. T. and J. Speier (2012). "Common medical problems of instrumental athletes." Curr Sports Med Rep 11(6): 316-322. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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| 379 | Schlechter JA. Reducing Cumulative Arm Overuse Injuries in Young Throwers. Pediatr Ann. 2016 Jan;45(1):e15-20. doi: 10.3928/00904481-20151209-01. PubMed PMID: 26783969. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 380 | Schnorenberg, A. J., et al. (2014). "Biomechanical model for evaluation of pediatric upper extremity joint dynamics during wheelchair mobility." J Biomech 47(1): 269-276. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 381 | Schupp, C. M. and A. Bedgood (2013). "Sideline management from head to toe of the skeletally immature athlete." Curr Sports Med Rep 12(3): 162-169. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 382 | Sciascia, A., et al. (2015). "Preseason Perceived Physical Capability and Previous Injury." J Athl Train 50(9): 937-943. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 383 | SEILS, DREW R., "A Comprehensive Methodology for Assessing Biomechanical Risks Associated with Hand Tool Use: Applied to Laparoscopic Surgical Instruments" (2012). Master's Theses. 282. http://digitalcommons.uconn.edu/gs_theses/282 | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | a |
| 384 | Seo, N. J., Armstrong, T. J., & Young, J. G. (2010). Effects of handle orientation, gloves, handle friction and elbow posture on maximum horizontal pull and push forces. Ergonomics, 53(1), 92-101. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 385 | Serazin, C., et al. (2013). "Employment and occupational outcomes of workers with musculoskeletal pain in a French region." Occup Environ Med 70(3): 143-148. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 386 | Sethi, A., et al. (2013). "Temporal structure of variability decreases in upper extremity movements post stroke." Clin Biomech (Bristol, Avon) 28(2): 134-139. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 387 | Shanley, Ellen, et al. "Influence of a Prevention Program on Arm Injury Risk: An RCT in Adolescent Pitchers." Orthopaedic Journal of Sports Medicine 2.2 suppl (2014): 2325967114S00089. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 388 | Shin, G., & Zhu, X. (2011). User discomfort, work posture and muscle activity while using a touchscreen in a desktop PC setting. Ergonomics, 54(8), 733-744. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 389 | Shiri, R. et al. (2007). Hand Dominance in Upper Extremity Musculoskeletal Disorders The Journal of Rheumatology 2007; 34:5 | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | b, c, e |
| 390 | Shiri R, Martimo KP, Miranda H, Ketola R, Kaila-Kangas L, Liira H, Karppinen J, Viikari-Juntura E. The effect of workplace intervention on pain and sickness absence caused by upper-extremity musculoskeletal disorders. Scand J Work Environ Health. 2011 Mar;37(2):120-8. doi: 10.5271/sjweh.3141. PubMed PMID: 21218270. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 391 | Shiri, R. and E. Viikari-Juntura (2011). "Lateral and medial epicondylitis: role of occupational factors." Best Pract Res Clin Rheumatol 25(1): 43-57. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | review, no single study |
| 392 | Shiri, R. (2016). "Arthritis as a risk factor for carpal tunnel syndrome: a meta-analysis." Scand J Rheumatol 45(5): 339-346. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |

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| 393 | Shechtman, O., et al. (2007). "Evaluation of the torque-velocity test of the BTE-Primus as a measure of sincerity of effort of grip strength." J Hand Ther 20(4): 326-334; quiz 335. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 394 | Silvetti, A., et al. (2015). "Kinematic and electromyographic assessment of manual handling on a supermarket green- grocery shelf." Work 51(2): 261-271. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 395 | Sinclair, A. J. and C. Smidt (2009). "Analysis of 10 years of injury in high school rodeo." Clin J Sport Med 19(5): 383-387. | EMBASE_08_02_2017_Abstract_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; because abstract is missing | 0 | no | 0 | no | 0 | a |
| 396 | Simkins, M., et al. (2014). "Stroke-induced synergistic phase shifting and its possible implications for recovery mechanisms." Exp Brain Res 232(11): 3489-3499. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 397 | Smith-Forbes, E. V., et al. (2016). "Specificity of the minimal clinically important difference of the quick Disabilities of the Arm Shoulder and Hand (QDASH) for distal upper extremity conditions." J Hand Ther 29(1): 81-88; quiz 88. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 398 | Sole, J. S., et al. (2015). "Sonographic evaluation of the extensor carpi ulnaris in asymptomatic tennis players." Pm r 7(3): 255-263. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 399 | Solidaki, E., et al. (2010). "Work-related and psychological determinants of multisite musculoskeletal pain." Scand J Work Environ Health 36(1): 54-61. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 400 | Soma DB. Opening the Black Box: Evaluating the Pediatric Athlete With Elbow Pain. PM R. 2016 Mar;8(3 Suppl):S101-12. doi: 10.1016/j.pmrj.2016.01.002. Review. PubMed PMID: 26972259. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 401 | Sood, D., Nussbaum, M. A., & Hager, K. (2007). Fatigue during prolonged intermittent overhead work: reliability of measures and effects of working height. Ergonomics, 50(4), 497-513. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 402 | Soong, M., et al. (2011). "Fracture of the distal radius: risk factors for complications after locked volar plate fixation." J Hand Surg Am 36(1): 3-9. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 403 | Spahn G, Lipfert J-U, Schmidt A, et al. Fall-Kontrolle-Studie zur Bestimmung von Risikofaktoren der lateralen Epikondylitis. Arbeitsmed Sozialmed Umweltmed 2016;51:360–68 | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 404 | Spyropoulos, E., Chroni, E., Katsakiori, P., & Athanassiou, G. (2013). A quantitative approach to assess upper limb fatigue in the work field. Occupational Ergonomics, 11(1), 45-57. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 405 | Srinivasan, D., Rudolfsson, T., & Mathiassen, S. E. (2015). Between-and within-subject variance of motor variability metrics in females performing repetitive upper-extremity precision work. Journal of Electromyography and Kinesiology, 25(1), 121-129. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 406 | Srinivasan, D., et al. (2015). "The combined influence of task accuracy and pace on motor variability in a standardised repetitive precision task." Ergonomics 58(8): 1388-1397. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 407 | Srinivasan, D., et al. (2015). "Effects of concurrent physical and cognitive demands on arm movement kinematics in a repetitive upper-extremity precision task." Hum Mov Sci 42: 89-99. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 408 | Srinivasan, D., Samani, A., Mathiassen, S. E., & Madeleine, P. (2015). The size and structure of arm movement variability decreased with work pace in a standardised repetitive precision task. Ergonomics, 58(1), 128-139. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 409 | Steinhilber, B., Seibt, R., Reiff, F. et al. Effect of a laparoscopic instrument with rotatable handle piece on biomechanical stress during laparoscopic procedures. Surg Endosc (2016) 30: 78. doi:10.1007/s00464-015-4164-3 | added by Seidel | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d, e |
| 410 | Steven L. Fischer, Kathryn Woodcock, A cross-sectional survey of reported musculoskeletal pain, disorders, work volume and employment situation among sign language interpreters, International Journal of Industrial Ergonomics, Volume 42, Issue 4, July 2012, Pages 335-340, ISSN 0169-8141, http://dx.doi.org/10.1016/j.ergon.2012.03.003. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 411 | Stephens, B. and D. P. Gross (2007). "The influence of a continuum of care model on the rehabilitation of compensation claimants with soft tissue disorders." Spine (Phila Pa 1976) 32(25): 2898-2904. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 412 | Sun Y, Cai J, Li F, Liu S, Ruan H, Fan C. The efficacy of celecoxib in preventing heterotopic ossification recurrence after open arthrolysis for post-traumatic elbow stiffness in adults. J Shoulder Elbow Surg. 2015 Nov;24(11):1735-40. doi: 10.1016/j.jse.2015.07.006. PubMed PMID: 26480878. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 413 | Sutton, D., et al. (2016). "Multimodal care for the management of musculoskeletal disorders of the elbow, forearm, wrist and hand: a systematic review by the Ontario Protocol for Traffic Injury Management (OPTIMa) Collaboration." Chiropr Man Therap 24: 8. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 414 | Suzuki, H., et al. (2013). "Effects of a vertical console position on operator muscular stress during ultrasonic diagnosis." J Med Ultrason (2001) 40(3): 189-195. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 415 | Svendsen SW, Johnsen B, Fuglsang-Frederiksen A, et al Ulnar neuropathy and ulnar neuropathy-like symptoms in relation to biomechanical exposures assessed by a job exposure matrix: a triple case–referent study Occup Environ Med 2012;69:773-780. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 416 | Tajika, T., et al. (2014). "Prevalence and risk factors of lateral epicondylitis in a mountain village in Japan." J Orthop Surg (Hong Kong) 22(2): 240-243. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e |
| 417 | Talbot CL, Ring J, Holt EM. Litigation relating to conditions affecting the shoulder and elbow: an analysis of claims against the National Health Service. Bone Joint J. 2014 May;96-B(5):574-9. doi: 10.1302/0301-620X.96B5.33257. PubMedPMID: 24788489. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 418 | Tanaka, H., et al. (2007). "The mode of destruction in shoulders with rheumatoid arthritis based on radiographic findings." J Shoulder Elbow Surg 16(5): 539-543. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 419 | Taneja, A. K., et al. (2013). "Peroneal tendon abnormalities in subjects with an enlarged peroneal tubercle." Skeletal Radiol 42(12): 1703-1709. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 420 | Tang, K., et al. (2009). "Comparison of the psychometric properties of four at-work disability measures in workers with shoulder or elbow disorders." J Occup Rehabil 19(2): 142-154. | PubMed_03_02_2017/ | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |

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| 421 | Tashjian, R. Z., et al. (2016). "Evidence for an Environmental and Inherited Predisposition Contributing to the Risk for Global Tendinopathies or Compression Neuropathies in Patients With Rotator Cuff Tears." Orthop J Sports Med 4(4): 2325967116642173. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 422 | Taspinar, O., et al. (2014). "Upper extremity problems in doner kebab masters." J Phys Ther Sci 26(9): 1433-1436. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 423 | Tat, J., et al. (2016). "Relative displacement of the tendon and subsynovial connective tissue using ultrasound captures different phenomena than mechanical tendon shear." J Biomech 49(15): 3682-3687. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 424 | Thiese, M. S., et al. (2016). "Psychosocial Factors Related to Lateral and Medial Epicondylitis: Results From Pooled Study Analyses." J Occup Environ Med 58(6): 588-593. | EMBASE_08_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 425 | Thomas, S. J., et al. (2007). "Prevalence of symptoms and signs of shoulder problems in people with diabetes mellitus." J Shoulder Elbow Surg 16(6): 748-751. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d |
| 426 | Tiric-Campara, M., et al. (2014). "Occupational overuse syndrome (technological diseases): carpal tunnel syndrome, a mouse shoulder, cervical pain syndrome." Acta Inform Med 22(5): 333-340. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 427 | Titchener, A. G., et al. (2013). "Risk factors in lateral epicondylitis (tennis elbow): a case-control study." J Hand Surg Eur Vol 38(2): 159-164. | PubMed_03_02_2017/EMBASE_08_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | e, b |
| 428 | Titchener AG, White JJ, Hinchliffe SR, Tambe AA, Hubbard RB, Clark DI. Comorbidities in rotator cuff disease: a case-control study. J Shoulder Elbow Surg. 2014 Sep;23(9):1282-8. doi: 10.1016/j.jse.2013.12.019. PubMed PMID: 24618192. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 429 | Tjoumakaris, F. P., et al. (2012). "Eminence-based medicine versus evidence-based medicine: it's okay for 12-year-old pitchers to throw curveballs; it's the pitch count that matters." Phys Sportsmed 40(3): 83-86. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b |
| 430 | Toosi, K. K., Impink, B. G., Baker, N. A., & Boninger, M. L. (2011). Effects of computer keyboarding on ultrasonographic measures of the median nerve. American journal of industrial medicine, 54(11), 826-833. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 431 | Torabi, M., Martell, B., Tuohy, C. et al. Curr Radiol Rep (2016) 4: 10. doi:10.1007/s40134-015-0137-5 | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 432 | Tunc, A. and B. D. Gungen (2016). "Carpal tunnel syndrome: Investigating the sensitivity of initial-diagnosis with electro-diagnostic tests in 600 cases and associated risk factors especially manual milking." J Back Musculoskelet Rehabil. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 433 | Tsikopoulos K, Tsikopoulos A, Natsis K. Autologous whole blood or corticosteroid injections for the treatment of epicondylopathy and plantar fasciopathy? A systematic review and meta-analysis of | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |

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| | randomized controlled trials. Phys Ther Sport. 2016 Nov;22:114-122. doi: 10.1016/j.ptsp.2016.02.002.Review. PubMed PMID: 27085490. | | | | | | | | | | | | | | | | |
| 434 | Ustuner, E., et al. (2013). "Sonographic examination of the common extensor tendon of the forearm at three different locations in the normal asymptomatic population." Surg Radiol Anat 35(7): 547-552. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 435 | Uzunkulaoglu, A., et al. (2016). "Association Between Gender, Body Mass Index, and Ulnar Nerve Entrapment at the Elbow: A Retrospective Study." J Clin Neurophysiol 33(6): 545-548. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 436 | Valdes, K., et al. (2014). "Hand therapist use of patient report outcome (PRO) in practice: A survey study" Journal of Hand Therapy Volume 27, Issue 4, Pages 299–308 http://www.jhandtherapy.org/article/S0894-1130(14)00076-3/abstract | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 437 | van der Molen HF, Lehtola MM, Lappalainen J, Hoonakker PLT, Hsiao H, Haslam R, Hale AR, Frings-Dresen MHW,Verbeek JH. Interventions to prevent injuries in construction workers. Cochrane Database of Systematic Reviews 2012, Issue 12. Art. No.: CD006251. DOI: 10.1002/14651858.CD006251.pub3. | CochraneWork_06_01_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, d, e |
| 438 | van de Stadt, L. A., et al. (2010). "The value of ultrasonography in predicting arthritis in auto-antibody positive arthralgia patients: a prospective cohort study." Arthritis Res Ther 12(3): R98. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 439 | van Rijn, R. M., et al. (2009). "Associations between work-related factors and specific disorders at the elbow: a systematic literature review." Rheumatology (Oxford) 48(5): 528-536. | EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | key paper |
| 440 | van Middelkoop, M., et al. (2015). "Incidence and Risk Factors for Upper Extremity Climbing Injuries in Indoor Climbers." Int J Sports Med 36(10): 837-842. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 441 | Van Sonhonven, F., Eric Geusens, and Stefaan Nijs. "Osteochondrosis dissecans of the elbow." Journal Belge de Radiologie 92.4 (2009): 207. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 442 | van Vilsteren M, van Oostrom SH, de Vet HCW, Franche RL, Boot CRL, Anema JR. Workplace interventions to prevent work disability in workers on sick leave. Cochrane Database of Systematic Reviews 2015, Issue 10. Art. No.: CD006955. DOI: 10.1002/14651858.CD006955.pub3. | CochraneWork_06_01_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 443 | Vance, M. C., et al. (2012). "The association of hemoglobin A1c with the prevalence of stenosing flexor tenosynovitis." J Hand Surg Am 37(9): 1765-1769. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 444 | Vehmas, T., et al. (2013). "The relations of obesity indicators and early metabolic disturbance with upper extremity pain." Pain Med 14(7): 1081-1087. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 445 | Verhagen AP, Bierma-Zeinstra SMA, Burdorf A, Stynes SM, de Vet HCW, Koes BW. Conservative interventions for treating work-related complaints of the arm, neck or shoulder in adults. Cochrane Database of Systematic Reviews 2013, Issue 12. Art. No.: CD008742. DOI: 10.1002/14651858.CD008742.pub2. | CochraneWork_06_01_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | c, e |
| 446 | Vieira, E. R., Schneider, P., Guidera, C., Gadotti, I. C., & Brunt, D. (2016). Work-related musculoskeletal disorders among physical therapists: a systematic review. Journal of back and musculoskeletal rehabilitation, 29(3), 417-428. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | systematic review, no |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | single study |
| 447 | Vieira, E. R., et al. (2011). "Work disability benefits due to musculoskeletal disorders among Brazilian private sector workers." BMJ Open 1(1): e000003. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 448 | Vimercati, L., et al. (2009). "Bilateral carpal tunnel syndrome and ulnar neuropathy at the elbow in a pizza chef." BMJ Case Rep 2009. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 449 | Vincent JI, MacDermid JC, Michlovitz SL, Rafuse R, Wells-Rowsell C, Wong O, Bisbee L. The push-off test: development of a simple, reliable test of upper extremity weight-bearing capability. J Hand Ther. 2014 Jul-Sep;27(3):185-90; quiz 191. doi: 10.1016/j.jht.2014.03.002. PubMed PMID: 24794466. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 450 | Violante, F. S., et al. (2016). "Carpal tunnel syndrome and manual work: the OCTOPUS cohort, results of a ten-year longitudinal study." Scand J Work Environ Health 42(4): 280-290. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 451 | Waersted, M., et al. (2010). "Computer work and musculoskeletal disorders of the neck and upper extremity: a systematic review." BMC Musculoskelet Disord 11: 79. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | systematic review, no single study |
| 452 | Walker-Bone, K., et al. (2012). "Occupation and epicondylitis: a population-based study." Rheumatology (Oxford) 51(2): 305-310. | PubMed_03_02_2017/ EMBASE_08_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | yes | 1 | no |
| 453 | Wang, A. W. and S. Erak (2007). "Fractional lengthening of forearm extensors for resistant lateral epicondylitis." ANZ J Surg 77(11): 981-984. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 454 | Wang, K., et al. (2013). "Risk factors in idiopathic adhesive capsulitis: a case control study." J Shoulder Elbow Surg 22(7): e24-29. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, d, e |
| 455 | Wang, D., Dai, F., & Ning, X. (2015). Risk assessment of work-related musculoskeletal disorders in construction: state-of-the-art review. Journal of Construction Engineering and management, 141(6), 04015008. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 456 | Wang, L. H., et al. (2016). "The effects of forearm fatigue on baseball fastball pitching, with implications about elbow injury." J Sports Sci 34(12): 1182-1189. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 457 | Wang, P. C., Rempel, D. M., Harrison, R. J., Chan, J., & Ritz, B. R. (2007). Work-organisational and personal factors associated with upper body musculoskeletal disorders among sewing machine operators. Occupational and environmental medicine, 64(12), 806-813. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 458 | Watts, A. C. & Bain, G. (2009). Patient-Rated Outcome of Ulnar Nerve Decompression: A Comparison of Endoscopic and Open In Situ Decompression. Journal of Hand Surgery Volume 34, Issue 8, Pages 1492–1498 | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 459 | Waryasz GR, Daniels AH, Gil JA, Suric V, Eberson CP. Personal Trainer Demographics, Current Practice Trends and Common Trainee Injuries. Orthop Rev (Pavia). 2016 Oct 3;8(3):6600. PubMed PMID: 27761219; PubMed Central PMCID:PMC5066109. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 460 | Whibley D, Martin KR, Lovell K, Jones GT. A systematic review of prognostic factors for distal upper limb pain. Br J Pain. 2015 Nov;9(4):241-55. doi: 10.1177/2049463715590885. PubMed PMID: 26526466; PubMed Central PMCID: PMC4616981. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 461 | Whiteside, D., et al. (2016). "Predictors of Ulnar Collateral Ligament Reconstruction in Major League Baseball Pitchers." Am J Sports Med 44(9): 2202-2209. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 462 | Widanarko B, Legg S, Devereux J, Stevenson M. The combined effect of physical, psychosocial/organisational and/or environmental risk factors on the presence of work-related musculoskeletal symptoms and its consequences. Appl Ergon. 2014 Nov;45(6):1610-21. doi: 10.1016/j.apergo.2014.05.018. PubMed PMID: 24934982. | EMBASE_08_02_2017_Double | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | yes | 1 | no | 0 | d |
| 463 | Wiggers JK, Helmerhorst GT, Brouwer KM, Niekel MC, Nunez F, Ring D. Injury complexity factors predict heterotopic ossification restricting motion after elbow trauma. Clin Orthop Relat Res. 2014 Jul;472(7):2162-7. PubMed PMID: 24078170; PubMed Central PMCID: PMC4048434. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 464 | Wiggers, J. K., et al. (2012). "Predictors of diagnosis of ulnar neuropathy after surgically treated distal humerus fractures." J Hand Surg Am 37(6): 1168-1172. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 465 | Wilhelmus Johannes Andreas, G., Wernstedt, P., & Campo, M. (2011). Work-related musculoskeletal disorders in female Swedish physical therapists with more than 15 years of job experience: prevalence and associations with work exposures. Physiotherapy theory and practice, 27(3), 213-222. | added by Seidel | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | e |
| 466 | Wilke, C., et al. (2011). "Motor activity as a way of preventing musculoskeletal problems in string musicians." Med Probl Perform Art 26(1): 24-29. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 467 | Wilson AT, Pidgeon TS, Morrell NT, DaSilva MF. Trends in Revision Elbow Ulnar Collateral Ligament Reconstruction in Professional Baseball Pitchers. J Hand Surg Am. 2015 Nov;40(11):2249-54. doi: 10.1016/j.jhsa.2015.07.024. PubMed PMID: 26328904. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 468 | Wilson d'Almeida, K., et al. (2008). "Sickness absence for upper limb disorders in a French company." Occup Med (Lond) 58(7): 506-508. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 469 | Winski, T. A. A systematic literature review: What are the sources of risk to health associated with new technologies in the office environment?. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 470 | Wolf, B. R., et al. (2009). "Injury patterns in Division I collegiate swimming." Am J Sports Med 37(10): 2037-2042. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 471 | Wolf, J. M., et al. (2009). "Incidence of carpal tunnel syndrome in the US military population." Hand (N Y) 4(3): 289-293. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 472 | Wolf, J. M., et al. (2009). "Incidence of de Quervain's tenosynovitis in a young, active population." J Hand Surg Am 34(1): 112-115. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 473 | Wolf, J. M., et al. (2010). "Epidemiology of lateral and medial epicondylitis in a military population." Mil Med 175(5): 336-339. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | c, e |
| 474 | Wright, C., et al. (2014). "Who develops carpal tunnel syndrome during pregnancy: An analysis of obesity, gestational weight gain, and parity." Obstet Med 7(2): 90-94. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 475 | Wroblewski, Andrew P., Hector A. Mejia, and Vonda J. Wright. "Application of platelet-rich plasma to enhance tissue repair." Operative Techniques in Orthopaedics 20.2 (2010): 98-105. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 476 | Wymore, L. and J. Fronek (2015). "Shoulder functional performance status of National Collegiate Athletic Association swimmers: baseline Kerlan-Jobe Orthopedic Clinic scores." Am J Sports Med 43(6): 1513-1517. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 477 | Yamada, E. and D. C. Thomas (2011). "Common musculoskeletal diagnoses of upper and lower extremities in older patients." Mt Sinai J Med 78(4): 546-557. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 478 | Yamazaki, H., et al. (2008). "Extensor tendon rupture associated with osteoarthritis of the distal radioulnar joint." J Hand Surg Eur Vol 33(4): 469-474. | PubMed_03_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |
| 479 | Yang, Z. and T. W. Cheung (2016). "The inclusion of homemakers as an occupation amongst people with upper limb repetitive stress injuries." Work 55(1): 181-186. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, e |
| 480 | Yoshii, Y., et al. (2015). "Measurement of wrist flexion and extension torques in different forearm positions." Biomed Eng Online 14: 115. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | yes | 1 | no | 0 | c, e |
| 481 | You, D., et al. (2014). "Meta-analysis: association between wrist posture and carpal tunnel syndrome among workers." Saf Health Work 5(1): 27-31. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 482 | Yu, D., et al. (2012). "Quantitative posture analysis of 2D, 3D, and optical microscope visualization methods for microsurgery tasks." Work 41 Suppl 1: 1944-1947. | PubMed_03_02_2017 | yes | 1 | no | 0 | 1 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | d, e |
| 483 | Yang, Y., Zhao, X., Dong, T., Du, C., Zhang, Y., & Zhang, Q. (2016). A meta-analysis of risk factors for heterotopic ossification after elbow trauma. Int J Clin Exp Med, 9(3), 5308-5317. | EMBASE_08_02_2017 | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | d, e |
| 484 | Yung, M., et al. (2012). "Variation of force amplitude and its effects on local fatigue." Eur J Appl Physiol 112(11): 3865-3879. | PubMed_03_02_2017 | yes | 1 | yes | 1 | 3 | 2 | 2 | 1 | inclusion for scanning full-text | 5 | no | 0 | no | 0 | d |
| 485 | Zeng, Q. Y., et al. (2010). "Epidemiologic study of soft tissue rheumatism in Shantou and Taiyuan, China." Chin Med J (Engl) 123(15): 2058-2062. | PubMed_03_02_2017/ EMBASE_08_02_2017 | no | 0 | yes | 1 | 2 | 1 | 1 | 1 | discussion necessary | 4 | no | 0 | no | 0 | b |
| 486 | Zhang, S., et al. (2016). "Cost-Minimization Analysis of Open and Endoscopic Carpal Tunnel Release." J Bone Joint Surg Am 98(23): 1970-1977. | added by Seidel | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | b, c, d, e |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 487 | Title: Tennis elbow: Subject matter of concern. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 488 | Title: Heterotrophic ossification following a elbow dislocation and coronoid process fracture causing significant morbidity. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 489 | Title: Evaluation of the unified approach to radial tunnel syndrome and tennis elbow syndrome. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 490 | Title: The use of growth mixture models to characterise recovery trajectories of patients with tennis elbow. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 491 | Title: Hypovitaminosis D in postmenopausal women with a distal radius fracture. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 492 | Title: A rare complication of eswt application in a patient with lateral epicondylitis ESWT Uygulanan Lateral Epikondilitli Hastada Gelisen Nadir Bir Komplikasyon. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 493 | Title: Investigation of the effectiveness of laser in the treatment of lateral epicondylitis Lateral Epikondilit Tedavisinde Lazerin Etkinli inin Arastirilmasi. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |
| 494 | Title: Coexistence of lateral epicondylitis and ulnar nerve entrapment Lateral Epikondilit ve Ulnar Tuzak Noropati Birlikteli i. | EMBASE_08_02_2017_Reference_not found | no | 0 | no | 0 | 0 | 0 | 0 | 0 | exclusion; after scanning title & abstract (no; no) | 1 | no | 0 | no | 0 | a |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0 | | 322 | 322 | 340 | 340 | 18 | 463 | 484 |
| 1 | | 63 | 78 | 85 | 154 | 304 | 31 | 10 |
| 2 | | 15 | 94 | 69 | | 18 | | |
| 3 | | 94 | | | | 25 | | |
| 4 | | | | | | 60 | | |
| 5 | | | | | | 69 | | |
| | ∑ | 494 | 494 | 494 | 494 | 494 | 494 | 494 |

