Assessment and design of manual handling to reduce physical ergonomics hazards – use and development of assessment tools

Mik Pieniazek Ergonomics Thesis Report 1983
Updated 2014 - funded by
UNISON Manchester Branch investment projects

TRITA-STH Report 2017:7

ISBN 978-91-7729-423-8

ISSN 1653-3836

ISRN/KTH/STH/2017:7-SE

Published by KTH Royal Institute of Technology

Printed by US-AB, Stockholm

This academic thesis, with the approval of KTH Royal Institute of Technology, will be presented to fulfill the requirements of the Degree of Doctor of Philosophy. The public defense will be held in Room T1 (Emmy Rappesalen) at KTH Royal Institute of Technology, Hälsovägen 11C, Huddinge at 13:00, on the 7th of June 2017.

Abstract

Despite efforts of reducing harmful physical ergonomics exposures related to manual handling operations, the occurrence of hazardous exposures such as heavy or repetitive manual handling, non-neutral postures and hand-arm and whole-body vibrations is high in many occupational sectors. These physical ergonomics exposures are considered to substantially contribute to a large proportion of work related musculoskeletal disorders and occupational diseases in many industrial sectors such as the manufacturing industry. To reduce these harmful exposures (risk factors), interventions and job design strategies can utilize risk assessment, which is also a requirement for jobs involving manual handling operations or hazardous exposures. Despite several observation-based tools to support risk assessment of manual handling jobs, a need was identified of an observation-based tool which supported occupational health and safety practitioners with detailed assessments of a broad range of risk factors related to manual handling and which supported each step in a systematic work environment management.

The aim of this thesis was to explore the use and important usability-related aspects of observation-based assessment tools among professional ergonomists employed in Sweden. Furthermore, to develop new research based assessment and screening tools, to present their scientific basis and to evaluate their reliability and usability.

A web-based questionnaire was employed to gain knowledge on the use of risk assessment tools among professional ergonomists in Sweden and which usability-related aspects they considered important of such tools. To develop the new assessment tools (i.e. RAMP I and RAMP II), literature searches were performed to identify quantitatively described risk factors related to manual handling and important task parameters affecting the workers capacity in manual handling. The tools were developed in an iterative process with input from more than 80 practitioners, including more than 30 ergonomists, and with expert group judgments. The two tools were evaluated concerning their inter-rater reliability using assessment made by professional ergonomists and engineers of videotaped industrial manual handling jobs. A paper-based questionnaire was employed to evaluate the tools usability among 20 occupational health and safety practitioners, and the ease of use of the parts of RAMP II among 22 professional ergonomists.

The thesis points to a low proportional use of several internationally spread assessment tools among professional ergonomists in Sweden, and a relatively higher use of tools promoted by the Swedish Work Environment Authority. Several usability-related aspects for assessment tool were identified as important for this population. In particular, these aspects were related to the tools being easy and quick to use, the tools' ability to communicate and visualize the results, and the tools' ability to facilitate improvement measures. The developed screening and assessment tools support assessment of a broad range of risk factors related to industrial manual handling. The thesis supports that assessments with acceptable reliability can be achieved for the majority of items of the two developed tools, and improvement areas have been identified. The thesis supports that the two developed tools are usable in supporting risk assessments targeting musculoskeletal disorder risk factors related to industrial manual handling.

Keywords: Ergonomics, Human Factors, Risk Assessment, Hazard Assessment, Screening, Observation, the RAMP tool, Design, Lifting, Pushing, Pulling, Postures, Usability, Musculoskeletal Disorders, Ergonomists, Evaluation, Reliability.

Table of contents

Abbreviations

3DSSPP	3D Static Strength Prediction Program
KIM	Key Indicator Method
LI	Lifting index
MSD	Musculoskeletal disorder
MAF	Maximum acceptable force
MAL	Maximum acceptable load
MAW	Maximum acceptable weight
MAWL	Maximum acceptable weight for lifting and/or lowering
MMH	Manual materials handling
MHO	Manual handling operation
NIOSH-LE	NIOSH lifting equation
OBRAT	Observation-based risk assessment tools
OHS	Occupational health and safety
OHS-practitioner	Occupational health and safety practitioner
OHSM	Occupational health and safety management
OHSs	Occupational health services
RAMP	Risk Assessment and Management tool for manual handling Proactively
RNLE	Revised NIOSH lifting equation
RPL	Risk and priority level
RPT	Registered Physiotherapist
SWEA	The Swedish Work Environment Authority
WMSD	Work-related musculoskeletal disorder

1. Background

This thesis presents research related to the development and evaluation of the screening tool RAMP I, and the assessment tool RAMP II, which are part of the RAMP Tool[1] [1]. RAMP I, and RAMP II are designed to support occupational health and safety practitioners in screening of, and for assessing work-related musculoskeletal disorder risk factors related to industrial manual handling operations.

1.1 Musculoskeletal disorders and work-related health problem

Musculoskeletal disorders (MSDs) and pain are major problems globally as well as in Europe , causing human suffering for the individual and economic burden for companies and societies. Among musculoskeletal disorders, low back pain (LBP) and neck pain account globally for about 70% of disability years [2]. For activity-limiting LBP, the point and one-month prevalence globally, have been estimated to 12% and 23%, respectively [3]. Globally, LBP attributed to exposures at work has been estimated to more than 20 million disability-adjusted life years annually [4]. In the US, 1.15 million nonfatal occupational injury and illness cases requiring days away from work were reported in 2015. Overexertion due to manual handling operations (MHOs), adverse posture, and repetitive movements accounted for 33%, followed by falls, slips and trips (27%), and contact with objects or equipments (23%) [5]. The direct financial costs to US business in 2014 attributed to overexertion due to MHO, adverse posture, and repetitive movements were estimated to $19.5 billion, and 1/3 of the direct costs were due to non-fatal disabling workplace injuries [6]. The estimated financial costs due to MSDs in other countries are also substantial, e.g. about 3–5% of the gross national product in the Nordic Countries [3, 4], and about 3.4 % of the gross domestic product in Canada [7].

1.1.1 Work-related health problems and risk factors in the European Union

In the European Union[2], about 20 million workers experience work-related health problem annually [8]. Close to 2/3 of these work-related health problems concern the musculoskeletal system, where the back represents the largest category, followed by the upper-extremities and the lower extremities [8]. The musculoskeletal system also accounts for the largest category among occupational diseases, accounting for 4/10 of reported occupational diseases [9]. A substantial proportion of the EU workforce is exposed to major MSDs risk factors during work. For example, more than 30% of the workers report handling heavy loads at least a quarter of their workday. Furthermore, close to half are exposed to tiring or painful work postures, and about 2/3 carry out repetitive hand or arm movements for at least a quarter of their workday [10]. Additionally, about 1/5 report being exposed to heat, cold and vibration at least a quarter of their workday [10].

Note: [1] Risk Assessment and Management tool for manual handling Proactively; [2] EU 27, excluding France.

1.1.2 Work-related health problem in the Swedish manufacturing industry

The manufacturing industry in Sweden, is strongly over-represented in terms of reported occupational accidents and diseases [11]. Awkward postures, lifting and repetitive work were attributed about half of the occupational diseases in the manufacturing industry [11]. According to recent data from the Swedish Work Environment Authority (SWEA) [12], about one third of the employees in the manufacturing or process industries reported pain in the upper back or neck, lower back, shoulders/arms, and lower limb at least 1 day per week. More than half report being physically fatigued at least 1 day per week after the workday has ended [12]. Clearly, work-related MSDs (WMSDs) are a substantial problem globally and nationally, and a large proportion of the workforce is exposed to major risk factors daily.

1.2 Requirements of risk assessment

According to EU Directive, the employer shall 'ensure the safety and health of workers in every aspect related to the work' ([13], p.3). Furthermore, measures should be taken to avoid risks and to combat their sources. If the risks cannot be avoided, they should be evaluated. The employers shall, according to EU Directives [14], organize their work so that the need of handling loads manually is avoided. If this is not possible, the risk needs to be assessed and reduced as much as feasibly possible. These Directives have been transposed to Swedish law, which stipulates that the employer shall 'regularly investigate working conditions and assess the risks of any person being affected by ill-health or accidents at work' ([15], p.7). Furthermore, the employer shall investigate if the employees perform work that may cause ill health or that is unnecessary fatiguing due to postures, movements, manual handling or repetitive work [16]. In the (risk) assessment, the duration, frequency, and intensity of the exposure need to be considered. In operating machinery, action shall be taken to minimize the physical and psychological stress, fatigue and discomfort faced by the workers [17]. Thus, for work involving manual handling and operation of machinery, psychological stress, fatigue, and discomfort of the operators need to be considered in addition to other hazards.

1.3 WMSDs risk factors

WMSDs have multifactorial origin. Physical, psychosocial stressors, and individual factors are believed to be important contributors to WMSDs [18, 19]. Major physical risk factors for WMSDs include manual handling (e.g. lifting and pushing/pulling) [18, 20, 21, 22, 23, 24, 25, 26, 27, 28], non-neutral postures (e.g. bending and twisting) [18, 20, 21, 22, 24, 28, 29, 30, 31, 32], repetitive movements [18, 20, 21, 33, 34, 35, 36], and vibration [18, 20, 21, 34, 37, 38, 39, 40, 41, 42, 43, 44]. The attributable fraction of low back disorders due to e.g. manual materials handling (MMH) and frequent bending and twisting alone have been estimated to between 11–66% and 31–58% respectively [18, 45], indicating that a substantial proportion of these disorders has the potential of being prevented by risk reducing measures at the workplace.

1.4 Reducing WMSDs - Interventions

Evidence of positive health effects due to interventions is in general weak [46]. In order for interventions to have positive impact, commitment of key stakeholders are consider important, and interventions that target the employees at highest risk with measures that actively involve the employees [46]. Multi-component interventions are reported having more positive impact on health effects than single-component interventions [47]. Commonly used prevention strategies aimed at preventing WMSDs in manual handling jobs include, worker selection (e.g. based on medical screening), education and training (e.g. lifting techniques) and job design [48, 49]. Of these three strategies, job design has been regarded as most effective [48, 49]. Regarding the effect of training for employees exposed to MHO, a recent review by Verbeek et al. [50] found moderate evidence that training in manual handling techniques was not effective in preventing back pain or back pain-related disability. Rivilis et al. [51] reviewed the literature on participatory ergonomic interventions on health outcomes and found 12 studies that they rated having medium or high quality. Based on these 12 studies, Rivilis et al. [51] reported that there is moderate evidence that participatory ergonomic interventions can reduce MSD-related symptoms, and partial evidence that participatory ergonomic interventions can contribute to reducing days from work or sickness absence due to MSD, and reducing MSD injuries and workers' compensation claims.

For work involving mainly manual handling, van der Molen et al. [52] reported a reduction in physical work demands and musculoskeletal symptoms associated with interventions that introduced (mechanical) lifting devices. They additionally reported positive effects related to active involvement of the employees. Marras et al. [53] reported significant reduction in LBD incidence rate attributed to introduction of technical aid (i.e. lift tables and lift aids) for workers performing MHO in the manufacturing industry. Carravick et al. [54, 55] reported that participatory ergonomic interventions that included risk assessment were associated with a reduction of injury rates, workers' compensation claim costs and work hours lost due to manual handling injuries. A recent study by Cantley et al. [56] indicated, in agreement with Carravick et al. [54, 55] that participatory ergonomic interventions that include risk assessment, can have positive effects on reducing negative health consequences. Cantley et al.'s [56] study of 17 manufacturing plants in the US, reported a significant decrease in MSDs among those plants that applied a participatory ergonomic intervention which included a quantitative risk assessment of physical ergonomics hazards. Substantially more hazards were also identified among those who applied quantitative risk assessment, i.e. 4.7 per plant compared to 1.5 per plant among those who did not perform quantitative risk assessment. Hence, these results indicate the importance of having support of stakeholders and active involvements of employees, and a strategy to effectively identify risks and implementing risk reducing measures. Findings by Törnström et al. [57] indicate that the use of a risk assessment tools can, additionally, improve participation, internal collaboration and the effectiveness of the implementation process (i.e. implementing risk reducing measures). Job, or task rotation is a commonly used strategy to reduce or prevent WMSDs [58]. Evidence for its ability to reduce MSDs is, however weak (i.e. inconsistent evidence) [59]. For some occupations, job rotation has been associated with increased probability of low back complaints [60]. Although job rotation can reduce median cumulative loads or reduce the repetition rate of peak loads, it does not reduce the peak load magnitude [60, 61]. Therefore, if high peak loads occurs, intervention strategies utilizing job or task rotation should also include strategies to reduce peak loads.

In order to efficiently prevent WMSDs, ergonomic issues should be addressed early in the design process. Otherwise, the cost of re-design rapidly increases and the possibility for changes decreases. This emphasizes the importance of having relevant ergonomic performance indicators available for production system designers at early stages in the process [62]. Wulff et al. [63] showed that system designers request short, specific and quantitative data, and lack of this might lead to ergonomics issues being neglected. Experiences from professional ergonomists working in the field also indicate that quantitative data can be useful to facilitate decision makers to take actions [64].

1.5 Methods for assessment of WMSDs risk factors

Several tools, techniques or methods (hereafter collectively referred to as 'methods') have been developed for assessment (e.g. hazard, risk, or exposure assessment), or for collecting information on work-related physical or psychosocial factors [65, 66, 67, 68, 69, 70, 71]. The 'methods' targeting WMSD risk factors or determinants, are usually grouped in three broad categories: self report methods, observation-based methods, and direct measurement techniques [68, 72, 73, 74, 75]. In the first category, data can be collected using e.g. questionnaires, interviews or diaries (log books). In the second category, data is usually collected by direct observations or retrospective observation from video recordings with the guidance of an observation-based tool or protocol (checklist). In the third category, data can be obtained using *direct* measurement techniques such as e.g. EMG, heart rate monitors, and force gauge. Biomechanical models (e.g. 3DSSPP [76]) is sometimes regarded as a forth categories, although the categories to some extent overlaps. Biomechanical models have the advantages that they can be used for simulating workloads and predicting allowable loads for a range of population clusters and for planned (non-existing) work. Of the first three methods, direct measurement techniques are in general considered to produce the most precise, accurate, reliable and valid measurements, but at relatively high costs [72, 74, 77, 78]. On the other end of the spectra, and with regards to collecting data for epidemiological studies, it is generally considered that self-report accommodates collection of data from many individuals at relatively low costs [72, 74, 77, 78] (Figure 1.1). Self-reports also accommodate collection of a large battery of exposure parameters (versatility), and collection of retrospective data. The reliability and validity of self report methods are, however low for many parameters of exposures, as well as the precision and accuracy [72, 73, 74, 77, 78, 79, 80]. However, moderate to good agreement with more 'valid' methods have been reported for some gross activities, such as duration or presence in sitting posture [79, 81, 82], standing posture and whole-body vibration, presence of kneeling or squatting, walking, duration or frequency of having hands above shoulder height, and manual handling >5 kg [83].

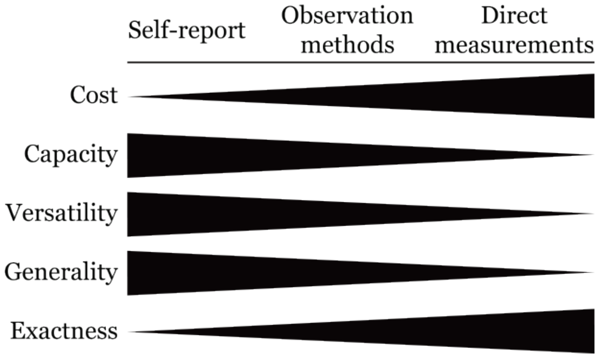


Figure 1.1. Strength and weaknesses with different types of methods when used in epidemiologic studies (redrawn from Winkel and Mathiassen [72].

Observation-based tools are often considered to be positioned in the middle of the spectra, producing measurements with higher agreement to more valid methods than obtained using self reports [73, 74, 84]. In general, accurate measurements can be obtained for gross work postures (e.g. trunk flexion) [74, 85, 86], especially when obtained from video observations [74, 86]. However, direct observation of rapid motion, small body joints (e.g. the wrist), and load weight in general produced inaccurate measurements [74, 85].

Direct or video observation using observation-based risk assessment tools (OBRATs) has been considered a feasible choice for occupational health and safety (OHS) practitioner such as ergonomists due to their versatility, relatively ease of use and low costs in comparison with direct measurements [68]. An evaluation of methods used by professional ergonomists in the US showed that a majority of the respondents used a combination of technical measurement techniques (e.g. tape measure, spring gauge, and scale, i.e. load cell) and observation-based assessment tools [87]. According to Eliasson [88], professional occupational health services (OHSs) employed ergonomists in Sweden often perform risk assessment without the use of a specific OBRAT. Furthermore, Eliasson et al. [89] found that such assessments (i.e. without the use of a specific OBRAT) performed by Swedish OHSs ergonomists on highly repetitive work tasks, produced results with low inter and intra-observer reliability. This indicates the disadvantage, in terms of reliability and validity, of assessments performed without the support of valid and reliable OBRATs.

1.6 Observation-based tools and methods

A large number of tools and methods have been developed during the last decades that utilize direct or indirect observation as their primary technique of collecting (recording) data. Two broad and partly overlapping categories can be distinguished for these tools and methods. The first category (Table 1.1) includes tools and methods that primarily are used for recording and classifying information on work-related exposures such as work postures and MHOs based on continuous observations or observations from fixed time intervals (e.g. 55-second intervals [75]). The scope of these tools and methods vary from mainly providing recordings of postures (e.g. Posturegram and HARBO), posture in combinations with MHO (e.g. Posture targeting and Back–EST), or comprehensive description of the characteristics of the job including e.g. physical and mental efforts (e.g. AET and PQA).

Table 1.1. Tools and methods for classification and recording of exposures and work tasks. Source: A) Kilbom et al., 1986 [90]; B) Kilbom, 1994 [91]; C) Juul-Kristensen et al., 1997 [65]; D) Li and Buckle, 1999 [66]; E) Denis et al., 2000 [67]; F) David, 2005 [68]; G) Chiasson et al., 2012 [92]; H) Dempsey et al., 2005 [87]; I) Takala et al., 2010 [85]; J) Palm et al., 2014 [93]; K) Sukadarin et al., 2016 [94]; L) Eliasson, 2017 [88]; M) additional tools and methods.

Tools and methods for classification and recording of exposures and work tasks	A	B	C	D	E	F	G	H	I	J	K	L	M
AET [95]	x								x				
Armstrong et al.'s upper extremity postures and work element recording sheet [96]			x	x		x							
Armstrong et al.'s methodology for documenting hand positions and forces [97]		x											
Chang et al.'s method [98]		x											
Back–EST; Back-Exposure Sampling Tool [99]									x				
Baty et al.'s 'Posture recording method' [100]		x											
Feuerstein and Fitzgerald's method [101]		x											
Foreman et al.'s ´Posture and activity classification system' [102]		x			x								
Genaidy et al.'s Standard Posture Classification System [103]			x										
Gil and Tune's 'Posture recordings' [104]				x									
Hand Activity Scale [105]							x						
HAMA; Hand-Arm-Movement Analysis [106]				x									
HARBO [107]				x	x	x							
Harber et al.'s 'coding scheme' [108]		x			x								
Keyserling's 'Posture analysis' [103]		x	x	x	x								
Lowe et al.'s 'Posture schema' [109]													x
Malchaire and Rezk-Kallah's 'Posture strain classifications schema' [110]					x								
Nygård's 'Observation method for poor work postures' [90]	x												
Observationsmetod for arbetsskador [90]	x												
PATH [111]					x	x		x	x		x		
PEO (and Hand PEO) [112]		x	x	x	x	x			x				
Posturegram [113]				x									
Posture targeting [114]	x	x		x	x				x				
PQA; Position Analysis Questionnaire [115]													x
ROTA [116]		x		x		x							
Ryan's ´Activity analysis' [117]		x			x								
Saari and Wickström's 'Observation method' [118, 119]	x	x			x								
TRAC; Task Recording and Analysis on Computer [116, 120]		x	x	x	x	x			x				
VIRA [121]	x	x	x	x									
Yen and Radwin's 'video-based system' [122]				x		x							
Magnusson and Örtengren's 'posture scheme' [123]					x								
PWSI [124]					x								

The tools or methods in the second category (i.e. observation-based assessment tools) (Table 1.2) provide, in addition to recordings of exposure, a classification system or weighing of the recorded exposures in terms of their magnitude or severity (i.e., exposure, hazard or risk assessment). All of these assessment tools do not include a risk assessment. Instead some of the tools express a general exposure level or action level. However, the term OBRAT will be used as a general term for these two categories of tools in this thesis.

Table 1.2. Tools and methods for assessment of exposure and work tasks. Source: A) Kilbom et al., 1986 [90]; B) Kilbom, 1994 [91]; C) Juul-Kristensen et al., 1997 [65]; D) Li and Buckle, 1999 [66]; E) Denis et al., 2000 [67]; F) David, 2005 [68]; G) Chiasson et al., 2012 [92]; H) Dempsey et al., 2005 [87]; I) Takala et al., 2010 [85]; J) Palm et al., 2014 [93]; K) Sukadarin et al., 2016 [94]; L) Eliasson, 2017 [88]; M) additional tools and methods.