| Statistics | n |
|---|---|
| CochraneWork_06_01_2017 | 10 |
| PubMed_03_02_2017 | 116 |
| EMBASE_08_02_2017 | 167 |
| PubMed_03_02_2017/EMBASE_08_02_2017 | 25 |
| EMBASE_08_02_2017_Double | 5 |
| added by Seidel | 147 |
| EMBASE_08_02_2017_Abstract_not found | 16 |
| EMBASE_08_02_2017_Reference_not found | 8 |

| | |
|---|---|
| Doubles | 30 |
| Cochrane Work | 10 |

| Exclusion | | BS | | total |
|---|---|---|---|---|
| | | no = 0 | Yes = 1 | |
| DHS | no = 0 | 322 | 15 | 337 |
| | yes = 1 | 63 | 94 | 157 |
| total | | 385 | 109 | 494 |
| p0 | = | 0.8421 (84,2% initial agreement) | | |
| cohens kappa | = | 0.6035 | | |
| pe | = | 0.6018 | | |
| K | = | 0.6035 | | |

| | |
|---|---|
| Pubmed | 141 |
| EMBASE | 226 |
| added by Seidel | 147 |
| Total | 524 |
| Total without double | 494 |
| Exclusion after scanning title & abstract | 322 |
| scanning full text | 172 |
| Exclusion after scanning full text | 141 |
| Exclusion after scanning full text | 463 |
| checking for eligibility | 31 |
| Exclusion after checking for eligibility | 21 |
| Exclusion in total | 484 |
| Included | 10 |

*File VII – Table S5: All relevant results of all included studies (incl. study attributes)*

**Table S5.** All relevant results of all included studies (incl. study attributes).

| Reference Author (year) | Design | Population / Sample | Exposure Assessment | Outcome Assessment | No. | Risk factor | Outcome | Gender | Measure (CI 95%) | Adjustment | Significance | Different risk factor specifications associated with at least one disorder<br>1 = non-significant;<br>2 = significant<br>3 = same risk factor as reported in previous study | Additional declaration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Descatha et al. (2013) [36] | CH | 1107 newly employed worker in St. Louis, USA<br><br>(76 cases at baseline, 699 participants completed follow up)<br><br>(at follow up: LE (n = 34), ME (n = 30), LE/ME (n = 48), LE or ME (n = 16)) | self-reported physical work exposures and psycho-social measures via question-naire<br><br>responses categorized by authors into 4 categories (none or less than 1 hour/day, 1-2 hours/day, 2-4 hours/day, ≥ 4 hours/day) | Question-naire<br><br>+ physical examination | | Frequently wrist bending or twisting on average | | | | | | | "... "bending" (On average, how long altogether each day did you frequently bend or twist your hands or wrists?)<br><br>"rotating" (On average, how long altogether each day did you do tasks where there was a rotating, twisting or screwing motion of the forearm?), and<br><br>"gripping" (On average, how long altogether each day did you use your hand in a forceful grip?). |
| | | | | | #58 | 1-2 hours/day | LE | | OR 0.80 (0.10, 7.40) | a) | / | 1 | |
| | | | | | | | LE / ME | | OR 2.50 (0.60, 11.40) | a) | / | | |
| | | | | | #13 | 2-4 hours/day | LE | | OR 2.80 (0.70, 10.50) | a) | / | 2 | |
| | | | | | | | ME | | OR 4.90 (1.10, 20.70) | a) | * | | |
| | | | | | | | LE / ME | | OR 3.90 (1.10, 13.80) | a) | * | | |
| | | | | | #14 | ≥ 4hours/day | LE | | OR 4.40 (1.50, 13.10) | a) | * | 2 | |
| | | | | | | | ME | | OR 8.20 (2.40, 27.90) | a) | * | | |
| | | | | | | | LE / ME | | OR 6.90 (2.40, 19.90) | a) | * | | |
| | | | | | | Forearm rotating (also twisting, or screwing motion) | | | | | | | |
| | | | | | #68 | 1-2 hours/day | LE | | OR 1.00 (0.20, 4.60) | a) | / | 1 | |
| | | | | | | | ME | | OR 0.50 (0.10, 3.90) | a) | / | | |
| | | | | | | | LE / ME | | OR 1.00 (0.30, 3.60) | a) | / | | |
| | | | | | #69 | 2-4 hours/day | LE | | OR 2.30 (0.80, 6.70) | a) | / | 1 | |
| | | | | | | | ME | | OR 2.80 (1.00, 7.70) | a) | / | | |
| | | | | | | | LE / ME | | OR 2.60 (1.10, 6.30) | a) | / | | |
| | | | | | #22 | ≥ 4 hours/day | LE | | OR 2.70 (1.20, 6.20) | a) | * | 2 | |
| | | | | | | | ME | | OR 2.50 (1.00, 5.80) | a) | / | | |
| | | | | | | | LE / ME | | OR 2.70 (1.30, 5.40) | a) | * | | |
| | | | | | | Hand in forceful grip on average | | | | | | | |
| | | | | | #46 | 1-2 hours/day | LE | | OR 1.30 (0.40, 4.20) | a) | / | 1 | |
| | | | | | | | ME | | OR 2.10 (0.60, 7.20) | a) | / | | |
| | | | | | | | LE / ME | | OR 1.70 (0.60, 4.50) | a) | / | | |
| | | | | | #47 | 2-4 hours/day | LE | | OR 1.50 (0.50, 4.30) | a) | / | 1 | |
| | | | | | | | ME | | OR 1.90 (0.50, 6.50) | a) | / | | |
| | | | | | | | LE / ME | | OR 1.50 (0.60, 4.00) | a) | / | | |
| | | | | | #2 | ≥ 4 hours/day | LE | | OR 1.70 (0.70, 4.00) | a) | / | 2 | |
| | | | | | | | ME | | OR 3.80 (1.50, 9.60) | a) | * | | |
| | | | | | | | LE / ME | | OR 2.80 (1.40, 5.80) | a) | * | | |
| | | | | | | Frequently wrist bending ≥ 4h/day and forearm rotating on average | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | #15 | ≥ 2h/day | LE | | OR | 2.50 (1.10, 5.30) | b) | * | 2 | |
| | | | | | | | ME | | OR | 3.10 (1.40, 6.80) | b) | * | | |
| | | | | | | | LE / ME | | OR | 3.00 (1.60, 5.80) | b) | * | | |
| | | | | | | | LE / ME | Men | OR | 2.80 (1.20, 6.20) | b) | * | | |
| | | | | | | | LE / ME | Women | OR | 3.60 (1.20, 11.00) | b) | * | | |
| Fan et al. (2009) [31] | CSS | 733 worker (695 non-cases, 38 LE cases) in manufacturing sectors in western Washington State | observation and videotaping (2 synchronized cameras with different positions), measurements for biomechanical exposures, self-administered psycho-social questionnaire for psychosocial factors time-based posture analysis via software, based on video frames; frequency and percent of time (duty cycle) of forceful exertions based on time-studies object weight and push or pull forces measured | structured interviews and specific body map was used + physical examination | | Frequency of forceful exertions (times/min) | | | | | | | | high - high: high force – high posture at median intermediate: low on either posture or force and high on the other (high force: pinch grip > 9N; power grip, push/pull or lifting force> 44N) Forceful exertion (pinch grip force ≥ 8.9 N (2 lbs/ 0.9 kg); power grip forces, lifting object weights or push/ pull forces ≥ 44.1 N (10 lbs/ 4.5 kg) Bao & Silverstein (2005) [43] |
| | | | | | #29 | ≤ 1 to < 5 vs. < 1 | LE | | OR | 4.47 (1.57, 13.71) | d) | * | 2 | |
| | | | | | #30 | ≥ 5 vs. < 1 | LE | | OR | 5.17 (1.78, 15.02) | d) | * | 2 | |
| | | | | | | Duty cycle of forceful exertions (% time) | | | | | | | | |
| | | | | | #31 | ≤ 3 to < 15 % | LE | | OR | 3.36 (1.28, 8.84) | i) | * | 2 | |
| | | | | | #32 | ≥ 15 % | | | OR | 3.00 (1.13, 7.96) | i) | * | 2 | |
| | | | | | | Frequency of shoulder movement (times/min) | | | | | | | | |
| | | | | | #55 | ≤ 10 to < 20 | LE | | OR | 2.03 (0.73, 5.66) | i) | / | 1 | |
| | | | | | #56 | ≥ 20 | LE | | OR | 2.70 (0.96, 7.63) | i) | / | 1 | |
| | | | | | | Forceful lifting, time-weighted average (% time) | | | | | | | | |
| | | | | | #6 | > 0 % | LE | | OR | 2.65 (1.21, 5.83) | i) | * | 2 | |
| | | | | | | Frequency of forceful lifting, time-weighted average (times/min) | | | | | | | | |
| | | | | | #53 | < 0 to < 2 | LE | | OR | 2.30 (0.95, 5.59) | i) | / | 1 | |
| | | | | | #7 | ≥ 2 | LE | | OR | 3.06 (1.28, 7.27) | i) | * | 2 | |
| | | | | | | Forearm supination ≥ 45° (% time) | | | | | | | | |
| | | | | | #26 | ≥ 5 % | LE | | OR | 2.25 (1.13, 4.50) | i) | * | 2 | |
| | | | | | | Wrist flexion or extension ≥ 45° (% time) | | | | | | | | |
| | | | | | #63 | ≥ 1 % | LE | | OR | 0.66 (0.34, 1.27) | i) | / | 1 | |
| | | | | | | Wrist radial deviation < 5° or ulnar deviation ≥ 20° (% time) | | | | | | | | |
| | | | | | #59 | ≥ 4 % | LE | | OR | 0.62 (0.32, 1.22) | i) | / | 1 | |
| | | | | | | Forearm supination ≥ 45° and forceful lifting (% time) | | | | | | | | |
| | | | | | #91 | Intermediate | LE | | OR | 1.21 (0.44, 3.38) | i) | / | 1 | |
| | | | | | #33 | High - high | LE | | OR | 3.65 (1.47, 9.07) | i) | * | 2 | |
| | | | | | | Forearm supination (≥ 45°) ≥ 5% of time (duty cycle) | | | | | | | | |
| | | | | | #92 | or forceful lifting (> 0 % time) | LE | | OR | 1.09 (0.38, 3.09) | d) | / | 1 | |
| | | | | | #34 | and forceful lifting (> 0 % time) | LE | | OR | 2.98 (1.18, 7.55) | d) | * | 2 | |

| | | | | | | | | | | | | | |
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| | | | using force gauges + using a force matching method | | | | | | | | | | |
| Fan et al. (2014) [37] | CH | 733 worker at baseline, 611 at follow up, (57 cases and 554 non-cases, cases at follow up) in manufacturing sectors in western Washington State | observation and videotaping, measurements for biomechanical exposures, self-administered psycho-social questionnaire for psycho-social factors; time-based posture analysis via software, based on video frames; frequency and percent of time (duty cycle) of forceful exertions based on time-studies; forceful exertions measured via force gauges (object | structured interviews + physical examinations | #60 | Wrist flexion/extension ≥ 15° for ≥ 40% time | LE | HR | 0.94 (0.56, 1.58) | a) | / | 1 | Forceful exertions: pinch grip force ≥ 0.9 kg of object weight/ 1.8-kg pinch grip force power grip forces: ≥ 4.5 kg of object weight / 4.5-kg power grip, lifting/ lowering as object weights ≥ 4.5 kg, and pushing/pulling forces as ≥ 4.5 kg force Bao et al. (2006a) [42] Forceful exertion included lifting/lowering, pushing/pulling, power gripping, pinch gripping, other types of forceful hand exertions (e.g., thumb press, one hand pull) [37], awkward postures: wrist flexion or extension ≥ 15°, forearm supination ≥ 45°, forearm pronation ≥ 45°, and forearm rotation (either forearm supination or pronation) ≥ 45° Bao et al. (2006b) [44] forearm rotation = forearm supination or forearm pronation qualitative specification: any pinch grip fore (LE; HR 1.20 (0.64, 2.24); a); /) |
| | | | | | #61 | Wrist flexion/extension ≥ 45° for ≥ 2% time | LE | HR | 0.98 (0.58, 1.66) | a) | / | 1 | |
| | | | | | #64 | Forearm pronation ≥ 45° for ≥ 40% time | LE | HR | 1.60 (0.93, 2.73) | a) | / | 1 | |
| | | | | | #26 | Forearm supination ≥ 45° for ≥ 5% time | LE | HR | 1.19 (0.71, 2.00) | a) | / | 3 | |
| | | | | | #65 | Forearm rotation ≥ 45° for ≥ 45% time | LE | HR | 1.41 (0.82, 2.42) | a) | / | 1 | |
| | | | | | #50 | Lifting ≥ 3% time | LE | HR | 1.28 (0.76, 2.15) | a) | / | 1 | |
| | | | | | #54 | Duty cycle ≥ 10% time | LE | HR | 1.43 (0.84, 2.43) | a) | / | 1 | |
| | | | | | #90 | Frequency of forceful exertion for ≥ 2 times/min | LE | HR | 1.18 (0.69, 2.00) | a) | / | 1 | |
| | | | | | | Wrist flexion/extension ≥ 15° for | | | | | | | |
| | | | | | #93 | ≥ 40% time and any power grip | LE | HR | 1.52 (0.78, 2.96) | a) | / | 1 | |
| | | | | | #94 | ≥ 40% time and no power grip | LE | HR | 0.77 (0.40, 1.50) | a) | / | 1 | |
| | | | | | #95 | < 40% time and any power grip | LE | HR | 1.32 (0.55, 3.15) | a) | / | 1 | |
| | | | | | | Wrist flexion/extension ≥ 15° for | | | | | | | |
| | | | | | #96 | ≥ 40% time and lifting ≥ 3% time | LE | HR | 1.18 (0.60, 2.33) | a) | / | 1 | |
| | | | | | #97 | ≥ 40% time and lifting < 3% time | LE | HR | 0.74 (0.36, 1.50) | a) | / | 1 | |
| | | | | | #98 | < 40% time and lifting ≥ 3% time | LE | HR | 0.96 (0.43, 2.13) | a) | / | 1 | |
| | | | | | | Wrist flexion/extension ≥ 15° for | | | | | | | |
| | | | | | #71 | ≥ 40% time and duty cycle ≥ 10% time | LE | HR | 1.30 (0.66, 2.54) | a) | / | 1 | |
| | | | | | #72 | ≥ 40% timeand duty cycle < 10% time | LE | HR | 0.68 (0.33, 1.43) | a) | / | 1 | |
| | | | | | #73 | < 40% time and duty cycle ≥ 10% time | LE | HR | 0.99 (0.45, 2.20) | a) | / | 1 | |
| | | | | | | Wrist flexion/extension ≥ 15° for | | | | | | | |
| | | | | | #119 | ≥ 40% time and Freq force ≥ 2/min | LE | HR | 1.09 (0.56, 2.13) | a) | / | 1 | |
| | | | | | #120 | ≥ 40% time and Freq force < 2/min | LE | HR | 0.67 (0.33, 1.36) | a) | / | 1 | |
| | | | | | #121 | < 40% time and Freq force ≥ 2/min | LE | HR | 0.77 (0.34, 1.74) | a) | / | 1 | |
| | | | | | | Wrist flexion/extension ≥ 45° for | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| weight and push/pull forces) | #99 | ≥ 5% time and any power grip | LE | HR | 1.39 (0.67, 2.89) | a) | / | 1 | |
| | #100 | ≥ 5% time and no power grip | LE | HR | 0.91 (0.46, 1.79) | a) | / | 1 | any power grip fore (LE; HR 1.65 (0.90, 2.82); a); /) |
| | #101 | < 5% time and any power grip | LE | HR | 1.94 (0.85, 4.39) | a) | / | 1 | |
| + grip dynamometers (pinch and power grip | | Wrist flexion/extension ≥ 45° for | | | | | | | |
| | #102 | ≥ 5% time and lifting ≥ 3% time | LE | HR | 1.11 (0.54, 2.27) | a) | / | 1 | |
| | #103 | ≥ 5% time and lifting < 3% time | LE | HR | 0.93 (0.45, 1.95) | a) | / | 1 | |
| | #104 | < 5% time and lifting ≥ 3% time | LE | HR | 1.52 (0.68, 3.43) | a) | / | 1 | |
| + using a force matching method) | | Wrist flexion/extension ≥ 45° for | | | | | | | |
| | #74 | ≥ 5% time and duty cycle ≥ 10% time | LE | HR | 1.22 (0.60, 2.50) | a) | / | 1 | |
| | #75 | ≥ 5% time and duty cycle < 10% time | LE | HR | 1.00 (0.47, 2.11) | a) | / | 1 | |
| | #76 | < 5% time and duty cycle ≥ 10% time | LE | HR | 2.06 (0.91, 4.66) | a) | / | 1 | |
| | | Wrist flexion/extension ≥ 45° for | | | | | | | |
| | #122 | ≥ 5% time and Freq force ≥ 2/min | LE | HR | 1.02 (0.51, 2.04) | a) | / | 1 | |
| | #123 | ≥ 5% time and Freq force < 2/min | LE | HR | 0.86 (0.41, 1.77) | a) | / | 1 | |
| | #124 | < 5% time and Freq force ≥ 2/min | LE | HR | 1.28 (0.55, 3.02) | a) | / | 1 | |
| | | Forearm pronation ≥ 45° for | | | | | | | |
| | #38 | ≥ 40% time and any power grip | LE | HR | 2.80 (1.35, 5.77) | e) | ** | 2 | |
| | #105 | ≥ 40% time and no power grip | LE | HR | 1.97 (1.00, 3.89) | e) | / | 1 | |
| | #106 | < 40% time and any power grip | LE | HR | 1.65 (0.69, 3.96) | e) | / | 1 | |
| | | Forearm pronation ≥ 45° for | | | | | | | |
| | #39 | ≥ 40% time and lifting ≥ 3% time | LE | HR | 2.50 (1.19, 5.24) | e) | * | 2 | |
| | #107 | ≥ 40% time and lifting < 3% time | LE | HR | 1.98 (0.96, 4.07) | e) | / | 1 | |
| | #108 | < 40% time and lifting ≥ 3% time | LE | HR | 1.58 (0.77, 3.22) | e) | / | 1 | |
| | | Forearm pronation ≥ 45° for | | | | | | | |
| | #25 | ≥ 40% time and duty cycle ≥ 10% time | LE | HR | 2.25 (1.09, 4.66) | e) | * | 2 | |
| | #77 | ≥ 40% time and duty cycle < 10% time | LE | HR | 1.61 (0.76, 3.39) | e) | / | 1 | |
| | #78 | < 40% time and duty cycle ≥ 10% time | LE | HR | 1.76 (0.85, 3.62) | e) | / | 1 | |
| | | Forearm pronation ≥ 45° for | | | | | | | |
| | #125 | ≥ 40% time and Freq force ≥ 2/min | LE | HR | 2.28 (1.00, 5.19) | a) | / | 1 | |
| | #126 | ≥ 40% time and Freq force < 2/min | LE | HR | 1.36 (0.63, 2.94) | a) | / | 1 | |
| | #127 | < 40% time and Freq force ≥ 2/min | LE | HR | 1.03 (0.44, 2.42) | a) | / | 1 | |
| | | Forearm supination ≥ 45° for | | | | | | | |
| | #109 | ≥ 5% time and any power grip | LE | HR | 1.48 (0.62, 3.55) | a) | / | 1 | |
| | #110 | ≥ 5% time and no power grip | LE | HR | 1.86 (0.96, 3.60) | a) | / | 1 | |
| | #36 | < 5% time and any power grip | LE | HR | 2.86 (1.41, 5.82) | a) | ** | 2 | |
| | | Forearm supination ≥ 45° for | | | | | | | |
| | #111 | ≥ 5% time and lifting ≥ 3% time | LE | HR | 1.32 (0.66, 2.62) | a) | / | 1 | |
| | #112 | ≥ 5% time and lifting < 3% time | LE | HR | 1.89 (0.92, 3.90) | a) | / | 1 | |
| | #35 | < 5% time and lifting ≥ 3% time | LE | HR | 2.09 (1.02, 4.27) | a) | * | 2 | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Forearm supination ≥ 45° for | | | | | | | | |
| | | | | | #79 | ≥ 5% time and duty cycle ≥ 10% time | LE | | HR | 1.47 (0.74, 2.93) | a) | / | 1 | |
| | | | | | #80 | ≥ 5% time and duty cycle < 10% time | LE | | HR | 1.59 (0.76, 3.34) | a) | / | 1 | |
| | | | | | #81 | < 5% time and duty cycle ≥ 10% time | LE | | HR | 2.02 (0.98, 4.13) | a) | / | 1 | |
| | | | | | | Forearm supination ≥ 45° for | | | | | | | | |
| | | | | | #128 | ≥ 5% time and Freq force ≥ 2/min | LE | | HR | 1.29 (0.66, 2.51) | a) | / | 1 | |
| | | | | | #129 | ≥ 5% time and Freq force < 2/min | LE | | HR | 1.36 (0.65, 2.82) | a) | / | 1 | |
| | | | | | #130 | < 5% time and Freq force ≥ 2/min | LE | | HR | 1.35 (0.64, 2.83) | a) | / | 1 | |
| | | | | | | Forearm rotation ≥ 45° for | | | | | | | | |
| | | | | | #37 | ≥ 45% time and any power grip | LE | | HR | 2.83 (1.16, 6.90) | a) | * | 2 | |
| | | | | | #113 | ≥ 45% time and no power grip | LE | | HR | 1.88 (0.83, 4.28) | a) | / | 1 | |
| | | | | | #114 | < 45% time and any power grip | LE | | HR | 2.31 (0.82, 6.53) | a) | / | 1 | |
| | | | | | | Forearm rotation ≥ 45° for | | | | | | | | |
| | | | | | #115 | ≥ 45% time and lifting ≥ 3% time | LE | | HR | 2.27 (0.88, 5.88) | a) | / | 1 | |
| | | | | | #116 | ≥ 45% time and lifting < 3% time | LE | | HR | 1.50 (0.58, 3.84) | a) | / | 1 | |
| | | | | | #117 | < 45% time and lifting ≥ 3% time | LE | | HR | 1.25 (0.43, 3.61) | a) | / | 1 | |
| | | | | | | Forearm rotation ≥ 45° for | | | | | | | | |
| | | | | | #24 | ≥ 45% time and duty cycle ≥ 10% time | LE | | HR | 3.10 (1.05, 9.15) | a) | * | 2 | |
| | | | | | #82 | ≥ 45% time and duty cycle < 10% time | LE | | HR | 2.20 (0.77, 6.30) | a) | / | 1 | |
| | | | | | #83 | < 45% time and duty cycle ≥ 10% time | LE | | HR | 2.22 (0.70, 7.04) | a) | / | 1 | |
| | | | | | | Forearm rotation ≥ 45° for | | | | | | | | |
| | | | | | #131 | ≥ 45% time and Freq force ≥ 2/min | LE | | HR | 1.96 (0.80, 4.84) | a) | / | 1 | |
| | | | | | #132 | ≥ 45% time and Freq force < 2/min | LE | | HR | 1.52 (0.63, 3.66) | a) | / | 1 | |
| | | | | | #133 | < 45% time and Freq force ≥ 2/min | LE | | HR | 1.20 (0.42, 3.37) | a) | / | 1 | |
| Herquelot, et al. (2013a) [32] | CSS | 3710 adult, temporary and part-time worker in a French region (90 LE cases in men, 39 LE cases in women) | self-adminis-tered question-aire, physical work load assessed via Borg Rating of Perceived Exertion Scale Responses categorized into 4-point Likert-type | physical exami-nations | | Doing repetitive tasks | | | | | | | | Elbow movements = elbow flexion/extension more than 2 h/day and wrist bending more than 2 h/day hard = hard physical exertion; Borg Rating of Perceived Exertion [47] Scale (6 to 20); less hard exertion (6–13) and hard exertion to exhaustion (14–20), qualitative specification: hard physical exertion: (LE; Men; OR; 2.57 (1.34, 4.90); adjusted for |
| | | | | | #9 | > 4 h/day | LE | Men | OR | 1.05 (0.54, 2.02) | l) | / | 2 | |
| | | | | | | | LE | Women | OR | 2.46 (1.30, 4.65) | a) | ** | | |
| | | | | | | | LE | Women | OR | 1.80 (0.91, 3.59) | l) | / | | |
| | | | | | | Elbow flexion/ extension | | | | | | | | |
| | | | | | #21 | > 2 h/day | LE | Men | OR | 2.41 (1.38, 4.22) | a) | ** | 2 | |
| | | | | | | | LE | Women | OR | 2.65 (1.40, 5.02) | a) | ** | | |
| | | | | | | Extreme wrist bending | | | | | | | | |
| | | | | | #20 | > 2 h/day | LE | Men | OR | 2.27 (1.30, 3.97) | a) | ** | 2 | |
| | | | | | | | LE | Women | OR | 1.98 (1.04, 3.75) | a) | * | | |
| | | | | | | Use of vibrating handtools | | | | | | | | |
| | | | | | #88 | > 2 h/day | LE | Men | OR | 0.95 (0.46, 1.97) | a) | / | 1 | |
| | | | | | | | LE | Women | OR | 2.08 (0.62, 6.98) | a) | / | | |
| | | | | | | Elbow-specific combined physical exposure | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | scale,:<br>never or practically never;<br>rarely (< 2 h/day),<br>often (2–4 h/day)<br>and always (> 4 h/day) | | #45 | Light and 1 to 2 elbow movements | LE | Men | OR | 1.34 (0.46, 3.90) | a) | / | 1 | individual characteristics, repetition, physical exertion, and social support, *)<br>(LE; Women; OR; 2.51 (1.24, 5.08); adjusted for individual characteristics, repetition, physical exertion, and social support, *) |
| | | | | | | | LE | Men | OR | 1.52 (0.52, 4.44) | l) | / | | |
| | | | | | | | LE | Women | OR | 0.53 (0.17, 1.60) | l) | / | | |
| | | | | | #118 | Hard and no elbow movement | LE | Men | OR | 0.56 (0.11, 2.92) | a) | / | 1 | |
| | | | | | | | LE | Men | OR | 0.76 (0.14, 3.98) | l) | / | | |
| | | | | | | | LE | Women | OR | 0.80 (0.24, 2.71) | l) | / | | |
| | | | | | #41 | Hard and 1 elbow movement | LE | Men | OR | 3.78 (1.85, 7.70) | m) | ** | 2 | |
| | | | | | | | LE | Women | OR | 2.54 (1.12, 5.76) | m) | / | | |
| | | | | | #42 | Hard and 2 elbow movements | LE | Men | OR | 5.27 (1.93, 14.37) | a) | *** | 2 | |
| | | | | | | | LE | Men | OR | 5.60 (2.76, 11.35) | m) | / | | |
| | | | | | | | LE | Women | OR | 2.89 (1.28, 6.51) | m) | / | | |
| Herquelot, et al. (2013b) [38] | CH | 3710 adult, temporary and part-time worker in a French region<br><br>(1046 at follow up, 103 LE cases in men and 68 LE cases in women at follow up) | self-reported occupation-al exposures<br><br>Responses categorized into 4-point Likert-type scale,:<br>never or practically never;<br>rarely (< 2 h/day),<br>often (2–4 h/day)<br>and always (> 4 h/day) | Standard-ized physical examina-tions<br><br>(method-logy and clinical tests of the Saltsa consensus) | | Doing repetitive tasks (> 4 h/day) | | | | | | | | Elbow-specific combined physical exposure:<br>High physical exertion with elbow flexion/ extension > 2 hours/day and extreme wrist bending > 2 hours/day |
| | | | | | #9 | at first Questionnaire (at baseline investigation) | LE | Men | IRR | 1.20 (0.40, 3.60) | n) | / | 3 | |
| | | | | | | | LE | Women | IRR | 2.70 (1.00, 7.00) | n) | / | | |
| | | | | | #9 | at second Questionnaire (at follow up investigation) | LE | Men | IRR | 1.20 (0.40, 3.50) | n) | / | | |
| | | | | | | | LE | Women | IRR | 1.00 (0.30, 3.80) | n) | / | | |
| | | | | | #9 | at both Questionnaires (at baseline and at follow up | LE | Men | IRR | 2.80 (1.20, 6.20) | n) | * | | |
| | | | | | | | LE | Women | IRR | 2.20 (0.80, 6.30) | n) | / | | |
| | | | | | | Elbow-specific combined physical exposure | | | | | | | | |
| | | | | | #42 | at first Questionnaire (at baseline investigation) | LE | Women | IRR | 1.50 (0.50, 4.70) | f) | / | 3 | |
| | | | | | #42 | at second Questionnaire (at follow up investigation) | LE | Men | IRR | 2.70 (1.10, 6.10) | f) | * | | |
| | | | | | #42 | at both Questionnaires (at baseline and at follow up | LE | Men | IRR | 3.20 (1.50, 6.40) | f) | ** | | |
| | | | | | | | LE | Women | IRR | 3.30 (1.40, 7.60) | f) | ** | | |
| Nordander et al. (2009) [33] | CSS | 4961 adult worker (1241 males, 3720 females, worker with homogen-eous work tasks were grouped, 43 groups); | Homogen-eous jobs (similar work tasks) were grouped for job titles and authors classified them in 2 exposure | Nordic Question-naire in interview or as mailed question-naire + physical examination (only for | | repetitive/constrained vs. varied/mobile work | | | | | | | | Repetitive work: cycle time < 30 s or > 50% cycle time (involved the same fundamental cycle)<br>Constrained work: > 50% of working time involved prolonged awkward posturesstatistically significant, 95% CI exceeds 1.0 |
| | | | | | #43 | | LE | Men | PR | 1.00 (0.30, 2.80) | c) | / | 2 | |
| | | | | | | | LE | Women | PR | 1.90 (1.00, 3.80) | c) | / | | |
| | | | | | | | ME | Men | PR | 4.00 (1.10, 15.00) | c) | * | | |
| | | | | | | | ME | Women | PR | 3.50 (1.00, 12.00) | c) | / | | |
| | | | | | | | Pronator | Women | PR | 3.40 (0.40, 29.00) | c) | / | | |
| | | | | | | | Radial | Men | PR | 1.30 (0.10, 21.00) | c) | / | | |
| | | | | | | | Radial | Women | PR | 3.40 (0.80, 15.00) | c) | / | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | repetitive/ constrained work (female: 85 cases female, male: 19 cases); varied / mobile work (female: 18 cases, male: 13 cases) | | some groups) | | | | | | | | | |
| Nordander et al. (2013) [34] | CSS | 2652 adult worker (761 males, 1891 females, 27 different groups, worker representing repetitive and/or constrained as well as varied/ mobile work) | wrist postures + movements measured using biaxial flexible electrogonio-meters; Flexion/ extension angles recorded via data logger; bipolar surface electro-myography (EMG) used to record the muscular load; psycho-social factors: Swedish version of the Job Content Questionnaire Ruben-owitz standard-ized question-naire, | Nordic Question-naire + physical examination | | Wrist flexion β in [%/°] | | | | | | | Physical exposures recorded in subsample of workers in each group<br><br>β = sex-adjusted slope of the regression line |
| | | | | | #16 | at -40° Flexion | LE | PR | 0.30 (0.04, 0.60) | g) | * | 2 | |
| | | | | | | | ME | PR | 0.17 (-0.02, 0.40) | g) | / | | |
| | | | | | #17 | at -20° Flexion | LE | PR | 0.04 (-0.07, 0.20) | g) | / | 2 | |
| | | | | | | | ME | PR | 0.08 (0.01, 0.10) | g) | * | | |
| | | | | | #62 | at 0° Flexion | LE | PR | 0.05 (-0.06, 0.20) | g) | / | 1 | |
| | | | | | | | ME | PR | 0.05 (-0.02, 0.10) | g) | / | | |
| | | | | | | Wrist angular velocity β in [%/(°/s)] | | | | | | | |
| | | | | | #10 | at 5°/s | LE | PR | 0.00 (-0.08, 0.08) | g) | / | 2 | |
| | | | | | | | ME | PR | 0.10 (0.10, 0.20) | g) | * | | |
| | | | | | | Muscular activity β in [%/%MVE] | | | | | | | |
| | | | | | #48 | at 1 % MVE | LE | PR | -0.34 (-1.10, 0.50) | g) | / | 1 | |
| | | | | | #49 | at 15 % MVE | LE | PR | -0.02 (-0.20, 0.10) | g) | / | 1 | |
| | | | | | | | ME | PR | 0.03 (-0.09, 0.10) | g) | / | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Copenhagen Psycho-social Question- | | | | | | | | | | | |
| Spahn et al. (2016) [40] | CRS | 197 adult worker; 71 cases (38 males, 33 females); 126 controls (89 males, 37 females) | Question-naire, interview | structured question-naire + physical examination + clinical-functional tests | | Standing work | | | | | | | | |
| | | | | | #84 | > 1h/day | LE | Men | OR | 2.40 (0.80, 6.70) | g) | / | 1 | |
| | | | | | | | LE | Women | OR | 1.90 (0.40, 8.10) | g) | / | | |
| | | | | | | Sedentary work | | | | | | | | |
| | | | | | #85 | > 1h/day | LE | Men | OR | 0.50 (0.20, 1.10) | g) | / | 1 | |
| | | | | | | | LE | Women | OR | 0.50 (0.20, 2.10) | g) | / | | |
| | | | | | | PC work | | | | | | | | |
| | | | | | #86 | > 1h/day | LE | Men | OR | 1.00 (0.30, 3.50) | g) | / | 1 | |
| | | | | | | | LE | Women | OR | 0.30 (0.10, 0.80) | g) | / | | |
| | | | | | | Constant moving, lifting and carrying of loads | | | | | | | | |
| | | | | | #51 | > 10 kg | LE | Men | OR | 2.20 (0.80, 6.10) | g) | / | 1 | |
| | | | | | #52 | > 5 kg | LE | Women | OR | 4.00 (0.90, 27.10) | g) | / | 1 | |
| | | | | | | overhead working | | | | | | | | |
| | | | | | #12 | > 1h/day | LE | Men | OR | 12.00 (3.20, 43.80) | g) | *** | 2 | |
| | | | | | | | LE | Women | OR | 1.00 (0.30, 4.20) | g) | / | | |
| | | | | | | Arm holding in front of body | | | | | | | | |
| | | | | | #66 | > 1h/day | LE | Men | OR | 1.40 (0.40, 5.00) | g) | / | 1 | |
| | | | | | | | LE | Women | OR | 2.20 (0.50, 9.20) | g) | / | | |
| | | | | | | Swinging movements with the arm | | | | | | | | |
| | | | | | #67 | > 1h/day | LE | Men | OR | 2.60 (0.80, 8.80) | g) | / | 1 | |
| | | | | | | | LE | Women | OR | 1.90 (0.40, 8.30) | g) | / | | |
| | | | | | | Vibration stress | | | | | | | | |
| | | | | | #89 | > 1h/day | LE | Men | OR | 1.50 (0.50, 4.10) | g) | / | 1 | |
| | | | | | | Maximum forceful efforts of the Hand | | | | | | | | |
| | | | | | #1 | > 1h/day | LE | Men | OR | 6.90 (2.70, 17.50) | g) | *** | 2 | |
| | | | | | | | | Women | OR | 9.60 (3.10, 30.40) | g) | *** | | |
| | | | | | | Repetition (> 3 motion sequences /sec or minimum 10,000 / h) | | | | | | | | |
| | | | | | #8 | > 1h/day | LE | Men | OR | 10.60 (4.00, 28.30) | g) | *** | 2 | |
| | | | | | | | | Women | OR | 11.00 (2.60, 45.10) | g) | ** | | |
| | | | | | | Forceful turning | | | | | | | | |
| | | | | | #40 | > 1h/day | LE | Men | OR | 4.70 (1.40, 16.20) | g) | ** | 2 | |
| | | | | | | | LE | Women | OR | 1.40 (0.30, 6.80) | g) | / | | |
| | | | | | | Pat with the hand | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | #5 | > 1h/day | LE | Men | OR | 13.80 (2.90, 66.10) | g) | *** | 2 | |
| | | | | | | Maximum forceful efforts of the Hand and repetition | | | | | | | | |
| | | | | | #28 | > 1h/day | LE | Men | OR | 14.70 (5.20, 41.50) | g) | *** | 2 | |
| | | | | | | | | Women | OR | 29.30 (3.40, 34.80) | g) | *** | | |
| | | | | | | Wrist Extension | | | | | | | | |
| | | | | | #18 | > 1h/day | LE | Men | OR | 12.00 (3.00, 47.90) | g) | *** | 2 | |
| | | | | | | | | Women | OR | 7.50 (1.80, 31.60) | g) | *** | | |
| | | | | | | Wrist Flexion | | | | | | | | |
| | | | | | #19 | > 1h/day | LE | Men | OR | 4.20 (1.20, 14.80) | g) | * | 2 | |
| | | | | | | | LE | Women | OR | 1.20 (0.40, 3.60) | g) | / | | |
| Svendsen et al. (2012) [39] | TCRS | 4296 adult worker (546 patients with UN, 1450 referents) | mailed question-naire + exposure classify-cation via Job Exposure Matrix and experts' ratings | Neuro-physio-logical examination via electro-neuro-graphy | | Repetition time (excluding computer use) | | | | | | | | Repetion: (≥ 4 wrist or elbow movements /min), McAtamney & Nigel Corlett (1993) [45] excluding computer use<br><br>non-neutral postures of elbow (flexion > 100°, or ≥ near maximal pronation/supination) or wrist (> 5° radial deviation, > 10° ulnar deviation or > 15° palmar/dorsal flexion McAtamney & Nigel Corlett (1993), Thomsen et al. (2007) [45,46]; force score as maximal strength across a full working day (Moore & Garg (1995) [41]): 0 (mean force < 10% MVC (maximum voluntary contraction)) 1 (10 to 29% MVC) |
| | | | | | #57 | > 0 to < 2.5 h/day | UN | | OR | 0.85 (0.51, 1.41) | j) | / | 1 | |
| | | | | | #11 | ≥ 2.5 h/day | UN | | OR | 2.22 (1.41, 3.51) | j) | * | 2 | |
| | | | | | | Nonneutral-posture-time | | | | | | | | |
| | | | | | #70 | ≥ 1 to < 2 h/day | UN | | OR | 1.29 (0.82, 2.02) | j) | / | 1 | |
| | | | | | #23 | ≥ 2 h/day | UN | | OR | 1.82 (1.15, 2.89) | j) | * | 2 | |
| | | | | | | Hand-arm vibration [HAV] - time (acceleration ≥ 3 m/s²) | | | | | | | | |
| | | | | | #87 | > 0 to < 1 h/day | UN | | OR | 1.97 (0.95, 4.10) | j) | / | 1 | |
| | | | | | #27 | ≥ 1h/day | UN | | OR | 2.19 (1.05, 4.56) | j) | * | 2 | |
| | | | | | | Force score | | | | | | | | |
| | | | | | #3 | > 0 to < 1 | UN | | OR | 2.73 (1.42, 5.25) | h) | * | 2 | |
| | | | | | #4 | ≥ 1 | UN | | OR | 3.85 (2.04, 7.24) | h) | * | 2 | |
| Walker-Bone et al. (2012) [35] | CSS | 6038 adult worker (45 LE cases, 34 ME cases) | self-defined exposures according to a carefully validated exposure list (ranging | Question-naire + standard-ized interview | | repetitive bending/ straightening of the elbow | | | | | | | | |
| | | | | | #44 | > 1h/ day | LE | | OR | 2.50 (1.20, 5.30) | k) | * | 2 | |
| | | | | | | | ME | | OR | 5.30 (1.90, 14.90) | k) | ** | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | from working with the neck bent/ twisted; working | + physical examination | | | |

| | |
|---|---|
| Different non-significant risk factor specifications associated with at least one specific disorder of the elbow ∑ | 89 |
| Different significant risk factor specifications associated with at least one specific disorder of the elbow ∑ | 44 |
| Total same risk factor as reported in previous study associated with at least one specific disorder of the elbow ∑ | 3 |
| Total different significant and non-significant risk factor specifications associated with at least one specific disorder of the elbow ∑ | 133 |

*Study design:* CRS = Case Referent Study; CH = Cohort Study; CSS = Cross-Sectional Study; TCRS = Triple Case Referent Study

*Outcome*: UN = ulnar neuropathy; LE = lateral epicondylitis; ME = medial epicondylitis, LE / ME = lateral and / or medial epicondylitis, Radial = Radial tunnel syndrome, Pronator = Pronator teres syndrome

*Measure:* odds ratio [OR]; hazard ratio [HR]; incidence rate ratio [IRR]; prevalence ratio [PR]

*Adjustment:*
a) = univariate analysis;
b) = multivariate analysis; adjustment not reported;
c) = adjustment not reported;
d) = final model (age, gender, BMI, smoking status, personal, psychosocial, and work organizational variables);
e) = adjusted for age and gender;
f) = adjusted for age and combined physical work exposure including physical exertion and elbow movements;
g) = sex-adjusted;
h) = fully adjusted for body mass index, pack-years of smoking (continuous), alcohol consumption (continuous), side-specific fractures (never/ever), full anaesthesia within a 5-year period up to the index year (no/yes), predisposing disorders (no/yes), use of crutches within a 5-year period up to the index year (no/yes), hand–arm intensive sports (0, 1, 2) and weight loss ≥ 10 kg within half a year during a 5-year period up to the index year (no/yes) and all occupational exposure variables in table 2 of Svendsen et al. (2012) [39];
i) = adjusted for age (continuous), gender, BMI (continuous);
j) = partly adjusted for body mass index, pack-years of smoking (continuous), alcohol consumption (continuous), side-specific fractures (never/ever), full anaesthesia within a 5-year period up to the index year (no/yes), predisposing disorders (no/yes), use of crutches within a 5-year period up to the index year (no/yes), hand–arm intensive sports (0, 1, 2) and weight loss ≥ 10 kg within half a year during a 5-year period up to the index year (no/yes);
k) = multivariate analyses; adjusted for vitality, white/blue collar, age in four age bands and sex;
l) = adjusted for individual characteristics, repetition, combined physical work exposure including physical exertion, elbow flexion/extension and wrist bending, and social support
m) = adjusted for individual characteristics, repetition, combined physical work exposure including physical exertion, elbow flexion/extension and wrist bending, and social support with aggregation of low categories for combined physical work exposure;
n) = adjusted for age and repetitiveness;

*Significance:* / = *non-significant;** p < 0.05; ** p < 0.01; *** p < 0.001

*File VIII – Table S6: Overview of relevant physical risk factors non-significantly associated with the development of specific disorders at the elbow*

**Table S6.** Overview of relevant physical risk factors non-significantly associated with the development of specific disorders at the elbow.