Tools and methods for assessment of exposure and work tasks	A	B	C	D	E	F	G	H	I	J	K	L	M
AAWS; the Automotive Assembly Worksheet [125]													x
Arbouw [126]									x				
ARBAN/ERGAN [127]	x	x							x				
ACGIH TLV for HAL [128]						x		x	x				
ACGIH TLV 'Lifting' [129]						x			x				
ART Tool [130]										x			
BASIK; Bättre arbetssätt i kassan [131, 132]													x
Berns and Milner's TRAM method [90]	x												
Chung et al.'s postural stress evaluation method [133]									x				
CTD Risk Assessment model [134]													x
Damlund et al.'s 'Strain assessment method' [90, 135]	x				x								
DUTCH; 'the Push and Pull Check' [136, 137]													x
Caution and Hazard Zone Checklists, 'CHZ-Checklists' [138, 139]									x	x		x	
DINO; DIrect Nurse Observation instrument for assessment of work technique during patient transfers [140]													x
EWA; Ergonomic Workstation Assessment [141]													x
Ergonomic Workplace Analysis [142]													x
ERIN [143]													x
ERGONOVA and ErgoVSM [144, 145]													x
ERGO X/ FAST ERGO X [146, 147]													x
ERGOtool [148]													x
EAWS; the Assembly Specific Force Atlas [149]													x
Keyserling et al.'s 'Upper extremity CTD checklist' [150]									x				
Keyserling et al.'s 'Checklist for awkward posture of the legs, trunk and neck' [151]						x							
HARM [152]										x		x	
Holm et al.'s TI-METODE (TI Method) [90]	x												
Ketola et al.'s 'upper-limb expert tool' [153]						x			x				
Ergonomic Workplace Analysis method [142]							x						
Job load and hazard analysis [154]													x
KILA [155]													x
KIM 1; Key Item Method, Lifting, Holding, Carrying, 'KIM-LHC' [156, 157]										x		x	
KIM 2; Key Item Method, Pulling, Pushing, 'KIM-PP' [156, 158]										x		x	
KIM 3; Key Item Method, Manual Handling Operations, 'KIM-MHO' [159]										x		x	
LUBA; Postural loading on the upper-body assessment [160]						x			x				
MAC; Manual Handling Assessment Charts [161]						x			x				
ManTRA [162]									x				
MAPO [163]													x
HSE Manual handling of loads assessment checklists [164]						x							
RAPP ; Risk assessment of pushing and pulling tool [165, 166]													x
HSE Risk Filter and the Risk Assessment work sheet, 'HSE-RF/RA'[167]						x			x				
New Zealand code for material handling [168]									x				
NIOSH lifting equations (NIOSH-LE) [169, 170]								x	x	x		x	
OCRA; Occupational Repetitive Actions , the OCRA 'methods' [171, 172]						x	x		x	x		x	
OWAS; Ovako working posture assessment system [173]	x	x	x	x	x	x		x	x		x		
PLIBEL [174]						x			x		x		
QEC; Quick Exposure Check [175]				x		x	x			x	x	x	
REBA; Rapid Entire Body Assessment [176]				x		x	x	x	x	x	x	x	
Revised Strain Index [177]						x							
RAMP; Risk Assessment and Management tool for manual handling Proactively [1]												x	
ROSA; The Rapid Offce Strain Assessment [178]													x
PTAI [179, 180]													x
RULA; Rapid upper-limb assessment [181]			x	x	x	x	x	x	x	x		x	
Stetson et al.'s 'Hand Exertion Classification System' [182]		x							x				
Strain Index [183]						x	x	x	x	x		x	

‘SWEA-AFS’; the SWEA’s provisions on physical ergonomics [16, 184]			x		
ULRA/RTI [185]					x
WERA; Workplace ergonomic risk assessment [186]				x	
VIDAR; Video- och databaserad arbetsanalys [187]			x		
WEST; Work Environment Screening Tool [188]					x
WOPALAS; Working Posture Analysing System [189]	x				
WRAP [190]					x

1.7 Observation-based assessment tools

Many of these observation-based assessment tools have been developed for assessment of specific jobs or work tasks such as patient transfers (MAPO, DINO and PTAI), supermarket cash register work (BASIK), computer work (ROSA), kitchen work (KILA), assembly work (ERGOtool, AAWS, EAWS, and the Assembly Specific Force Atlas), or for a specific industry such as the construction industry (Arbouw and ERGAN) (Table 1.3).

Table 1.3. Examples of tools developed for assessments of specific work, work task, or type of industry.

Work, work task, or type of industry	Examples of observation-based assessment tools
Computer work	ROSA [178], Ergonomic Workstation Assessment [141]
Construction work	Arbouw [126], ERGAN (ARBAN) [127]
Kitchen work	KILA [155]
Supermarket cashiers	BASIK [131, 132]
Patient transfer/lifting	MAPO [163], DINO [140], PTAI [179, 180]
Manufacturing industry, including assembly work	ERGO X [146], FAST ERGO X [147], ERGONOM [191], ERGOtool [148], AAWS [125], EAWS [149], The Assembly Specific Force Atlas [192]

In terms of potential users, many of these tools are mostly feasible for researchers, while some are suitable for ergonomists and other OHS practitioners. In a recent review of observation-based assessment tools by Takala et al. [85], among the 30 observation-based assessment tools (Table 1.2) that fulfilled the inclusion criteria, Takala et al. [85] reported that QEC, VIDAR, the Risk filter and the Risk Assessment sheet by HSE were potentially suitable for supervisors and workers, and possibly also WAC, MAC and ManTRA. Pascual and Naqvi [193] reported that ergonomics checklists were the type of method used by the largest proportion of health and safety committee members, while Arezes et al. [194] reported that the NIOSH-LE and KIM were those OBRATs with the highest proportion of users among Portuguese health and safety practitioners. The Key Items Methods were developed to be used by managers [156], while both MAC [161] and ART [130] were developed for health and safety inspectors. In contrast to the handful number of tools that were judged as suitable for supervisors and workers, Takala et al. [85] considered that 21 of the 30 included tools or methods were suitable for ergonomists. The large number of different methods, tools and techniques used among professional ergonomists in the US, reported by Dempsey et al. [87], indicates the need of a large ‘tool box’ of assessment methods.

The OBRATs differ from each other in terms of which and the number of exposures are addressed as well as parts of the body. The targeted exposures and body parts of recently developed OBRATs that have been developed for OHS practitioners (including e.g. OHS inspectors) or have been reported to be used by OSH practitioners in several countries are shown in Tables 1.4a–1.4c. The tools in Table 1.4a mainly address heavy MHO such as lifting/lowering or pushing/pulling, while the tools in Table 1.4b mainly target repetitive (non-heavy) MHO primarily involving the upper limbs. The tools in Table 1.4c mainly target assessment of adverse work postures or screening of a broad range of MSDs risk factors of exposures (Table 1.4c). The tools targeting heavy MHO (Table 1.4a) focus on either lifting and lowering or pushing and pulling. While the RNLE targets only lifting and lowering, MAC and KIM 1 additionally address carrying. The three tools targeting heavy manual pushing and pulling (i.e. KIM 2, RAPP and DUTCH) use the load weight, the type and characteristics of the load carrier used, and environmental factors (e.g. inclination angle of the floor) as measures of the work load. This is in contrast to the European and global standard (EN 1005-3, and ISO 11228-3, Table 1.5) and the provisions on physical ergonomics by SWEA ('SWEA-AFS') who instead uses hand force as measure of the workload in the assessment. While the former approach eliminates the need of direct technical measurements of the hand force magnitude, the later approach requires assessment of a range of factors contributing the hand force magnitude such as acceleration, floor inclination angle [195, 196, 197, 198, 199], floor material [199, 200, 201], wheel diameter [199, 200, 201] and direction of the wheels [200]. Since each factor is inherent with a significant variability, the validity of the estimation of the work load requirements may be negatively affected using this approach.

It is generally agreed that assessments of mechanical exposures should include the magnitude, duration and frequency of the exposure [72, 77]. Among the three tools in Table 1.4a targeting (heavy) lifting and lowering, only RNLE explicitly addresses these three exposure dimensions. The exposure dimensions are addressed via the load weight (magnitude), the number of operations per fifteen minutes (frequency) and continuous time performing lifting or lowering without added breaks (duration). However, the cumulative duration (e.g. number of seconds exposed to MHO) and the total number of operations are only partly addressed. For KIM 1 and KIM 2, the numbers of operations per day are assessed, but not explicitly the frequency. Furthermore, KIM 1 and KIM 2 do not distinguish if for example, 1000 or 3000 operations are performed daily (i.e. about 2 times/min and 6 times/min, respectively, for eight hours work). For MAC and RAPP, the frequency is addressed, but not the duration. The tools targeting repetitive MHO and work posture (Table 1.4b and 1.4c) include all three exposure dimensions (at least indirectly). However, all three dimensions are in most cases not addressed for each single exposure (e.g. neck posture). With the exception of WRAP, the exposure dimensions addressed for assessment of posture usually include the magnitude (e.g. angle relative to the vertical line of gravity) in combination with either the duration or the frequency. For example, the exposure dimensions for assessment of postures of the neck, upper arms or the wrists in HARM and the ART tool include the duration (proportion of time, and duration of the task per workday) and dichotomous categorization of the magnitude (neutral or non-neutral posture), but not frequency. As shown in Tables 1.4b and 1.4c, the tools target different parts of the body. For example, while SI, RSI, OCRA and HARM mainly target exposures to the upper limbs, REBA, WRAP and the 'CHZ checklists' include exposures to both the upper and lower limbs and the back.

The assessment of postures is often based on the most stressful posture (e.g. RULA, REBA and QEC), or proportion of time in non-neutral postures (e.g. HARM, WRAP, the ART Tool and OCRA). Selecting the most stressful task may require the assessor to assess multiple situations in order to identify the most stressful task (according to the tool). If the stressful task only occurs for a short proportion of the workday, the assessor may additionally need to assess the most commonly adopted postures, as also proposed for e.g. RULA and KIM 3.

The assessment models in the provisions on physical ergonomics by SWEA [16] include: heavy lifting; heavy pushing/pulling; work postures of the neck, trunk, upper arm and lower limbs; and repetitive work or repetitive movements. For lifting, the number of lifts; the duration; vertical height and the coupling (hand grip) should also be addressed. For pushing and pulling, the travel distance; the number of operations or duration; the vertical height; and if the force is exerted using one or two hands should also be addressed. Other factors that need to be addressed is hand-arm and whole body vibration [202], recovery time and psychosocial factors [16]. None of the tools in the Tables 1.4a–1.4c target all of these exposures/risk factors. Therefore, assessment of jobs that includes an array of exposures such as heavy lifting and pushing, and occurrence of non-neutral postures of the upper arms and neck, would generally require the use of multiple tools. Additionally, none of these tools include assessment of discomfort which may be useful since additional factors not included by the tools may also be relevant to address, and since discomfort have also been associated with MSDs [203, 204, 205].

Table 1.4a. OBRATs mainly targeting heavy manual handling.

	Heavy manual handling					
	RNLE	MAC	KIM 1	KIM 2	RAPP	DUTCH
Heavy MHO						
Lifting/Lowering ('heavy')						
Load weight	Yes	Yes	Yes	-	-	-
Frequency/duration	Yes	Yes[A]	Yes[D]	-	-	-
Posture	Indirect	Yes	Yes	-	-	-
Carrying ('heavy')						
Load weight	-	Yes	Yes	-	-	-
Frequency/duration	-	Yes[A]	No	-	-	-
Distance	-	Yes	Yes[E]	-	-	-
Pushing/Pulling ('heavy')						
Magnutide of force	-	-	-	Indirect[F]	Indirect[F]	Indirect[F]
Frequency/duration	-	-	-	Yes	Partly[G]	Yes
Posture	-	-	-	Yes	Yes	Indirect[J]
Postures (excl. heavy MHO)						
Neck						
Magnitude	-	-	-	-	-	-
Duration	-	-	-	-	-	-
Frequency (i.e. movements)	-	-	-	-	-	-
Upper arms						
Magnitude	-	-	-	-	-	-
Duration	-	-	-	-	-	-
Frequency (i.e. movements)	-	-	-	-	-	-
Trunk						
Magnitude	-	-	-	-	-	-
Duration	-	-	-	-	-	-
Frequency (i.e. movements)	-	-	-	-	-	-
Wrist						
Magnitude	-	-	-	-	-	-
Duration	-	-	-	-	-	-
Frequency (i.e. movements)	-	-	-	-	-	-
Kneeling/Squatting	-	-	-	-	-	-
Additional factors						
Hand-arm vibration	No	No	No	No	No	No
Whole-body vibration	No	No	No	No	No	No
Breaks/recovery time	Yes	No	No	No	Yes	No
Ambient temperature (e.g. heat, cold and draught)	No	Yes	n/s	No	Yes	No
Psychosocial factors	No	Indirect[B]	No	No	No[B]	No
Discomfort reports	No	No[C]	No	No	No[C]	No

Notes: not stated (N/S); [A] includes frequency, but not total operations/workday; [B] not specified in the tool, refers to other source; [C] refers to signs related to exhaustion or fatigue; [D] number of operations/workday and duration/workday; [E] total distance/workday, not per operation; [F] load weight or total weight (e.g. carrier and load weight) in combination with type of equipment or other factors is used as instead of force; [G] mainly qualitatively (3 categories). Does not include duration or frequency/workday; [J] based on the grip height.

Table 1.4b. OBRATs mainly targeting repetitive manual handling.

	Repetitive manual handling				
	ART tool	KIM 3	HARM	OCRA	SI/RSI
Heavy MHO					
Lifting/Lowering ('heavy')					
Load weight	-	-	-	-	-
Frequency/duration	-	-	-	-	-
Posture	-	-	-	-	-
Carrying ('heavy')					
Load weight	-	-	-	-	-
Frequency/duration	-	-	-	-	-
Distance	-	-	-	-	-
Pushing/Pulling ('heavy')					
Magnutide of force	-	n/a[H]	-	-	-
Frequency/duration	-	-	-	-	-
Posture	-	-	-	-	-
Postures (excl. heavy MHO)					
Neck					
Magnitude	Yes	Partly	Yes	No	No
Duration	Yes	Partly	Yes	No	No
Frequency (i.e. movements)	No	No	No	No	No
Upper arms					
Magnitude	Yes	n/s	Yes	Yes	No
Duration	Yes	n/s	Yes	Yes	No
Frequency (i.e. movements)	Indirect[I]	Indirect[I]	No	Indirect[I]	No
Trunk					
Magnitude	Yes	Partly	No	No	No
Duration	Yes	Partly	No	No	No
Frequency (i.e. movements)	No	No	No	No	No
Wrist					
Magnitude	Yes	Yes	Yes	Yes	Yes
Duration	Yes	Partly	Yes	Yes	Yes
Frequency (i.e. movements)	No	No	No	Potentially	Yes
Kneeling/Squatting	-	No	No	No	-
Additional factors					
Hand-arm vibration	Yes	No	Yes	Yes	No
Whole-body vibration	No	No	No	No	No
Breaks/recovery time	Yes	No	No	Yes	No
Ambient temperature (e.g. heat, cold and draught)	Yes	Yes	Yes	Yes	No
Psychosocial factors	Yes	No	Partly	Partly	No
Discomfort reports	No	No	No	No	No

Notes: not applicable (n/a); not stated (n/s); [H] includes force exertions involving e.g. pushing buttons, exertion involving e.g. tightening, loosening bolts; [I] includes frequency of different types of force exertions.

Table 1.4c. OBRATs mainly targeting posture or screening of a range of exposures.

	Posture			Screening		
	WRAP	RULA	REBA	QEC	‘HSE-RF/RA’	‘CHZ-Checklists’
Heavy MHO						
Lifting/Lowering ('heavy')						
Load weight	-	Yes	Yes	Yes	-	Yes
Frequency/duration	-	Partly[K]	Partly[K]	No[N]	-	Yes
Posture	-	Yes	Yes	Yes	-	Indirect
Carrying ('heavy')						
Load weight	-	Potentially [O]	Potentially [O]	Potentially [O]	-	-
Frequency/duration	-	Partly[K]	Partly[K]	No[N]	-	-
Distance	-	Yes	Yes	Yes	-	-
Pushing/Pulling ('heavy')		s				
Magnutide of force	-	Yes [O]	Yes [O]	Potentially[O]	-	-
Frequency/duration	-	Partly[K]	Partly[K]	No[N]	-	-
Posture	-	Yes	Yes	Yes	-	-
Postures (excl. heavy MHO)						
Neck						
Magnitude	Yes	Yes	Yes	Yes	Yes	Yes
Duration	Yes	No[L]	No[L]	Partly	Yes	Yes
Frequency (i.e. movements)	Yes	Partly[K]	Partly[K]	-	Yes	-
Upper arms						
Magnitude	Yes	Yes	Yes	Yes	Yes	Yes
Duration	Yes	No[L]	No[L]	-	Yes	Yes
Frequency (i.e. movements)	Yes	Partly[K]	Partly[K]	Yes	Yes	-
Trunk						
Magnitude	Yes	Yes	Yes	Yes	Yes	Yes
Duration	Yes	No[L]	No[L]	-	-	Yes
Frequency (i.e. movements)	Yes	Partly[K]	Partly[K]	Yes	-	No
Wrist						
Magnitude	Yes	Yes	Yes	Yes	Partly[P]	-
Duration	Yes	No[L]	No[L]	Yes	Partly[P]	-
Frequency (i.e. movements)	Yes	Partly[K]	Partly[K]	-	Yes	-
Kneeling/Squatting	Yes	No[L]	Potentially[M]	-	-	Yes
Additional factors						
Hand-arm vibration	-	-	-	Yes	Yes	Yes
Whole-body vibration	-	-	-	Yes	-	-
Breaks/recovery time	-	-	-	-	No[Q]	-
Ambient temperature (e.g. heat, cold and draught)	-	-	-	-	Yes	-
Psychosocial factors	-	-	-	-	Yes	-
Discomfort reports	-	-	-	-	-	-

Notes: [K] includes loads/force >10kg, and repetition rate e.g. >4 times/min; [L] only if it occurs continuously >1 min or not; [M] includes knee flexion angle; [N] includes the duration of the task; [O] includes force exertions, e.g. >4 kg; [P] includes duration of extreme joint positions; [Q] only included as a note.

European and global ergonomics standards concerning work postures, repetitive upper limb movements and manual handling operations are shown in Table 1.5. The European ergonomics standards (i.e. EN 1005) targets design of machinery and the ISO standard targets design of work, jobs and products.

Table 1.5. European and global ergonomics standard for assessing posture, repetitive upper limb movements and manual handling operations.

Exposure	European ergonomics standard	Global ergonomics standard
Lifting/lowering	EN 1005-2	ISO 11228-1
Carrying	(EN 1005-3)*	ISO 11228-2
Holding objects	-	-
Pushing/pulling	EN 1005-3	ISO 11228-2
Postures	EN 1005-4	ISO 11226
Repetitive upper limb movements	EN 1005-5	ISO 11228-3

Note: * = does not provide any reduction of the ‘allowable load’ (i.e. recommended mass limit) due to carrying distance.

In terms of MHO, the EN standards 1005-2 and 1005-3, and the ISO standards 11228-1 and 11228-2 can be used for risk (hazard) assessments of existing jobs as well as for predicting the ‘allowable’ workload for a specified population group. Both the EN 1005-2 and 11228-1 are largely based on the revised NIOSH lifting equation [169] (Table 1.2), while ISO 11228-2 is largely based on the manual handling tables by Mital et al. [206]. Examples of additional tools and models developed for predicting ‘allowable’ workload for different types of MHO are shown in Table 1.6.

Table 1.6. Examples of manual handling models or tools (including e.g. lifting, pushing/pulling, and carrying)

	Lifting	Lowering	Pushing	Pulling	Carrying	CMHO
SSP [207, 208]	X	(X)	ns	ns	ns	-
3DSSPP [76, 209]	X	(X)	X	X	-	-
Drury & Pfeil model [210]	X	ns	-	-	-	-
Garg et al.’s ’Oxygen consumption prediction model’ [211]*	X	X	X	X	X	-
The 1981 NIOSH lifting equation (NIOSH-LE 1981) [170] and the revised NIOSH lifting equation (RNLE) [169]	X	X	-	-	-	-
Job Severity Index [212, 213]	X	ns	-	-	-	-
Taboun & Dutta prediction models [214]*	X	X	-	-	X	X
Mital et al.’s ´Manual Handling Model’ [206, 215, 216]	X	X	X	X	X	X
‘Shoaf et al. model’ [217]	X	X	X	X	X	-
‘Hidalgo et al.’s lifting model’ [218]	X	ns	-	-	-	-
’Dempsey et al.’s Óxygen consumption prediction model’ [219]*	X	X	X	X	X	X
Genaidy et al. model [220]	X	X	X	X	X	X
‘General lifting equation’ [221]	X	-	-	-	-	-
NIOSH 2D YBM [222]	X	X	X	X	X	-
Garg et al.’s ‘Psychophysical pushing and pulling equations’ [199]	-	-	X	X	-	-
The ‘Arm Force Field’ method [223]	-	-	X	X	-	-

Note: Combined manual handling operations (CMHO); not stated (ns); * predicts metabolic costs related to the task (i.e. oxygen consumption).

The tools and models shown in Table 1.6 target either lifting, lifting and lowering, pushing and pulling, lifting lowering and carrying, or lifting, lowering, pushing, pulling and carrying. Although combined manual handling operations (CMHO) is stated as commonly occurring [224, 225, 226] or even as constituting the main part of manual handling [227], relatively few tools or models have been developed for assessment of CMHO [220]. Most of these tools can be used for predicting allowable load weight or push/pull force for a range of frequencies, travel distances and vertical heights. For example, the RNLE can predict allowable weight (i.e. recommended maximum weight limit) taking in to account, the horizontal and vertical location of the load, as wells as quality of the grip (coupling) and displacement of the center of gravity of the object, travel distance, duration, frequency, rest allowance, and load asymmetry. Hidalgo et al. [218], expanded the range of variables by additionally including a variables related to heat stress, body weight, age and the targeted percentile of a female or male population. The tools and models in Table 1.6 have been derived from studies using different research methodologies, such as physiology (e.g. Garg et al.'s and Dempsey et al.'s models), psychophysics (e.g. Garg et al.'s 'Psychophysical pushing and pulling equations' [199] and The 'Arm Force Field' method), or a combination e.g. both biomechanics and psychophysics (e.g. 3DSSPP [76, 209]), or combining all of these methodologies together with epidemiology (e.g. RNLE [169]). Because of their different basis, their application for different types of task can diverge. For example, the SSP and 3DSSPP are manly restricted (valid) for assessment of occasional exertions while the tools and models based on physiology (e.g. oxygen consumption) may exceed the capacity if predicting allowable workload at low frequencies [49].

In addition to the assessment tools and models presented, several national guidelines exist [228]. In Sweden, this includes the provision on physical ergonomics ('SWEA-PE') [16, 184] that covers aspects such as repetitive work, work posture, lifting, pushing/pulling, and psychosocial factors. Despite the large number of assessment tools available, some companies in e.g. the vehicle manufacturing industry, with production located in Sweden (e.g. Saab Automobile, SCANIA CV, Volvo Car Corporation) have developed their own assessment tools to fit the companies specific needs [229]. Examples of such tools developed and used in Europe are displayed in Table 1.7. These tools have in common that they visualize the risk levels in a color category system, and some of them include a numerical score system to communicate the risk. They also facilitate guidance of design, for example by explicitly stating allowable workloads (e.g. push/pull force or load weight) for different situations.

Table 1.7. Examples of tools developed for assessment in the vehicle manufacturing industry

Work, work task, or type of industry	Examples of assessment tools
Assembly; cars	BME [230]; AAWS)[125]; EAWS [149]; the Assembly Specific Force Atlas [192]; ECM, DACORS and METEO [231]; Associate Job Analysis [232].
Assembly; trucks	SES [233]; the Ergonomics Memorandum [234]; SARA [235]; WERA [236].

1.7.1 Criteria for evaluating observation-based risk assessment tools

No consensus exists on which single criteria should be used for evaluating OBRATs. As reported earlier, cost (and capacity), versatility, generality, reliability and validity were considered important aspects when evaluating advantages and disadvantages for methods to be used for collecting data in epidemiological studies [72]. With regards to evaluating ergonomics standards and guidelines, Fallentin et al. [228] used three criteria: (1) *Scientific coherency*, i.e. the degree to which it relates to scientific knowledge on the causes of the occupational disease and injury in question, (2) *Effectiveness*, i.e. impact on prevention of occupational disease and injury in question. This included its possibility to identify risk factors, and to contribute to a reduction of (adverse) exposure levels and adverse health effects, and (3) '*Usability'*, here defined as its potential of being implemented, which was assessed with regards to its ‘user friendliness’. Kilbom [91], evaluated observation-based tools and methods, and discussed the type of exposures (e.g. lifting, pushing, posture) they included, as wells as their inter and intra-observer reliability (i.e. repeatability), internal validity (i.e. concurrent validity), external validity (i.e. predictive validity), and their applicability. Denis et al. [67], also included inter and intra-observer reliability in their overview of observation-based methods, which they consider could be influenced by the training of the observers. Recently, Takala et al. [85] evaluated 30 observation-based tools and methods with regards to their concurrent validity, predictive validity, intra- and interobserver repeatability, and face validity. Assessment of face validity included, in addition to judgments of its scientific coherency, its possibility to facilitate decision making and assessment of the data collection and analysis process.