| Exposure (main- and sub-category (S)*) | | | Non-Significant risk factor specification | Reference | Outcome | Gender | Measure (95% - CI) | | Adjustment |
|---|---|---|---|---|---|---|---|---|---|
| Force | S2 Forceful exertion | #46 | Hand in forceful grip on average 1 to 2 h/day | [36] | LE | - | OR | 1.30 (0.40, 4.20) | a) |
| | | | | | ME | - | OR | 2.10 (0.60, 7.20) | a) |
| | | | | | LE / ME | - | OR | 1.70 (0.60, 4.50) | a) |
| | | #47 | Hand in forceful grip on average 2 to 4 h/day | [36] | LE | - | OR | 1.50 (0.50, 4.30) | a) |
| | | | | | ME | - | OR | 1.90 (0.50, 6.50) | a) |
| | | | | | LE / ME | - | OR | 1.50 (0.60, 4.00) | a) |
| | | #2 | Hand in forceful grip on average ≥ 4 h/day | [36] | LE | - | OR | 1.70 (0.70, 4.00) | a) |
| | | #48 | at 1% Muscular activity in [%/%MVE] | [34] | LE | - | PR | -0.34 (-1.10, 0.50) | g) |
| | | #49 | at 15% Muscular activity in [%/%MVE] | [34] | LE | - | PR | -0.02 (-0.20, 0.10) | g) |
| | | | | | ME | - | PR | 0.03 (-0.09, 0.10) | g) |
| | S4 Manual load handling | #50 | Lifting (power grip: ≥ 4.5 kg; pinch grip: ≥ 0.9 kg) ≥ 3% time | [37] | LE | - | HR | 1.28 (0.76, 2.15) | a) |
| | | #51 | Constant moving, lifting and carrying of loads (> 10 kg) | [40] | LE | Men | OR | 2.20 (0.80, 6.10) | g) |
| | | #52 | Constant moving, lifting and carrying of loads (> 5 kg) | [40] | LE | Women | OR | 4.00 (0.90, 27.10) | g) |
| | | #53 | Forceful lifting (≥ 4.5 kg) < 0 to < 2 times/min | [31] | LE | - | OR | 2.30 (0.95, 5.59) | i) |
| Repetition | S6 Repetitiveness | #9 | Doing repetitive tasks ≥ 4 h/day | [32] | LE | Men | OR | 1.05 (0.54, 2.02) | l) |
| | | | | | LE | Women | OR | 1.80 (0.91, 3.59) | l) |
| | | | at baseline investigation) | [38] | LE | Men | IRR | 1.20 (0.40, 3.60) | n) |
| | | | | | LE | Women | IRR | 2.70 (1.00, 7.00) | n) |
| | | | (at follow up investigation) | | LE | Men | IRR | 1.20 (0.40, 3.50) | n) |
| | | | | | LE | Women | IRR | 1.00 (0.30, 3.80) | n) |
| | | | (at baseline and at follow up investigation) | | LE | Women | IRR | 2.20 (0.80, 6.30) | n) |
| | | #54 | Duty cycle ≥ 10% time | [37] | LE | - | HR | 1.43 (0.84, 2.43) | a) |
| | | #55 | Frequency of shoulder movement ≤ 10 to < 20 times/min | [31] | LE | - | OR | 2.03 (0.73, 5.66) | i) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | #56 | Frequency of shoulder movement ≥ 20 times/min | [31] | LE | - | OR | 2.70 (0.96, 7.63) | i) |
| | | #10 | Wrist angular velocity (5°/s) in [%/(°/s)] | [34] | LE | - | PR | 0.00 (-0.08, 0.08) | g) |
| | | #57 | Repetitive elbow or wrist movements (≥ 4/min) > 0 to < 2.5 h/day, excluding computer use | [39] | UN | - | OR | 0.85 (0.51, 1.41) | j) |
| Posture/movement | S7 Overhead work | #12 | Overhead working > 1h/day | [40] | LE | Women | OR | 1.00 (0.30, 4.20) | g) |
| | S8 Hand movements | #58 | Frequent wrist bending or twisting on average 1 to 2 h/day | [36] | LE | - | OR | 0.80 (0.10, 7.40) | a) |
| | | | | | LE / ME | - | OR | 2.50 (0.60, 11.40) | a) |
| | | #13 | Frequent wrist bending or twisting on average 2 to 4 h/day | [36] | LE | - | OR | 2.80 (0.70, 10.50) | a) |
| | | #59 | Wrist radial deviation < 5° or ulnar deviation ≥ 20° ≥ 4% of time | [31] | LE | - | OR | 0.62 (0.32, 1.22) | i) |
| | | #60 | Wrist flexion/extension ≥ 15° for ≥ 40% time | [37] | LE | - | HR | 0.94 (0.56, 1.58) | a) |
| | | #61 | Wrist flexion/extension ≥ 45° for ≥ 2% time | [37] | LE | - | HR | 0.98 (0.58, 1.66) | a) |
| | | #16 | Wrist flexion (- 40.0°) in [%/°] | [34] | ME | - | PR | 0.17 (-0.02, 0.40) | g) |
| | | #17 | Wrist flexion (- 20.0°) in [%/°] | [34] | LE | - | PR | 0.04 (-0.07, 0.20) | g) |
| | | #62 | Wrist flexion (0.0°) in [%/°] | [34] | LE | - | PR | 0.05 (-0.06, 0.20) | g) |
| | | | | | ME | - | PR | 0.05 (-0.02, 0.10) | g) |
| | | #63 | Wrist flexion or extension ≥ 45° ≥ 1 % of time | [31] | LE | - | OR | 0.66 (0.34, 1.27) | i) |
| | | #19 | Wrist flexion > 1 h/day | [40] | LE | Women | OR | 1.20 (0.40, 3.60) | g) |
| | S9 Forearm & elbow movements | #66 | Arm holding in front of body > 1h/day | [40] | LE | Men | OR | 1.40 (0.40, 5.00) | g) |
| | | | | | LE | Women | OR | 2.20 (0.50, 9.20) | g) |
| | | #67 | Swinging movements with the arm > 1h/day | [40] | LE | Men | OR | 2.60 (0.80, 8.80) | g) |
| | | | | | LE | Women | OR | 1.90 (0.40, 8.30) | g) |
| | | #68 | Forearm rotating (also twisting, or screwing motion) 1 to 2 h/day | [36] | LE | - | OR | 1.00 (0.20, 4.60) | a) |
| | | | | | ME | - | OR | 0.50 (0.10, 3.90) | a) |
| | | | | | LE / ME | - | OR | 1.00 (0.30, 3.60) | a) |
| | | #69 | Forearm rotating (also twisting, or screwing motion) 2 to 4 h/day | [36] | LE | - | OR | 2.30 (0.80, 6.70) | a) |
| | | | | | ME | - | OR | 2.80 (1.00, 7.70) | a) |
| | | | | | LE / ME | - | OR | 2.60 (1.10, 6.30) | a) |
| | | #22 | Forearm rotating (also twisting, or screwing motion) ≥ 4 h/day | [36] | ME | - | OR | 2.50 (1.00, 5.80) | a) |
| | S10 Non- neutral posture | #70 | Non-neutral posture (elbow flexion > 100°, or ≥ near maximal pronation/supination; or wrist deviation (> 5° radial, > 10° ulnar) or > 15° palmar/dorsal flexion) ≥ 1 to < 2 h/day | [39] | UN | - | OR | 1.29 (0.82, 2.02) | j) |
| | | #71 | Wrist flexion/extension ≥ 15° for ≥ 40% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 1.30 (0.66, 2.54) | a) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | #72 | Wrist flexion/extension ≥ 15° for ≥ 40% time and duty cycle < 10% time | [37] | LE | - | HR | 0.68 (0.33, 1.43) | a) |
| | | #73 | Wrist flexion/extension ≥ 15° for < 40% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 0.99 (0.45, 2.20) | a) |
| | | #74 | Wrist flexion/extension ≥ 45° for ≥ 5% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 1.22 (0.60, 2.50) | a) |
| | | #75 | Wrist flexion/extension ≥ 45° for ≥ 5% time and duty cycle < 10% time | [37] | LE | - | HR | 1.00 (0.47, 2.11) | a) |
| | | #76 | Wrist flexion/extension ≥ 45° for < 5% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 2.06 (0.91, 4.66) | a) |
| | | #77 | Forearm pronation ≥ 45° for ≥ 40% time and duty cycle < 10% time | [37] | LE | - | HR | 1.61 (0.76, 3.39) | e) |
| | | #78 | Forearm pronation ≥ 45° for < 40% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 1.76 (0.85, 3.62) | e) |
| | | #64 | Forearm pronation ≥ 45° for ≥ 40% time | [37] | LE | - | HR | 1.60 (0.93, 2.73) | a) |
| | | #26 | Forearm supination ≥ 45° for ≥ 5% time | [37] | LE | - | HR | 1.19 (0.71, 2.00) | a) |
| | | #79 | Forearm supination ≥ 45° for ≥ 5% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 1.47 (0.74, 2.93) | a) |
| | | #80 | Forearm supination ≥ 45° for ≥ 5% time and duty cycle < 10% time | [37] | LE | - | HR | 1.59 (0.76, 3.34) | a) |
| | | #81 | Forearm supination ≥ 45° for < 5% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 2.02 (0.98, 4.13) | a) |
| | | #65 | Forearm rotation ≥ 45° for ≥ 45% time | [37] | LE | - | HR | 1.41 (0.82, 2.42) | a) |
| | | #82 | Forearm rotation ≥ 45° for ≥ 45% time and duty cycle < 10% time | [37] | LE | - | HR | 2.20 (0.77, 6.30) | a) |
| | | #83 | Forearm rotation ≥ 45° for < 45% time and duty cycle ≥ 10% time | [37] | LE | - | HR | 2.22 (0.70, 7.04) | a) |
| | S11 Body posture | #84 | Standing work > 1h/day | [40] | LE | Men | OR | 2.40 (0.80, 6.70) | g) |
| | | | | | LE | Women | OR | 1.90 (0.40, 8.10) | g) |
| | | #85 | Sedentary work > 1h/day | [40] | LE | Men | OR | 0.50 (0.20, 1.10) | g) |
| | | | | | LE | Women | OR | 0.50 (0.20, 2.10) | g) |
| | | #86 | PC work > 1h/day | [40] | LE | Men | OR | 1.00 (0.30, 3.50) | g) |
| | | | | | LE | Women | OR | 0.30 (0.10, 0.80) | g) |
| Vibration | S12 Hand-arm vibration | #87 | Hand-arm vibration: acceleration ≥ 3 m/s² > 0 to < 1 h/day | [39] | UN | - | OR | 1.97 (0.95, 4.10) | j) |
| | | #88 | Use of vibrating hand tools > 2 h/day | [32] | LE | Men | OR | 0.95 (0.46, 1.97) | a) |
| | | | | | LE | Women | OR | 2.08 (0.62, 6.98) | a) |
| | | #89 | Vibration stress > 1h/day | [40] | LE | Men | OR | 1.50 (0.50, 4.10) | g) |
| | S13 Force & repetition | #90 | Frequency of forceful exertions (≥ 44.1 N or ≥ 4.5 kg) ≥ 2 times/min | [37] | LE | - | HR | 1.18 (0.69, 2.00) | a) |
| | S14 Posture & force | #91 | Forearm supination ≥ 45°; forceful lifting (≥ 4.5 kg) (low on either posture or force and high on the other) in [% time] | [31] | LE | - | OR | 1.21 (0.44, 3.38) | i) |
| | | #92 | Forearm supination ≥ 45° ≥ 5 % (duty cycle) or forceful lifting (≥ 4.5 kg) > 0% of time | [31] | LE | - | OR | 1.09 (0.38, 3.09) | d) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Combined Exposures | | #93 | Wrist flexion/extension ≥ 15° for ≥ 40% time and any power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.52 (0.78, 2.96) | a) |
| | | #94 | Wrist flexion/extension ≥ 15° for ≥ 40% time and no power grip (≥ 44.1 N) | [37] | LE | - | HR | 0.77 (0.40, 1.50) | a) |
| | | #95 | Wrist flexion/extension ≥ 15° for < 40% time and any power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.32 (0.55, 3.15) | a) |
| | | #96 | Wrist flexion/extension ≥ 15° for ≥ 40% time and lifting (≥ 4.5 kg) ≥ 3% time | [37] | LE | - | HR | 1.18 (0.60, 2.33) | a) |
| | | #97 | Wrist flexion/extension ≥ 15° for ≥ 40% time and lifting (≥ 4.5 kg) < 3% time | [37] | LE | - | HR | 0.74 (0.36, 1.50) | a) |
| | | #98 | Wrist flexion/extension ≥ 15° for < 40% time and lifting (≥ 4.5 kg) ≥ 3% time | [37] | LE | - | HR | 0.96 (0.43, 2.13) | a) |
| | | #99 | Wrist flexion/extension ≥ 45° for ≥ 5% time and any power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.39 (0.67, 2.89) | a) |
| | | #100 | Wrist flexion/extension ≥ 45° for ≥ 5% time and no power grip (≥ 44.1 N) | [37] | LE | - | HR | 0.91 (0.46, 1.79) | a) |
| | | #101 | Wrist flexion/extension ≥ 45° for < 5% time and any power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.94 (0.85, 4.39) | a) |
| | | #102 | Wrist flexion/extension ≥ 45° for ≥ 5% time and lifting (≥ 4.5 kg) ≥ 3% time | [37] | LE | - | HR | 1.11 (0.54, 2.27) | a) |
| | | #103 | Wrist flexion/extension ≥ 45° for ≥ 5% time and lifting (≥ 4.5 kg) < 3% time | [37] | LE | - | HR | 0.93 (0.45, 1.95) | a) |
| | | #104 | Wrist flexion/extension ≥ 45° for < 5% time and lifting (≥ 4.5 kg) ≥ 3% time | [37] | LE | - | HR | 1.52 (0.68, 3.43) | a) |
| | | #105 | Forearm pronation ≥ 45° for ≥ 40 % time and no power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.97 (1.00, 3.89) | e) |
| | | #106 | Forearm pronation ≥ 45° for < 40 % time and any power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.65 (0.69, 3.96) | e) |
| | | #107 | Forearm pronation ≥ 45° for ≥ 40 % time and lifting (≥ 4.5 kg) < 3 % of time | [37] | LE | - | HR | 1.98 (0.96, 4.07) | e) |
| | | #108 | Forearm pronation ≥ 45° for < 40 % time and lifting (≥ 4.5 kg) ≥ 3 % of time | [37] | LE | - | HR | 1.58 (0.77, 3.22) | e) |
| | | #109 | Forearm supination ≥ 45° for ≥ 5% time and any power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.48 (0.62, 3.55) | a) |
| | | #110 | Forearm supination ≥ 45° for ≥ 5% time and no power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.86 (0.96, 3.60) | a) |
| | | #111 | Forearm supination ≥ 45° for ≥ 5% time and lifting (≥ 4.5 kg) ≥ 3% time | [37] | LE | - | HR | 1.32 (0.66, 2.62) | a) |
| | | #112 | Forearm supination ≥ 45° for ≥ 5% time and lifting (≥ 4.5 kg) < 3% time | [37] | LE | - | HR | 1.89 (0.92, 3.90) | a) |
| | | #113 | Forearm rotation ≥ 45° for ≥ 45% time and no power grip (≥ 44.1 N) | [37] | LE | - | HR | 1.88 (0.83, 4.28) | a) |
| | | #114 | Forearm rotation ≥ 45° for < 45% time and any power grip (≥ 44.1 N) | [37] | LE | - | HR | 2.31 (0.82, 6.53) | a) |
| | | #115 | Forearm rotation ≥ 45° for ≥ 45 % time and lifting (≥ 4.5 kg) ≥ 3 % of time | [37] | LE | - | HR | 2.27 (0.88, 5.88) | a) |
| | | #116 | Forearm rotation ≥ 45° for ≥ 45 % time and lifting (≥ 4.5 kg) < 3 % of time | [37] | LE | - | HR | 1.50 (0.58, 3.84) | a) |
| | | #117 | Forearm rotation ≥ 45° for < 45 % time and lifting (≥ 4.5 kg) ≥ 3 % of time | [37] | LE | - | HR | 1.25 (0.43, 3.61) | a) |
| | | #40 | Forceful exertion (turning) > 1 h/day | [40] | LE | Women | OR | 1.40 (0.30, 6.80) | g) |
| | | #45 | Less hard physical exertion (BORG Score 6 to 13) and | [32] | LE | Men | OR | 1.52 (0.52, 4.44) | l) |
| | | | 1 to 2 elbow movements | | LE | Women | OR | 0.53 (0.17, 1.60) | l) |
| | | #118 | Hard physical exertion (BORG Score 14 to 20) and no elbow movement | [32] | LE | Men | OR | 0.56 (0.11, 2.92) | a) |
| | | | | | LE | Men | OR | 0.76 (0.14, 3.98) | l) |
| | | | | | LE | Women | OR | 0.80 (0.24, 2.71) | l) |
| | | #41 | Hard physical exertion (BORG Score 14 to 20) and 1 elbow movement | [32] | LE | Women | OR | 2.54 (1.12, 5.76) | m) |
| | | #42 | Hard physical exertion (BORG Score 14 to 20) and 2 elbow movements | [32] | LE | Men | OR | 5.60 (2.76, 11.35) | m) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | (elbow movements = elbow flexion/extension > 2 h/day and wrist bending > 2 h/day | | LE | Women | OR | 2.89 (1.28, 6.51) | m) |
| | | | High physical exertion with elbow flexion/ extension > 2 hours/day wrist and extreme bending > 2 hours/day (at baseline investigation) | [38] | LE | Women | IRR | 1.50 (0.50, 4.70) | f) |
| | S15 Repetition & posture | #43 | Repetitive/constrained work with > 30 s or > 50 % of cycle time involved same fundamental cycle) vs. > 50% (working time) involved prolonged awkward postures | [33] | LE | Men | PR | 1.00 (0.30, 2.80) | c) |
| | | | | | LE | Women | PR | 1.90 (1.00, 3.80) | c) |
| | | | | | ME | Women | PR | 3.50 (1.00, 12.00) | c) |
| | | | | | Pronator | Women | PR | 3.40 (0.40, 29.00) | c) |
| | | | | | Radial | Men | PR | 1.30 (0.10, 21.00) | c) |
| | | | | | Radial | Women | PR | 3.40 (0.80, 15.00) | c) |
| | S16 Posture & repetition & force | #119 | Wrist flexion/extension ≥ 15° for ≥ 40% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.09 (0.56, 2.13) | a) |
| | | #120 | Wrist flexion/extension ≥ 15° for ≥ 40% time and forceful exertions (≥ 44.1 N) < 2/min | [37] | LE | - | HR | 0.67 (0.33, 1.36) | a) |
| | | #121 | Wrist flexion/extension ≥ 15° for < 40% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 0.77 (0.34, 1.74) | a) |
| | | #122 | Wrist flexion/extension ≥ 45° for ≥ 5% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.02 (0.51, 2.04) | a) |
| | | #123 | Wrist flexion/extension ≥ 45° for ≥ 5% time and forceful exertions (≥ 44.1 N) < 2/min | [37] | LE | - | HR | 0.86 (0.41, 1.77) | a) |
| | | #124 | Wrist flexion/extension ≥ 45° for < 5% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.28 (0.55, 3.02) | a) |
| | | #125 | Forearm pronation ≥ 45° for ≥ 40% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 2.28 (1.00, 5.19) | a) |
| | | #126 | Forearm pronation ≥ 45° for ≥ 40% time and forceful exertions (≥ 44.1 N) < 2/min | [37] | LE | - | HR | 1.36 (0.63, 2.94) | a) |
| | | #127 | Forearm pronation ≥ 45° for < 40% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.03 (0.44, 2.42) | a) |
| | | #128 | Forearm supination ≥ 45° for ≥ 5% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.29 (0.66, 2.51) | a) |
| | | #129 | Forearm supination ≥ 45° for ≥ 5% time and forceful exertions (≥ 44.1 N) < 2/min | [37] | LE | - | HR | 1.36 (0.65, 2.82) | a) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | #130 | Forearm supination ≥ 45° for < 5% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.35 (0.64, 2.83) | a) |
| | | #131 | Forearm rotation ≥ 45° for ≥ 45% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.96 (0.80, 4.84) | a) |
| | | #132 | Forearm rotation ≥ 45° for ≥ 45% time and forceful exertions (≥ 44.1 N) < 2/min | [37] | LE | - | HR | 1.52 (0.63, 3.66) | a) |
| | | #133 | Forearm rotation ≥ 45° for < 45% time and forceful exertions (≥ 44.1 N) ≥ 2/min | [37] | LE | - | HR | 1.20 (0.42, 3.37) | a) |

_Legend:_ * Forceful exertions were only shown for power grip, details for pinch grip were shown in Supplementary File VII (Table S5); sub-categories of exposure S, S3 and S5 are significant and are not presented here.
_Outcome:_ UN = ulnar neuropathy; LE = lateral epicondylitis; ME = medial epicondylitis; LE / ME = lateral and / or medial epicondylitis, Radial = Radial tunnel syndrome, Pronator = Pronator teres syndrome
_Measure:_ odds ratio [OR]; hazard ratio [HR]; incidence rate ratio [IRR]; prevalence ratio [PR]
_Adjustment:_
a) = univariate analysis;
c) = adjustment not reported;
d) = final model (age, gender, BMI, smoking status, personal, psychosocial, and work organizational variables);
e) = adjusted for age and gender;
f) = adjusted for age and combined physical work exposure including physical exertion and elbow movements;
g) = sex-adjusted;
i) = adjusted for age (continuous), gender, BMI (continuous);
j) = partly adjusted for body mass index, pack-years of smoking (continuous), alcohol consumption (continuous), side-specific fractures (never/ever), full anaesthesia within a 5-year period up to the index year (no/yes), predisposing disorders (no/yes), use of crutches within a 5-year period up to the index year (no/yes), hand–arm intensive sports (0, 1, 2) and weight loss ≥ 10 kg within half a year during a 5-year period up to the index year (no/yes);
l) = adjusted for individual characteristics, repetition, combined physical work exposure including physical exertion, elbow flexion/extension and wrist bending, and social support
m) = adjusted for individual characteristics, repetition, combined physical work exposure including physical exertion, elbow flexion/extension and wrist bending, and social support with aggregation of low categories for combined physical work exposure;
n) = adjusted for age and repetitiveness

## 8.2 Publication 2 – additional information for Seidel et al. 2021b

### *8.2.1 More detailed materials, methods, and results*

**Table 3.** "*Characteristics of the study population (n = 500)*" (Seidel et al. 2021b, p. 6) as categorial distribution. Table was extracted from Seidel et al. 2021b, p. 6 extended and modified.

| Characteristics | n | % |
|---|---|---|
| **Age [years]** | **500** | **100.0** |
| Age [years] ≥ 55 | 65 | 13.0 |
| ≥ 45 to < 55 | 140 | 28.0 |
| ≥ 35 to < 45 | 128 | 25.6 |
| ≥ 25 to < 35 | 134 | 26.8 |
| < 25 | 33 | 6.6 |
| **Gender** | **500** | **100.0** |
| Female | 92 | 18.4 |
| Male | 408 | 81.6 |
| **BMI [kg/m²]** | **500** | **100.0** |
| Obese I/II/III, ≥ 30 | 102 | 20.4 |
| Overweight, ≥ 25 to < 30 | 205 | 41.0 |
| Normal weight, < 25 | 193 | 38.6 |
| **Sport practice (regularly)** | **500** | **100.0** |
| Regular | 154 | 30.8 |
| Occasional | 130 | 26.0 |
| Never | 216 | 43.2 |
| **Smoker** | **500** | **100.0** |
| Yes | 239 | 47.8 |
| No | 261 | 52.2 |
| **Dominant hand** | **500** | **100.0** |
| Right | 434 | 86.8 |
| Left | 50 | 10.0 |
| Both sided | 16 | 3.2 |

| Education | n | % |
|---|---|---|
| **Education Job** | **498[a]** | **100.0** |
| Trainee/Student | 5 | 1.0 |
| No vocational qualification | 105 | 21.1 |
| Vocational training completed | 288 | 57.8 |
| Business/vocational-school education | 44 | 8.8 |
| Completed technical, master craftsman's, vocational or specialist academy | 22 | 4.4 |
| University of applied sciences completed | 9 | 1.8 |
| University degree completed | 16 | 3.2 |
| Another professional qualification | 9 | 1.8 |

| Outcomes | n | % |
|---|---|---|
| **Musculoskeletal disorders of the back, limbs, other body parts** | **496[a]** | **100.0** |
| Yes, < 12 months | 43 | 8.7 |
| Yes, < 4 weeks | 194 | 39.1 |
| No | 259 | 52.2 |
| **Musculoskeletal disorders of the distal upper extremity** | **500** | **100.0** |
| **Arthrosis of the distal joints** | **500** | **100.0** |
| Cases | 34 | 6.8 |
| **Lateral Epicondylitis** | **500** | **100.0** |
| Cases | 60 | 12.0 |
| **Medial Epicondylitis** | **500** | **100.0** |
| Cases | 15 | 3.0 |
| **Complaints (month prevalence)** | | |
| **Elbow** | **500** | **100.0** |
| Cases | 66 | 13.2 |

BMI, body mass index; n = number of subjects in the analyses.

[a] Cases missing due to incomplete information provided by participants (does not correspond to any exclusion criterion).

**Table 4.** "*Characteristics of the study population (n = 500)*" (Seidel et al. 2021b, p. 6) based on continuous variables. Table was extracted from Seidel et al. 2021b, p. 6 extended and modified.

| Characteristics | n | Mean | SD | Min | P5 | P25 | P50 | P75 | P95 | Max |
|---|---|---|---|---|---|---|---|---|---|---|
| Age [years] | 500 | 41.1 | 11.2 | 18.0 | 23.1 | 32.0 | 41.0 | 50.0 | 59.0 | 65.0 |
| BMI [kg/m$^2$] | 500 | 26.8 | 4.5 | 17.7 | 20.5 | 23.9 | 26.1 | 29.4 | 35.3 | 47.7 |
| Job satisfaction[a] | 500 | 62.8 | 11.3 | 9.5 | 42.9 | 57.1 | 64.3 | 66.7 | 76.2 | 100.0 |
| Working duration [h/day] | 499[b] | 7.6 | 0.9 | 3.0 | 6.0 | 7.5 | 8.0 | 8.0 | 8.5 | 10.0 |
| Working duration [h/week] | 498[b] | 37.9 | 4.5 | 10.0 | 26.0 | 37.0 | 38.5 | 40.0 | 43.5 | 50.0 |
| Work in current job [years] | 498[c] | 9.8 | 8.3 | 0.3 | 1.5 | 3.0 | 7.0 | 15.0 | 26.0 | 48.0 |

P5, 5$^{th}$ percentile; BMI, body mass index; COPSOQ, Copenhagen Psychosocial Questionnaire; h, hours; Max, Maximum; Min, Minimum; n, number of subjects in the analyses; SD, standard deviation.

[a] Job satisfaction: 7 four-level items were measured using the COPSOQ (Kristensen 2002; Nübling et al. 2005); The items were combined and standardized to 100 points (continuously modelled), 0 = no satisfaction, 100.0 = high satisfaction (BAuA 2019b).

[b] Cases missing due to incomplete information provided by participants (does not correspond to any exclusion criterion).

[c] 2 cases were missing, but since only subjects with a general work experience of more than 3 months at the workplace were included (general inclusion criterion in MEGAPHYS), it was assumed that the subjects simply forgot to provide this information (at least 3 months experience at current workplace), so these cases were not generally excluded a priori from the data set.

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*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$.
*TLV Forearm right categories 2 to 4 - multivariate adjusted for confounders - and D04.
GENLIN D04_dichot_model (REFERENCE=FIRST) BY Raucher_JN_model Sport_JN_model Gender_12_rev_model
   New_Workplace_Code_v2_model New_Company_Code_v2_model Age_group_model BMI_definit_cat_model
   D01_dichot_model D02_dichot_model D03_dichot_model D05_dichot_model
   D06_dichot_model D07_dichot_model D08_dichot_model D09_dichot_model D10_dichot_model D11_dichot_model
   E3_k1_model   E3_k2_model E3_k3_model E3_k6_model E3_k7_new_model E3_k8_model E3_k9_new_model E3_k10_model
   E3_k11_new_model E3_k12_model E3_k13_model E3_k18_model E3_k19_model
   WristR_TLV_2_to_4_model WristL_TLV_2_to_4_model ForeArmR_TLV_2_to_4_model ForeArmL_TLV_2_to_4_model
      (ORDER=DESCENDING) WITH Alter_Jahre_model Satisfaction_work_model Co_morbidity_N_other_dis_D04_model
 /MODEL Alter_Jahre_model Gender_12_rev_model BMI_definit_cat_model
    Raucher_JN_model Sport_JN_model Co_morbidity_N_other_dis_D04_model Satisfaction_work_model
    ForeArmR_TLV_2_to_4_model INTERCEPT=YES
 DISTRIBUTION=BINOMIAL LINK=LOGIT
 /CRITERIA METHOD=FISHER(1) SCALE=1 MAXITERATIONS=100 MAXSTEPHALVING=5
    PCONVERGE=1E-006(ABSOLUTE)
   SINGULAR=1E-012 ANALYSISTYPE=3(WALD) CILEVEL=95 LIKELIHOOD=FULL
 /REPEATED SUBJECT=New_Workplace_Code_v2_model SORT=YES CORRTYPE=EXCHANGEABLE ADJUSTCORR=YES
   COVB=ROBUST MAXITERATIONS=100 PCONVERGE=1e-006(ABSOLUTE) UPDATECORR=1
 /MISSING CLASSMISSING=EXCLUDE
 /PRINT CPS MODELINFO FIT SOLUTION (EXPONENTIATED).
*$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$.
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**Figure 1.** Original SPSS script code – GEE model for multivariate association analysis (mTLV for HAL right elbow and LE).

GEE, generalized estimating equation; LE, lateral epicondylitis; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level. Due to the strict data protection guidelines in the MEGAPHYS project, the variables cannot be explained here in more detail.

**Table 5.** Association analyses mTLV for HAL elbow right and LE (n = 500).
LE, lateral epicondylitis; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; n, number of subjects in the analyses. Parts of the table were extracted from Seidel et al. 2021b, p. 8 and modified.

| **Lateral Epicondylitis** | **UNIVARIATE Analysis** | | | | **ADJUSTED[a] Analysis** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **OR** | **LCI** | **UCI** | | **OR** | **LCI** | **UCI** | |
| Intercept | – | | | | **0.02** | **0.00** | **0.20** | **0.001** |
| Age (continuous) | **1.05** | **1.03** | **1.08** | **<0.0001** | **1.06** | **1.03** | **1.09** | **<0.0001** |
| Gender | | | | | | | | |
| Females | 0.90 | 0.46 | 1.78 | 0.765 | 0.59 | 0.27 | 1.30 | 0.189 |
| Males [Reference] | 1.00 | – | | | 1.00 | – | | |
| BMI, [kg/m$^2$] | | | | | | | | |
| Obese I/II/III, ≥ 30.0 | 1.47 | 0.69 | 3.14 | 0.322 | 1.34 | 0.58 | 3.10 | 0.499 |
| Overweight, ≥ 25.0 to < 30.0 | 1.19 | 0.62 | 2.26 | 0.599 | 1.08 | 0.55 | 2.12 | 0.814 |
| Normal weight, < 25.0 [Reference] | 1.00 | – | | | 1.00 | – | | |
| Smoking | | | | | | | | |
| Yes | 1.52 | 0.88 | 2.63 | 0.130 | 1.79 | 0.95 | 3.39 | 0.074 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Sport (regularly) | | | | | | | | |
| Regularly | 1.01 | 0.56 | 1.79 | 0.985 | 1.56 | 0.74 | 3.27 | 0.243 |
| Occasionally | 0.70 | 0.34 | 1.44 | 0.336 | 0.90 | 0.40 | 2.05 | 0.810 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Co-morbidity (# of MSDs) (continuous) | **1.29** | **1.10** | **1.50** | **0.001** | **1.23** | **1.04** | **1.45** | **0.015** |
| Job satisfaction (continuous) | 0.99 | 0.96 | 1.01 | 0.200 | 0.98 | 0.95 | 1.01 | 0.118 |
| mTLV for HAL, elbow right | | | | | | | | |
| Category 3[b]; ≥ TLV | 0.22 | 0.04 | 1.14 | 0.071 | 0.14 | 0.01 | 1.57 | 0.111 |
| Category 2[b]; ≥ AL to < TLV | 1.15 | 0.49 | 2.71 | 0.745 | 1.08 | 0.44 | 2.68 | 0.862 |
| Category 1[b]; < AL [Reference] | 1.00 | – | | | 1.00 | – | | |

AL, Action Limit; BMI, body mass index; LCI, lower 95 %-confidence interval limit; MSDs, musculoskeletal disorders; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; OR, Odds Ratio; *p*, *p*-value (significant results in **bold**, $p < 0.05$); TLV, Threshold Limit Value; UCI, upper 95 %-confidence interval limit; #, number.

[a] adjusted for: Age (continuous), Gender (nominal), BMI (ordinal), Smoking (nominal), regularly Sport (ordinal), Job satisfaction (continuous), Co-morbidity (# of MSDs (number of additional musculoskeletal disorders), continuous).

[b] Exposure category classification according to Kapellusch et al. 2017: Category 1: less exposed, under AL threshold (< AL, reference category); Category 2: exposed, above AL and below TLV (≥ AL to < TLV); Category 3: highly exposed, above TLV (≥ TLV).

**Table 6.** Association analyses mTLV for HAL elbow left and LE (n = 500).
LE, lateral epicondylitis; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; n, number of subjects in the analyses. Parts of the table were extracted from Seidel et al. 2021b, p. 8 and modified.

| **Lateral Epicondylitis** | **UNIVARIATE Analysis** | | | | **ADJUSTED[a] Analysis** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **OR** | **LCI** | **UCI** | | **OR** | **LCI** | **UCI** | |
| Intercept | – | | | | **0.02** | **0.00** | **0.17** | **<0.001** |
| Age (continuous) | **1.05** | **1.03** | **1.08** | **<0.0001** | **1.06** | **1.03** | **1.09** | **<0.0001** |
| Gender | | | | | | | | |
| Females | 0.90 | 0.46 | 1.78 | 0.765 | 0.65 | 0.30 | 1.43 | 0.285 |
| Males [Reference] | 1.00 | – | | | 1.00 | – | | |
| BMI, [kg/m²] | | | | | | | | |
| Obese I/II/III, ≥ 30.0 | 1.47 | 0.69 | 3.14 | 0.322 | 1.35 | 0.59 | 3.07 | 0.473 |
| Overweight, ≥ 25.0 to < 30.0 | 1.19 | 0.62 | 2.26 | 0.599 | 1.11 | 0.56 | 2.17 | 0.770 |
| Normal weight, < 25.0 [Reference] | 1.00 | – | | | 1.00 | – | | |
| Smoking | | | | | | | | |
| Yes | 1.52 | 0.88 | 2.63 | 0.130 | 1.86 | 0.99 | 3.50 | 0.055 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Sport (regularly) | | | | | | | | |
| Regularly | 1.01 | 0.56 | 1.79 | 0.985 | 1.54 | 0.75 | 3.15 | 0.239 |
| Occasionally | 0.70 | 0.34 | 1.44 | 0.336 | 0.93 | 0.42 | 2.07 | 0.864 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Co-morbidity (# of MSDs) (continuous) | **1.29** | **1.10** | **1.50** | **0.001** | **1.20** | **1.02** | **1.42** | **0.030** |
| Job satisfaction (continuous) | 0.99 | 0.96 | 1.01 | 0.200 | 0.98 | 0.95 | 1.01 | 0.121 |
| mTLV for HAL, elbow left | | | | | | | | |
| Category 3[b]; ≥ TLV | 0.88 | 0.53 | 1.46 | 0.622 | 1.14 | 0.55 | 2.33 | 0.728 |
| Category 2[b]; ≥ AL to < TLV | 0.91 | 0.29 | 2.89 | 0.872 | 0.77 | 0.22 | 2.68 | 0.680 |
| Category 1[b]; < AL [Reference] | 1.00 | – | | | 1.00 | – | | |

AL, Action Limit; BMI, body mass index; LCI, lower 95 %-confidence interval limit; MSDs, musculoskeletal disorders; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; OR, Odds Ratio; *p*, *p*-value (significant results in **bold**, $p < 0.05$); TLV, Threshold Limit Value; UCI, upper 95 %-confidence interval limit; #, number.

[a] adjusted for: Age (continuous), Gender (nominal), BMI (ordinal), Smoking (nominal), regularly Sport (ordinal), Job satisfaction (continuous), Co-morbidity (# of MSDs (number of additional musculoskeletal disorders), continuous).

[b] Exposure category classification according to Kapellusch et al. 2017: Category 1: less exposed, under AL threshold (< AL, reference category); Category 2: exposed, above AL and below TLV (≥ AL to < TLV); Category 3: highly exposed, above TLV (≥ TLV).

**Table 7.** Association analyses mTLV for HAL elbow right and arthrosis (n = 500).

mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; n, number of subjects in the analyses. Parts of the table were extracted from Seidel et al. 2021b, p. 8 and modified.

| **Arthrosis of the distal joints** | **UNIVARIATE Analysis** | | | | **ADJUSTED[a] Analysis** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **OR** | **LCI** | **UCI** | | **OR** | **LCI** | **UCI** | |
| Intercept | – | | | | **0.00** | **0.00** | **0.03** | **<0.0001** |
| Age (continuous) | **1.07** | **1.03** | **1.12** | **0.001** | **1.05** | **1.00** | **1.09** | **0.036** |
| Gender | | | | | | | | |
| Females | 1.38 | 0.55 | 3.45 | 0.487 | 0.75 | 0.32 | 1.74 | 0.508 |
| Males [Reference] | 1.00 | – | | | 1.00 | – | | |
| BMI, [kg/m$^2$] | | | | | | | | |
| Obese I/II/III, ≥ 30.0 | 1.95 | 0.85 | 4.47 | 0.116 | 1.24 | 0.51 | 3.04 | 0.639 |
| Overweight, ≥ 25.0 to < 30.0 | 1.01 | 0.44 | 2.30 | 0.989 | 0.84 | 0.34 | 2.05 | 0.704 |
| Normal weight, < 25.0 [Reference] | 1.00 | – | | | 1.00 | – | | |
| Smoking | | | | | | | | |
| Yes | 0.49 | 0.22 | 1.10 | 0.084 | 0.47 | 0.22 | 1.00 | 0.051 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Sport (regularly) | | | | | | | | |
| Regularly | 0.61 | 0.25 | 1.50 | 0.284 | 0.66 | 0.26 | 1.65 | 0.373 |
| Occasionally | 0.70 | 0.29 | 1.69 | 0.422 | 0.78 | 0.33 | 1.89 | 0.589 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Co-morbidity (# of MSDs) (continuous) | **1.51** | **1.28** | **1.79** | **<0.0001** | **1.38** | **1.16** | **1.64** | **<0.001** |
| Job satisfaction (continuous) | 1.02 | 0.99 | 1.05 | 0.190 | 1.02 | 0.98 | 1.06 | 0.398 |
| mTLV for HAL, elbow right | | | | | | | | |
| Category 3[b]; ≥ TLV | 1.70 | 0.84 | 3.43 | 0.143 | 1.14 | 0.44 | 2.96 | 0.786 |
| Category 2[b]; ≥ AL to < TLV | **2.25** | **1.06** | **4.76** | **0.035** | 1.89 | 0.89 | 4.05 | 0.099 |
| Category 1[b]; < AL [Reference] | 1.00 | – | | | 1.00 | – | | |

AL, Action Limit; BMI, body mass index; LCI, lower 95 %-confidence interval limit; MSDs, musculoskeletal disorders; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; OR, Odds Ratio; *p*, *p*-value (significant results in **bold**, $p < 0.05$); TLV, Threshold Limit Value; UCI, upper 95 %-confidence interval limit; #, number.

[a] adjusted for: Age (continuous), Gender (nominal), BMI (ordinal), Smoking (nominal), regularly Sport (ordinal), Job satisfaction (continuous), Co-morbidity (# of MSDs (number of additional musculoskeletal disorders), continuous).

[b] Exposure category classification according to Kapellusch et al. 2017: Category 1: less exposed, under AL threshold (< AL, reference category); Category 2: exposed, above AL and below TLV (≥ AL to < TLV); Category 3: highly exposed, above TLV (≥ TLV).

**Table 8.** Association analyses mTLV for HAL elbow left and arthrosis (n = 500).
mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; n, number of subjects in the analyses. Parts of the table were extracted from Seidel et al. 2021b, p. 8 and modified.

| **Arthrosis of the distal joints** | **UNIVARIATE Analysis** | | | | **ADJUSTED[a] Analysis** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **OR** | **LCI** | **UCI** | | **OR** | **LCI** | **UCI** | |
| Intercept | – | | | | **0.00** | **0.00** | **0.03** | **<0.0001** |
| Age (continuous) | **1.07** | **1.03** | **1.12** | **0.001** | **1.04** | **1.00** | **1.09** | **0.042** |
| Gender | | | | | | | | |
| Females | 1.38 | 0.55 | 3.45 | 0.487 | 0.72 | 0.30 | 1.76 | 0.475 |
| Males [Reference] | 1.00 | – | | | 1.00 | – | | |
| BMI, [kg/$m^2$] | | | | | | | | |
| Obese I/II/III, ≥ 30.0 | 1.95 | 0.85 | 4.47 | 0.116 | 1.31 | 0.51 | 3.36 | 0.570 |
| Overweight, ≥ 25.0 to < 30.0 | 1.01 | 0.44 | 2.30 | 0.989 | 0.84 | 0.35 | 2.01 | 0.694 |
| Normal weight, < 25.0 [Reference] | 1.00 | – | | | 1.00 | – | | |
| Smoking | | | | | | | | |
| Yes | 0.49 | 0.22 | 1.10 | 0.084 | 0.47 | 0.21 | 1.05 | 0.067 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Sport (regularly) | | | | | | | | |
| Regularly | 0.61 | 0.25 | 1.50 | 0.284 | 0.57 | 0.20 | 1.65 | 0.302 |
| Occasionally | 0.70 | 0.29 | 1.69 | 0.422 | 0.79 | 0.32 | 1.93 | 0.605 |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Co-morbidity (# of MSDs) (continuous) | **1.51** | **1.28** | **1.79** | **<0.0001** | **1.42** | **1.19** | **1.69** | **<0.0001** |
| Job satisfaction (continuous) | 1.02 | 0.99 | 1.05 | 0.190 | 1.02 | 0.98 | 1.06 | 0.336 |
| mTLV for HAL, elbow left | | | | | | | | |
| Category 3[b]; ≥ TLV | **4.88** | **2.98** | **7.97** | **<0.0001** | **9.23** | **3.29** | **25.87** | **<0.0001** |
| Category 2[b]; ≥ AL to < TLV | **2.23** | **1.06** | **4.67** | **0.034** | 2.10 | 0.87 | 5.10 | 0.100 |
| Category 1[b]; < AL [Reference] | 1.00 | – | | | 1.00 | – | | |

AL, Action Limit; BMI, body mass index; LCI, lower 95 %-confidence interval limit; MSDs, musculoskeletal disorders; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; OR, Odds Ratio; *p*, *p*-value (significant results in **bold**, $p < 0.05$); TLV, Threshold Limit Value; UCI, upper 95 %-confidence interval limit; #, number.

[a] adjusted for: Age (continuous), Gender (nominal), BMI (ordinal), Smoking (nominal), regularly Sport (ordinal), Job satisfaction (continuous), Co-morbidity (# of MSDs (number of additional musculoskeletal disorders), continuous).

[b] Exposure category classification according to Kapellusch et al. 2017: Category 1: less exposed, under AL threshold (< AL, reference category); Category 2: exposed, above AL and below TLV (≥ AL to < TLV); Category 3: highly exposed, above TLV (≥ TLV).

**Table 9.** Association analyses mTLV for HAL elbow right and elbow complaints based on month prevalence (n = 500).
n, number of subjects in the analyses. Parts of the table were extracted from Seidel et al. 2021b, p. 8 and modified.

| Elbow complaints | UNIVARIATE Analysis | | | | ADJUSTED[a] Analysis | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **OR** | **LCI** | **UCI** | | **OR** | **LCI** | **UCI** | |
| Intercept | – | | | | **0.03** | **0.00** | **0.27** | **0.002** |
| Age (continuous) | **1.04** | **1.02** | **1.06** | **<0.001** | **1.04** | **1.01** | **1.06** | **0.003** |
| Gender | | | | | | | | |
| Females | **2.55** | **1.52** | **4.29** | **<0.001** | 1.84 | 0.89 | 3.81 | 0.099 |
| Males [Reference] | 1.00 | – | | | 1.00 | – | | |
| BMI, [kg/m²] | | | | | | | | |
| Obese I/II/III, ≥ 30.0 | 0.89 | 0.46 | 1.73 | 0.740 | 1.14 | 0.52 | 2.51 | 0.744 |
| Overweight, ≥ 25.0 to < 30.0 | 1.11 | 0.63 | 1.95 | 0.720 | 1.36 | 0.72 | 2.60 | 0.344 |
| Normal weight, < 25.0 [Reference] | 1.00 | – | | | 1.00 | – | | |
| Smoking | | | | | | | | |
| Yes | 1.69 | 0.98 | 2.93 | 0.060 | **2.07** | **1.09** | **3.95** | **0.026** |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Sport (regularly) | | | | | | | | |
| Regularly | 0.97 | 0.52 | 1.81 | 0.922 | 1.43 | 0.66 | 3.10 | 0.369 |
| Occasionally | 1.49 | 0.82 | 2.71 | 0.186 | **1.92** | **1.02** | **3.59** | **0.043** |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Co-morbidity (# of MSDs) (continuous) | **1.40** | **1.21** | **1.62** | **<0.0001** | **1.31** | **1.12** | **1.53** | **0.001** |
| Job satisfaction (continuous) | 0.98 | 0.96 | 1.00 | 0.084 | 0.98 | 0.95 | 1.00 | 0.083 |
| mTLV for HAL, elbow right | | | | | | | | |
| Category 3[b]; ≥ TLV | 0.47 | 0.08 | 2.70 | 0.398 | 0.46 | 0.06 | 3.61 | 0.458 |
| Category 2[b]; ≥ AL to < TLV | **1.99** | **1.08** | **3.67** | **0.028** | 1.52 | 0.68 | 3.42 | 0.306 |
| Category 1[b]; < AL [Reference] | 1.00 | – | | | 1.00 | – | | |

AL, Action Limit; BMI, body mass index; LCI, lower 95 %-confidence interval limit; MSDs, musculoskeletal disorders; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; OR, Odds Ratio; *p, p*-value (significant results in **bold**, $p < 0.05$); TLV, Threshold Limit Value; UCI, upper 95 %-confidence interval limit; #, number.

[a] adjusted for: Age (continuous), Gender (nominal), BMI (ordinal), Smoking (nominal), regularly Sport (ordinal), Job satisfaction (continuous), Co-morbidity (# of MSDs (number of additional musculoskeletal disorders), continuous).

[b] Exposure category classification according to Kapellusch et al. 2017: Category 1: less exposed, under AL threshold (< AL, reference category); Category 2: exposed, above AL and below TLV (≥ AL to < TLV); Category 3: highly exposed, above TLV (≥ TLV).