1.7.2 Usability attributes of observation-based risk assessment tools

In terms of usefulness for professional ergonomists and other OHS practitioners, additional usability aspects might also be of importance. Literature on important attributes of OBRATs among professional ergonomists, and reasons for the OBRATs being used are scarce, despite that this type of information is considered important when developing new tools [175]. Buckle and Li [237] surveyed the user needs among health and safety professionals and ‘experts’ in the development of the Quick Exposure Check [175], and Diego-Mas et al. [238] among 244 Spanish-speaking OHS practitioners from 20 countries. Important usability aspects identified in those studies (Table 1.8) includes, e.g. it being quick and easy to use, as wells as facilitating assessment of relevant job exposures and supporting risk reducing measures (i.e. decision and priority of measures). The expert’s needs identified by Buckle and Li [237] included e.g. it being valid, reliable, backed by regulatory bodies, and being applicable for assessments of a range of jobs (i.e. across plants).

Table 1.8. Identified needs regarding OBRATs among practitioners and experts, based on studies by Buckle and Li [237], David [68] 2005, and Diego-Mas et al. [238].

Buckle and Li, 1996		David , 2005	Diego-Mas et al., 2015
Practitioners/H&S professionals[†]’ needs	Experts’ needs	OHS practitioners’ needs	OHS practitioners’ needs
Quick to apply Being clear User friendly Having Tick/Check boxes Easy to learn Requiring limited paperwork Being specific to the task/job being assessed under consideration Not requiring collection of unnecessary data	Valid Reliable High face validity Having equal balance across risk factors Comprehensive Can generalize results across plants Being backed by regulatory bodies	Quick to use Cost effective to use Not requiring excessive skills Facilitate optimal (broader solutions) Facilitate priority order of interventions Facilitation of measures (i.e. capacity for convince managers, e.g. by scoring system) Capacity Versatility Generality Exactness	Relatively important: Facilitates decision regarding measures Properly addresses the relevant risks of the job Is applicable to different types of jobs *Potentially less relatively important :* Requirements of training Time for application (i.e. being quick to apply)

Note: [†]Health and safety professionals.

The survey by Diego-Mas et al. [238] indicated that the tools’ capability of supporting decision on measures, applicability to the jobs of interest, and to what extent assessment using the tool reflect the ‘true’ risk were all considered important among the OHS practitioners. Conversely, aspects related to the relative training required, time required for applying the tool and its relative complexity (or of it being 'simple') were indicated as having less importance.

In a recent study concerning workplace assessments performed by professional ergonomics in Canada, Wells et al. [64] reported, in agreement with Eliasson [88], that ergonomists often initiated a workplace assessment without using an OBRAT. Instead, interviews and general observation were used in the initial phase. However, in cases where they needed to gain more understanding or needed to persuade the person responsible for taking action; they often gravitated towards using more 'objective' methods including OBRATs, as displayed in Figure 1.2.

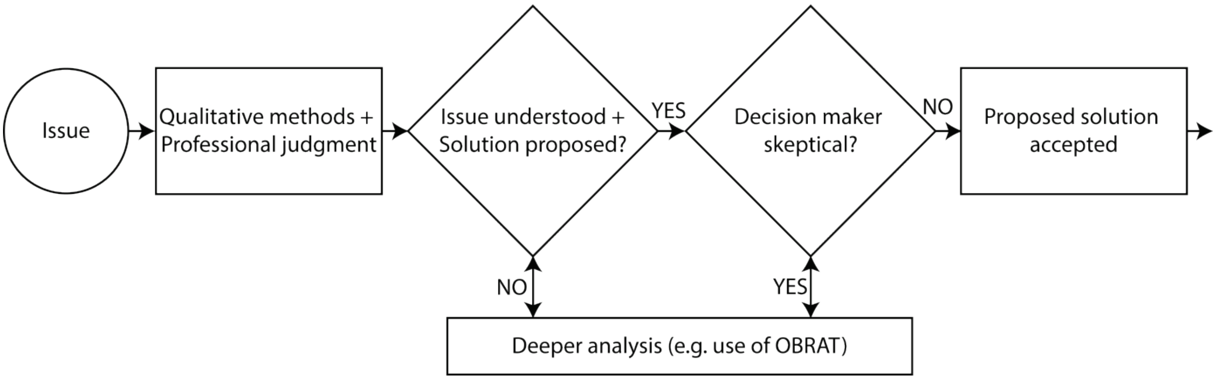


Figure 1.2. Contextual factors for using qualitative methods (or tools), and deeper analysis with the use of e.g. OBRATs (adapted from Wells et al. [64]).

This indicates the importance of the ability, of the tool, to facilitate the assessor with a greater understanding of the issue, and its ability to support communication to key stakeholders.

1.7.3 Use of OBRAT among professional ergonomists and other OHS practitioners

Due to the various distribution of WMSDs risk factors in different types of jobs or work tasks, and the specialization of many of the OBRATs (e.g. targeting mainly repetitive upper-limb movements, or manual lifting), the assessor (e.g. the ergonomists) may require a large palette of tools and methods to cover the relevant exposures or risk factors of the jobs being assessed. Additionally, this has, at least in theory, the potential to partly compensate for some of the limitations of each specific tool or method. Despite the substantial number of OBRATs for assessing WMSD risk factors available for OHS practitioners, relatively few peer-reviewed studies have explored the extent to which they are used among OHS practitioners, including professional ergonomists.

The issue has, however, been explored among certified ergonomists in the US [239] and Canada [193], and among Spanish speaking ergonomics-practitioners [238], and OHS practitioners in Canada [193] and Portugal [194].

In general, these studies indicate that NIOSH-LE [169], RULA/REBA [176, 181], OWAS [173], and the psychophysical manual handling tables by Snook and Ciriello [240] or Mital et al. [206] are among those with the largest proportion of users among the practitioners in these studies. For example, NIOSH-LE was used by more than 8/10 of the respondents among US and Canadian certified ergonomists [193, 239], and about 6/10 of Spanish speaking ergonomics-practitioners [238], and about half of the OHS practitioners in Portugal

[194]. RULA and REBA were used by about 52, and 18% among US certified ergonomists [239], and about 80 and 57% among Spanish speaking ergonomics-practitioners [238], and about half of the certified ergonomists used either RULA or REBA [193]. However, with the exception of the study among certified ergonomists in the US [239] which was based on answers from 308 respondents and had a response rate of 53%, the other studies had either a low response rate (i.e. 9% [194] and 31% of the eligible [238]) or included a small number of respondents (i.e. 17 ergonomists [193].

In Sweden, assessment of WMSD risk factors are often carried out by professional ergonomists employed at OHSs, which in general are registered physiotherapists (RPT) [88]. The usage of OBRATs among ergonomists with a background as physiotherapists, as many of those within OHS-companies in Sweden, may diverge. It is also likely that the extent to which specific OBRATs are used differs between countries, as indicated by the studies cited above. Information of usage of specific OBRATs among Swedish ergonomists is, however, scarce. Nordander [241] surveyed to use of different OBRATs among OHSs organizations in Sweden. Of the 21 respondents, 20 reported that the provision on physical ergonomics by SWEA [184] was used within their OHSs organization. The use of other OBRATs were, however low (i.e. ≤15%). While this survey provided some indications of the use of some OBRATs at the level of the OHSs organization, the use at the individual level among ergonomists may diverge. Other surveys by Sturesson [242] and Laring et al. [243], referred to the use of some OBRATs among ergonomists in Sweden, but did not provide detail information on the extent they were used. New OBRATs have been introduced since Nordander’s survey was performed, and it is possible that the use of OBRATs among OHSs ergonomists in Sweden has changed since Nordander’s survey was performed.

1.7.4. Practitioners need of new observation-based risk assessment tools

Together with ergonomics experts at two global manufacturing companies with production located in Sweden, Rose et al. [244] identified a need for a new easy-to-use observation-based tool that could support risk assessment and risk management in the manufacturing industries for a broad range or manual handling work tasks and jobs. Despite the existing assessment tools, the companies could not find an assessment tool fulfilling their needs. This included e.g. an easy to use tool, that can be applied by different users, and which provides detailed assessment of a broad range of MSD risk factors related to industrial MHO. Additionally the tool should be usable as input for tailoring risk-reducing measures [245]. In concordance with the overview of OBRATs (section 1.7), several tools may be needed to address a range of exposures related to industrial MHO, as those addressed by the provisions on physical ergonomics by SWEA [16].

2. Research objective

The overall objective of the research project presented in this thesis has been to develop a usable research-based screening tool and an assessment tool for ergonomists employed in occupational health service organizations and other health and safety practitioners targeting major work-related musculoskeletal disorders related to industrial manual handling operations. To achieve this, the use of existing assessment tools among professional ergonomists in Sweden is explored, as wells as important usability aspects of assessment tools. Furthermore, strategies to derive usable observation-based assessment criteria from research literature related are to be presented. Lastly in order to assess the usability of the tools, their reliability as well other usability aspects are to be explored.

2.1 Aims

This thesis is based on the following aims:

- Aim I. Explore the use and important usability-related aspects of observation-based assessment tools among professional ergonomists employed in Sweden.
- Aim II. Develop a research based screening tool, and present its scientific basis.
- Aim III. Evaluate the reliability and the usability of the screening tool.
- Aim IV. Develop a research based assessment tool, and present its scientific basis.
- Aim V. Evaluate the reliability and the usability of the assessment tool.

Table 2.1. The aims and in which Papers they are explored.

	Papers				
Aims	A	B	C[†]	D	E[‡]
I. Explore the use and important usability aspects of observation-based assessment tools among professional ergonomists employed in Sweden.	√				
II. Develop a research based screening tool, and present its scientific basis.		√			
III. Evaluate the reliability and the usability of the screening tool.		√			√
IV. Develop a research based assessment tool, and present its scientific basis.			√	√	
V. Evaluate the reliability and the usability of the assessment tool.			√	√	√

Note: [†]Paper C presents parts of the assessment tool (i.e. a tool for assessing manual pushing and pulling), and its scientific basis, and additionally, an evaluation of its usability; [‡]Paper E presents parts of the usability evaluation for the screening tool and the assessment tool.

2.2 Delimitation

- Because the job title 'ergonomist' is unprotected in Sweden, the exploration of use and preferred qualities of observation-based risk assessment tools was restricted to professional OHSs ergonomists employed in Sweden who performed risk assessment on physical MSDs risks at least once per year, and who were registered physiotherapists.
- Paper A additionally includes data derived from interviews with twelve professional OHSs ergonomists employed in Sweden. The results from these interviews have been presented in a licentiate thesis by Eliasson [88] and are not part of this thesis.

3. Theoretical framework

3.1 Ergonomics

This thesis is positioned within the Ergonomics (or Human Factors) scientific discipline, which concerns knowledge of interactions among humans and other system elements [246, 247], or more specific, the 'understanding of human behaviour and performance in purposeful interacting sociotechnical systems' ([246], p.560). As an applied domain, Ergonomics utilizes this knowledge in design to optimize both human well-being and system performance, using theories, principles, data and methods [246, 247, 248]. Of the different subdisciplines of Ergonomics (e.g. Physical Ergonomics, Cognitive Ergonomics, Organizational Ergonomics, and Macroergonomics), this thesis manly targets the Physical Ergonomics domain, which concerns e.g. MMH, working postures, and WMSDs [247].

3.2 WMSDs risk factors, and exposures

A theoretical model of possible pathways of influencing factors that affect the workers (employees), and that could potentially cause short term effects such as discomfort and pain, and long term effects such as impairment and disability, was presented by the U.S. National Research Council [18] (Figure 3.1). According to this model, external loads (task demands) give rise to internal loading and physiological responses to copy with the increased demands. The strain is dependent on the internal load and the capacity of the worker. If the external loads cause internal loads exceeding the capacity of the worker, fatigue can develop, or if prolonged excessive loading occurs without sufficient recovery, impairment or disability. According to the EU Directive mentioned earlier, design should prevent both the short term effects such as pain, discomfort and fatigue as wells as negative (long term) outcomes such as impairment or disability presented in the model.

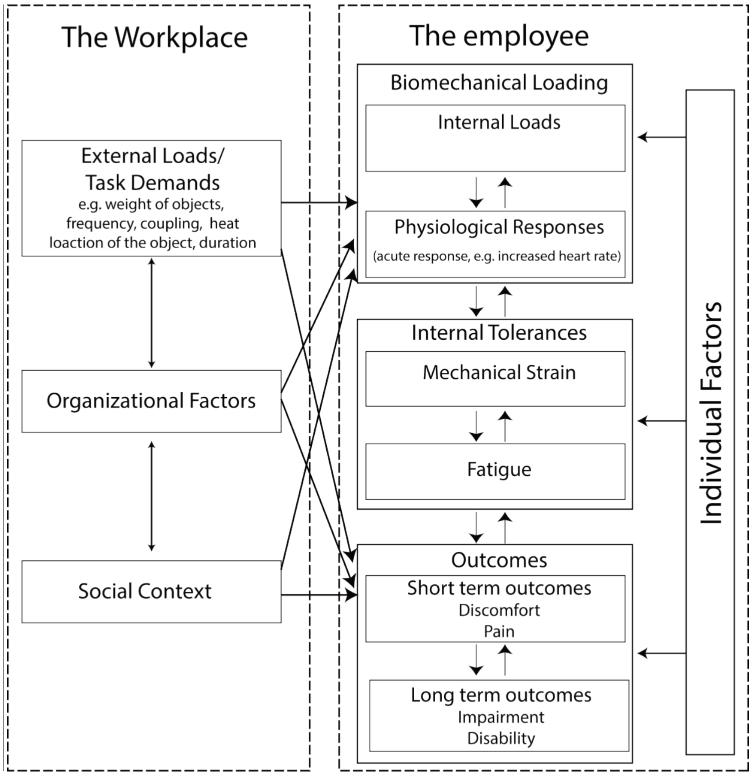


Figure 3.1. Theoretical model displaying the relationship between external loads and development of pain, discomfort and WMSDs (adapted from the U.S. National Research Council [18]).

Conversely to exposure of some toxic agents, both a high and a low exposure of physical load (including physical activity) are associated with negative health effects [249, 250, 251, 252, 253, 254, 255, 256], as visualized in Figure 3.2. Hence, design (ergonomics) should strive for an optimum loading, including temporal dimensions.

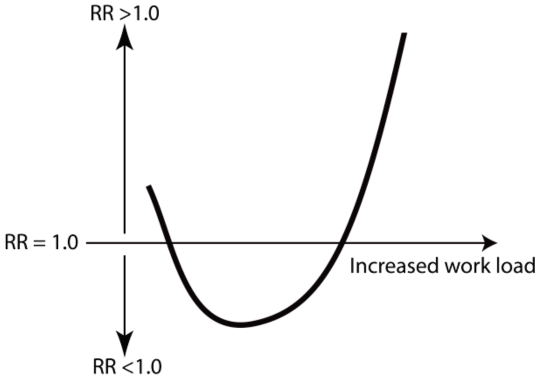


Figure 3.2. Theoretical model of a J-shaped relationship between workload and relative risk (RR) of WMSDs (adapted from Marras [254]; Winkel and Westgaard [257]).

3.3. Definitions of WMSDs, and WMSDs risk factors

In this thesis, the term work related musculoskeletal disorders (WMSDs) is used as a general term denoted to injuries and illnesses of the locomotor apparatus (i.e. tendons, ligaments, joints, nerves, vessels and supporting structures that are involved in locomotion) that may be caused by, aggravated, accelerated, or exacerbated by interaction with known or unknown risk factors in the workplace, and they may impair work capacity (based on definitions by the U.S. National Research Council [18] and Silverstein [258]). In this thesis WMSDs include work-related pain and disorders of the upper and lower extremities, and the back and lower back. The term WMSD risk factors is, in this thesis, denoted to those factors or exposures which have an association with WMSD [259].

3.4 Design Criteria - Manual Handling

MSDs often develop gradually, with reported latency periods ranging from several weeks to several years [35, 44, 45, 260]. According to Ferguson and Marras [261], this development may occur as a chain of observable events, starting with (excessive) physical loading which may induce discomfort and other short-term responses (Figure 3.3). In the event of continued exposure to excessive physical load, the symptom may worsen, leading to injures, lost workdays and disability. Instead of solely monitoring MSD incidence cases or lost workdays, design of MHO and surveillance of MSDs related to MHO can target earlier events (observable precursors) in the chain. Using this approach, assessment and design can address a reduction of excessive physical loading (i.e. mechanical exposure) [262], discomfort [203, 204, 205, 263], and excessive fatigue [16, 240]. To compass with this proactive approach, assessment tools targeting these events need to be employed. The necessity of minimizing discomfort and excessive fatigue is, additionally, required by SWEA [16, 17].

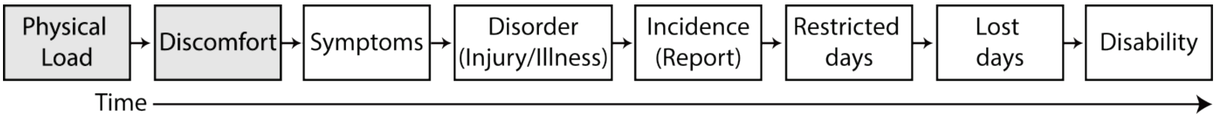


Figure 3.3. Observable events in the progression of LBDs (adopted from Ferguson and Marras [261]; Marras [254])

It can be argued that design criteria for MHO (including MHO task parameters) should be based on, or at least supported by findings from RCT-studies or prospective longitudinal studies of high quality. However, based on the available literature, use of findings exclusively from epidemiological studies limits the possibility to establish maximum '*allowable*' or '*safe*' levels for MHO. For example, Hoozemans et al. [27] found strong evidence for an association between pushing/pulling and upper extremity symptoms based on epidemiological studies. However, based on the available epidemiological literature, the harmful exposure level could not be established. Instead, the authors advocated for the use of biomechanics, targeting the structure of concern (here: e.g. the rotator cuff), and additionally to determine the capacity not only for occasional but also frequent operations. Hence to determine maximum allowable levels for MHO other methodologies need to be employed, including biomechanics, physiology and psychophysics. These methodologies can give more precise information on '*allowable*' or '*safe*' load levels and interaction effects of commonly occurring task parameters. Additionally they can address issues of local and whole body fatigue and discomfort in design of MHO.

The physical load imposed on the worker results in strain of the musculoskeletal and cardiovascular (and respiratory) systems, which has to be balanced against the worker's capacity [49]. For MHOs, in addition to the weight of the handled object, or the magnitude of the force required, additional factors affect the strain and the margin of the residual capacity, e.g. the duration and frequency of the operations, ambient temperature and psychosocial stress. Each of these factors will impose stress to the musculoskeletal and cardiovascular systems, and hence influence the margin of the worker's capacity. Jobs that do not adequately accommodate the individual worker's capacity or the capacity for a large proportion of workers performing the tasks may result in discomfort, fatigue, MSD disorders or injuries [25, 48, 212, 213, 264, 265, 266, 267, 268, 269]. It can additionally, have negative effects on the performance, such as increased rate of quality deficiencies [270, 271, 272, 273, 274]. To determine allowable workload levels in MHO, several studies have utilized biomechanics, physiology or psychophysics as design criteria [49, 206, 216, 275, 276] , or a combination of these approaches [169, 206].

3.4.1 Design Criteria - Biomechanics

Design criteria using biomechanics as basis have often targeted compression force limits of the lumbar intervertebral discs (L4/L5 or L5/S1) and maximum joint torques [49]. The probably most commonly used (allowable) compression force limit is the 3.4 kN *action limit* proposed by NIOSH [169, 170]. However, this action limit has been criticized for having weak scientific support [277, 278, 279], and other allowable compression force limits have been proposed, e.g. 3930 N for men and 2689 N for women [206], or 2.3–6.0 kN for men and 1.8–4.4 kN for women depending on their age [197, 280]. In addition to compression force, shear and torsion forces also acts on e.g. the lumbar spine [254]. Recently, the action and maximum permissible shear force limits of 500 N and 1000 N, respectively by McGill et al. [281] were revised by Gallagher and Marras [282]. Instead, Gallagher and Marras [282] proposed a shear force limits for the lumbar intervertebral discs of 1000 N and 700 N depending of the frequency of the exposures, i.e. ≤100 or 100–1000 loadings/day, respectively. Maximum joint torques have been collected by different research groups, most often based on single maximum voluntary isometric force exertions (e.g. [76, 209, 223]). These data can be applied to determine maximum force capabilities for infrequent exertions for specific population percentiles of a targeted worker population. However, these data are usually not applicable to determine acceptable force levels for frequent exertions. Additionally, the maximum voluntary force usually decreases as the velocity increases [283, 284, 285], and forces derived from isometric force exertions usually exceed those derived from dynamic exertions such as isokinetic and isoinertial [283, 284, 285].

3.4.2 Design Criteria - Physiology

Design criteria using physiology as basis for design of MHOs often target whole body fatigue, using aerobic work capacity, daily energy expenditure, or heart rate as measures. For eight hours work, it is usually recommended that the workload should not exceed 30–35% or 30–40% of the maximum aerobic work capacity (maximum oxygen uptake) [170, 286, 287, 288]. Mital et al. [206] suggested a slightly lower upper limit, i.e. 28–29% aerobic work capacity (obtained by bicycle Ergometer) for eight-hour workdays, and 23–24% for twelve-hour workdays. Because the percentages of maximum aerobic work capacity at a fixed output (workload) are affected by the size of the active muscle mass [289, 290], the aerobic capacity for the specific task of interest should be targeted. This also includes taking into account static or dynamic components of the task. For example, for manual handling that to a large extent utilizes the muscles of the upper limbs and with a static component such as lifting from table to shoulder height, 18.5% of the aerobic work capacity (derived from bicycle Ergometer) was suggested as the upper limit for eight hours work [291, 292]. Therefore, MHO models predicting the specific oxygen consumption, or predicting allowable workload based on the task-dependent work capacity as presented in Table 1.6 should be used. For RNLE, a limit of about 30% of the aerobic work capacity measured by treadmill was used for 8 hours lifting below knuckle height (i.e. ≤75 cm), and about 21% for lifting above knuckle height (i.e. >75cm) [169, 287]. Additionally, recent findings indicate that high occupational physical activity is significantly associated with increased probability of cardiovascular disease among workers with low cardiorespiratory fitness [293].

3.4.3 Design Criteria - Psychophysics

Psychophysics [294] has been extensively employed to develop maximum ‘allowable’ workload levels for MHOs [295, 296]. Examples of such MHOs include; lifting [297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314]; lowering [300, 301, 302, 303, 304, 305, 306, 315]; pushing [199, 300, 301, 302, 303, 304, 305, 306, 316, 317, 318]; pulling [199, 300, 301, 302, 303, 304, 305, 306]; carrying [300, 301, 302, 303, 304, 305, 306, 319, 320]; force exertions using primarily the upper body [223, 321, 322]; and force exertions involving the wrist or fingers (e.g. wrist flexion, extension or deviation, finger pinch, and press or pull exertions) [323, 324, 325, 326, 327, 328, 329, 330]. To determine the maximum workload levels in these studies, the participants are usually instructed to adjust the workload to the subjects’ own (perceived) maximum ‘acceptable’ workload level, i.e. a workload level that can be sustained for a regular 8-hours workday without being ‘strained’, excessive fatigued or over-exerted [295, 300], or experience unusual discomfort [323, 328]. In some studies workload levels for 7 hour [328] or less, e.g. 1 hour [320] are instead investigated. The instruction protocols resemblance to requirements by SWEA (see Section 1.2), i.e. preventing '*unnecessary fatiguing'* workload and discomfort [16, 17]. Instead of determining the maximum *acceptable* level, some studies have instructed the participants to adjust the workload to maximum level that the subjects perceived to be '*safe´* (i.e. 'without a feeling of possible injury' [297], p.6), or without increasing probability of LBP or muscular overexertion [331]. This 'maximum safe weight of lift' (MSWL), was reported to be about 17% lower than the 'maximum acceptable weight of lift' (MAWL) [331].

When determining the maximum acceptable level, the participants usually control one task parameter, usually the load weight in lifting and lowering operations (MAWL), and the force level (resistance) (MAF) in pushing and pulling operations. In some studies, the participants instead adjust the frequency [311, 332], which for one-hour lifting operations have resulted in significantly increased workload levels compared adjusting the load weight [311]. The psychophysical approach has been criticized for not being objective [295], and sensitive for the instructions employed and the test settings (e.g. adjustment time and training), and for producing load levels exceeding the physiological design criterion when employed at operations of high frequency levels [295]. Additionally, it is not established to what extent it can produce 'safe' load levels (i.e. not increasing the probability of MSDs or injuries) [295]. Strengths of the psychophysical approach, include e.g. enabling realistic simulations of dynamic (complex) industrial tasks with high reproducibility [295], and that it takes into account a broad range of dimensions, including e.g. psychosocial, biomechanical and physiological dimensions. Several studies give support to that the psychophysical approach employed to determine load levels in MHO incorporate both physiological and biomechanical dimensions [333, 334, 335, 336]. However, these three approaches have been reported rendering partly incompatible load levels [206, 337, 338, 339], as illustrated in Figure 3.4. At high frequencies (i.e. more than about 6 times/min [295]), the load levels derived using the psychophysical approach may exceed the physiological design criterion. At low frequencies however, the workload level derived using the physiological approach can result in load levels exceeding both the psychophysical and biomechanical design criteria. Hence, it has therefore been advocated to use the load level from the most conservative approach for each specific case [49, 169, 338], as illustrated by the red line in Figure 3.4.

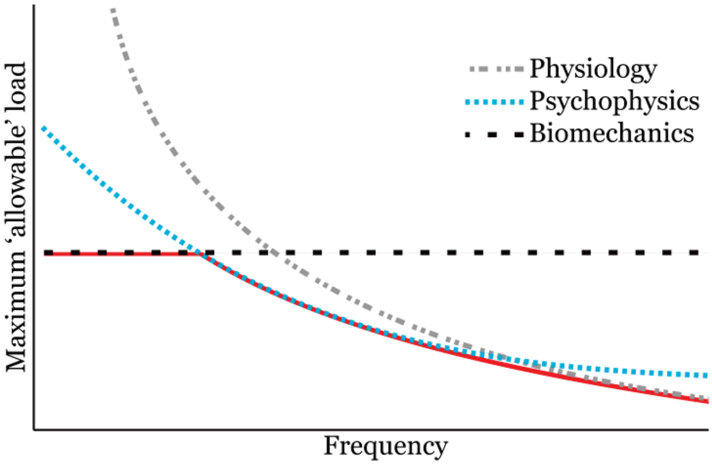


Figure 3.4. Illustration of the different load levels at different frequencies derived from the three approaches (adopted from Ayoub and Woldstad [338], and Mital et al. [206]).

This 'composite approach', i.e. of using the most conservative workload level from the psychophysical, physiological, biomechanical, and to some extent the epidemiological approach, was employed in the development of 1981 NIOSH lifting equation [170], and the (1991) revised NIOSH lifting equation (RNLE) [169]. Using the lifting index (i.e. the ration of the handled load weight and the maximum allowable weight determined according to the RNLE [169]), increased probability of LBP has been associated with a (composite or peak composite) lifting index exceeding between 1–2 [25, 267, 268].

Some studies indicate that load levels derived using the psychophysical approach are poorly related with biomechanical load at the lumbar spine [340, 341, 342, 343], instead indicating that maximum acceptable load level (MALL) is instead more influenced by muscular strain [340], or tactile sensations from the hands [341]. It is however, not clear to what extent the biomechanical design criterion used adequately reflects 'safe' levels for the population included in these studies, especially since spinal compression alone has been poorly related with low-back disorder [344]. Conversely, Kuijer et al. [345] reported high correlations between MAWL and lower-back extension moment (L5/S1) for free style, stoop and squat lifting. Other recent studies also give support to the relationship of psychophysically derived MALL and biomechanical load via the concept of 'the weakest link' [276, 335]. In similarity with the 'composite approach' the 'weakest link' approach determine the capability for a specific task via the limiting factor including components such as joint strength and balance. For several MHO including pushing and pulling, the shoulder moment joint strength may be the limiting factor [346], and upper limb strength when lifting to high vertical heights [347].

Data collected using the psychophysical approach has been compiled to different 'lookup-tables' by e.g. Snook [348], Snook and Ciriello [240], Ayoub and Mital [216], and Mital et al. [206]. Using these tables MALLs can be determined for lifting, lowering, pushing, pulling, and carrying for a specified population percentile of (western) adult male and female manual material handlers. The tables by Mital et al. [206] have employed the tables by Snook and Ciriello [240] as a basis, and have adjusted the data from Snook and Ciriello [240] to accommodate the physiological and biomechanical design criteria [206]. For pushing and pulling, these tables can be employed to determine MAF at six travel distances, three handle heights and at 3–5 frequencies. For lifting and lowering, these tables include eight frequencies, three different box sizes, and four vertical heights. These psychophysically based 'manual handling tables' were reported to be used by about ¾ or more of certified ergonomists in the US [87] and Canada [193], but they were not considered to be applicable for health and safety inspectors in the UK [349]. These tables were only used by about ¼ of Portuguese health and safety practitioners among those who reported being familiar with the manual handling tables (i.e. the Liberty Mutual Manual Handling Tables) [194].

3.5 Definition of observation-based risk assessment tools

In this thesis, the term observation-based risk assessment *tool* is used. Other terms have also been used, e.g. *method* [68, 85], *technique* [87], or both [66]. According to Merriam Webster, the term *tool* has several definitions, e.g. 'a handheld device that aids in accomplishing a task', or 'something (such as an instrument or apparatus) used in performing an operation or necessary in the practice of a vocation or profession' [350]. While *method* denotes a 'procedure or process for attaining an object' e.g. a 'systematic procedure, technique, or mode of inquiry employed by or proper to a particular discipline or art' [351], and a *technique* is defined as either: a 'body of technical methods (as in a craft or in scientific research)', or a 'method of accomplishing a desired aim' [352]. Hence, method can in the context of this thesis be interpreted as the procedure or process applied when conducting risk assessment, while tool denotes some types of artifact used within this process. Although, no definite clear cut boundaries exist in this context, the term tool is used in this thesis in resemblance with the interpretation made by Åteg et al. [353]. Hence, in this thesis, OBRATs, checklists or a force gauge are all examples of tools, while method denotes to the procedure in which a specific OBRATs (e.g. RAMP II) are applied. The term *observation-based* denotes, in this thesis to the utilization of mainly direct or indirect observation (i.e. retrospective observation of video-recordings or still photos). The term *risk* has different meanings and is sometimes used to describe the probability of an undesirable event [354]. According to EN ISO 12100:2010 [355] *risk* is defined as the 'combination of the probability of occurrence of harm and the severity of that harm', and *risk assessment* as the 'overall process comprising a risk analysis and a risk evaluation' ([355], p.3). This definition implies a judgment whether the risk reduction objectives have been obtained. In the thesis, the term *risk assessment tools* is additionally used for tools that describe the exposure level without stating if the *risk* is acceptable or not.

3.6 Usability

According to ISO 9241-11:1998 [356] and ISO 9241-210:2010 [357], usability is defined as the 'extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' ([356], p.2). According to this definition, the specific user population, their goals, and the context in which they operate needs to be considered. Jordan [358, 359] proposed a hierarchy of the user needs building on Maslow's theory on human motivation [360] (Figure 3.5). According to Jordan's model, appropriate functionality of a product must first be achieved, and thereafter, the product needs to be usable (e.g. easy to use). In addition, aspects related to product pleasurability need to be fulfilled, or perhaps even hedonomics needs [361]. According to ISO/IEC 25010:2011 [362] functionality comprises functional suitability, completeness, correctness and functional appropriateness. Therefore, to judge functionality of OBRATs, an understanding of the user needs is necessary.

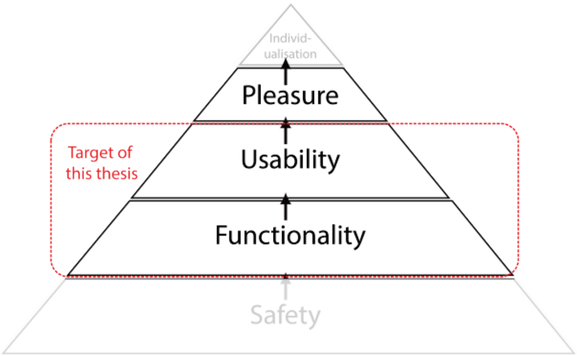


Figure 3.5. Hierarchy of user (consumer) needs (based on Jordan [358, 359], Hancock et al. [361] and Högberg [363].

Furthermore, according the Shackel [364], learnability, flexibility, effectiveness, and attitude are important aspects related to usability. Shackel [364] proposed that evaluations of usability should include subjective assessments (evaluations) of its ease of use and objective performance measures regarding effectiveness of applying the tool. According to Nielsen [365] (Figure 3.6), multiple components constitute usability: easy and quick to learn (*Learnability*), efficient to use i.e. high productivity (*Efficiency),* easy to remember, i.e. low need for re-learning (*Memorability*), low error rate and low consequence of error, i.e. low risk (*Errors*), and it should be pleasant to use, i.e. the user should be satisfied (*Satisfaction).*

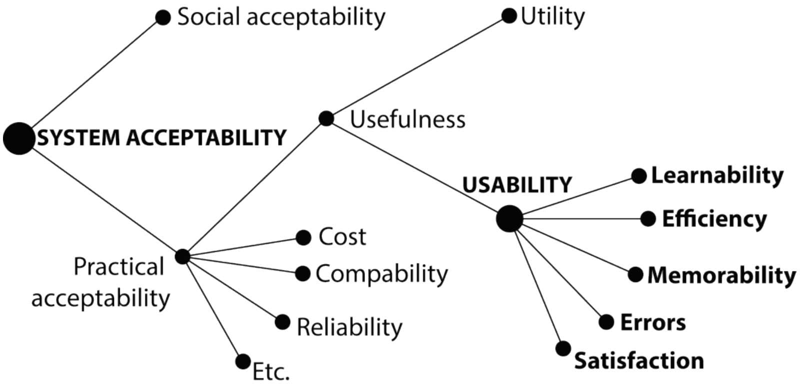


Figure 3.6. Model of attributes of system acceptability (adapted from Nielsen [365]).

3.7 Design Research Methodology

According to Blessing and Chakrabarti [366], the main objectives of design research are to formulate and validate theories and models of *design*, and based on these theories and models, develop and validate knowledge, tools, and methods to increase the probability of producing 'successful' products (i.e. products fulfilling their goals). Blessing and Chakrabarti [366] introduced a framework (Figure 3.7) to support the design research process. The design research process is iterative and the stages covered by the research study or project can differ, as wells as the depth in each single stage. In the 'Research Clarification'-stage, the overall goal of the project is formulated and the existing knowledge of the issue of interest is explored. Using this information, initial evaluation criteria can be formulated. In the 'Descriptive Study I'-stage, empirical data are collected and more specific criteria to measure the goals of the project can be formulated. Using this base, different scenarios can be tested in the 'Prescriptive Study'-stage. In the fourth stage 'Descriptive Study II', the results can be evaluated according to the developed evaluation criteria, as well as the results applicability.

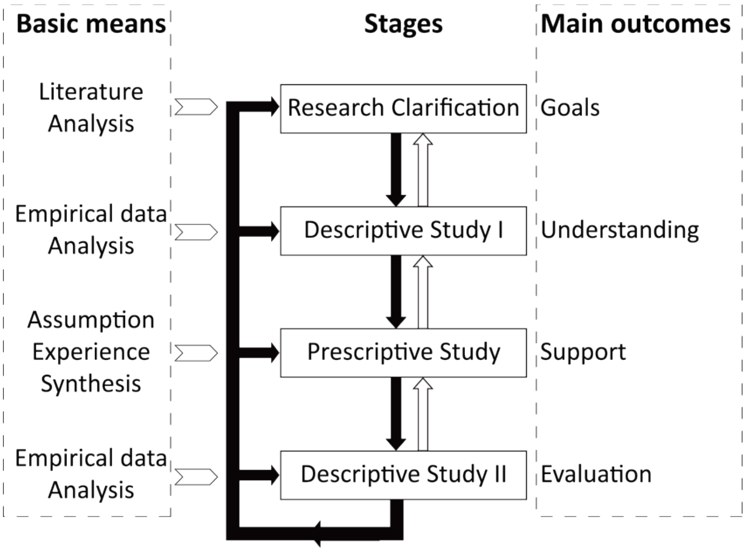


Figure 3.7. The Design Research Methodology framework (re-drawn and adapted from Blessing and Chakrabarti [366]).

4. Methods

In agreement with the Design Research Methodology framework by Blessing and Chakrabarti [366], the goal of the research project was specified (see Section 1.7.4). A literature search was performed to identify recently developed assessment tools (see Paper C). To gain a better understanding of the users' needs existing studies on this issue were explored (see Section 1.7.1 and 1.7.2). Furthermore, workshops with potential end users were performed (see Section 4.2.2), and a survey was conducted exploring the use and important usability-related aspects of existing assessment tools among professional ergonomists employed in Sweden (see Section 4.1.1). In Phase 2 and 3 (see Paper B and D) prototype versions of RAMP I and RAMP II were developed, and an additional literature search was performed on task parameters related to lifting/lowering and pushing/pulling (see Paper C and D, and Table 4.3). In Phase 4 (i.e. the 'Descriptive Study II'-stage [366]), the RAMP I and RAMP II tools were evaluated concerning their reliability (see Section 4.2.4) and usability (see Section 4.2.5).

The six main methods used in the thesis and in which paper they are employed are shown in Table 4.1.

Table 4.1. Methods used in each paper.

Web-based questionnaire	Litterature search	Workshops	Expert judgements	Reliability evaluation	Usability evaluation
Paper A	Paper B Paper C Paper D	Paper B Paper C Paper D Paper E	Paper B Paper C Paper D	Paper B Paper D	Paper B Paper C Paper D Paper E

4.1 Survey

4.1.1 Web-based questionnaire

In Paper A, a web-based questionnaire was employed to explore the use and preferred qualities of OBRATs among professional ergonomists. The survey targeted OHSs-employed ergonomists in Sweden who were registered physiotherapists (RPT), and who performed risk assessment of physical load at least once per year (i.e. inclusion criteria). The questionnaire included background information of the study subjects, their use of different OBRATs, their reasons for using different OBRATs, and questions on usability aspects affecting their use. Seventeen OBRATs were included in the questionnaire (Table 4.2). They were retrieved from an earlier survey by Dempsey et al. [239], a literature review by Takala et al. [85], three studies on tools use among Swedish ergonomists [241, 242, 243] and by the research group.

Prior the distribution of the questionnaire to the study population, a paper-based version of the questionnaire was piloted on a group of students (with backgrounds as RPTs or occupational therapists) enrolled at Masters level program at Karolinska Institutet, of whom; several were employed as OHSs ergonomists [88]. After slight revision, the questionnaire was converted into a web-based questionnaire (see Mattes and Ternblad [367] for a paper-based version of the questionnaire). The web-based questionnaire was thereafter distributed by the Ergonomic Section within the Swedish Association of Physiotherapists, via their periodical e-newsletter, which was distributed to their members (n = 598) by email. Only those members that opened the newsletter (n = 251) received information about the survey. To reach the questionnaire, the respondents were referred to an external website which contained information about the survey and contact information in case of questions. The questionnaire was open during four weeks in early spring 2012. Two reminders were sent, the first by e-mail after one week and the second after another two weeks via the Ergonomic Sections Facebook page. Of the 251 members that open the e-newsletter, 107 (43%) answered the web-based questionnaire. Of these 107 respondents, 37 (35%) were excluded due to not fulfilling the inclusion criteria, resulting in a study population of 70 ergonomists.

Table 4.2. The 17 OBRATs included, and the primarily source they were retrieved from. Source A) Dempsey et al., 2005 [239]; B) Sturesson, 2006 [242]; C) Andersson et al., 2006 [241]; D) Laring et al., 2007 [243]; E) Takala et al. 2010 [85]; F) additional OBRATs included by the research group.

OBRATs	A	B	C	D	E	F
'SWEA-AFS'[16, 184]			x			
ALBA [368]		x				
ACGIH HAL [128]	x*				x	
KIM 1 ('KIM I') [156, 157]						x
KIM 2 ('KIM II') [156, 158]						x
LUBA [160]					x	
MAC [161]					x	
NIOSH-LE [169, 170]	x		x		x	
OCRA [171]					x	
OWAS [173]	x				x	
PLIBEL [174]			x		x	
QEC [175]			x		x	
REBA [176]	x				x	
RULA [181]	x				x	
Strain Index ('SI') [183]	x				x	
VIDAR [187]			x	x	x	
WEST [188]		x	x			

Note: * reported as 'hand activity limit'

4.2 Development and evaluation of RAMP I and RAMP II

An iterative development process was applied for the development of RAMP I and RAMP II (Paper B–D). In resemblance with the DRM framework [366], in the first phase, the goals for RAMP I, and RAMP II were defined based on an analysis of the user needs (Paper B and D, and Rose et al. [244]). Thereafter, existing assessment tools from e.g. earlier literature reviews [66, 68, 85] were scrutinized. A literature search on WMSD risk factors and factors affecting the capacity in manual handling was conducted (see Section 4.2.1). Thereafter, several prototype versions were developed and evaluated iteratively. In the final Phase, the developed tools (i.e. RAMP I and RAMP II) were evaluated.

4.2.1 Literature search

A combination of strategies was employed to derive the literature basis for RAMP I and RAMP II (Paper B–D). To derive literature on epidemiological risk factors, a search for recent systematic literature reviews were performed in Scopus (Paper B and D). The literature search was restricted to peer-reviewed articles of literature reviews written in English published 1997–2012. To include literature published before 1997, earlier literature reviews by Kuorinka and Forcier [259], Bongers et al. [369, 370], Bernard [20], Sluiter et al. [21], and the U.S. National Research Council [18] were scrutinized. Studies targeting mainly non-occupational activities, workplace interventions, and performance measures were excluded, as wells as occupational groups with exposures differing from exposures related to industrial manual handling such as musicians, athletes or pilots. In the next step, original studies which presented work-related exposures quantitatively (e.g. >10 kg), rather than qualitatively (e.g. 'heavy lifting') were targeted for inclusion in the literature basis. The reference lists of the retrieved studies were scanned for additional studies using a 'snowball' approach [371]. To identify additional studies (also including other research approaches including psychophysics, biomechanics, and physiology), the reference lists of recently developed assessment tools including Keyserling et al.'s checklists [150, 151], RNLE [169], Strain Index [183], RULA [181], REBA [176], LUBA [160], OCRA [171, 372], MAC [161], QEC [175], the ART tool [130], RAPP [349] were scrutinized as wells as textbooks on manual handling and work postures [206, 216, 373, 374]. An additional literature search was performed, searching for recent published risk assessment tools (Paper C). To derive the literature basis for the assessment items for lifting/lowering (Paper D) and pushing/pulling (Paper C) in RAMP II additional searches were performed in Scopus targeting peer-reviewed literature written in English regarding task parameter for lifting and pushing/pulling (Search I–IV in Table 4.3).

Table 4.3. Search terms (I, III, IV) used for the push/pull tool and search terms (I, II) used for the lifting model in RAMP II.

Search	First order	Second order
I	*maximum acceptable*	*load*, *force*, *torque* , *effort*
II	*hand coupling*, *asymmetry*, *team handling*, *floor friction*, *one-handed**, *temperature*, *heat*, or *height*	*lift**, *lower**, *acceptable*, *capacity*, *strength*, *MAW*, or *MAWL*
III	*hand coupling*, *asymmetry*, *team handling*, *handle height*, *floor friction*, or *one-handed**	*push**, *pull**, *acceptable*, *capacity*, *strength*, *MAW*, or *MAF*
IV†	*temperature*, *heat*,	*push**, *pull**, *acceptable*, *capacity*, *strength*, *MAW*, or *MAF*

Note: †The search terms 'temperature' and 'heat' did not render any additional studies.

4.2.2 Workshops

In concordance with Perez and Neumann [375], workshops containing semi-structured focus group sessions were used to gain an understanding of the strength and weaknesses of the tools that were currently used, as well as preferred attributes of new tools [244]. During the development of RAMP I and RAMP II (Paper B–E), similar workshops were conducted, in which the participants tested prototype version of the tools. Their strength and weaknesses were discussed, as well as suggestions for improvements. The reasons for using this qualitative research approach were that this approach enabled exploring these issues of interest in detail, as well as enabling interaction with the participants.

4.2.3 Expert judgments

For the development of the assessment criteria in RAMP I and RAMP II (including the push/pull tool) (Paper B–D), expert judgments were employed, using the derived literature as basis, in congruence with development of several other assessment tools (e.g. Stentson et al.'s Hand Exertion Classification System [182], RNLE [169] and HARM [152]). While some assessment tools or models e.g. LUBA [160], the Snook and Ciriello tables[240], the 'Arm Force Field' method [223], and Dempsey et al.'s oxygen consumption prediction model [219] are based on data collected from a specific population using a single methodological approach e.g. psychophysics or physiology, RAMP I and RAMP II are in congruence with e.g. RNLE based on results derived from different methodological approach, making it in this case, a necessity to apply expert judgments. The reasons for using expert judgments were due to the divergent research approaches, measures of exposure and outcomes used in the identified literature which had to be combined, as well as the scarce available data in many areas, ruling out the possibility of a meta-analysis without excluding a large part of the relevant literature.