**Table 10.** Association analyses mTLV for HAL elbow left and elbow complaints based on month prevalence (n = 500).
n, number of subjects in the analyses. Parts of the table were extracted from Seidel et al. 2021b, p. 8 and modified.

| **Elbow complaints** | **UNIVARIATE Analysis** | | | | **ADJUSTED[a] Analysis** | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **OR** | **LCI** | **UCI** | | **OR** | **LCI** | **UCI** | |
| Intercept | – | | | | **0.03** | **0.00** | **0.23** | **0.001** |
| Age (continuous) | **1.04** | **1.02** | **1.06** | **<0.001** | **1.04** | **1.01** | **1.06** | **0.002** |
| Gender | | | | | | | | |
| Females | **2.55** | **1.52** | **4.29** | **<0.001** | **2.23** | **1.14** | **4.35** | **0.019** |
| Males [Reference] | 1.00 | – | | | 1.00 | – | | |
| BMI, [kg/m²] | | | | | | | | |
| Obese I/II/III, ≥ 30.0 | 0.89 | 0.46 | 1.73 | 0.740 | 1.13 | 0.52 | 2.47 | 0.759 |
| Overweight, ≥ 25.0 to < 30.0 | 1.11 | 0.63 | 1.95 | 0.720 | 1.34 | 0.70 | 2.56 | 0.375 |
| Normal weight, < 25.0 [Reference] | 1.00 | – | | | 1.00 | – | | |
| Smoking | | | | | | | | |
| Yes | 1.69 | 0.98 | 2.93 | 0.060 | **2.13** | **1.12** | **4.03** | **0.021** |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Sport (regularly) | | | | | | | | |
| Regularly | 0.97 | 0.52 | 1.81 | 0.922 | 1.52 | 0.70 | 3.28 | 0.289 |
| Occasionally | 1.49 | 0.82 | 2.71 | 0.186 | **1.97** | **1.07** | **3.64** | **0.030** |
| No [Reference] | 1.00 | – | | | 1.00 | – | | |
| Co-morbidity (# of MSDs) (continuous) | **1.40** | **1.21** | **1.62** | **<0.0001** | **1.30** | **1.12** | **1.52** | **0.001** |
| Job satisfaction (continuous) | 0.98 | 0.96 | 1.00 | 0.084 | 0.98 | 0.95 | 1.00 | 0.070 |
| mTLV for HAL, elbow left | | | | | | | | |
| Category 3[b]; ≥ TLV | 0.86 | 0.55 | 1.35 | 0.512 | **0.48** | **0.27** | **0.86** | **0.013** |
| Category 2[b]; ≥ AL to < TLV | 1.41 | 0.60 | 3.31 | 0.433 | 1.29 | 0.49 | 3.41 | 0.602 |
| Category 1[b]; < AL [Reference] | 1.00 | – | | | 1.00 | – | | |

AL, Action Limit; BMI, body mass index; LCI, lower 95 %-confidence interval limit; MSDs, musculoskeletal disorders; mTLV for HAL, measurement-based Threshold Limit Value for Hand Activity Level; OR, Odds Ratio; *p*, *p*-value (significant results in **bold**, $p < 0.05$); TLV, Threshold Limit Value; UCI, upper 95 %-confidence interval limit; #, number.

[a] adjusted for: Age (continuous), Gender (nominal), BMI (ordinal), Smoking (nominal), regularly Sport (ordinal), Job satisfaction (continuous), Co-morbidity (# of MSDs (number of additional musculoskeletal disorders), continuous).

[b] Exposure category classification according to Kapellusch et al. 2017: Category 1: less exposed, under AL threshold (< AL, reference category); Category 2: exposed, above AL and below TLV (≥ AL to < TLV); Category 3: highly exposed, above TLV (≥ TLV).

### *8.2.2 Comparability verification between RepScore and HAL*

The compatibility between the measurement-based RepScore and observational-based HAL was verified before the RepScore was tested in large-scaled association analyses in the field (Seidel et al. 2021b). Therefore, based on 140 technically recorded exposure profiles (including synchronized videos) as presented in chapter 2.3 repetitive tasks of the right upper extremity were additionally analyzed in a pilot investigation at 10 industrial workplaces. The workplaces were selected not randomized but according to a workplace typical cycle time of less than 30 seconds on average (Seidel et al. 2021b). This time was defined by Silverstein et al. 1986 for a repetitive task. For comparison of HAL and RepScore, the workload was determined on the one hand by frame-by-frame analysis of 10 different videos (Seidel et al. 2021b). On the other hand, it was determined by analysis of continuous sensor data. For this video-based purpose, 5 repetitive cycles per workplace were analyzed in synchronized videos (in total 5 cycles x 10 videos). The number and durations of exertions, working time and breaks as well as durations of partial tasks were determined video-frame-accurately using updated CUELA-related software WIDAAN. Intervals and time stamps were set in the software for each exertion and cycle. The updated software was precisely described by Weber et al. 2020a and Seidel et al. 2021b. Based on WIDAAN data and using Microsoft Excel 2016, the following parameters were determined for each cycle according to ACGIH 2001, 2018 and Radwin et al. 2015: Period, Frequency (*F*) and Duty Cycle (*D*). HAL was calculated in Excel using equation 8, as published elsewhere (ACGIH 2018; Akkas et al. 2015; Radwin et al. 2015; Seidel et al. 2021b).

"$HAL = 6.56\, ln\, D \left[\frac{F^{1.31}}{1+3.18F^{1.31}}\right]$" (Seidel et al. 2021b, p. 2) (8)

This formula can be used to calculate a HAL with several decimal places. For each cycle interval, the time-weighted RepScore was automatically calculated using CUELA-related software as described in Seidel et al. 2021b. In total, 50 cycles were analyzed (similar to 50 analyzed industrial tasks in Akkas et al. 2017). The two ordinally scaled values (HAL, RepScore) were each assigned to the same cycle and were therefore be considered as a paired sample. It was assumed that the difference can be quantified by a t-test on paired samples. Therefore, both data series (HAL, RepScore) were first tested for normal distribution using the software SPSS v23 (IBM® SPSS®, IBM, Ehningen,

Germany) including Kolmogorov-Smirnov test. In case of absence of normal distribution, the "*non-parametric Wilcoxon signed-rank test*" (Seidel et al. 2021b, p. 2) was subsequently applied. The following questions build the basis for these investigations: Is there a difference between the methods HAL (wrist, right) and repetition score (wrist, right)? **Alternative hypothesis**: There is a difference. **Null hypothesis**: There is no difference. In any case, the following question is of interest as well: How large is the difference between the methods?
Effect size ('$r$') was calculated according to equation 9 as published by Zbogar et al. 2017 with '$n$' is the number of cycles and '$Z$' corresponds to Z-*value*.

"$r = \frac{Z}{\sqrt{n}}$" (Zbogar et al. 2017, p. 174) (9)

The following effect size classifications as described by Zbogar's group in 2017 were applied: large: $r = 0.5$, medium: $r = 0.3$, and small: $r = 0.1$. Correlations were calculated using Spearman's rho ('$\rho$'). In a graphical comparison, a Bland-Altman plot was used according to Giavarina 2015 for verifying the difference between HAL and RepScore.
The characteristics of the data set for comparison of HAL and RepScore is shown in **Table 11.**.

**Table 11.** Sample characteristics of comparability verification HAL vs. RepScore.

| Parameter | Mean (n = 50) | SD (n = 50) |
|---|---|---|
| Period [s/exertion] | 1.75 | 1.46 |
| Frequency [exertions/s] | 1.08 | 0.80 |
| Duty Cycle [%] | 74.20 | 12.60 |
| **HAL wrist right** | **5.86** | **1.83** |
| Cycle Time [s] | 18.04 | 15.71 |
| Duration partial task [s] | 6.16 | 3.19 |
| MP wrist flex/ext at P50 [%] | 7.98 | 8.91 |
| ω wrist flex/ext at P50 [°/s] | 20.92 | 14.95 |
| MPF wrist flex/ext at P50 [Hz] | 0.33 | 0.12 |
| MP-score wrist right | 1.23 | 0.78 |
| ω-score wrist right | 2.31 | 1.15 |
| MPF-score wrist right | 2.43 | 1.18 |
| **RepScore wrist right** | **5.96** | **2.86** |

HAL, Hand Activity Level; MP, Kinematic micro-pauses; MPF, Mean power frequency of the power spectra of angular data; n, number of cycles in the analyses; P50, 50th percentile; RepScore, repetition score; SD, standard deviation; ω, Angular velocity.
Main values are highlighted in **bold**.

Based on **Table 11.**, the HAL score and repetition score show similar scores on average across the 50 cycles. To quantify the existing difference between the two methods, the normal distribution of both data series was tested (Seidel et al. 2021b). The result is shown in **Table 12.**.

**Table 12.** Results Kolmogorov-Smirnov Test, HAL vs. RepScore.

| | Kolmogorov-Smirnov[a] | | |
|---|---|---|---|
| | **Statistic** | **df** | **Significance *p*-value[b]** |
| HAL wrist right | 0.134 | 50 | **0.025** |
| RepScore wrist right | 0.120 | 50 | 0.069 |

df, degrees of freedom, HAL, Hand Activity Level; RepScore, repetition score.
[a] Significance correction according to Lilliefors.
[b] significance ($p < 0.05$) is marked in **bold.**

**Table 12.** implicated that, HAL was not normally distributed ($p < 0.05$) while RepScore showed a normal distribution ($p \geq 0.05$). As the precondition for a t-test was unsatisfied, the test statistics were adjusted, and the non-parametric Wilcoxon signed-rank test was used (**Table 13.**). For 20 cycles, RepScore has a lower value than HAL and for 30 cycles RepScore has a higher value than HAL.

**Table 13.** Results non-parametric Wilcoxon signed-rank test, rank estimation, HAL vs. RepScore.

| | | n | Mean Rank | Sum of Ranks |
|---|---|---|---|---|
| **RepScore wrist right – HAL wrist right** | Negative Ranks | 20[a] | 27.75 | 555.00 |
| | Positive Ranks | 30[b] | 24.00 | 720.00 |
| | Ties | 0[c] | | |
| | Total | 50 | | |

HAL, Hand Activity Level; n, number of subjects in the analysis; RepScore, repetition score.
[a] RepScore wrist right < HAL wrist right.
[b] RepScore wrist right > HAL wrist right.
[c] RepScore wrist right = HAL wrist right

Based on the Wilcoxon signed-rank test (**Table 14.**), there is no statistically significant difference between both methods ($p = 0.426$) as mentioned by Seidel et al. 2021b.

**Table 14.** Results non-parametric Wilcoxon signed-rank test with Z-value, and effect size estimation.

| | *Z*-value | *p*-value | *r*-value | Effect size classification |
|---|---|---|---|---|
| **RepScore wrist right – HAL wrist right** | -0.796[a] | 0.426 | -0.113[b] | small |

HAL, Hand Activity Level; RepScore, repetition score.
[a] based on negative ranks.
[b] $r = \frac{-0.796}{\sqrt{50}}$

Using Spearman's rho rank correlation coefficient, HAL and RepScore "*show a high correlation (Spearman's rho: ρ = 0.847, p < 0.0001)*" (Seidel et al. 2021b, p. 2). Based on all these calculations, the alternative hypothesis was rejected, and the null hypothesis was applied. That means, there is no statistically significant difference between the methods. On average this difference was minimal (mean 0.10 ± 1.73) and can be neglected (**Figure 2.**, p. 201). This figure also shows that as soon as the mean between RepScore and HAL increases, increasing convergence of both methods can be expected. Finally, based on this pilot investigation, HAL and RepScore seem to be equivalent. Thus, equation 10 can be considered as valid.

"$RepSc_{Wrist} = HAL_{Wrist}$ (10)

$\{RepSc \in \mathbb{N} \mid 0 \leq RepSc \leq 10\}; \{HAL \in \mathbb{R} \mid 0 \leq HAL \leq 10\}$" (Seidel et al. 2021b, p. 2).

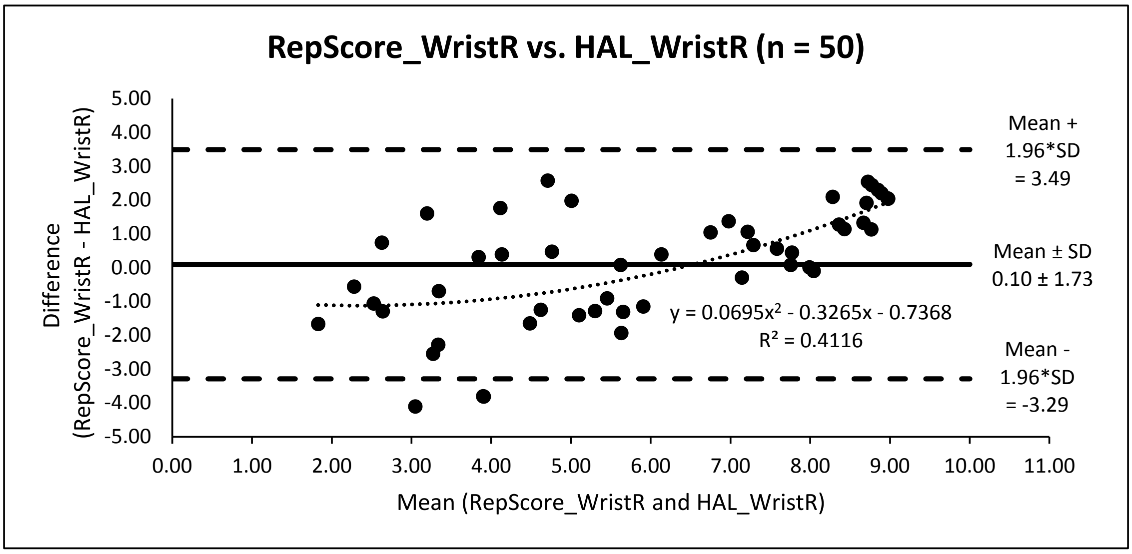


**Figure 2.** Bland-Altman Plot, RepScore and HAL at right wrist.
HAL, Hand Activity Level; $R^2$, coefficient of determination; RepScore, repetition score; SD, standard deviation; WristR, right wirst; x, variable; y, regression equation. HAL and RepScore have no unit.

## 8.3 Publication 3 – Seidel et al. 2021a – reprint of original German manuscript

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# Messdatenbasierte Gefährdungsbeurteilung

## Kategorisierung messtechnischer Methoden zur Beurteilung physischer Belastungen der oberen Extremität

**Bei Gefährdungsbeurteilungen physischer Belastungen kann zwischen beobachtungs- und messdatenbasierten Methoden unterschieden werden. Messdatenbasierte Verfahren zeichnen sich durch Objektivität und Genauigkeit aus und werden zunehmend kostengünstiger und praktikabler. Dieser Artikel gibt eine Übersicht zu potenziellen messtechnischen Verfahren und unterstützt betriebliche Akteure bei der Auswahl geeigneter Methoden für die jeweilige Bewertungssituation.**

Die Durchführung der Gefährdungsbeurteilung physischer Belastungen ist ein zentraler Bestandteil deutscher Arbeitsschutzrichtlinien, Vorschriften, Gesetze und Rechtsverordnungen. Arbeitgeber sind verpflichtet (Arbeitsschutzgesetz [3], § 5 I–III), im Rahmen der Gefährdungsbeurteilung die relevanten Gefährdungen an Arbeitsplätzen, -bereichen oder bei auszuführenden Tätigkeiten zu erfassen, zu bewerten, Schutzmaßnahmen abzuleiten und deren Wirksamkeit zu überprüfen. Gefährdungsbeurteilungen tragen zur Prävention arbeitsbezogener Muskel-Skelett-Belastungen bei, was als ein wichtiges Ziel der Gemeinsamen Deutschen Arbeitsschutzstrategie (GDA) von Bund und Ländern sowie Trägern der gesetzlichen Unfallversicherung vereinbart wurde.

Zur Verbesserung der Prävention und des Arbeitsschutzes macht die Europäische Agentur für Sicherheit und Gesundheitsschutz am Arbeitsplatz (*European Agency for Safety and Health at Work*, EU-OSHA) in der aktuellen Kampagne „Gesunde Arbeitsplätze – entlasten Dich!“ auf die Förderung von Präventionsmaßnahmen und Gefährdungsbeurteilungen in Verbindung mit arbeitsbezogenen Muskel-Skelett-Erkrankungen (MSE) aufmerksam [12]. Bis 2022 möchte die EU-OSHA eine Übersicht geeigneter Methoden und Bewertungsinstrumente bereitstellen.

Zwischen 20 und 57 % aller arbeitsbezogenen MSE betreffen den Hand-Arm-Schulter-Bereich [24]. Fehlbelastungen der oberen Extremitäten sind damit eine häufige Ursache für krankheitsbedingte Arbeitsausfälle. Für Gefährdungsbeurteilungen ist es erforderlich, entsprechende Risikofaktoren im Vorfeld zu identifizieren, um eine Auswahl geeigneter Expositionsbewertungsmethoden treffen zu können. Neben hoch repetitiver oder kraftvoller Arbeit sowie ungünstigen Haltungen wurden auch Kombinationen aus Kraftanforderungen und dem Bewegungsverhalten als arbeitsbedingte Risikofaktoren der oberen Extremität bereits quantitativ beschrieben [25].

Für Gefährdungsbeurteilungen physischer Belastungen wurde bereits 2010 ein 5-stufiges Ebenenmodell vorgeschlagen [11], das die Grundlage für das Vorgehen im Projekt „Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz“ (MEGAPHYS) [6, 9] darstellte sowie im Bereich der oberen Extremität angewandt werden kann. Die Ebenen lassen sich in beobachtungsbasierte (Grob-Screening, Spezielles Screening, Experten-Screening) und messtechnische Verfahren (betriebliche Messung, Labormessungen/Simulationen) einteilen.

Der Vorteil von beobachtungsbasierten Methoden liegt vor allem in der einfachen und praxisnahen Anwendung, insbesondere bei zusätzlicher Beurteilung von Arbeitsplatzumgebungen, -bedingungen oder -organisation [6, 9]. Sie sind vorteilhaft für erste Expositionsabschätzungen. In der Literatur werden jedoch auch einige Limitationen beschrieben. Beobachtungsbasierte Verfahren können durch subjektive Erfahrungen beeinflusst werden [13]. Das heißt, zwischen unterschiedlichen Beobachtenden kann es zum Teil zu erheblichen Unterschieden bei der Bewertung kommen. Weitere Einflussfaktoren sind z. B. Blickwinkel (Verdeckung), Tagesform oder Erinnerungsvermögen [13, 16, 17, 23]. Holtermann et al. [17] merken in diesem Zusammenhang ebenfalls an, dass erfahrene Beobachter benötigt werden, was kostenintensiv für jede beobachtete Arbeitszeiteinheit ist und meist kurze Beurteilungssequenzen oder limitierte Stichprobenanzahlen zur Folge hat. Beobachtungen können auch zu ethischen Komplikationen führen, z. B. bei Tätigkeiten in der Pflege [17]. Beobachtungsverfahren scheinen für grobe Erhebungen ausreichend zu sein, jedoch sind für weitere Untersuchungen ergänzende technische Methoden mit höherer Reliabilität von Vorteil [13, 23].

Lin et al. [18] weisen bspw. darauf hin, dass messwertbasierte Systeme in den letzten Jahren praktikabler und genauer geworden sind, längere Betriebszeiten ermöglichen und in der Lage sind, mehr Daten als früher zu speichern bzw. zu verarbeiten. Diese Verfahren sind objektiv, weisen einen hohen Detaillierungsgrad auf und ermöglichen eine genaue Quantifizierung von Expositionen. Ebenfalls werden technische Methoden für die Erstellung objektiver Expositionskataster [10] und für Analysen komplexer Arbeitsplätze mit schnell wechselnden oder parallel vorkommenden Belastungsarten [15] eingesetzt. Auch für Risikoabschätzungen zur Evaluation von Interventionen werden messtechnische Methoden empfohlen [23]. Messtechnische Methoden zur Erfassung der physischen Arbeitsbelastung unterliegen keinen subjektiven Verzerrungen, sind in der Regel auch an verdeckten oder engen Arbeitsplätzen anwendbar und weisen eine hohe Validität und Reliabilität auf [16]. Limitationen waren bisher ein gegenüber Beobachtungsverfahren höherer Zeit- und Kostenaufwand (oftmals bedingt durch aufwendige Instrumentierungen und Auswertungen), eine Nutzung vorrangig durch Experten und eine mögliche Interferenz mit dem Arbeitsablauf [14]. Durch den Technikfortschritt werden jedoch die objektiven und genauen Systeme immer praktikabler und günstiger [13, 18] und bereits international zur Gefährdungsbeurteilung empfohlen [16]. Das bietet gute Voraussetzungen für andere Nutzergruppen und künftige Weiter- und Neuentwicklungen messwertgestützter Methoden bzw. Bewertungsverfahren auch im Rahmen der hierzulande durchzuführenden Gefährdungsbeurteilung physischer Belastungen, z. B. im Bereich der oberen Extremität. Bisher war es in der betrieblichen Praxis sehr schwierig, die geeignete messtechnische Methode für die jeweiligen Zwecke auszuwählen.

Das Ziel dieser Arbeit ist es daher, eine übersichtliche Kategorisierung am Beispiel aktuell verfügbarer Methoden für die messtechnisch basierte Gefährdungsbeurteilung arbeitsbedingter physischer Belastungen im Bereich der oberen Extremität zu erstellen. Beispiele sollen die Einsatzbereiche verdeutlichen und betriebliche Praktiker zukünftig bei der Auswahl geeigneter messtechnischer Verfahren unterstützen.

## Messmethoden zur Belastungsquantifizierung

Zur objektiven Quantifizierung arbeitsbezogener Muskel-Skelett-Belastungen der oberen Extremität sind zahlreiche Methoden verfügbar. **Kamerabasierte** Methoden als Basis für automatisierte Bewegungsanalysen unter Verwendung von passiven oder aktiven, reflektierenden Markern sind überwiegend an spezielle stationäre Laborumgebungen gebunden. Entsprechend sind solche Methoden nur eingeschränkt für den mobilen Einsatz geeignet und somit in Abhängigkeit von den Rahmenbedingungen wenig praktikabel für eine praxisnahe Gefährdungsbeurteilung vor Ort, z. B. an nichtstationären Arbeitsplätzen. Für Quantifizierungen werden heutzutage auch videobasierte Mustererkennungen (nicht markerbasiert) verbunden mit biomechanischen Modellierungen verwendet [1]. Wenn die Arbeitsabläufe und Arbeitsinhalte dies erlauben, lassen sich videobasierte Verfahren oftmals problemlos in der Praxis an industriellen Arbeitsplätzen einsetzen, da als *Hardware* nur eine Videokamera, ein *Smartphone* oder *Tablet* benötigt wird. Jedoch ist hier zur Bewertung der Arbeitsplatzbelastungen eine spezifische zusätzliche Videoanalyse-*Software* notwendig. Zudem sind die bisher verfügbaren Bewertungsansätze häufig nur auf bestimmte Bewegungsmuster bezogen. Obwohl eine Datenerfassung prinzipiell möglich ist, erfordert die nachfolgende Auswertung somit erhöhte Aufwände, wie z. B. einen zusätzlichen Programmieraufwand. Problematisch ist ein Kameraeinsatz auch an Arbeitsplätzen, an denen aus datenschutzrechtlichen, ethischen oder betrieblichen Gründen keine Videoaufzeichnungen erfolgen dürfen. Nicht nur für derartige Arbeitsplätze, sondern auch für den Einsatz an nichtstationären Arbeitsplätzen eignen sich daher personengetragene **Bewegungssensoren**. Die Bandbreite erstreckt sich dabei vom Einsatz einzelner Beschleunigungssensoren bis hin zur Anwendung von Inertialsensoren als Multisensorsysteme, synchronisiert mit weiterer Sensorik, z. B. zur Erfassung von Kräften oder physiologischer Vorgänge.

### Kategoriensystem

In der Literatur werden messtechnische Verfahren zur Erfassung und Bewertung beruflicher körperlicher Aktivität und spezifischer physischer Arbeitsbelastungen in einem Kategoriensystem eingeteilt, das eine Differenzierung in 3 Messsystem-Kategorien vorsieht [8, 16, 17, 29]. Im Folgenden wird dieses Kategoriensystem als Grundlage genutzt, um eine entsprechende Klassifizierung messtechnischer Systeme zur Erfassung und Bewertung arbeitsbezogener Belastungen der oberen Extremitäten vorzunehmen.

### Kategorie 1

Hierzu zählen Messverfahren mit 1–2 Sensoreinheiten, welche die Belastung einer spezifischen Lokalisation (z. B. Handgelenk, Ellenbogen) abbilden. Solche Verfahren basieren in der Regel auf dem Einsatz von Bewegungs-, Haltungs- oder Positionssensoren wie Accelerometer (Beschleunigungsmesser) oder Goniometer (Winkelmesser). Diese Sensoren waren früher oft kabelgebunden und kostenintensiv und ihre Handhabung setzte spezielle Kenntnisse für die Sensoranbringung und Datenauswertung voraus. Durch technische Optimierung sind die zur Erfassung von Arbeitsbewegungen geeigneten Systeme heute kostengünstiger und nutzerfreundlicher. Sie sind beispielsweise häufig kabellos, und durch intelligente Algorithmen werden Fehler bei der Anbringung oder Datenauswertung vermieden [29].