4.2.4 Reliability evaluations

To evaluate the inter-rater reliability of RAMP I (Paper B) and of RAMP II (Paper D), two groups both including professional ergonomists and production engineers were recruited. After receiving training, the participants evaluated 6 videotaped jobs. Proportion of agreement among the assessors (p_o) [376] and linearly weighted kappa (κ_W) were employed as measures of inter-rater reliability. As indication of acceptable inter-rater reliability, the criterion used by Palm et al. [131] i.e. a proportional agreement of >0.7 and a kappa of >0.40, was used. This criterion for kappa (i.e. a kappa of >0.40), is close to the criterion for moderate agreement (kappa ≥0.41) as proposed by Landis and Koch [377].

4.2.5 Usability evaluation

Paper-based questionnaires, which is one of the recommended methods for evaluation of an existing product or system [378], were employed to evaluate usability-related aspects of RAMP I (Paper B), the push/pull tool in RAMP II (Paper C), and RAMP II (Paper D). The evaluation of RAMP I (Paper B and E) and RAMP II (Paper D and E) included ratings made by twenty OHS practitioners. The evaluation of the push/pull tool in RAMP II (Paper C) included ratings made by twenty-two ergonomists/physiotherapists. Before the participants responded to the questionnaires, they received training in both RAMP I and RAMP II including assessment of video recordings of manual handling tasks (Paper B–E). To evaluate the ease of use of the assessment items of RAMP I (Paper B) and the push/pull tool in RAMP II, a five-level categorical rating scale was applied with the anchor points 'easy' and 'difficult'. To evaluate usability aspects of each tool (i.e. RAMP I and RAMP II) as wells as the participants general view on its usability as an assessment tool, a set of statements were used and the participants were asked to rate to what extent they agreed or disagreed with the statements regarding RAMP I (Paper B and E), and RAMP II (Paper D and E) using a five-level categorical rating scale with the anchor points 'fully agree' and 'fully disagree'[1].

4.3 Ethical considerations

No sensitive data on individuals was collected, and due to the character of the data collected [379, 380, 381], it was judged that external ethical approval was not needed. However, care was applied to comply with ethical principles according to the Swedish Research Council [382]. This included gaining informed consent of each participants, that the participants were informed of the purpose of the data collection, that participations was voluntary, that the participants could abort the participation at any time without need of stating any reasons, only utilizing data for research purpose, secure handling and storage of potentially sensitive data. Additionally, no data from the survey or from the evaluations are presented so that they can be traced back to answers made by any specific individual.

---

[1] *Note: The questionnaire employed has, in the articles, been translated from Swedish to English. In Paper E, the anchor point 'håller inte med alls' is translated as 'totally disagree' while it was translated as 'fully disagree' in Paper B and D.*

5. Main results

5.1 Paper A: Ergonomics Risk Assessment: The Processes and use of observation-based tools

Paper A present the results of the survey exploring the use of OBRATs and important usability-related aspects of OBRATs among professional ergonomists in Sweden.

5.1.1 Use of OBRATs among professional ergonomists in Sweden

Regarding the use of OBRATs among professional ergonomists in Sweden, the findings from Paper A, showed that all of the eligible respondents had used 'SWEA-AFS', while KIM 1, and KIM 2 were used by 1/3, and 1/4, respectively. The percentages among the respondents that had used several widely spread OBRATs, such as the NIOSH-LE, RULA, REBA and OWAS was low, i.e. they was used by 16, 16, 12, and 3%, respectively. For example, the percentages that had used the NIOSH-LE (i.e. 16%), was substantially lower than reported among certified ergonomists in the US and Canadian (i.e. >80%) [75, 76], and among Spanish speaking ergonomics-practitioners (i.e. about 60%) [77]. Furthermore, about 1/4 of the respondents used only one OBRAT, while 6/10 used three OBRATs or more.

5.1.2 Usability-related aspects of OBRATs

According to the survey presented in Paper A, lack of knowledge or training was the most commonly reported reason for not using an OBRAT, indicating the importance of sufficient training to increase the use of OBRATs among this population. However, several OBRATs were not used despite that the ergonomists had experience of them. Important usability-related aspects among those OBRATs with the highest proportion of users included, it being 'easy to use' and 'easy to communicate to the client'. These aspects were stated by >1/2 of the respondents as main aspects for using 'SWEA-AFS', KIM 1, KIM 2, and QEC. It being quick to use was stated as a main aspect by about half of the users of 'SWEA-AFS', KIM 1, KIM 2 and QEC. When the respondents were asked to rate the importance of 15 usability-related aspects, ability communicating the results and facilitating improvement measures, being easy and quick to use and scientifically based, and having a clear client benefit were the usability-related aspects with the largest proportion of respondents rating as important ('important' or 'very important', i.e. a score ≥4) for them being used.

5.2 Paper B: Development and evaluation of RAMP I. A practitioner tool for screening for musculoskeletal disorder risks in manual handling

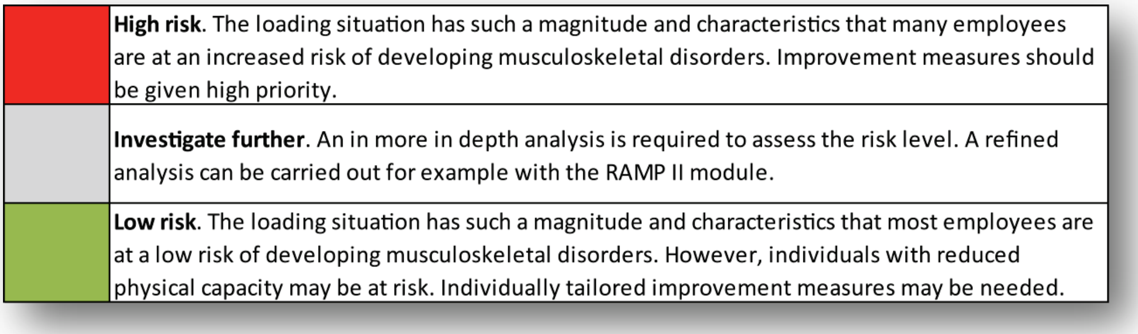
Paper B presents the screening tool RAMP I, and its development which includes the scientific basis of the assessment items in the tool. In addition, the paper presents the results of an evaluation of its reliability, and an evaluation of its usability.

5.2.1 RAMP I

The screening tool RAMP I is mainly based on direct or in-direct observation of the work being assessed, but additionally utilizes direct measurements (e.g. of load weights and push forces) and self reports (e.g. perceived workload and discomfort). RAMP I constitutes of dichotomous questions (assessment items) grouped in seven main categories:

1. Postures
2. Work movements and repetitive work
3. Lifting
4. Pushing and pulling
5. Influencing factors
6. Reports on physically strenuous work
7. Perceived physical discomfort

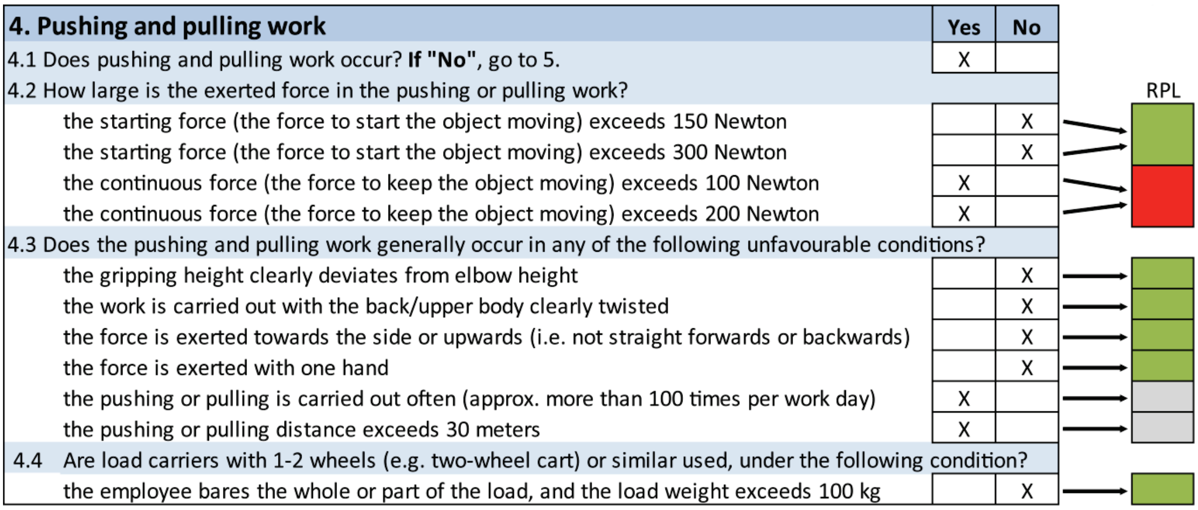
In the first category duration and frequency of non-neutral work postures of the upper and lower body can be assessed. In the second category, the proportion and duration of repetitive movements can be assessed. Category 4 and 5, include load weight and push/pull force for assessing MHO, as well as several task parameters such as e.g. frequency, and single-hand exertions. Category 5 includes both physical factors such as e.g. whole-body and hand-arm vibration, and organizational/psychosocial aspects such as e.g. decision latitude. In category 6, reports on physically strenuous tasks (i.e. workload) is targeted, and the perceived physical discomfort in category 7. The results of a screening is communicated via a three level color-code scale shown in Figure 5.1, representing the risk and priority level (RPL).



🟥	**High risk**. The loading situation has such a magnitude and characteristics that many employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be given high priority.
⬜	**Investigate further**. An in more in depth analysis is required to assess the risk level. A refined analysis can be carried out for example with the RAMP II module.
🟩	**Low risk**. The loading situation has such a magnitude and characteristics that most employees are at a low risk of developing musculoskeletal disorders. However, individuals with reduced physical capacity may be at risk. Individually tailored improvement measures may be needed.

Figure 5.1. The three level color-code scale for communication of risk and priority level used in RAMP I (adapted from Paper B and E).

A hypothetical screening of a manual pushing or pulling operation is used to illustrate how the assessment items relate to the color-code scale (Figure 5.2). In terms of screening of e.g. manual pushing and pulling, multiple aggravating or influencing factors (task parameters) are targeted in RAMP I, such as e.g. force, travel distance, one or two handed exertion. The basis for the assessment items is presented in Paper B. These task parameters are assessed independently in RAMP I. In this example, the continuous force exceeds the criterion of 200 N, resulting in a high RPL. A duration of >100 times/workday, and a travel distance >30 meters both exceeds the criteria presented in Paper B, and thereby warrant further investigations.



4. Pushing and pulling work	**Yes**	**No**	RPL
4.1 Does pushing and pulling work occur? **If "No"**, go to 5.	X		
4.2 How large is the exerted force in the pushing or pulling work?			
the starting force (the force to start the object moving) exceeds 150 Newton		X	🟩
the starting force (the force to start the object moving) exceeds 300 Newton		X	
the continuous force (the force to keep the object moving) exceeds 100 Newton	X		🟥
the continuous force (the force to keep the object moving) exceeds 200 Newton	X		
4.3 Does the pushing and pulling work generally occur in any of the following unfavourable conditions?			
the gripping height clearly deviates from elbow height		X	🟩
the work is carried out with the back/upper body clearly twisted		X	🟩
the force is exerted towards the side or upwards (i.e. not straight forwards or backwards)		X	🟩
the force is exerted with one hand		X	🟩
the pushing or pulling is carried out often (approx. more than 100 times per work day)	X		⬜
the pushing or pulling distance exceeds 30 meters	X		⬜
4.4 Are load carriers with 1-2 wheels (e.g. two-wheel cart) or similar used, under the following condition?			
the employee bares the whole or part of the load, and the load weight exceeds 100 kg		X	🟩

Figure 5.2. Illustration of screening of manual pushing/pulling operations using RAMP I.

5.2.2 Reliability of RAMP I

In terms of inter-rater reliability of RAMP I, the evaluation presented in Paper B indicate that the majority of the 64 assessment items (67% or the ergonomists and 56% for the engineers) tested in RAMP I can be assessed with acceptable reliability after about 1 hour of training. In agreement with the inter-rater reliability evaluation of RAMP II (Paper D), assessment of upper arm posture (location of the hands in space) did not reach acceptable reliability according to the criteria. The evaluation in Paper B also indicates that it is difficult to achieve high inter-rater agreement of assessment of repetitive movements, including repetitive work and cycle time, and additionally assessments of wrist posture, and among the engineers' assessments of neck posture (flexion/rotation).

5.2.3 Usability of RAMP I

The main finding from the usability evaluation of RAMP I presented in Paper B (and partly in Paper E) gives support to that RAMP I is usable for OHS practitioners. The finding is supported by the results from the questionnaire, showing that for six of the seven (risk) categories in RAMP I, ≥80% of the respondents perceived the assessment as being 'easy' or 'fairly easy'. Additionally, ≥85% of the respondents agreed fully or partly, that RAMP I is usable as decision base and has clear results. A majority (74%) also reported that the time needed for performing an assessment using RAMP I is acceptable. These three aspects were similar to those identified as important in Paper A, i.e. easy to interpret the results, provides a good basis for intervention proposals, and quick to use. Furthermore, all respondents agreed (fully or partly), that RAMP I is usable for assessing risks.

5.3 Paper C: Pushing and pulling: an assessment tool for occupational health and safety practitioners

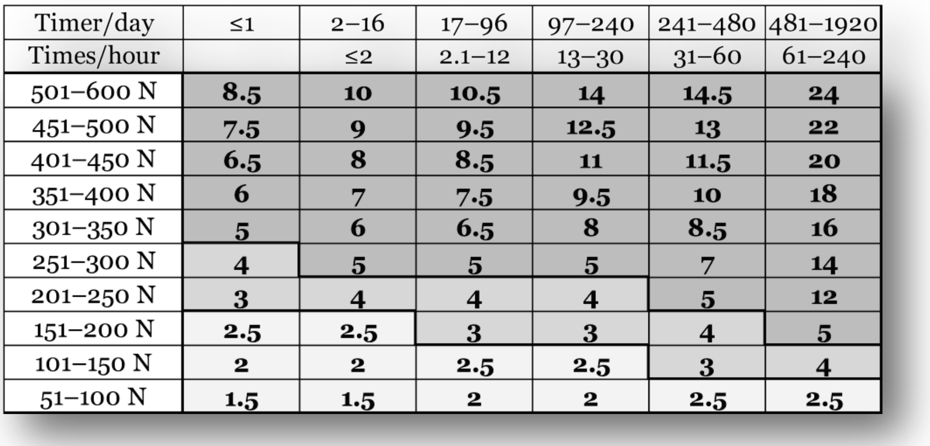
Paper C presents a tool for assessing manual pushing and pulling operations that is part of the assessment tool RAMP II. The paper presents the development of the tool and the reserach basis of the tool. Furthermore, the results of the tool are compared against the manual handling tables by Mital et al. [206], female static shoulder moment strength according to 3DSSPP, and back loads obtained from force exertions obtained in a laboratory setting by Knapik and Marras [383]. Lastly, the paper presents the results of an evaluation of its usability (ease of use).

5.3.1 The push/pull tool

The push/pull tool facilitate assessments of manual pushing and pulling, using the force as an exposure parameter. The tool contains an eight-multiplier equation (presented below) and two tables for establishing the multiplier for the combination of frequency and force (and distances) for initial (Figure 5.3) and sustained force.

$$M_{\mathrm{freq-force}} \times M_{\mathrm{one-hand}} \times M_{\mathrm{sideways}} \times M_{\mathrm{height}} \times M_{\mathrm{twist}} \times M_{\mathrm{grip}} \times M_{\mathrm{heat}} \times M_{\mathrm{surface}} \times M_{\mathrm{team}}$$

(Equation presented in Paper C)



Timer/day	≤1	2–16	17–96	97–240	241–480	481–1920
Times/hour		≤2	2.1–12	13–30	31–60	61–240
501–600 N	**8.5**	**10**	**10.5**	**14**	**14.5**	**24**
451–500 N	**7.5**	**9**	**9.5**	**12.5**	**13**	**22**
401–450 N	**6.5**	**8**	**8.5**	**11**	**11.5**	**20**
351–400 N	**6**	**7**	**7.5**	**9.5**	**10**	**18**
301–350 N	**5**	**6**	**6.5**	**8**	**8.5**	**16**
251–300 N	**4**	**5**	**5**	**5**	**7**	**14**
201–250 N	**3**	**4**	**4**	**4**	**5**	**12**
151–200 N	**2.5**	**2.5**	**3**	**3**	**4**	**5**
101–150 N	**2**	**2**	**2.5**	**2.5**	**3**	**4**
51–100 N	**1.5**	**1.5**	**2**	**2**	**2.5**	**2.5**

Figure 5.3. Frequency–force table for establishing the multiplier for the initial pushing or puling operations.

Each equation multiplier represents a task parameter (e.g. one-handed exertions or team handling) which influences the capacity in manual force exertions. The literature basis for deriving at the multipliers for the task parameter presented in Paper C considers biomechanical, physiological and psychophysical design criteria. For most task parameters however, psychophysically derived data from experiments using maximum acceptable force or load, or maximum voluntary isometric strength was the main literature source. The equation results in a score which correspond to an assigned RPL.

5.3.2 Usability of the push/pull tool

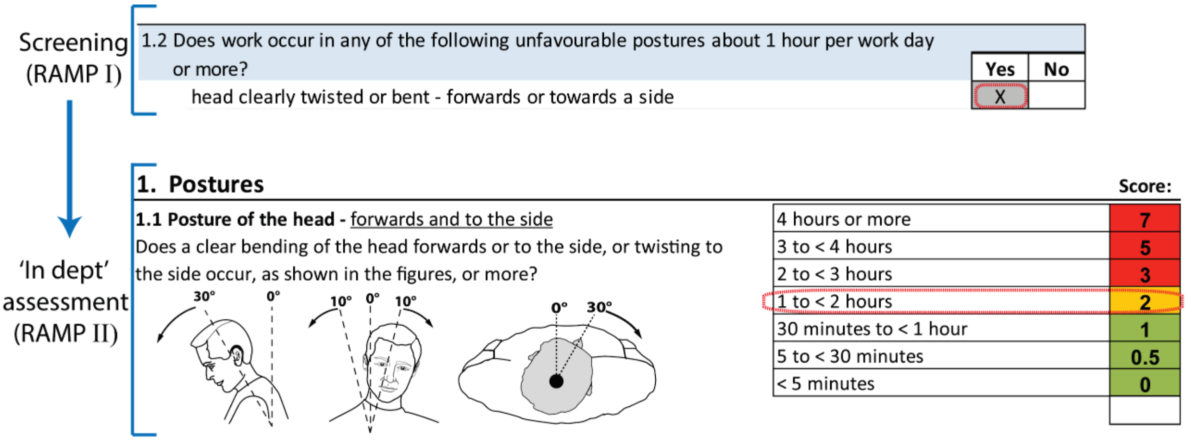
The results from the usability evaluation of the push/pull tool presented in Paper C, support the usability of the tool with regards to ease of use. This finding is supported by the results from the questionnaire, were a majority (i.e. ≥2/3) of the respondents reported it to be easy or fairly easy to make assessment using the push/pull tool.

5.4 Paper D: Development and evaluation of RAMP II - a practitioner's tool for assessing musculoskeletal disorder risk factors in industrial manual handling

Paper D presents the assessment tool RAMP II, and its development which includes the scientific basis for the assessment items in the tool. In addition, the paper presents the results of an evaluation of its reliability, and an evaluation of its usability.

5.4.1 RAMP II

The assessment tool RAMP II is, in concordance with RAMP I, mainly based on direct or in-direct observation of the work being assessed, but additionally utilizes direct measurements (e.g. of load weights and push forces) and self reports (e.g. perceived workload ad discomfort). In congruence with RAMP I, it constitutes of the same seven main categories: 1.Postures, 2.Work movements and repetitive work, 3.Lifting, 4.Pushing and pulling, 5.Influencing factors, 6.Reports on physically strenuous work, and 7.Perceived physical discomfort. However, RAMP II was developed to enable a more in-depth assessment, compared to RAMP I, as illustrated in Figure 5.4. For example, screening of adverse neck posture using RAMP I includes the duration of the exposure (i.e. more or less than about 1 hour per workday) and, in accordance with David et al. [175], a qualitatively defined magnitude of the posture (i.e. a 'clearly' bent or twist neck/head). The assessment items of adverse neck postures in RAMP II, are however based on a quantitatively defined angles in combination with a seven-categories time scale.



1.2 Does work occur in any of the following unfavourable postures about 1 hour per work day or more?

	Yes	No
head clearly twisted or bent - forwards or towards a side	X	

1. Postures **Score:**

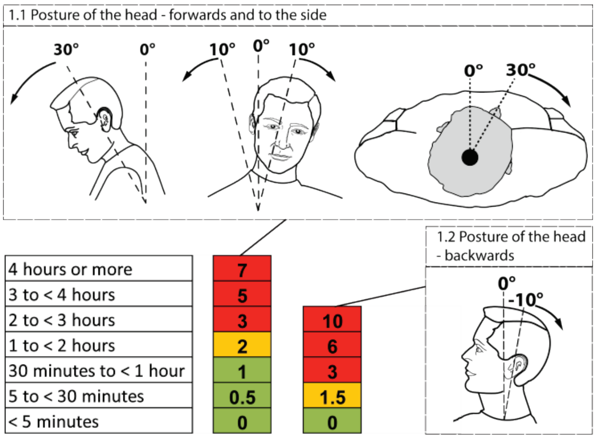
1.1 Posture of the head - forwards and to the side

Does a clear bending of the head forwards or to the side, or twisting to the side occur, as shown in the figures, or more?

4 hours or more	7
3 to < 4 hours	5
2 to < 3 hours	3
1 to < 2 hours	2
30 minutes to < 1 hour	1
5 to < 30 minutes	0.5
< 5 minutes	0

Figure 5.4. Screening of neck posture using RAMP I, and assessment using RAMP II (adopted from Paper D).

To classify the exposure of time in non-neutral postures of the neck, trunk, upper arms, and the lower extremities, a seven-categories time scale showed in Figure 15 is used (and a five-categories scale for neck extension) in RAMP II. As illustrated in Figure 5.5, for assessment items 1.1. the observer assesses if the time in non-neutral posture (i.e. a forward neck flexion/inclination or axial rotation of ≥30°, or lateral flexion/inclination ≥10°) occurs for a duration of more or equal to 5, 30, 60, 120, 180 or 240 minutes. In addition to the score system, the results of an assessment is communicated via a three level color-code scale shown in Figure 5.6.