## Kategorie 2

Mit Messverfahren mit ≥2 Sensoreinheiten lassen sich Belastungen eines Lokalisationsbereichs betrachten (Kette von Lokalisationen, z.B. Schulter-Ellenbogen-Hand-Bereich). Die Sensoreinheiten können in *smart textiles* eingearbeitet oder individuell am Körper angebracht werden. Neben Sensorik zur Bewegungserfassung (z.B. Inertialsensoren) kann beispielsweise Elektromyographie (EMG), Nahinfrarotspektroskopie (NIRS) oder Hand-Arm-Vibration(HAV)-Erfassungssensorik zum Einsatz kommen. Es gibt eine Reihe an *wearables*, die anhand von Inertialsensoren, Dynamometern und Oberflächen-EMG zur biomechanischen Datenerfassung bei der Arbeit als Basis für die Risikobewertung geeignet sind [22].

## Kategorie 3

Bei diesen komplexen Messverfahren werden viele Sensoren kombiniert, um die Belastung mehrerer Ketten von Lokalisationen oder des gesamten Körpers zu betrachten. Hierzu zählen Multisensorsysteme, die in der Regel auf Inertialsensoren basieren, aber auch mit weiterer Messtechnik kombinierbar sind (z.B. Computer-unterstützte Erfassung und Langzeit-Analyse von Belastungen des Muskel-Skelett-Systems (CUELA), Xsens, [28]).

## Methodenüberblick und Anwendungsbeispiele

Eine prinzipielle Übersicht zu den 3 Kategorien von Messsystemen ist in **Abb. 1** illustriert. Beispiele für die jeweilige Messsystemkategorie für die Erfassung und Bewertung arbeitsbezogener Belastungen der oberen Extremitäten sind in **Abb. 2** zusammengefasst. Hierbei erscheinen wegen der hohen Praktikabilität die Kategorien 1 und 2 für den Einsatz im Betrieb besonders bedeutsam. Beispiele für derartige Sensorik und mögliche Bewertungsansätze, die aus der Literatur herangezogen werden können, werden in **Abb. 3** präsentiert.

**Zusammenfassung · Abstract**

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### Messdatenbasierte Gefährdungsbeurteilung. Kategorisierung messtechnischer Methoden zur Beurteilung physischer Belastungen der oberen Extremität

**Zusammenfassung**

**Hintergrund.** Beobachtungsbasierte Methoden zur Gefährdungsbeurteilung physischer Belastungen im Bereich der oberen Extremität können durch subjektive Erfahrungen der Untersuchenden beeinflusst werden. Darüber hinaus ist eine Quantifizierung biomechanischer Belastungen, wie Zeitverläufe von Gelenkwinkeln, Winkelgeschwindigkeiten oder Kräften durch Beobachtungen, schwer möglich. Zur objektiven Quantifizierung von Expositionen im Rahmen von spezifischen Gefährdungsbeurteilungen eignen sich daher vor allem messtechnische Methoden, wobei die Auswahl der entsprechenden Methode herausfordernd sein kann.
**Zielsetzung.** Dieser Artikel soll Arbeitsschutzfachleute dabei unterstützen, aus der Bandbreite der unterschiedlichen Verfahren die geeignete messtechnische Methode für eine vorliegende Expositionssituation zu identifizieren.
**Methoden.** Ausgehend von einer Literaturübersicht wurden Messmethoden für die obere Extremität in Anlehnung an ein etabliertes Kategoriensystem hinsichtlich ihrer Komplexität klassifiziert. Zusätzlich werden Anwendungsbeispiele für alle Kategorien skizziert.
**Ergebnisse.** Dieser Artikel liefert eine Übersicht und Klassifizierung von unterschiedlichen messtechnischen Erfassungs- und Bewertungsmethoden arbeitsbezogener Muskel-Skelett-Belastungen, die in 3 Kategorien von einfach bis komplex eingeteilt werden.
**Diskussion.** Vereinfachte Sensorik in Kombination mit spezifischen Bewertungsansätzen kann zukünftig die objektive Gefährdungsbeurteilung physischer Belastungen unterstützen.

**Schlüsselwörter**
Quantifizierung arbeitsbedingter Exposition · Objektives Bewertungsverfahren · Messsystem-Kategorie · Sensor · Schulter-Ellenbogen-Hand-Bereich

### Measurement-based risk assessment. Categorization of measurement methods for assessing physical workloads of the upper extremity

**Abstract**

**Background.** Observation-based methods for risk assessment of physical workloads of the upper extremity can be influenced by subjective experiences of the investigators. In addition, it is difficult to quantify biomechanical workloads, of e.g., time courses of joint angles, angular velocities, or forces by observations. For objective and precise quantification of exposures in the context of specific risk assessments, technical measurement-based methods are therefore particularly suitable, although the choice of the appropriate method can be challenging.
**Objective.** This article is intended to support occupational safety experts to identify the appropriate measurement-based method for an existing exposure situation from the range of different methods.
**Methods.** Based on a literature review, measurement methods for the upper extremity were classified according to their complexity based on an established category system. In addition, application examples are presented for all categories.
**Results.** This article provides an overview and classification of different recording and assessment methods of work-related musculoskeletal loads, which are divided into three categories from simple to complex.
**Discussion.** Simplified sensor technology in combination with specific assessment approaches might support the objective risk assessment of physical workload in the future.

**Keywords**
Quantification of work-related exposure · Objective assessment approach · Measurement system category · Sensor · Shoulder-Elbow-Hand-area

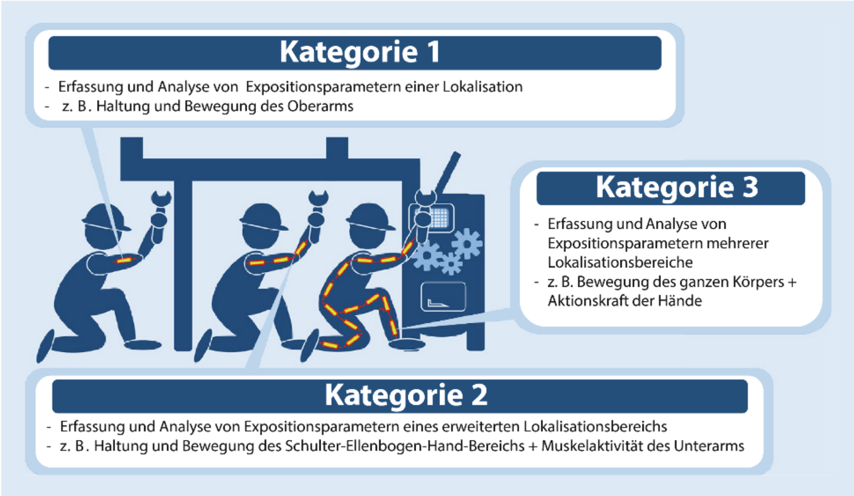
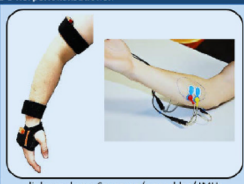
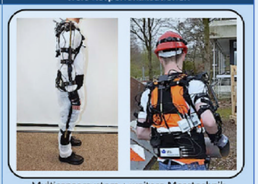
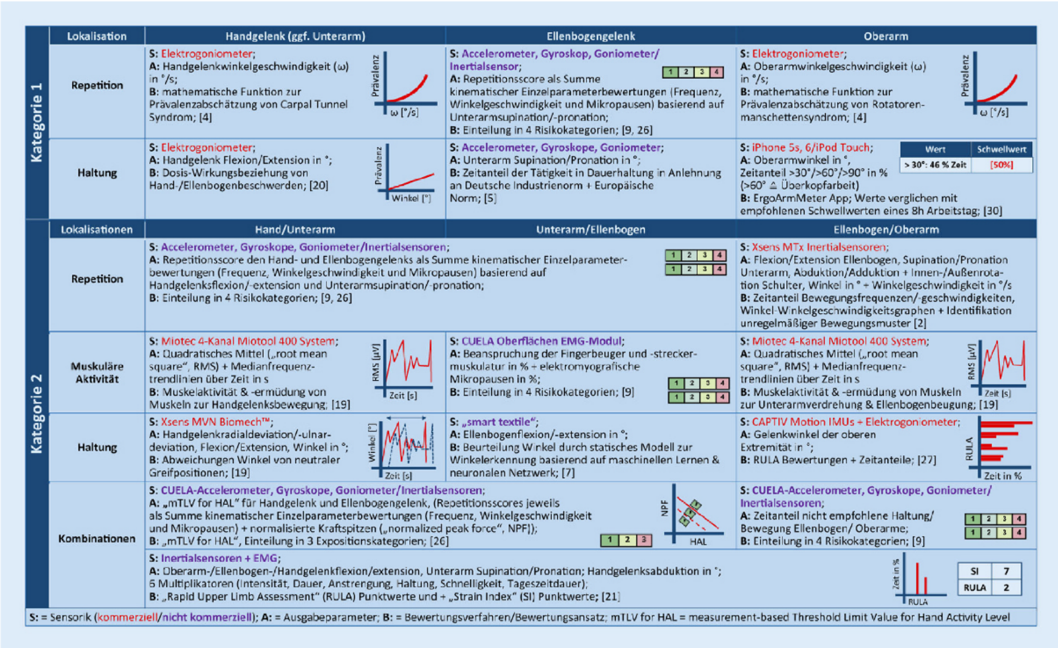



**Abb. 1** ◄ Kategorisierung von Messsystemen zur Erfassung und Bewertung arbeitsbezogener Belastungen der oberen Extremitäten in Anlehnung an die in der Literatur beschriebenen Klassifizierungen von Messungen physischer Aktivitäten. (Nach [8, 16, 17, 29])

| Messsystemkategorie | Kategorie 1<br>1-2 Sensoreinheiten,<br>1 Körperlokalisation | Kategorie 2<br>≥2 Sensoreinheiten,<br>2-3 Körperlokalisationen | | Kategorie 3<br>Komplexere Messverfahren,<br>viele Körperlokalisationen |
|---|---|---|---|---|
| Beispiele für Sensorik [a] | <br>links: wearable;<br>rechts: einzelne Sensoren | <br>„smart textile" | <br>links: mehrere Sensoren/wearables/ IMU;<br>rechts: Oberflächen-Elektromyografie (EMG) | <br>Multisensorsystem + weitere Messtechnik<br>links: CUELA, rechts: CUELA & EMG |
| **Beurteilung von Risikofaktoren:** Muskuläre Aktivität | - | - | -/+ | -/+ |
| Repetition | + | o/+ | + | + |
| Haltung | + | + | + | + |
| Kombination aus Kraftanforderungen & Bewegungsverhalten | - | - | o | o/+ |
| **Expertise für Sensoranbringung** | gering | gering-mittel | mittel/hoch | hoch |
| **Mögliche Anzahl Probanden** | viele | mehrere | mehrere | wenige |
| **Zeit-/Kostenaufwand pro Proband** | gering | gering | moderat | hoch |
| **Potenzielle Nutzergruppen [b]** | AG: **o**, AF: **+**, W: **+** | AG: **+**, AF: **+**, W: **+** | AG: **-/o**, AF: **o/+**, W: **+** | AG: **-**, AF: **o**, W: **+** |
| **Beispiele für spezifische Anwendungen** | **ErgoArmMeter [30]**;<br>ErgoArmMeter als iOS Applikation kombiniert mit in iPhone oder iPod Touch integrierten Accelerometern und Gyroskopen zur Analyse und Perzentilbildung von Winkeln & Winkelgeschwindigkeiten + Werte in Relation zu empfohlenen Schwellwerten eines 8-h Tages | **Winkelmessungen [7]**:<br>Sensoren integriert in Pullover zur Erfassung und Darstellung des Flexionswinkels im Ellenbogengelenk, Beurteilung durch statisches Modell zur Winkelerkennung basierend auf maschinellen Lernen & neuronalen Netzwerk | **Quantifizierung von Expositions-Wirkungs-Beziehungen [4]**;<br>Accelerometer, Elektrogoniometer zur Erfassung von Oberarm- & Handgelenks-bewegungen & -haltungen + Perzentilbestimmung, Bewertung Expositions-Wirkungsbeziehung über Exponentialfunktion und Abschätzung unterschiedlicher Prävalenzen<br><br>**Quantifizierung von Kraftaufwendungen [9]**;<br>4-Kanal Oberflächen EMG Modul zur Erfassung und Bewertung muskulärer Belastungen der Unterarme durch Quantifizierung der Beanspruchung + Einteilung in Risikokategorien | **Komplexe Expositionserfassung und Bewertung kombinierter Risikofaktoren [9, 26]**;<br>CUELA-Multisensor-Messsystem + 4-Kanal Oberflächen EMG Modul zur Erfassung und Bewertung von Kraft, Repetition & Kombination sowie nicht empfohlener Haltungen/Bewegungen unterschiedlicher Lokalisationen + Einteilung in Risikokategorien |

+ empfohlen, **o** teilweise empfohlen/bedingt geeignet, - nicht empfohlen; „inertial measurement unit"-Anwendungen = IMU; [a] Weitere Beispiele für einsatzfähige „wearables" sind nach Walmsley et al. [28] u. a. Xsens, ADPM Opal, Shimmer, InvenSense MPU9150 chip, BioKin WMS, YEI Technology, CAPTIV Motion, L-P Research Motion Sensor B2, Noraxon Myomotion, ArduMuV3 chip oder MSULS.
[b] Nutzergruppen: Arbeitsschutzfachleute mit geringer messtechnischer Erfahrung = AG; Arbeitsschutzfachleute mit fortgeschrittener messtechnischer Erfahrung = AF; Wissenschaftler (mit Mess-Expertise) = W

**Abb. 2** ▲ Beispiele für mobile, körpergetragene messtechnische Methoden (Kategorien 1–3) zur Expositionsermittlung der oberen Extremität. Einschätzung bezüglich der erforderlichen Expertise für die Anbringung von Sensoren, der möglichen Anzahl von Probanden, des Zeit-/Kostenaufwands pro Proband und die Empfehlung bezüglich der Nutzergruppen basieren auf der PEROSH-Klassifikation (*Partnership for European Research in Occupational Safety and Health, PEROSH*). (Nach [4, 7, 9, 16, 17, 26, 28, 29, 30])



| | Lokalisation | Handgelenk (ggf. Unterarm) | Ellenbogengelenk | Oberarm |
|---|---|---|---|---|
| Kategorie 1 | Repetition | **S:** Elektrogoniometer;<br>**A:** Handgelenkwinkelgeschwindigkeit (ω) in °/s;<br>**B:** mathematische Funktion zur Prävalenzabschätzung von Carpal Tunnel Syndrom; [4] | **S:** Accelerometer, Gyroskop, Goniometer/ Inertialsensor;<br>**A:** Repetitionsscore als Summe kinematischer Einzelparameterbewertungen (Frequenz, Winkelgeschwindigkeit und Mikropausen) basierend auf Unterarmsupination/-pronation;<br>**B:** Einteilung in 4 Risikokategorien; [9, 26] | **S:** Elektrogoniometer;<br>**A:** Oberarmwinkelgeschwindigkeit (ω) in °/s;<br>**B:** mathematische Funktion zur Prävalenzabschätzung von Rotatoren-manschettensyndrom; [4] |
| Kategorie 1 | Haltung | **S:** Elektrogoniometer;<br>**A:** Handgelenk Flexion/Extension in °;<br>**B:** Dosis-Wirkungsbeziehung von Hand-/Ellenbogenbeschwerden; [20] | **S:** Accelerometer, Gyroskope, Goniometer;<br>**A:** Unterarm Supination/Pronation in °;<br>**B:** Zeitanteil der Tätigkeit in Dauerhaltung in Anlehnung an Deutsche Industrienorm + Europäische Norm; [5] | **S:** iPhone 5s, 6/iPod Touch;<br>**A:** Oberarmwinkel in °, Zeitanteil >30°/>60°/>90° in % (>60° ≙ Überkopfarbeit)<br>**B:** ErgoArmMeter App; Werte verglichen mit empfohlenen Schwellwerten eines 8h Arbeitstag; [30]<br>Wert: > 30°: 46 % Zeit; Schwellwert: [50%] |
| | **Lokalisationen** | **Hand/Unterarm** | **Unterarm/Ellenbogen** | **Ellenbogen/Oberarm** |
| Kategorie 2 | Repetition | **S:** Accelerometer, Gyroskope, Goniometer/Inertialsensoren;<br>**A:** Repetitionsscore den Hand- und Ellenbogengelenks als Summe kinematischer Einzelparameter-bewertungen (Frequenz, Winkelgeschwindigkeit und Mikropausen) basierend auf Handgelenksflexion/-extension und Unterarmsupination/-pronation;<br>**B:** Einteilung in 4 Risikokategorien; [9, 26] | | **S:** Xsens MTx Inertialsensoren;<br>**A:** Flexion/Extension Ellenbogen, Supination/Pronation Unterarm, Abduktion/Adduktion + Innen-/Außenrotation Schulter, Winkel in ° + Winkelgeschwindigkeit in °/s<br>**B:** Zeitanteil Bewegungsfrequenzen/-geschwindigkeiten, Winkel-Winkelgeschwindigkeitsgraphen + Identifikation unregelmäßiger Bewegungsmuster [2] |
| Kategorie 2 | Muskuläre Aktivität | **S:** Miotec 4-Kanal Miotool 400 System;<br>**A:** Quadratisches Mittel („root mean square", RMS) + Medianfrequenz-trendlinien über Zeit in s<br>**B:** Muskelaktivität & -ermüdung von Muskeln zur Handgelenksbewegung; [19] | **S:** CUELA Oberflächen EMG-Modul;<br>**A:** Beanspruchung der Fingerbeuger und -strecker-muskulatur in % + elektromyografische Mikropausen in %;<br>**B:** Einteilung in 4 Risikokategorien; [9] | **S:** Miotec 4-Kanal Miotool 400 System;<br>**A:** Quadratisches Mittel („root mean square", RMS) + Medianfrequenz-trendlinien über Zeit in s<br>**B:** Muskelaktivität & -ermüdung von Muskeln zur Unterarmverdrehung & Ellenbogenbeugung; [19] |
| Kategorie 2 | Haltung | **S:** Xsens MVN Biomech™;<br>**A:** Handgelenkradialdeviation/-ulnar-deviation, Flexion/Extension, Winkel in °;<br>**B:** Abweichungen Winkel von neutraler Greifpositionen; [19] | **S:** „smart textile";<br>**A:** Ellenbogenflexion/-extension in °;<br>**B:** Beurteilung Winkel durch statisches Modell zur Winkelerkennung basierend auf maschinellen Lernen & neuronalen Netzwerk; [7] | **S:** CAPTIV Motion IMUs + Elektrogoniometer;<br>**A:** Gelenkwinkel der oberen Extremität in °;<br>**B:** RULA Bewertungen + Zeitanteile; [27] |
| Kategorie 2 | Kombinationen | **S:** CUELA-Accelerometer, Gyroskope, Goniometer/Inertialsensoren;<br>**A:** „mTLV for HAL" für Handgelenk und Ellenbogengelenk, (Repetitionsscores jeweils als Summe kinematischer Einzelparameterbewertungen (Frequenz, Winkelgeschwindigkeit und Mikropausen) + normalisierte Kraftspitzen („normalized peak force", NPF]);<br>**B:** „mTLV for HAL", Einteilung in 3 Expositionskategorien; [26] | | **S:** CUELA-Accelerometer, Gyroskope, Goniometer/ Inertialsensoren;<br>**A:** Zeitanteil nicht empfohlene Haltung/ Bewegung Ellenbogen/ Oberarme;<br>**B:** Einteilung in 4 Risikokategorien; [9] |
| Kategorie 2 | Kombinationen | **S:** Inertialsensoren + EMG;<br>**A:** Oberarm-/Ellenbogen-/Handgelenkflexion/extension, Unterarm Supination/Pronation; Handgelenksabduktion in °; 6 Multiplikatoren (Intensität, Dauer, Anstrengung, Haltung, Schnelligkeit, Tageszeitdauer);<br>**B:** „Rapid Upper Limb Assessment" (RULA) Punktwerte und + „Strain Index" (SI) Punktwerte; [21]<br>SI: 7; RULA: 2 | | |

S: = Sensorik (kommerziell/nicht kommerziell); A: = Ausgabeparameter; B: = Bewertungsverfahren/Bewertungsansatz; mTLV for HAL = measurement-based Threshold Limit Value for Hand Activity Level

**Abb. 3** ▲ Beispiele für Messtechnik, Ausgabeparameter und zugrundeliegende Bewertungsansätze für Geräte der Messsystemkategorien 1 und 2. (Nach [2, 4, 5, 7, 9, 19–21, 26, 27, 30])

## Anwendungsszenarien aus der betrieblichen Praxis

**Szenario a)** Nach Umstrukturierungen in der Montagelinie treten bei Monteuren von Heckklappenkabelbäumen häufig Beschwerden im Schulterbereich auf. Da die Kabelbäume vorrangig über Schulterniveau montiert werden, entstehen Körperzwangshaltungen und problematische Gelenkbelastungen. Der Ergonomieexperte des Unternehmens wird beauftragt, besonders hohe Schulterbelastungen während der Montage zu identifizieren, um mögliche Verbesserungsmaßnahmen im Arbeitsprozess entwickeln zu können. Da nach der Tätigkeitsbeobachtung und orientierenden Bewertung ungünstige Oberarmhaltungen (z. B. Armhebungen über 60°) als Ursache für die Fehlbelastungen im Bereich der Schulter angenommen werden, eignet sich in diesem Fall zur Quantifizierung der Belastung ein einfaches System der Kategorie 1, wie z. B. der Einsatz eines *Smartphones* in Kombination mit einer entsprechenden Applikation (**Abb. 3**, Kategorie 1, Haltung, Oberarm). Die kostengünstige Applikation stellt unabhängig von Arbeitsplätzen und Teiltätigkeiten objektive Parameter bereit, wie z. B. Perzentile von Winkelverteilungen, prozentuale Schichtanteile ungünstiger Armhaltungen oder den Median der Winkelgeschwindigkeit, welche sich nicht genau durch Beobachtungen quantifizieren lassen. Basierend auf den Daten zur kumulativen Dauer von Armhebungen über 60° sowie zur Dauer von ununterbrochenen Armhebungen über 60° während einer typischen Arbeitsschicht lassen sich Belastungsspitzen genauer als durch die Beobachtung von umschriebener Dauer identifizieren. Durch die objektiven Parameter und den Vergleich von Winkeldaten mit empfohlenen Schichtschwellwerten sind Maßnahmen zur Reduktion der durchschnittlichen Winkelgeschwindigkeit denkbar, welche sich durch Beobachtungen nicht objektiv evaluieren lassen. Anhand des Schichtbelastungsprofils können dann gegebenenfalls Maßnahmen zur Reduzierung der Schulterbelastung abgeleitet werden, beispielsweise durch Job- bzw. Arbeitsplatzrotationen.