4 hours or more	🟥 7	
3 to < 4 hours	🟥 5	
2 to < 3 hours	🟥 3	🟥 10
1 to < 2 hours	🟨 2	🟥 6
30 minutes to < 1 hour	🟩 1	🟥 3
5 to < 30 minutes	🟩 0.5	🟨 1.5
< 5 minutes	🟩 0	🟩 0

Figure 5.5. The seven-categories time scale used in Category in RAMP II for assessment of time in adverse postures.

The scientific literature basis for the assessment criteria in RAMP II is presented in Paper C, and D and includes studies using an epidemiological, biomechanical, physiological and psychophysical methodology. For example, the basis for the assessment criteria for assessment items 1.1 and 1.2 ('Posture of the head', Figure 5.5) in RAMP II, includes studies and overviews with results obtained by all of these four methodologies [33, 133, 160, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406].

🟥	**High risk.** The loading situation has such a magnitude and characteristics that many employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be given high priority.
🟨	**Risk**. The loading situation has such a magnitude and characteristics that certain employees are at an increased risk of developing musculoskeletal disorders. Improvement measures should be taken.
🟩	**Low risk**. The loading situation has such a magnitude and characteristics that most employees are at a low risk of developing musculoskeletal disorders. However, individuals with reduced physical capacity may be at risk. Individually tailored improvement measures may be needed.

Figure 5.6. The three level color-code scale for communication of the RPL used in RAMP II (adapted from Paper D and Paper E).

5.4.2 Reliability of RAMP II

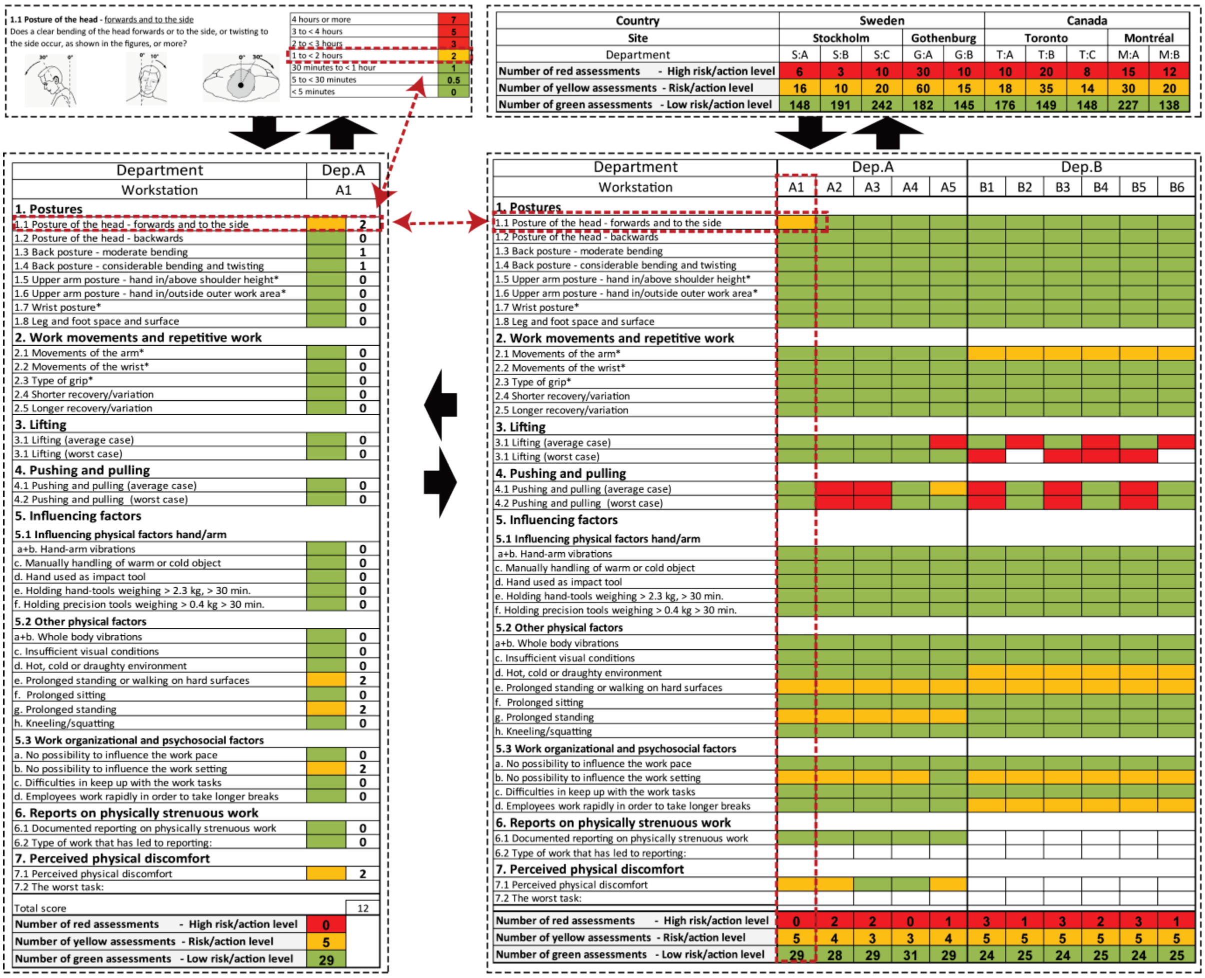
In terms of inter-rater reliability of RAMP II, the evaluation presented in Paper D indicates that the majority (i.e. 73%) of the assessment items in RAMP II can be assessed with acceptable reliability (i.e. a p_0 >0.7 and κ_w >0.40). For some assessment items, however, the proportional agreement among the assessors were low, i.e. assessment of upper arm posture, movements of the arm/wrist, *long* recovery, and influence of work had a proportional agreement <0.7. Although assessment of *severe* back posture, and grip did not reach acceptable level of kappa according to the criteria used by Palm et al. [131], they had both a relatively high proportional agreement of about 90%.

5.4.3 Usability of RAMP II

The main finding from the usability evaluation of RAMP II presented in Paper D (and partly in Paper E) gives support to that RAMP II is usable for OHS practitioners. The finding is supported by the results from the questionnaire-based survey were ≥84% agreed fully or partly, that RAMP II is usable as decision base and has clear result. In addition, 2/3 also agreed fully or partly, that the time needed for risk assessment using RAMP II is acceptable.

5.5 Paper E: Shifting to proactive risk management: Risk communication using the RAMP tool

Paper E presents how the results from assessments performed using RAMP II and RAMP I can be communicated using their three-level color code scale. The development of this risk communication system is presented, and assessment performed in the industry is presented to display how it can be used for communicating risks. Lastly, the paper presents an evaluation of the usability to communicate risk for RAMP II and RAMP I (see results for Paper B and Paper D). Paper E presents the three-level color code scales for RAMP I, and RAMP II which was designed to facilitate communication of risk and to facilitate decision and prioritization when implementing risk reducing measures (Figure 5.3 and 5.6). The paper illustrates the concept for how RAMP I and RAMP II can be used to identify hazards at different levels of detail. This is illustrated using assessments performed using RAMP II, by a company within the manufacturing industry in Sweden. As shown in Figure 5.7, the results can be viewed bottom-up or top-down, i.e. at the level of each assessment items (upper left) or for a single work station (bottom left), to an overview of several departments (bottom right) or at company level (upper right). The visualization presented in Paper E, illustrates how the status of potential hazards can be monitored at department or organizational level. To implement risk reducing measures, more detail information for each assessment items can be analyzed at the level of single or multiple workstations.



1.1 Posture of the head - forwards and to the side
Does a clear bending of the head forwards or to the side, or twisting to the side occur, as shown in the figures, or more?

4 hours or more	7
3 to < 4 hours	5
2 to < 3 hours	3
1 to < 2 hours	2
30 minutes to < 1 hour	1
5 to < 30 minutes	0.5
< 5 minutes	0

Country	Sweden					Canada				
Site	Stockholm			Gothenburg		Toronto			Montréal	
Department	S:A	S:B	S:C	G:A	G:B	T:A	T:B	T:C	M:A	M:B
Number of red assessments - High risk/action level	6	3	10	30	10	10	20	8	15	12
Number of yellow assessments - Risk/action level	16	10	20	60	15	18	35	14	30	20
Number of green assessments - Low risk/action level	148	191	242	182	145	176	149	148	227	138

Department	Dep.A	
Workstation	A1	
1. Postures		
1.1 Posture of the head - forwards and to the side	🟨	2
1.2 Posture of the head - backwards	🟩	0
1.3 Back posture - moderate bending	🟩	1
1.4 Back posture - considerable bending and twisting	🟩	1
1.5 Upper arm posture - hand in/above shoulder height*	🟩	0
1.6 Upper arm posture - hand in/outside outer work area*	🟩	0
1.7 Wrist posture*	🟩	0
1.8 Leg and foot space and surface	🟩	0
2. Work movements and repetitive work		
2.1 Movements of the arm*	🟩	0
2.2 Movements of the wrist*	🟩	0
2.3 Type of grip*	🟩	0
2.4 Shorter recovery/variation	🟩	0
2.5 Longer recovery/variation	🟩	0
3. Lifting		
3.1 Lifting (average case)	🟩	0
3.1 Lifting (worst case)	🟩	0
4. Pushing and pulling		
4.1 Pushing and pulling (average case)	🟩	0
4.2 Pushing and pulling (worst case)	🟩	0
5. Influencing factors		
5.1 Influencing physical factors hand/arm		
a+b. Hand-arm vibrations	🟩	0
c. Manually handling of warm or cold object	🟩	0
d. Hand used as impact tool	🟩	0
e. Holding hand-tools weighing > 2.3 kg, > 30 min.	🟩	0
f. Holding precision tools weighing > 0.4 kg > 30 min.	🟩	0
5.2 Other physical factors		
a+b. Whole body vibrations	🟩	0
c. Insufficient visual conditions	🟩	0
d. Hot, cold or draughty environment	🟩	0
e. Prolonged standing or walking on hard surfaces	🟨	2
f. Prolonged sitting	🟩	0
g. Prolonged standing	🟨	2
h. Kneeling/squatting	🟩	0
5.3 Work organizational and psychosocial factors		
a. No possibility to influence the work pace	🟩	0
b. No possibility to influence the work setting	🟨	2
c. Difficulties in keep up with the work tasks	🟩	0
d. Employees work rapidly in order to take longer breaks	🟩	0
6. Reports on physically strenuous work		
6.1 Documented reporting on physically strenuous work	🟩	0
6.2 Type of work that has led to reporting:	🟩	0
7. Perceived physical discomfort		
7.1 Perceived physical discomfort	🟨	2
7.2 The worst task:		
Total score		12
Number of red assessments - High risk/action level	0	
Number of yellow assessments - Risk/action level	5	
Number of green assessments - Low risk/action level	29	

Department	Dep.A					Dep.B					
Workstation	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6
1. Postures											
1.1 Posture of the head - forwards and to the side	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.2 Posture of the head - backwards	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.3 Back posture - moderate bending	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.4 Back posture - considerable bending and twisting	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.5 Upper arm posture - hand in/above shoulder height*	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.6 Upper arm posture - hand in/outside outer work area*	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.7 Wrist posture*	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.8 Leg and foot space and surface	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2. Work movements and repetitive work											
2.1 Movements of the arm*	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨
2.2 Movements of the wrist*	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2.3 Type of grip*	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2.4 Shorter recovery/variation	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2.5 Longer recovery/variation	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
3. Lifting											
3.1 Lifting (average case)	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟥
3.1 Lifting (worst case)	🟩	🟩	🟩	🟩	🟩	🟥		🟥	🟥	🟥	
4. Pushing and pulling											
4.1 Pushing and pulling (average case)	🟩	🟥	🟥	🟩	🟨	🟥	🟩	🟥	🟩	🟥	🟩
4.2 Pushing and pulling (worst case)	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟥	🟩
5. Influencing factors											
5.1 Influencing physical factors hand/arm											
a+b. Hand-arm vibrations	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
c. Manually handling of warm or cold object	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
d. Hand used as impact tool	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
e. Holding hand-tools weighing > 2.3 kg, > 30 min.	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
f. Holding precision tools weighing > 0.4 kg > 30 min.	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
5.2 Other physical factors											
a+b. Whole body vibrations	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
c. Insufficient visual conditions	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
d. Hot, cold or draughty environment	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨
e. Prolonged standing or walking on hard surfaces	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
f. Prolonged sitting	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
g. Prolonged standing	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩
h. Kneeling/squatting	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
5.3 Work organizational and psychosocial factors											
a. No possibility to influence the work pace	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
b. No possibility to influence the work setting	🟨	🟨	🟨	🟨	🟩	🟨	🟨	🟨	🟨	🟨	🟨
c. Difficulties in keep up with the work tasks	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
d. Employees work rapidly in order to take longer breaks	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨
6. Reports on physically strenuous work											
6.1 Documented reporting on physically strenuous work	🟩	🟩	🟩	🟩	🟩						
6.2 Type of work that has led to reporting:											
7. Perceived physical discomfort											
7.1 Perceived physical discomfort	🟨	🟨	🟩	🟩	🟨						
7.2 The worst task:											
Number of red assessments - High risk/action level	0	2	2	0	1	3	1	3	2	3	1
Number of yellow assessments - Risk/action level	5	4	3	3	4	5	5	5	5	5	5
Number of green assessments - Low risk/action level	29	28	29	31	29	24	25	24	25	24	25

Figure 5.7. Visualization on how assessment using RAMP II can be presented at different levels of detail and scope (adapted from Paper E).

6. Discussion

This thesis aimed to increase knowledge on the use of OBRATs and important usability-related aspects among OHSs ergonomists in Sweden. Furthermore, this thesis aimed to present RAMP I and RAMP II, their development and scientific basis, and evaluating their reliability and usability.

6.1 Use and usability-related aspects of OBRATs

The finding in Paper A, that a majority (here: all) of the ergonomists included in the study population used the provision 'SWEA-AFS' issued by the SWEA, was expected and is in agreement with results by Nordlander [241]. Buckle and Li [237] reported that being seen as a standard tool backed by regulatory bodies was considered important among experts. This aspect has also been identified as important among professional OHSs ergonomists in Sweden [88], and was occasionally used to facilitate action being taken by the decision makers. This issue was, however, not addressed in the web-based survey in Paper A, but the fact the two other OBRATs with the largest proportion of users, i.e. KIM 1 and KIM 2, were also promoted by SWEA (i.e. SWEA issued Swedish version of the tools) [157, 158], seems to strengthen the importance of being backed by the national regulatory body. Furthermore, the findings in Paper A indicate a low proportional use of several internationally spread OBRATs including the NIOSH-LE, RULA, REBA and OWAS, as well as most of the other OBRATs included in this survey. Given that neither of 'SWEA-AFS', KIM 1, and KIM 2 accommodate in-depth assessments of e.g. MHO, higher use of tools that provide in-depth assessments may be desirable for those actors having the position as OHS experts. Consequently, this may result in assessments largely based on subjective judgments, and as indicated by Eliasson et al. [89], result in assessments with low intra- and inter-reliability, and hence low validity. The use of the NIOSH-LE, which has strong connections with both European and global ergonomics standards [407, 408], was substantially lower among the ergonomists in the survey than among certified ergonomists in the US [87], Canada [193], and among Spanish speaking ergonomics practitioners [238]. The reason for this difference cannot, however, be answered due to the study design employed in Paper A. Lack of knowledge (or training) was the most commonly reported reason for not using an OBRAT. However, training seems to not solely increase the use as displayed in Figure 6.1. Despite that ergonomists reported being familiar with some OBRATs (i.e. not being unfamiliar), many of them were still not used. For example, only about 30% of those who were familiar with NISOH-LE, RULA, and REBA had used these OBRATs and only 9% for OWAS. This may indicate the importance of other factors contributing to the use of OBRATs.

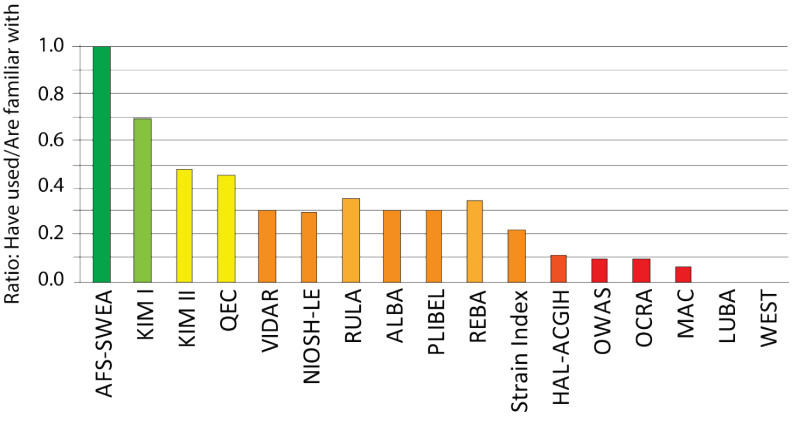


Figure 6.1. Proportion of the tools being used of those the respondents were familiar with (i.e. not unfamiliar with). Based on data reported in Paper A.

The results from Paper A, indicate that several aspects related to usability and performance need to be considered. As indicated by Whysall et al. [409], Wells et al. [64], and Eliasson [88], the type of ‘methods’ used is context dependent. For example, observation without specific OBRATs was reported as often used in the initial phase. The use of an OBRAT or other types of ‘in-depth’ assessment tools, was, on the other hand, reported to be used to gain a deeper understanding of the issue of concern [64], or for promoting (‘convincing’) the stakeholders taking actions [64, 88]. The latter aspect seems to be closely related to usability aspects concerning communication of the results of the assessment.

Being easy and quick to apply and aspects related to communication or visualization of the results were identified as important aspects among both the OBRATs with the largest proportion of users and when the ergonomists rated the importance of usability-related aspects. An OBRAT being scientifically based, and its ability to support improvement measures (i.e. providing a good basis for intervention proposals) were, additionally, rated as important by a large proportion of the respondents. The importance of an OBRAT being quick to use is in agreement with others [237, 244], as well as its ability to support improvement measures [238]. A larger proportion of the respondents in Paper A rated it being ‘easy to use’ as very important compared to ‘quick to use’, i.e. 55% and 39%, respectively. Rose et al. [244] also reported that ‘easy to use’ was rated higher compared to being ‘quick to use’. Furthermore, Buckle and Li [237] identified that the tool should limit requirements of paperwork and have check boxes. As reported by Eliasson [88] and Wells et al. [64], OBRATs can also be used as a basis for the report to the commissioner. Some of the tools developed and used in the manufacturing industry (e.g. SES [233] and BUMS [410]), include standardized report sheets, thereby reducing the additional resources of writing an additional report (personnel communication Lena Nord-Nilsson, Scania CV AB, March 2017). These results suggest that a broad range of usability related aspects than merely ease of use and time of the application need to be considered when evaluating or developing OBRATs for OHS practitioners.

6.2 Development of RAMP I and RAMP II

To be applicable for assessments of a broad range of exposures/MSDs risk factors related to MHO, the extent to which the most important factors are addressed relates to basic components of the tools functionality. As showed in Tables 1.4a–1.4c, assessment tools are often developed to target specific type of work or MHOs, e.g. lifting, pushing/pulling, repetitive movements of the upper limbs, or work postures. As shown in Table 6.1, RAMP I and RAMP II include a broad range of factors such as heavy lifting/lowering and pushing/pulling; postures of the upper and lower limbs and trunk; hand-arm and whole-body vibrations; recovery time; ambient temperature and draught; psychosocial factors and discomfort reports. Additionally factors include e.g. hand tool use, surface (floor), visual conditions, prolonged standing and sitting, and reports of physical strenuous work. This implies that a broad range of exposures/MSDs risk factors related to manual handling can be targeted using both RAMP I and RAMP II. The tools were developed to support a two-stage process where RAMP I facilitates OHS practitioners in screening of a hazards in manual handlings jobs or work tasks. For those jobs or work tasks identified as potentially hazardous, a more in-depth assessment can be performed using RAMP II. This two-stage process is considered suitable for workplace assessment concerning WMSDs [411].

As shown in Table 6.1, postures are mainly assessed based on magnitude and duration in RAMP II, while RAMP I also includes frequency (with the exception of the wrist). The main reason for this difference was the scarcely identified data on frequency for postures of the trunk and neck to derive RPLs in RAMP II. The main principle for RAMP I was to quickly identify potential risk factors with a high level of sensitivity (which was superordinate to high specificity) and without the need of detailed assessment contributing task parameters. Therefore, the basis for the assessment criteria regarding frequency of postures included a cutoff used for screening of hazards in the manufacturing industry (Paper B). Because the tools include multiple risk factors, this could potentially reduce the probability of sub-optimized solutions where new harmful exposures may be introduced when others are reduced. Furthermore, RAMP I and RAMP II should be regarded as parts of an assessment where other tools and methods are used.

Table 6.1. Included exposures, and parameters of the exposures in RAMP I and RAMP II.

		RAMP I	RAMP II
Heavy MHO			
Lifting/Lowering ('heavy')	Load weight	Yes	Yes
	Frequency/duration	Yes	Yes
	Posture	Yes	Yes
Carrying ('heavy')		n/a[A]	n/a[A]
Pushing/Pulling ('heavy')	Magnutide of force	Yes	Yes
	Frequency/duration	Yes	Yes
	Posture	Yes	Yes
Postures (excl. heavy MHO)			
Neck	Magnitude	Yes	Yes
	Duration	Yes	Yes
	Frequency (i.e. movements)	Yes	No
Upper arms	Magnitude	Yes	Yes
	Duration	Yes	Yes
	Frequency (i.e. movements)	Yes	Yes[B]
Trunk	Magnitude	Yes	Yes
	Duration	Yes	Yes
	Frequency (i.e. movements)	Yes	No[C]
Wrist	Magnitude	Yes	Yes
	Duration	Yes	Yes
	Frequency (i.e. movements)	No	Yes
Kneeling/Squatting	Frequency/duration	Yes	Yes
Additional factors			
Hand-arm vibration		Yes	Yes
Whole-body vibration		Yes	Yes
Breaks/recovery time		Yes	Yes
Ambient temperature (e.g. heat, cold and draught)		Yes	Yes
Psychosocial factors		Yes	Yes
Discomfort reports		Yes	Yes

Notes; not applicable (n/a); [A] only included as a note; [B] three mainly qualitative categories; [C] indirectly for heavy lifting/lowering.

In congruence with e.g. the ART, MAC and RAPP tools, many of the assessment items e.g. postures of the back, upper arms and wrists are assessed independently of other exposures. For lifting/lowering and pushing/pulling the position of the hands in space is considered in RAMP I and RAMP II, thereby at least indirectly, considering the postures of the back and upper arms. Substantially increased MSD risks have been associated with exposures of high level of repetition in combination with high forces [412]. Furthermore, the combination of hand force and wrist posture is also believed to interact in a similar multiplicative manner

[177]. This implies that assessments that address these factors without considering the interaction effects may underestimate the risk. Hence, if accurately accounting for these interaction effects, improvements of the specificity and sensitivity of the assessments could be expected. For lifting/lowering and pushing/pulling, a range of task parameters are combined using a multiplicative interaction. A multiplicative interaction has been found to better represent the interaction compared to an additive interaction [413, 414] and has been used in several tools and models for MHO [171, 177, 183, 217, 218, 415]. However, as indicated by Davis and Marras [416], the magnitude of the interaction effect is not always constant, but can be influenced by other task parameters. For example, vertical location of the load influenced the magnitude of the interaction effects of load asymmetry. The most pronounced effect in the spinal loading occurred when lifting was performed at low vertical heights. Hence, based on biomechanical spinal loading, this suggests that the weighing of the multiplier could be improved by taking into account the differences due to vertical location.