**Szenario b)** In einer großen Filiale im Lebensmitteleinzelhandel berichten die Beschäftigten von Beschwerden im Bereich der Handgelenke und Ellenbogen, vor allem bei Kassiertätigkeiten, weniger jedoch bei dem Auffüllen der Regale mit neuen Waren. Ausgehend von der Tätigkeitsbeobachtung wird vermutet, dass hochfrequente Beugungen der Handgelenke und Ellenbogen sowie Verdrehungen der Unterarme kombiniert mit den Warengewichten bei Tätigkeiten am Kassenband zu typischen Beschwerden und Erkrankungen im erweiterten Lokalisationsbereich (Handgelenk/Ellenbogen) führen können. Um den Belastungsunterschied zwischen beiden Arbeitsplätzen zu quantifizierten, sollen jeweils die Belastungen im Hand-Arm-Bereich durch eine Arbeitsschutzfachkraft verglichen werden. Zur einfachen Handhabung eignet sich beispielsweise ein mit Inertialsensoren bestücktes *smart textile* aus Kategorie 2 zusätzlich zu einer handelsüblichen Waage für die Erfassung der Warengewichte. Die ermittelten Ergebnisse wie Winkel-Zeitverläufe, Anzahl und Gewichte bewegter Waren und die Bewertung des Ausmaßes der Repetition vor dem Hintergrund von Daten aus der Literatur können genutzt werden, um objektive Belastungsprofile zu erstellen. Diese Ergebnisse können die Basis für fundierte Anpassungen des Kassentisches sein, um ergonomische Tätigkeiten zu ermöglichen.

**Szenario c)** In einem Unternehmen, das sich auf Wegebau mit Betonsteinpflaster spezialisiert hat, steht die Geschäftsführung vor der Überlegung, eine neue kostenintensive Maschine anzuschaffen, welche die manuelle Steinsetzung in großen Teilen ersetzen soll. Die Geschäftsführung erhofft sich von der Maschine einen wirtschaftlichen Vorteil aufgrund der Zeitersparnis und der Reduzierung krankheitsbedingter Arbeitsausfälle. Die Beschäftigten hatten häufiger über Beschwerden in mehreren Lokalisationen (Arme, Schultern, Nacken, Rücken, Knie) geklagt. Daher ist in Kooperation mit einer Hochschule ein wissenschaftliches Projekt zum Vergleich des Pflasterns mit und ohne maschinelle Unterstützung geplant. Unter Berücksichtigung des Zeitfaktors sollen für beide Arbeitsweisen die Auswirkungen auf das Muskel-Skelett-System genau quantifiziert werden. Da die erwarteten Effekte auf den Bewegungsablauf komplex sind und den gesamten Körper betreffen, müssen die Genauigkeit und der Detaillierungsgrad der Ausgabeparameter sehr hoch sein. Daher ist für dieses Projekt ein Multisensorsystem der Kategorie 3 mit Oberflächen-EMG und HAV-Erfassungssensorik und mehreren hinterlegten Bewertungsansätzen zur Belastungsbeurteilung bei mehreren Lokalisationen geeignet. Durch die umfangreiche Messtechnik lassen sich komplexe Bewegungen, Haltungen, Kraftaufwendungen und mögliche Belastungen durch maschinenbedingte Schwingungen quantifizieren. Anhand der ermittelten Expositionsdaten beim Pflastern mit und ohne maschinelle Unterstützung lassen sich jeweils Schichtbelastungsprofile erstellen, in welchen beispielsweise Belastungen der Bandscheiben, ungünstige Körperhaltungen und Belastungsspitzen durch Repetitionen und hohe Kräfte enthalten sein können. Der ermittelte Expositionsunterschied soll in Kombination mit der zeitlichen Betrachtung bewertet werden und kann die Grundlage für die Kaufentscheidung liefern.

## Diskussion und Ausblick

Die Methodenübersicht und Anwendungsbeispiele im vorliegenden Artikel sollen betrieblichen Praktikern einen aktuellen Einblick in messtechnische Erfassungsmethoden sowie die zur Bewertung der Belastungen herangezogenen möglichen Parameter aus der Literatur ermöglichen. Eine in der Literatur empfohlene Messsystemkategorisierung zur Erfassung und Bewertung physischer Aktivitäten [8, 16, 17, 29] wurde erweitert auf den Bereich der oberen Extremität angewandt. Dieses Vorgehen und die erarbeitete Übersicht bieten eine Orientierung für die Einsatzmöglichkeiten einer messdatenbasierten Gefährdungsbeurteilung arbeitsbezogener physischer Belastungen der oberen Extremität. Die erarbeiteten Empfehlungen im Hinblick auf unterschiedliche Nutzergruppen können darüber hinaus als Hilfestellung dienen, welche Art von Messtechnik für die jeweilige Beurteilungssituation am ehesten geeignet sein könnte.

Mit zunehmender Komplexität der Messsysteme steigen die Anforderungen an die erforderliche Expertise für die Anbringung von Sensoren und die Datenanalyse und somit der Zeit- und Kostenaufwand. Auch der Datenschutz ist bei der Expositionserfassung mit *wearable technology* einzuhalten. Neben der Weiterentwicklung von Bewertungsverfahren ist auch die Festlegung und Bereitstellung praktikabler kommerzieller Sensorik bzw. entsprechender Messsysteme wünschenswert. In diesem Zusammenhang ist auch die gezielte messtechnische Analyse einzelner Parameter und ausgewählter Lokalisationen denkbar. Durch ein spezifischeres *Set-up* und einfach zu bedienende Messtechnik wäre zukünftig eine deutliche Reduzierung von Aufwand und Komplexität bei betrieblichen Messungen möglich. *Software* gestützt sind so auch schnellere und objektive Auswertungen möglich, wobei zielstellungsabhängig die Analysen problemlos erneut durchgeführt oder erweitert werden können. Neben Wissenschaftlern könnten auch betriebliche Praktiker Messdaten erheben. Um mögliche Fehlinterpretationen von Daten und damit verbundene fehlerhafte Gefährdungsbeurteilungen zu vermeiden, wird prinzipiell empfohlen sich über Möglichkeiten und Grenzen der jeweiligen Methode genau zu informieren. Dies gilt allerdings nicht nur für Messverfahren, sondern auch für alle anderen Verfahren der Gefährdungsbeurteilung.

Zur Expositionserfassung und -bewertung sind für die Lokalisationen Hand/Oberarm (Repetition, Haltung), Hand/Unterarm (Kraft, Haltung) und Ellenbogen/Oberarm (Repetition, Kraft, Haltung) bereits kommerziell verfügbare Sensoren mit Ausgabeparametern und Bewertungsansätzen als Grundlage für den Einsatz in der messdatenbasierten Gefährdungsbeurteilung physischer Belastungen vorhanden (**Abb. 3**). Perspektivisch ist es jedoch empfehlenswert, dass Bewertungsverfahren, die aktuell auf Daten zurückgreifen, die mit nicht kommerziell verfügbarer Sensorik erhoben werden, weiterentwickelt und auf die Verwendung von Messdaten aus der Anwendung kommerziell verfügbarer Sensorik übertragen werden. Walmsley et al. [28] stellen dazu z. B. 13 kommerzielle *wearable* Sensoren vor, welche sich für eine entsprechende Übertragung eignen. Damit werden beispielsweise für MEGAPHYS entwickelte Bewertungen (z. B. Repetitionsscore (RepScore) [9, 26]) und darauf aufbauende Ansätze (z. B. *measurement-based Threshold Limit Value for Hand Activity Level* (mTLV for HAL) [26]) für betriebliche Praktiker verfügbar und können die messdatenbasierte Gefährdungsbeurteilung physischer Belastungen unterstützen. Die im Projekt MEGAPHYS entwickelten und validierten Bewertungsverfahren für messtechnische Analysen arbeitsbezogener Muskel-Skelett-Belastungen können als Grundlage für die Bewertung lokalisationsbezogener Belastungen mittels Messsystemen der Kategorien 1–3 genutzt werden. Schnittstellen zu entsprechender kommerzieller Messtechnik werden derzeit am IFA definiert und implementiert, um den Zugang zu der Methodik für betriebliche Praktiker zu erleichtern.

Vor diesem Hintergrund empfiehlt sich die Anpassung des Ebenenmodells der Gefährdungsbeurteilung aus dem Jahr 2010 [11]. Dabei könnten Kategorie-1-Systeme durch eine einfache Handhabung das Spezielle Screening ergänzen. Der Einsatz von Kategorie-2-Systemen könnte durch detaillierte Expositionserfassungen das Niveau des Experten-Screenings erweitern. Einfache messtechnische Verfahren können Untersuchende zukünftig auch auf Screening-Niveau durch objektive Analysen unterstützen und somit einen neuen Standard in der Gefährdungsbeurteilung physischer Belastungen ermöglichen.

## Fazit für die Praxis

- **Eine Klassifizierung von kommerzieller und nicht kommerzieller Messtechnik sowie objektiver Bewertungsverfahren steht nun für die messdatenbasierte Gefährdungsbeurteilung physischer Belastungen der oberen Extremität zur Verfügung.**
- **Die Zuordnung der messtechnischen Lösungsansätze zu den Kategorien 1 bis 3 erfolgte unter anderem auf Basis von unterschiedlichen Nutzergruppen.**
- **Der Einsatz messdatenbasierter Gefährdungsbeurteilungen wird in Ergänzung zum bisherigen Vorgehen empfohlen.**
- **Die Weiterentwicklung von Sensorik inklusive *Software* zur Bewertung der Expositionsdaten ist zu befürworten, um zukünftig betrieblichen Praktikern den Einsatz der messdatenbasierten Gefährdungsbeurteilung bzw. Zugriff auf Messdaten zu ermöglichen.**

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## Einhaltung ethischer Richtlinien

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Für diesen Beitrag wurden von den Autoren keine Studien an Menschen oder Tieren durchgeführt. Für die aufgeführten Studien gelten die jeweils dort angegebenen ethischen Richtlinien.



## Literatur

1. Akkas O, Azari DP, Chen C-HE et al (2015) A hand speed and duty cycle equation for estimating the ACGIH hand activity level rating. Ergonomics 58:184–194
2. Álvarez D, Alvarez JC, González RC et al (2016) Upper limb joint angle measurement in occupational health. Comput Methods Biomech Biomed Engin 19:159–170
3. Arbschg (1996) Gesetz über die Durchführung von Maßnahmen des Arbeitsschutzes zur Verbesserung der Sicherheit und des Gesundheitsschutzes der Beschäftigten bei der Arbeit. „Arbeitsschutzgesetz (ArbSchG) vom 7. August 1996 (BGBl. I S. 1246), das zuletzt durch Artikel 427 der Verordnung vom 31. August 2015 (BGBl. I S. 1474) geändert worden ist". Bundesministerium der Justiz und für Verbraucherschutz, Bundesamt für Justiz, S 1–11
4. Balogh I, Arvidsson I, Björk J et al (2019) Work-related neck and upper limb disorders—quantitative exposure–response relationships adjusted for personal characteristics and psychosocial conditions. BMC Musculoskelet Disord 20(139):1–19
5. Barrero LH, Pulido JA, Berrio S et al (2012) Physical workloads of the upper-extremity among workers of the Colombian flower industry. Am J Ind Med 55:926–939
6. BAuA (2019) MEGAPHYS – Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Gemeinsamer Abschlussbericht der BAuA und der DGUV Bd. 1. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Dortmund, Berlin, Dresden, S 1–987
7. Bobin M, Amroun H, Coquillart S et al (2017) DNN based approach for the assessment of elbow flexion with smart textile sensor. In: SMC 2017—IEEE international conference on systems, man, and cybernetics Banff (hal-01677679v2)
8. Boudet G, Chausse P, Thivel D et al (2019) How to measure sedentary behavior at work? Front. Public Health 7:1–11
9. DGUV (2020) MEGAPHYS: Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz (DGUV Report 3/2020). Abschlussbericht zum Kooperationsprojekt von BAuA und DGUV, Bd. 2. Deutsche Gesetzliche Unfallversicherung e. V. (DGUV), Berlin, S 1–984
10. Ditchen D, Ellegast RP, Rehme G (2010) GonKatast – Ein Messwertkataster zu beruflichen Kniebelastungen (IFA-Report 1/2010). Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA), Sankt Augustin, S 1–137
11. Ellegast RP (2010) Quantifizierung physischer Belastungen am Arbeitsplatz. Zbl Arbeitsmed 60:386–389
12. Eu-Osha (2020) Gesunde Arbeitsplätze – entlasten Dich! Leitfaden zur Kampagne. Europäische Agentur für Sicherheit und Gesundheitsschutz am Arbeitsplatz (EU-OSHA). Eu-Osha, Luxemburg, S 1–36
13. Forsman M (2016) Ergonomic risk assessments—a need for reliable and attractive methods. In: Järvelin-Pasanen S (Hrsg) NES2016—Ergonomics in theory and practice—48th Annual Conference of Nordic Ergonomics and Human Factors Society University Eastern Finland, Kuopio. Report and Studies in Health Sciences, S 28–32
14. Grooten W, Johanssons E (2018) Observational methods for assessing ergonomic risks for work-related musculoskeletal disorders. A scoping review. Rev Cienc Salud 16(especial):8–38
15. Hartmann B, Spallek M, Ellegast R (2013) Arbeitsbezogene Muskel-Skelett-Erkrankungen. Ursachen –

Prävention – Ergonomie – Rehabilitation. ecomed MEDIZIN, Zwickau, S 1–440
16. Holtermann A, Mathiassen SE, Pinder A et al (2017) Assessing sedentary behaviour at work with technical assessment systems—final report. Partnership for European Research in Occupational Safety and Health (PEROSH), S 1–53
17. Holtermann A, Schellewald V, Mathiassen SE et al (2017) A practical guidance for assessments of sedentary behavior at work: a PEROSH initiative. Appl Ergon 63:41–52
18. Lin J-H, Kirlik A, Xu X (2018) New technologies in human factors and ergonomics research and practice. Appl Ergon 66:179–181
19. Merino G, Da Silva L, Mattos D et al (2019) Ergonomic evaluation of the musculoskeletal risks in a banana harvesting activity through qualitative and quantitative measures, with emphasis on motion capture (Xsens) and EMG. Int J Ind Ergon 69:80–89
20. Nordander C, Ohlsson K, Åkesson I et al (2013) Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands—a synthesis of group-level data on exposure and response obtained using uniform methods of data collection. Appl Ergon 44:241–253
21. Peppoloni L, Filippeschi A, Ruffaldi E et al (2016) A novel wearable system for the online assessment of risk for biomechanical load in repetitive efforts. Int J Ind Ergon 52:1–11
22. Ranavolo A, Draicchio F, Varrecchia T et al (2018) Wearable monitoring devices for biomechanical risk assessment at work: current status and future challenges—a systematic review. Int J Environ Res Public Health 15:1–26
23. Rhén IM, Forsman M (2020) Inter- and intra-rater reliability of the OCRA checklist method in video-recorded manual work tasks. Appl Ergon 84:103025
24. Schneider E, Irastorza X, Copsey S (2010) OSH in figures: work-related musculoskeletal disorders in the EU—facts and figures. In: European Agency for Safety and Health at Work (EU-OSHA) (Hrsg) European risk observatory report. Publications Office of the European Union, Luxembourg, S 1–184
25. Seidel DH, Ditchen DM, Hoehne-Hückstädt UM et al (2019) Quantitative measures of physical risk factors associated with work-related musculoskeletal disorders of the elbow: a systematic review. Int J Environ Res Public Health 16:1–23
26. Seidel DH, Heinrich K, Hermanns-Truxius I et al (2021) Assessment of work-related hand and elbow workloads using measurement-based TLV for HAL. Appl Ergon 92:103310
27. Vignais N, Bernard F, Touvenot G et al (2017) Physical risk factors identification based on body sensor network combined to videotaping. Appl Ergon 65:410–417
28. Walmsley CP, Williams SA, Grisbrook T et al (2018) Measurement of upper limb range of motion using wearable sensors: a systematic review. Sports Med Open 4(53):1–22
29. Weber B, Douwes M, Forsman M et al (2018) Assessing arm elevation at work with technical assessment systems. Partnership for European Research in Occupational Safety and Health (PEROSH), S 1–49
30. Yang L, Grooten WJA, Forsman M (2017) An iPhone application for upper arm posture and movement measurements. Appl Ergon 65:492–500

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# Curriculum vitae – David Henry Seidel

**Table 15.** shows the curriculum vitae and **Table 16.** lists further publications.

**Table 15.** Curriculum vitae David Henry Seidel.

| **PERSONAL INFORMATION** |
| --- |

**Table 16.** List of other publications (Date 26th September 2021).

| ***Congress and conference contributions – 2015 until 2022*** | |
| --- | --- |
| Contribution 1: Seidel et al. 2015 | **Seidel DH**, D'Souza SF, Alt WW and Wachowsky M (2015) Comparison of an inertial sensor based motion measurement system with a 3D-reflex marker based motion capture system. Gait Posture 42: S75. doi: 10.1016/j.gaitpost.2015.06.139. |
| Contribution 2: Ditchen et al. 2017 | Ditchen D, Gebhardt H, Hartmann B, Hermanns I, Jäger M, Jordan C, Klußmann A, Schaub K, Schust M, Sinn-Behrendt A, Weber B, Brandstädt F, Bruder R, Brütting M, Glitsch U, Hoehne-Hückstädt U, Kern G, Lang K, Lietz R, Liebers F, Post M, Rieger MA, Schäfer A, **Seidel D**, Serafin P und Steinberg U (2017) DGUV Report 2/2017. Gefährdungsbeurteilung physischer Belastungen – neue Ansätze im Projekt MEGAPHYS [DGUV Report 2/2017. Risk assessment of physical loads – New approaches in the MEGAPHYS project]: 87-92. In: Ellegast, R (Ed). 6. DGUV Fachgespräch Ergonomie – Zusammenfassung der Vorträge vom 2. und 3. November 2016. Sankt Augustin. DGUV. |
| Contribution 3: Heinrich et al. 2018 | Heinrich K, Ditchen D, Ellegast R, Hermanns I, Jaeger M, **Seidel D**, Sinn-Behrendt A and Weber B (2018) The assessment of physical workload using technical measurements within the MEGAPHYS project. In: 20th Congress International Ergonomics Association. Florence, Italy. IEA. |
| Contribution 4: Heinrich et al. 2019 | Heinrich K, Weber B, Hermanns I, **Seidel D**, Hoehne-Hückstädt U, Ditchen D und Ellegast R (2019) Entwicklung messwertbasierter biomechanischer Belastungsindikatoren für das Handgelenk [Development of measurement-based biomechanical load indicators for the wrist]. 34-35. In: DGAUM (ed). 59. Wissenschaftliche Jahrestagung der Deutschen Gesellschaft für Arbeitsmedizin und Umweltmedizin (DGAUM); Erfurt. DGAUM. |
| Contribution 5: Weber et al. 2018b | Weber B, Hoehne-Hückstädt U, Ditchen D, **Seidel D**, Hermanns I and Ellegast R (2018) 1631e Update on german risk assessment tools for upper limb msds. Occup Environ Med 75(Suppl 2): A259. doi: 10.1136/oemed-2018-ICOHabstracts.741. |
| Contribution 6: Weber et al. 2019b | Weber B, Heinrich K, **Seidel D**, Hermanns I, Hoehne-Hückstädt U, Ditchen D, Barrero LH and Ellegast R (2019) Biomechanical wrist load indicators using technically measured data: 72. In. PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders. Bologna, Italia. PREMUS. |

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|---|---|
| Contribution 7: Weber et al. 2019c | Weber B, Heinrich K, **Seidel D**, Hermanns I, Hoehne-Hückstädt U, Ditchen D, Jäger M, Barrero L and Ellegast R (2019) Method level 'technical field measurement': Updated and new approaches for exposure assessment: 87. In. PREMUS 2019: 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders. Bologna, Italia. PREMUS. |
| Contribution 8: Seidel et al. 2019a | **Seidel D**, Weber B, Heinrich K, Hermanns I, Hoehne-Hückstädt U, Ditchen D, Jäger M, Barrero L und Ellegast R (2019a) Messtechnische Analyse: Neue und weiterentwickelte Ansätze zur Abbildung und Bewertung der Belastung und Ergebnisse der Validierung [Measurement-based analysis: New and further developed approaches for illustration and assessment of the load and results of validation]: 22-23. In: 36th International Congress for Occupational Safety and Health (A+A) Safety – Health – Ergonomics; Düsseldorf, Germany. A+A, Basi, European Agency for Safety and Health at Work, issa, Messe Düsseldorf. |
| Contribution 9: Weber et al. 2019a | Weber B, Brütting M, Ditchen D, Eul M, Glitsch U, Heinrich K, Hermanns-Truxius I, Hoehne-Hückstädt U, Lietz R, Post M, **Seidel D** und Ellegast R (2019) DGUV Report 2/2020. Ergebnisse des Kooperationsprojektes MEGAPHYS [DGUV Report 2/2020. Results of the MEGAPHYS cooperation project]: 29-33. In: Freiberg S und Zieschang H (Edn). 7. DGUV Fachgespräch Ergonomie – Zusammenfassung der Vorträge vom 25. und 26. November 2019. Dresden, Deutschland. DGUV. |
| Contribution 10: Weber et al. 2021 | Weber B, Heinrich K, Hermanns-Truxius I, Seidel DH und Ellegast R (2021) Messwertbasierte Gefährdungsbeurteilung der distalen oberen Extremität [Measurement-based risk assessment of the distal upper extremity]: A.1.9: 1-3. In: Jäger M (Ed.). Arbeit HUMAINE gestalten. 67. Frühjahrskongress der Gesellschaft für Arbeitswissenschaft. 03. - 05.03.2021. Institut für Arbeitswissenschaft, GfA/GfA-Press: Dortmund/Bochum. |
| Contribution 11: Weber et al. 2022 | Weber B, Heinrich K, **Seidel DH**, Hermanns-Truxius I, Hoehne-Hückstädt U, Ditchen D, Jäger M, Barrero LH and Ellegast R (2022) Overview of Measurement-Based Assessment Approaches from the MEGAPHYS Project: 206-212. In: Black NL, Neumann WP and Noy I (eds). Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021). IEA 2021. Lecture Notes in Networks and Systems. Cham. vol 223. Springer. doi: 10.1007/978-3-030-74614-8_25. |
| ***Research report chapters – 2020*** | |
| Report chapter 1: Weber et al. 2020a | Weber B, **Seidel DH**, Brütting M, Ditchen D, Eul M, Glitsch U, Heinrich K, Hermanns-Truxius I, Hoehne-Hückstädt U, Lietz R, Post M, Barrero LH und Ellegast R (2020) Teil B. Weiterentwicklung und Evaluierung von Ansätzen zur Gefährdungsanalyse bei physischen Belastungen für die Methodenebene Messtechnische Analyse im Feld [Part B. Further development and evaluation of approaches to risk assessment for physical load for the method level measurement-based analysis in the field]: 269-410. In: DGUV Report 3/2020. MEGAPHYS: Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Abschlussbericht zum Kooperationsprojekt von BAuA und DGUV - Band 2. DGUV: Berlin. |

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| Report chapter 2: Schust et al. 2020 | Schust M, Liebers F, **Seidel DH**, Heinrich K und Weber B (2020) Teil D.2. Vergleich der Belastungsbewertungen des Speziellen Screenings und der Messtechnischen Analyse [Part D.2. Comparison of the load assessments of the special screening and the measurement-based analysis]: 883-952. In: DGUV Report 3/2020. MEGAPHYS: Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Abschlussbericht zum Kooperationsprojekt von BAuA und DGUV - Band 2. DGUV: Berlin. |
| Report chapter 3: Weber et al. 2020b | Weber B, **Seidel DH**, Hermanns-Truxius I, Heinrich K, Sinn-Behrendt A, Oberle M und Bruder R (2020) Teil D.3. Vergleich der Belastungsbewertungen des Experten-Screenings und der Messtechnischen Analyse [Part D.3. Comparison of the load assessments of the expert screening and measurement-based analysis]: 953-979. In: DGUV Report 3/2020. MEGAPHYS: Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Abschlussbericht zum Kooperationsprojekt von BAuA und DGUV - Band 2. DGUV: Berlin. |