Conversely to KIM 1 and MAC, little attention is given to carrying in RAMP I or in RAMP II. Carrying was not seen as equally important to include in the tools as lifting and pushing/pulling [244]. According to EN 1005-2 [407] lifting that includes a carrying distance <2 m can be assessed as a lifting operation. As discussed in Paper B, manual pushing/pulling and lifting/lowering, and carrying <2 m, have been reported constituting >90% of industrial MHO [417]. However, carrying >2 m still constitutes a non-negligible proportion of industrial MHO. While Taboun and Dutta [418] reported decreased MAW by about 7% when carrying 4 m compared to 0 m, Morrissey and Liou [419] reported a substantially decreased MAW by about 14% when carrying 2.1 m compared to 1 m, indicating that a substantial reduction in the load weight is needed when tasks include shorter carrying distance, at least for heavy loads (i.e. about 40–50kg). To broaden the applicability of RAMP I and RAMP II to other sectors, it is suggested to include carrying in future revisions of the tools.

Is should be noted that the basis for many of the multipliers in the pushing and pulling tool/model relies on maximum voluntary strength or maximum acceptable load or force. Although some studies support the ability of these approaches to predict increased risk of MSDs, injuries or pain [48, 212, 213, 264, 265, 420], it has not been validated that workloads derived from these approaches are below the threshold for manual handling related injuries or disorders [295, 371]. The emphasis on utilization of studies employing a psychophysical approach had several reasons. First, the psychophysical approach has been utilized for studying several manual handling task parameters. The psychophysical approach has been shown to yield reproducible data [295] and is believed to integrate both biomechanical and physiological aspects [276, 295, 421]. Furthermore, since the approach usually produces data on acceptable load weights or forces (i.e. a reduction due to introducing specific task parameters) these results are relatively transferable to modeling.

Expert judgments were, in agreement with many others (e.g. [152, 169, 182]) employed to enable the utilization of results from the studies with different research approaches, exposures (including different operational definitions or cutoffs for exposures or exposure levels), and different outcomes or case definitions identified from the literature search. Expert judgments can be criticized for being subjective, and the derived results from these approaches should, as discussed in paper B–E be regarded as hypothetical and treated with caution until they have been validated in experimental studies or high quality epidemiological studies. A possible alternative would be to use a meta-analysis. However, based on the identified literature this was, in accordance with Hoozemans et al. [27], judged as infeasible. Using meta-analysis exclusively, would likely have resulted in a need to exclude a large part of the relevant studies, likely resulting in crude assessment items with low usefulness for the targeted users. Since the use of expert judgments enabled utilization of relevant studies with different research approaches, studies presenting quantitative data and short term indicators for excessive loading could be used as basis for the assessment items in combination with studies using more longer term indicators, thereby to a larger extent utilizing the best available knowledge [422].

Potential limitations with the search strategy were that a single database (i.e. Scopus) was used to search for studies, and that relatively few search terms were used. This may have resulted in that some relevant studies were not identified. However, the retrieved literature reviews employed a broader search strategy, thereby increasing the coverage of the literature search strategy. An alternative strategy could have been to employ a broader set of search terms as used by SBU [423]. Their literature search was restricted to work-related exposures targeting the upper extremities including the neck and shoulders. Despite this restriction, their extensive number of search terms resulted in 22,587 studies. A later literature review by SBU [424] targeting work-related exposures influencing back disorders identified 5,122 studies on physical demands. A broad search strategy was initially performed in the development of RAMP I and RAMP II, but resulted in an unmanageable amount of studies. Therefore, the reference lists of literature reviews were used as one of the strategies to identify relevant studies in combination with the other strategies presented in Paper B–D, and Table 4.3.

Some recent studies have claimed that there is insufficient evidence of an association of e.g. repetitive or heavy work and carpal tunnel syndrome, and repetitive work or working with arms above shoulder height and pain disorders in the neck/shoulders [423] or that occupational lifting, pushing or pulling, bending or twisting and awkward occupational postures are all unlikely independently causative of LBP [425, 426, 427, 428]. Such claims are generally contradictory to what has been supported by others [18, 20, 45, 429] and have been criticized for e.g. excluding relevant studies [429] or for treating the view points of causality by Bradford Hill [430] as strict criteria of causality, applying those ‘criteria’ to single studies rather than to the risk factor, and for ignoring trends or tendencies of an association, interpreting a non-statistical significant relationship (e.g. at a 5% level) as support of a non-existing association although not having tested this hypothesis [431, 432]. Based on the large number of studies supporting and association of workplace-related ergonomics stressors [18, 20, 45, 429], an alternative would be to apply the ‘Precautionary Principle’ [429], i.e. applying precautionary measures to hazards or potentially harmful exposure agents although if the etiology linked to these hazards are not fully established.

RAMP I and RAMP II target assessments on group level. Therefore, other tools or methods are needed for assessments and work design targeting at specific individual workers. Furthermore, RAMP I and RAMP II target mainly a reduction of the exposures. In agreement with most assessment tools in Table 1.2, mainly high physical exposures are treated as being hazardous, while low physical exposures are treated as inducing a low risk. While this may be a reasonable focus for many industrial manual handling jobs, other types of jobs may benefit of increased physical loading [433], although little is known of the optimum physical loading [434]. However, such jobs were not the target for the development of RAMP I and RAMP II.

The RPLs in RAMP I and RAMP II are yet to be validated. Their basic function is to stimulate risk reducing measures and design of MHO to reduce physical exposures in order to prevent WMSDs, fatigue and discomfort. The definitions of the RPLs are qualitatively and include an exhortation to take actions. An alternative could have been to use more specific definitions of the risk levels as used by Marras et al. [435]. In their study, a 'high-risk job' was defined as jobs having 12 LBD injury cases per 200,000 hours of exposure and a 'low-risk job' as a job with no LBD injury cases (and no turnover) the last three years. It should however be noted that, the definition of a LBD injury differed and were in most cases retrieved from company medical reports. The definition of a 'high-risk job' used by Marras et al. [435] can, however, be exposed for criticism of being arbitrary. Their approach might have been feasible if only specific types of musculoskeletal injuries or disorders were targeted. Because the aim was to address potential MSDs risk factors in general, with focus on short terms indicators and on facilitating implementation of risk reducing measures rather that assessing the specific risk level of LBD injuries of a specific population, an approach similar to the one used by Marras et al. [435] was not seen as suitable or possible to pursue based on the aim of the project and the identified studies.

6.3 Reliability of RAMP I and RAMP II

As shown in the inter-reliability evaluation presented in Paper D, the majority of the evaluated assessment items in RAMP II (i.e. 73%) received acceptable reliability after the assessors had received one day training. For RAMP I, the majority of the evaluated assessment items, i.e. 67% for the ergonomists and 56% for the production engineers, received acceptable reliability after the assessors had received about one hour of training. Conversely, 27% of the assessment criteria in RAMP II did not receive acceptable reliability when applying Palm et al.'s criterion [131] to linearly weighted kappa [436, 437]. For RAMP I, 33% of the assessment criteria did not receive acceptable reliability for the ergonomists and 44% for the production engineers.

Considering the relatively large number of items to assess, it is possible that the inter-rater reliability could have been improved if more time for training had been given to the assessor. As discussed in Paper B, one hour of training is substantially less than used in several other studies were the time for training ranged from 4 hours to 2 weeks [111, 155, 239, 438, 439]. However, it is possible that some items need revision to receive acceptable reliability, or be assessed using more reliable methods, such as direct measurement techniques, e.g. triaxial accelerometers for assessment of upper arm elevation [440, 441]. This may be helpful since both of the reliability evaluations indicate that assessments of duration of upper arm posture and hand position in space are difficult to assess with high level of inter-rater agreement using the assessment items in the tools. Another strategy to improve the reliability could be to utilize team assessments [105] which have been found producing more reliable assessments compared assessments performed by single observers [442, 443].

For RAMP II, perfect agreement (p_o = 1.00 and κw >1.00) was achieved for the assessment items concerning neck and wrist postures. Assessment of wrist postures using observation often result in low reliability [85]. It is possible that the high agreement in reported in Paper D partly, could be attributed to a low proportion of the time in wrist postures corresponding to the wrist angle of the assessment items in RAMP II for the included jobs, hence resulting in a low distribution in different exposure categories. The mean proportion of the work time spent in considerable bent wrist posture in industrial manual handling jobs reported by Fan et al. [444], was substantially below the boarder to the intermediate RPL for wrist posture in RAMP II.

The evaluations were restricted to evaluation of the RPLs (consisting of two or three categories), since these are superordinate of the RPL scores. Therefore, no attempt was made to evaluate the reliability of the RPL scores in the Papers included in this thesis. It is, however, likely to expect a lower reliability if comparing the RPL scores within each assessment item, leading to increase in random misclassification errors due to increased number of bin boundaries [445].

The survey presented in Paper A identified several usability-related aspects that were rated as important for using an OBRAT, including e.g. ease of use, being quick to use, its ability to communicate and visualize the results, and its ability to facilitate improvement measures. A large part of the respondents agreed (fully or partly), that RAMP I and RAMP II are usable as decision base, that the time needed to perform an assessment using the tools is acceptable, that the results are clear, and that the assessment items are (in general) easy to understand. They also considered both RAMP I and RAMP II as being usable for assessing risks. Hence, according to a large majority of the respondents, both RAMP I and RAMP II fulfilled several usability-related aspects that were identified as important in Paper A. The fact that all participants agreed (fully or partly) on the more general question of them being usable for risk assessment gives additionally support for their usability.

6. 5 Additional methodological considerations

6.5.1 Survey

Considering the response rate of the survey (i.e. 43% for those opening the news letter), the results should be applied with caution when generalizing the result to the entire population of professional OHSs ergonomists in Sweden that perform ‘physical ergonomics’ risk assessments. The response rate was lower than the survey by Dempsey at al. [87] (i.e. 53%), but higher than in the surveys by Diego-Mas et al. [238] and Arezes et al. [194], and included substantially more respondents than the study by Pascual and Naqvi [193] and earlier surveys from Sweden [241, 242, 243]. The web-survey targeted OHSs ergonomists that were members of the Ergonomics Section within the Swedish Association of Physiotherapists [88], which at the time consisted of 598 members. At the same year about 525 full-time equivalent employments of ergonomists performed services for OHSs-organizations affiliated to Sveriges Företagshälsor[3], which according to their own figures, perform services that correspond to about 95% of the turnover in this sector (personnel communication, Sveriges Företagshälsor, March 2017). Furthermore, the proportion of women in the included study population (81%) was, however, close to that of those invited for participation in the study (79%) i.e. members of the Ergonomics Section within the Swedish Association of Physiotherapists [88]. However, it cannot be ruled out that the use of OBRATs is even lower among those who did not open or received the newsletter. It also needs to be stressed that the survey targeted professional ergonomists (RPT) working as OHSs ergonomists. Therefore, the use of OBRATs among other ergonomists in Sweden cannot be answered from the results presented in this thesis.

---

[3] *Note: (free translation):* ‘the Swedish Association of Occupational Health Services

Several usability-related aspects were judged as important by a large majority of the respondents. To distinguish which of these are considered most important, ranking [446] could have been applied. This was however judged as being too cumbersome for the participants, given the large number of questions in the survey. Other aspects could also have been included such as, importance of being seen as a standard tool backed by regulatory bodies, and reliability and validity as identified by Buckle and Li [237]. Since the OHSs ergonomists are intended to use evidence based tools, the term scientifically based was used as a broad term with the intention to cover a broad range of aspects, including validity.

6.5.2 Evaluations of RAMP I and RAMP II

As no single set of criteria exists for evaluating OBRATs, several of the usability related aspects identified as important in Paper A were used to evaluate the usability of RAMP I and RAMP II, as well as the general question whether the tools are usable for assessing risks. An alternative could have been to use the System Usability Scale developed [447], which was used to evaluated the usability of the ART tool [130]. However the questions in the System Usability Scale, developed for evaluating the usability of computer-based systems, were to a large part not conform with the identified usability aspects in Paper A, Buckle and Li [237], Diego-Mas et al. [238], Rose et al. [244], and those used in former evaluations of OBRATs [448] among Swedish ergonomists. Therefore, a five level ordinal rating scales, with the anchor points 'easy' to 'difficult' and 'fully agree' to 'fully disagree', were employed to evaluated the usability of RAMP I and RAMP II. Such five or seven-level scales with a neutral middle category are commonly used [449]. The anchor points 'ease' and 'difficult' were the same as used in former evaluations of OBRATs among labor inspectors [450] and OHS practitioners [451]. The anchor points 'fully agree' and 'fully disagree' have been used by Drury et al. [452] to evaluate computer-based 'checklists' for aircraft inspection, although Drury et al. [452] used a 9-level scale. These anchor points are in close resemblance to those used in the System Usability Scale [447] and the Likert scale (i.e. strongly disagree – strongly agree) [449]. Sharples and Cobb [449] raised concerns of using more than 7 points, questioning whether the respondents easily could make such precise judgments, therefore recommending rating scales with 5–7 points. The ordinal rating scales employed include a numerical and a categorical component. They were, however, treated as ordinal scales rather than interval scales in the analysis since the (mathematical) distances between the category levels was not validated. The usability evaluations were conducted in conjunction with the training sessions of the tools, therefore the participants' perception of the tools usability after longer term use has not been tested.

The criterion used to indicate acceptable reliability for collecting data using observation-based methods varies between studies, e.g. cutoff for proportional agreement of 0.7 to 0.9 have been used, and kappa of 0.41 to 0.6 [67, 131]. The cutoffs may be exposed for criticism to some extent, being arbitrary. To indicate acceptable inter-rater reliability for RAMP I and RAMP II, the criteria proposed by Palm et al. [131] (i.e. kappa >0.40, in combination with a proportional agreement >0.7) was used, since this criterion was developed to evaluate reliability of an OBRAT (BASIK) designed for similar purpose and users, i.e. workplace assessment by OHS practitioners, such as ergonomists. The other criteria reviewed by Denis et al. [67] were instead used as criteria in the context of epidemiological studies, or for collecting detailed information on task parameters for MHO [453]. Additionally, the criteria used by Palm et al. [131] is in close agreement with the cutoff by Landis and Koch [1971] of kappa ≥0.41 (0.41-0.60) to indicate moderate reliability. It should be noted that Palm et al.

[131] applied the criteria for the so-called ‘prevalence and bias adjusted kappa’ (i.e. PABAK) while, linearly weighted kappa [436, 437] was instead used in Paper B and D. As discussed in Paper D, employing PABAK as kappa would have increased the percentages of items receiving acceptable reliability, i.e. from 73, to 82% for RAMP II. For RAMP I, items receiving acceptable reliability would have increased from 67% to 73% for the ergonomists, and from 56% to 80% for the engineers if PABAK were used instead of linearly weighted kappa. Among the 5654 assessments collected in the reliability evaluation of RAMP I, missing data were less than 2%. Among the 1188 assessments collected for the 33 included assessment items, there were no missing data.

The reliability evaluations were based on 5 and 10-minutes retrospective video recordings of industrial manual handling tasks. These video recordings were assumed to show a representative distribution of exposures for eight hours work. It is, however, not clear to what extent these 5 and 10-minutes video recordings are representative for eight hours of work. The included jobs and tasks are to a large part standardized and paced by a fixed production rate. It can therefore be expected that the variability of the exposure in these ‘standardized’ tasks are lower than in many other non-paced ‘non- standardized ‘ tasks or jobs involving manual handling, although a certain degree of intra- and inter-worker-variability of the exposure [454, 455] can be expected, and possibly even seasonal variability of the exposure [456]. However, this methodological issue applies to assessment tools in general, and repeated observation of multiple workers may be needed to derive at accurate estimations of the ‘true’ exposure. It is, however, considered a strength that the participants in the reliability evaluation comprised intended end users, and that the video recordings comprised recordings of actual work, instead of highly standardized simulations of work tasks with a low degree of variability [239, 438, 457]. It can be argued that this gives a better test of the external reliability, compared to it only simulated jobs with low variability were assessed. In agreement with the proposal by Shackel [364] the evaluation of RAMP I and RAMP II were based on both subjective ratings of usability and on ‘objective’ indicators of their reliability.

7. Conclusions

In this thesis, the overall objective of the research project was to develop a usable research-based screening tool and assessment tool for occupational health and safety practitioners targeting major work-related musculoskeletal disorder risk factors related to industrial manual handling operations. The use of observation-based risk assessment tools among professional ergonomists in Sweden has been explored, as wells as important usability-related aspects of observation-based risk assessment tools. A research-based screening tool and an assessment tool have been developed and their scientific basis presented, and additionally, their reliability and usability have been evaluated.

The findings in the thesis point to a low proportional use of several internationally spread observation-based risk assessment tools, including the NIOSH lifting equation, RULA, REBA, and OWAS, among OHSs ergonomists in Sweden. Instead, the tools with the highest proportion of users, as indicated in this thesis, were 'SWEA-AFS', KIM 1, and KIM 2, which all were promoted by the Swedish Work Environment Authority. Several usability-related aspects for observation-based risk assessment tools were identified as important among professional ergonomists in Sweden. In particular, these aspects were related to the tools being easy and quick to use, the tools' ability to communicate and visualize the results, and the tools' ability to facilitate improvement measures.

The developed screening and assessment tools support assessment of a broad range of musculoskeletal disorder risk factors related to industrial manual handling. The thesis supports that assessments with acceptable inter-rater reliability can be achieved for the majority of tools' assessment items when industrial manual handling tasks are assessed by assessors with prior training in risk assessments of manual handling. The thesis supports that the two developed tools are usable in supporting risk assessments targeting musculoskeletal disorder risk factors related to industrial manual handling.

8. Theoretical & practical contribution

The developed tools (RAMP I, and RAMP II) have strong practical contribution in the sense that, according to reports from users, they are or have been employed to assess WMSDs risks related to manual handling in the manufacturing industries. At this point, several OHSs practitioners are reporting using RAMP II, which can be regarded as an indication of external usability, or at least practical acceptability. RAMP II (and to some extent RAMP I) can also be regarded as a theoretical model that based on available research literature on MSD risk factors and literature on influence on capacity of various task parameters related to manual handling can be used to quantity work related exposures. The emphasis on duration of exposures in RAMP II (e.g. for postures), allows OHS practitioners such as e.g. ergonomists to assess these exposures with higher resolution (level of detail) than for several of the existing observation-based risk assessment tools. The empirical data from this research can be used to increase the understanding of important usability attributes of observation-based risk assessment tools. This information is likely important when developing new tools or revising existing tools in order to achieve high usability. Additionally, these usability attributes, can also be used when developing theoretical models of usability aspects related to observation-based risk assessment tools.

9. Future work

Although it is sometimes claimed that specific observation-based assessment tools are widely spread or used, few peer-reviewed studies have addressed this issue systematically. The few available studies that have reported on this issue often have low response rates or are based on responses from a small number of respondents. More studies are therefore encouraged to explore the use among different practitioner groups and within different countries. Due to the large number of tools being developed to support OHS practitioners (and which will likely continue), more studies are needed to increase the understanding of how these tools are used in practice, and which usability-related aspects are important for different users and stakeholders. More research is also needed on how to design such tools, taking account both the development process and elements of the specific tool. Since only a few of the developed tools have been evaluated in longitudinal epidemiological studies for their predictive validity with regard to MSDs, more studies are needed on this matter, including evaluating the predictive validity of e.g. RAMP II.

Although several studies indicate that combined manual handling is common or potentially constitutes the majority of manual handling activities, relatively few studies and tools have addressed this issue. Despite the obvious difficulties of developing guidelines for combined manual handling, more attention should be directed to this issue. Despite the usefulness of the psychophysical and physiological approaches in developing guidelines for MHOs which include a range of task parameters, relatively few studies have evaluated their predictive validity with regard to MSDs, especially for pushing, pulling and carrying. Therefore, more high quality epidemiological studies are needed. The basis for many of the task parameters in the push/pull tool was derived from studies were only a few task parameters were combined. Therefore, the combined effect if many task parameters occur simultaneously is hard to predict using the available data. Although a multiplicative relationship has been claimed as superior to an additive relationship, more studies are needed that explores interaction effects of several task parameters. To derive the quantitative assessment criteria in RAMP II (and RAMP I), expert group judgments were needed due to the many times scarce epidemiologically derived data, crude categories used, and difference in how exposures and outcomes were defined and measured. More epidemiological studies collecting continuous data of high precision and accuracy would improve the possibilities to develop quantitative assessment criteria with increased precision.

References

1. Lind C, Rose L, Franzon H, Nord-Nilsson L. RAMP: Risk management Assessment tool for Manual handling Proactively. In: O. Broberg O, Fallentin N, Hasle P, Jensen PL, Kabel A, Larsen ME, Weller T, editors. Proceedings of the 11th International Symposium on Human Factors in Organisational Design and Management & 46th Annual Nordic Ergonomics Society Conference. Copenhagen (DK); IEA Press: 2014. p. 107–110.
2. March L, Smith EUR, Hoy DG, Cross MJ, Sanchez-Riera L, Blyth F, Buchbinder R, Vos T, Woolf AD. Burden of disability due to musculoskeletal (MSK) disorders. Best Pract Res Clin Rheumatol. 2014;28(3):353–366.
3. Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, Woolf A, Vos T, Buchbinder R. A systematic review of the global prevalence of low back pain. Arthritis Rheum. 2012;64(6):2028–2037.
4. Driscoll T, Jacklyn G, Orchard J, Passmore E, Vos T, Freedman G, Lim S, Punnett L. The global burden of occupationally related low back pain: estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis. 2014;73(6):975–981.
5. Bureau of Labor Statistics (US). Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work, 2015. USDL-16-2130. 2016.
6. Liberty Mutual Research Institute for Safety. 2017 Liberty Mutual Workplace Safety Index. Hopkinton (MA). https://www.libertymutualgroup.com/about-liberty-mutual-site/research-institute-site/Documents/2017%20WSI.pdf (cited Feb 28 2017). Jan 2017.
7. Coyte PC, Asche CV, Croxford R, Chan B. The economic cost of musculoskeletal disorders in Canada. Arthritis Care Res. 1998;11(5):315–325.
8. European Commission. Statistics in focus. Luxembourg (LU): Office for Official Publications of the European Communities; 2009. (Eurostat publication ISSN 1977-0316).
9. Schneider E, Irastorza X. OSH in Figures: Work-related Musculoskeletal Disorders in the EU - Facts and Figures. Luxembourg (LU): Publications Office of the European Union; 2010.
10. Eurofound. Sixth European working conditions survey – overview report. Luxembourg (LU): Publications Office of the European Union; 2016.
11. Swedish Work Environment Authority (SWEA). Korta arbetsskadefakta: Tillverkningsindustrin. Stockholm (SE): SWEA; 2014. (Korta arbetsskadefakta no. 3/2014). Swedish.
12. Swedish Work Environment Authority (SWEA). Arbetsmiljön 2015 [The Work Environment 2015]. Stockholm (SE): SWEA; 2016. (Arbetsmiljöstatistik Rapport 2016:2). Swedish.
13. European Unio. Council Directive 89/391/EC of 12 June 1989 on the Introduction of Measures to Encourage Improvements in the Safety and Health of Workers at Work. Official Journal of the European Communities; 1989.
14. European Unio. Council Directive 90/269/EEC of 29 May 1990 on the minimum health and safety requirements for the manual handling of loads where there is a risk particularly of back injury to workers. Official Journal of the European Communities. 1990.
15. Swedish Work Environment Authority (SWEA). Systematic Work Environment Management. Stockholm (SE). (SWEA publication; no. AFS 2001:1Eng). English. Retrieved February 25, 2017, from https://www.av.se/en/work-environment-work-and-inspections/publications/foreskrifter/systematic-work-environment-management-afs-20011-provisions/?hl=Systematic%20Work%20Environment%20Management.
16. Swedish Work Environment Authority (SWEA). Belastningsergonomi [Physical Ergonomics]. Stockholm (SE): SWEA; 2012. (SWEA publication; no. AFS 2012:2). Swedish.
17. Swedish Work Environment Authority (SWEA). Maskiner. Arbetsmiljöverkets föreskrifter om maskiner samt allmänna råd om tillämpningen av föreskrifterna. Stockholm (SE): SWEA; 2008. (SWEA publication; no. AFS 2008:3). Swedish.
18. National Research Council. Musculoskeletal disorders and the workplace: Low back and upper extremities. Washington (DC): National Academy Press; 2001.
19. Marras WS, Walter BA, Purmessur D, Mageswaran P, Wiet MG. The Contribution of Biomechanical-Biological Interactions of the Spine to Low Back Pain. Hum Factors. 2016;58(7):965–975.
20. Bernard BP. Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Cincinnati (OH): NIOSH; 1997. (NIOSH publication; no. 97–141).
21. Sluiter JK, Rest KM, Frings-Dresen MHW. Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. Scand J Work Environ Health. 2001;27(suppl. 1):1–102.
22. Lötters F, Burdorf A, Kuiper J, Miedema H. Model for the work-relatedness of low-back pain. Scand J Work Environ Health. 2003;29(6):431–440.
23. Kuiper JI, Burdorf A, Verbeek JHAM, Frings-Dresen MHW, Van Der Beek AJ, Viikari-Juntura ERA. Epidemiologic evidence on manual materials handling as a risk factor for back disorders:a systematic review. Int J Ind Ergon. 1999;24(4):389–404.
24. Hoogendoorn WE, Van Poppel MNM, Bongers PM, Koes BW, Bouter LM. Physical load during work and leisure time as risk factors for back pain. Scand J Work Environ Health. 1999;25(5):387–403.
25. Garg A, Boda S, Hegmann KT, Moore JS, Kapellusch JM, Bhoyar P, Thiese MS, Merryweather A, Deckow-Schaefer G, Bloswick D, Malloy EJ. The NIOSH lifting equation and low-back pain, part 1: Association with low-back pain in the BackWorks prospective cohort study. Hum Factors. 2014;56(1):6–28.

26. Garg A, Kapellusch JM, Hegmann KT, Moore JS, Boda S, Bhoyar P, Thiese MS, Merryweather A, Deckow-Schaefer G, Bloswick D, Malloy EJ. The NIOSH lifting equation and low-back pain, part 2: Association with seeking care in the BackWorks prospective cohort study. Human Factors. 2014;56(1):44–57.
27. Hoozemans MJM, Knelange EB, Frings-Dresen MHW, Veeger HEJ, Kuijer PPFM. Are pushing and pulling work-related risk factors for upper extremity symptoms? A systematic review of observational studies. Occup Environ Med. 2014;71(11):788–795.
28. Andersen LL, Fallentin N, Thorsen SV, Holtermann A. Physical workload and risk of long-term sickness absence in the general working population and among blue-collar workers: Prospective cohort study with register follow-up. Occup Environ Med. 2016;73(4):246–253.
29. Hoogendoorn WE, Bongers PM, De Vet HCW, Douwes M, Koes BW, Miedema MC, Ariëns GAM, Bouter LM. Flexion and rotation of the trunk and lifting at work are risk factors for low back pain: Results of a prospective cohort study. Spine (Phila Pa 1976). 2000;25(23):3087–3092.
30. Hoogendoorn WE, Bongers PM, De Vet HCW, Ariëns GAM, Van Mechelen W, Bouter LM. High physical work load and low job satisfaction increase the risk of sickness absence due to low back pain: results of a prospective cohort study. Occup Environ Med. 2002;59(5):323–328.
31. Jensen LK. Knee osteoarthritis: influence of work involving heavy lifting, kneeling, climbing stairs or ladders, or kneeling/squatting combined with heavy lifting. Occup Environ Med. 2008;65(2):72–89.
32. van Rijn RM, Huisstede BM, Koes BW, Burdorf A. Associations between work-related factors and specific disorders of the shoulder – a systematic review of the literature. Scand J Work Environ Health. 2010;36(3):189–201.
33. Andersen JH, Kaergaard A, Mikkelsen S, Jensen UF, Frost P, Bonde JP, Fallentin N, Thomsen JF. Risk factors in the onset of neck/shoulder pain in a prospective study of workers in industrial and service companies. Occup Environ Med. 2003;60(9):649–654.
34. van Rijn RM, Huisstede BMA, Koes BW, Burdorf A. Associations between work-related factors and the carpal tunnel syndrome–a systematic review. Scand J Work Environ Health. 2009;35(1):19–36.
35. Tabatabaeifar S, Svendsen SW, Johnsen B, Hansson G-Å, Fuglsang-Frederiksen A, Frost P. Reversible median nerve impairment after three weeks of repetitive work. Scand J Work Environ Health. doi:10.5271/sjweh.3619.
36. Kozak A, Schedlbauer G, Wirth T, Euler U, Westermann C, Nienhaus A. Association between work-related biomechanical risk factors and the occurrence of carpal tunnel syndrome: An overview of systematic reviews and a meta-analysis of current research. BMC Musculoskelet Disord. 2015;16(1).
37. Bovenzi M. Exposure-response relationship in the hand-arm vibration syndrome: An overview of current epidemiology research. Int Arch Occup Environ Health. 1998;71(8):509–519.
38. Bovenzi M, Hulshof CTJ. An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986–1997). Int Arch Occup Environ Health. 1999;72(6):351–365.
39. Burdorf A, Hulshof CTJ. Modelling the effects of exposure to whole-body vibration on low-back pain and its long-term consequences for sickness absence and associated work disability. J Sound Vib. 2006;298(3):480–491.
40. Hagberg M, Burström L, Lundström R, Nilsson T. Incidence of Raynaud's phenomenon in relation to hand-arm vibration exposure among male workers at an engineering plant a cohort study. J Occup Med Toxicol. 2008;3(13):1–6 DOI:10.1186/1745-6673-3-13.
41. van Rijn RM, Huisstede BMA, Koes BW, Burdorf A. Associations between work-related factors and specific disorders at the elbow: a systematic literature review. Rheum. 2009;48(5):528–536.
42. Edlund M, Burström L, Gerhardsson L, Lundström R, Nilsson T, Sandén H, Hagberg M. A prospective cohort study investigating an exposure-response relationship among vibration-exposed male workers with numbness of the hands. Scand J Work Environ Health. 2014;40(2):203–209.
43. Burström L, Nilsson T, Wahlström J. Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis. Int Arch Occup Environ Health. 2015;88(4):403–418.
44. Nilsson T, Wahlström J, Burström L. Systematiska kunskapsöversikter 9. Kärl-och nervskador i relation till exponering för handöverförda vibrationer. Arbets-och miljömedicin, Göteborgs universitet. Göteborg (SE). ISBN 978-91-85971-56-5. 2016.
45. Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. J Electromyogr Kinesiol. 2004;14(1):13–23.
46. Westgaard RH, Winkel J. Occupational musculoskeletal and mental health: Significance of rationalization and opportunities to create sustainable production systems - A systematic review. Appl Ergon. 2011;42(2):261–296.
47. Silverstein B, Clark R. Interventions to reduce work-related musculoskeletal disorders. J Electromyogr Kinesiol. 2004;14(1):135–152.
48. Snook SH, Campanelli RA, Hart JW. A study of three preventive approaches to low back injury. J Occup Med.1978;208(7):478–481.
49. Dempsey PG. A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks. Ergonomics. 1998;41(1):73–88.
50. Verbeek J, Martimo KP, Karppinen J, Kuijer PP, Takala EP, Viikari-Juntura E. Manual material handling advice and assistive devices for preventing and treating back pain in workers: A Cochrane Systematic Review. Occup Environ Med. 2012;69(1):79–80.

51. Rivilis I, Van Eerd D, Cullen K, Cole DC, Irvin E, Tyson J, Mahood Q. Effectiveness of participatory ergonomic interventions on health outcomes: A systematic review. Appl Ergon. 2008;39(3):342–358.
52. van der Molen HF, Sluiter JK, Hulshof CTJ, Vink P, Frings-Dresen MHW. Effectiveness of measures and implementation strategies in reducing physical work demands due to manual handling at work. Scand J Work Environ Health. 2005;31(suppl. 2):75–87.
53. Marras WS, Allread WG, Burr DL, Fathallah FA. Prospective validation of a low-back disorder risk model and assessment of ergonomic interventions associated with manual materials handling tasks. Ergonomics. 2000;43(11):1866–1886.
54. Carrivick PJW, Lee AH, Yau KKW. Effectiveness of a participatory workplace risk assessment team in reducing the risk and severity of musculoskeletal injury. J Occup Health. 2002;44(4):221–225.
55. Carrivick PJW, Lee AH, Yau KKW, Stevenson MR. Evaluating the effectiveness of a participatory ergonomics approach in reducing the risk and severity of injuries from manual handling. Ergonomics. 2005;48(8):907–914.
56. Cantley LF, Taiwo OA, Galusha D, Barbour R, Slade MD, Tessier-Sherman B, Cullen MR. Effect of systematic ergonomic hazard identification and control implementation on musculoskeletal disorder and injury risk. Scand J Work Environ Health. 2014;40(1):57–65.
57. Törnström L, Amprazis J, Christmansson M, Eklund J. A corporate workplace model for ergonomic assessments and improvements. Appl Ergon. 2008;39(2):219–228.
58. Jorgensen M, Davis K, Kotowski S, Aedla P, Dunning K. Characteristics of job rotation in the Midwest US manufacturing sector. Ergonomics. 2005;48(15):1721–1733.
59. Leider PC, Boschman JS, Frings-Dresen MHW, van der Molen HF. Effects of job rotation on musculoskeletal complaints and related work exposures: a systematic literature review. Ergonomics. 2015;58(1):18–32.
60. Kuijer PPFM, Van Der Beek AJ, Van Dieën JH, Visser B, Frings-Dresen MHW. Effect of job rotation on need for recovery, musculoskeletal complaints, and sick leave due to musculoskeletal complaints: A prospective study among refuse collectors. Am J Ind Med. 2005;47(5):394–402.
61. Frazer MB, Norman RW, Wells RP, Neumann WP. The effects of job rotation on the risk of reporting low back pain. Ergonomics. 2003;46(9):904–919.
62. Neumann WP, Kihlberg S, Medbo P, Mathiassen SE, Winkel J. A case study evaluating the ergonomic and productivity impacts of partial automation strategies in the electronics industry. Int J Prod Res. 2002;40(16):4059–4075.
63. Wulff IA, Westgaard RH, Rasmussen B. Ergonomic criteria in large-scale engineering design - II: Evaluating and applying requirements in the real world of design. Appl Ergon. 1999;30(3):207–221.
64. Wells RP, Neumann WP, Nagdee T, Theberge N. Solution Building Versus Problem Convincing: Ergonomists Report on Conducting Workplace Assessments. IIE Trans Occup Ergon Hum Factors. 2013;1(1):50–65.
65. Juul-Kristensen B, Fallentin N, Ekdahl C. Criteria for classification of posture in repetitive work by observation methods: A review. Int J Ind Ergon. 1997;19(5):397–411.
66. Li G, Buckle P. Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. Ergonomics. 1999;42(5):674–695.
67. Denis D, Lortie M, Rossignol M. Observation procedures characterizing occupational physical activities: critical review. Int J Occup Saf Ergon. 2000;6(4):463–491.
68. David GC. Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Occup Med. 2005;55(3):190–199.
69. Stanton N, Hedge A, Brookhuis K, Salas E, Hendrick H, editors. Handbook of human factors and ergonomics methods. Boca Raton (FL): CRC Press; 2005.
70. Marras WS, Karwowski W. Fundamentals and Assessment Tools for Occupational Ergonomic. Boca Raton (FL): CRC Press; 2006.
71. Tabanelli MC, Depolo M, Cooke RMT, Sarchielli G, Bonfiglioli R, Mattioli S, Violante FS. Available instruments for measurement of psychosocial factors in the work environment. Int Arch Occup Environ Health. 2008;82(1):1–12.
72. Winkel J, Mathiassen SE. Assessment of physical work load in epidemiologic studies: Concepts, issues and operational considerations. Ergonomics. 1994;37(6):979–988.
73. Burdorf A, Rossignol M, Fathallah FA, Snook SH, Herrick RF. Challenges in assessing risk factors in epidemiologic studies on back disorders. Am J Ind Med. 1997;32(2):142–152.
74. van der Beek AJ, Frings-Dresen MHW. Assessment of mechanical exposure in ergonomic epidemiology. Occup Environ Med. 1998;55(5):291–299.
75. Trask C, Mathiassen SE, Wahlström J, Forsman M. Cost-efficient assessment of biomechanical exposure in occupational groups, exemplified by posture observation and inclinometry. Scand J Work Environ Health. 2014;40(3):252–265.
76. Chaffin DB. Development of computerized human static strength simulation model for job design. Hum Factors Ergon Manuf. 1997;7(4):305–322.
77. Bao S, Silverstein B, Howard N, Spielholz P. The Washington State SHARP Approach to Exposure Assessment. In: Marras WS, Karwowski W, editors. Fundamentals and Assessment Tools for Occupational Ergonomics. Boca Raton (FL): CRC Press; 2006. p. 44.1–44.22.
78. Burdorf A. The role of assessment of biomechanical exposure at the workplace in the prevention of musculoskeletal disorders. Scand J Work Environ Health. 2010;36(1):1–2.

79. Burdorf A. Reducing random measurement error in assessing postural load on the back in epidemiologic surveys. Scand J Work Environ Health. 1995;21(1):15–23.
80. Andrews DM, Norman RW, Wells RP, Neumann P. The accuracy of self-report and trained observer methods for obtaining estimates of peak load information during industrial work. Int J Ind Ergon. 1997;19(6):445–455.
81. Wiktorin C, Karlqvist L, Winkel J. Validity of self-reported exposures to work postures and manual materials handling. Scand J Work Environ Health. 1993;19(3):208–214.
82. Viikari-Juntura E, Rauas S, Martikainen R, Kuosma E, Riihimäki H, Takala EP, Saarenmaa K. Validity of self-reported physical work load in epidemiologic studies on musculoskeletal disorders. Scand J Work Environ Health. 1996;22(4):251–259.
83. Stock SR, Fernandes R, Delisle A, Vézina N. Reproducibility and validity of workers' self-reports of physical work demands. Scand J Work Environ Health. 2005;31(6):409–437.
84. De Looze MP, Toussaint HM, Ensink J, Mangnus C, van der Beek AJ. The validity of visual observation to assess posture in a laboratory-simulated, manual material handling task. Ergonomics. 1994;37(8):1335–1343.
85. Takala EP, Pehkonen I, Forsman M, Hansson GA, Mathiassen SE, Neumann WP, Sjogaard G, Veiersted KB, Westgaard RH, Winkel J. Systematic evaluation of observational methods assessing biomechanical exposures at work. Scand J Work Environ Health. 2010;36(1):3–24.
86. Coenen P, Kingma I, Boot CRL, Bongers PM, Van Dieën JH. Inter-rater reliability of a video-analysis method measuring low-back load inafield situation. Appl Ergon. 2013;44(5):828–834.
87. Dempsey PG, McGorry RW, Maynard WS. A survey of tools and methods used by certified professional ergonomists. Appl Ergon. 2005;36(4):489–503.
88. Eliasson K. Occupational health services in the prevention of musculoskeletal disorders : Processes, tools and organizational aspects. [Licentiate thesis]. Stockholm (SE): KTH Royal Institute of Technology; 2017.
89. Eliasson K, Palm P, Nyman T, Forsman M. Inter - and intra - observer reliability of risk assessment of repetitive work without an explicit method. Appl Ergon. 2017;62:1–8.doi:10.1016/j.apergo.2017.02.004.
90. Kilbom Å, Horst D, Kemmlert K, A. R. Observationsmetoder för registering av belastningar på rörelseapparaten – en litteraturstudie [Observational methods to register load on the locomotor system – literature review]. Stockholm: Arbetarskyddsverket; 1986. Arbete och hälsa (21); p 1–90.
91. Kilbom A. Assessment of physical exposure in relation to work–related musculoskeletal disorders – what information can be obtained from systematic observations? Scand J Work Environ Health. 1994;20(Spec. Iss.):30–45.
92. Chiasson MT, Imbeau D, Aubry K, Delisle A. Comparing the results of eight methods used to evaluate risk factors associated with musculoskeletal disorders. Int J Ind Ergon. 2012;42(5):478–488.
93. Palm P, Eliasson K, Lindberg P, Hägg GM. Belastningsergonomisk riskbedömning - Vägledning och metoder. Uppsala (SE): Arbets- och miljömedicin, Akademiska sjukhuset, Upppsala Universitet. (Arbets- och miljömedicin publication; no.1/2014). Swedish.
94. Sukadarin EH, Deros BM, Ghani JA, Mohd Nawi NS, Ismail AR. Postural assessment in pen-and-paper-based observational methods and their associated health effects: a review. Int J Occup Saf Ergon. 2016;22(3):389–398.
95. Rohmert W. AET–a new job-analysis method. Ergonomics. 1985;28(1):245–254.
96. Armstrong TJ, Foulke JA, Joseph BS, Goldstein SA. Investigation of cumulative trauma disorders in a poultry processing plant. Am Ind Hyg Assoc J. 1982;43(2):103–116.
97. Armstrong TJ, Chaffin DB, Foulke JA. A methodology for documenting hand positions and forces during manual work. J Biomech. 1979;12(2):131–133.
98. Chang WS, Bejjani FJ, Chyan D, Bellegarde M. Occupational musculoskeletal disorders of visual artists a questionnaire and video analysis. Ergonomics. 1987;30(1):33–46.
99. Village J, Trask C, Luong N, Chow Y, Johnson P, Koehoorn M, Teschke K. Development and evaluation of an observational Back-Exposure Sampling Tool (Back-EST) for work-related back injury risk factors. Appl Ergon. 2009;40(3):538–544.
100. Baty D, Buckle PW, Stubbs DA. Posture recording by direct observation, questionnaire assessment and instrumentation: a comparison based on a recent field study. In: Corlett N, Wilson J, Manenica I, editors. The ergonomics of working postures: models, methods and cases. London (UK): Taylor & Francis; 1986. p. 283–292.
101. Feuerstein M, Fitzgerald TE. Biomechanical factors affecting upper extremity cumulative trauma disorders in sign language interpreters. J Occup Med. 1992;34(3):257–264.
102. Foreman TK, Davies JC, Troup JDG. A posture and activity classification system using a micro-computer. Int J Ind Ergon. 1988;2(4):285–289.
103. Keyserling WM. Postural analysis of the trunk and shoulders in simulated real time. Ergonomics. 1986;29(4):569–583.
104. Gil HJC, Tunes E. Posture recording: A model for sitting posture. Appl Ergon. 1989;20(1):53–57.
105. Latko WA, Armstrong TJ, Foulke JA, Herrin GD, Rabourn RA, Ulin SS. Development and evaluation of an observational method for assessing repetition in hand tasks. Am Ind Hyg Assoc J. 1997;58(4):278–285.

106. Christmansson M. The HAMA-method: A new method for analysis of upper limb movements and risk for work-related musculoskeletal disorders. In: McFadden S, Innes L, Hill M, editors.Proceedings of the 12th Triennial Congress of the International Ergonomics Association. Toronto (CA). IEA Press. 1994. p. 173–175.
107. Wiktorin C, Mortimer M, Ekenvall L, Kilbom A, Wigaeus Hjelm E. HARBO, a simple computer-aided observation method for recording work postures. Scand J Work Environ Health. 1995;21(6):440–449.
108. Harber P, Bloswick D, Peña L, Beck J, Lee J, Baker D. The ergonomic challenge of repetitive motion with varying ergonomic stresses: Characterizing supermarket checking work. J Occup Med. 1992;34(5):518–528.
109. Lowe BD, Weir PL, Andrews DM. Observation-based posture assessment: review of current practice and recommendations for improvement. Cincinnati (OH). U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH). 2014 (Publication No. 2014–131).
110. Malchaire JB, Rezk-Kallah B. Evaluation of the physical work load of bricklayers in the steel industry. Scand J Work Environ Health. 1991;17(2):110–116.
111. Buchholz B, Paquet V, Punnett L, Lee D, Moir S. PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Appl Ergon. 1996;27(30):177–187.
112. Fransson-Hall C, Gloria R, Kilbom Å, Winkel J, Karlqvist L, Wiktorin C. A portable ergonomic observation method (PEO) for computerized on-line recording of postures and manual handling. Appl Ergon. 1995;26(2):93–100.
113. Priel VZ. A Numerical Definition of Posture. Hum Factors. 1974;16(6):576–584.
114. Corlett EN, Madeley SJ, Manenica I. Posture targetting: A technique for recording working postures. Ergonomics. 1979;22(3):357–366.
115. McCormick EJ, Jeanneret PR, Mecham RC. The development and background of the position analysis questionnaire (PQA). Occupational Research Center, Purdue University. Lafayette (IN). 1969. (Report No. 5).
116. Ridd J, Nicholson AS, Montana AJ. A portable microcomputer based system for `on site' activity and posture recording. In: Megaw ED, editor. Contemporary Ergonomics 1989. London (UK). Taylor & Francis; 1989. p. 366–371.
117. Ryan GA. The prevalence of musculo–skeletal symptoms in supermarket workers. Ergonomics. 1989;32(4):359–371.
118. Saari J, Wickstrom G. Load on back in concrete reinforcement work. Scand J Work Environ Health. 1978;4(Suppl. 1):13–9.
119. Wickstrom G, Niskanen T, Riihimaki H. Strain on the back in concrete reinforcement work. Br J Ind Med. 1985;42(4):233–239.
120. van der Beek AJ, van Gaalen LC, Frings-Dresen MHW. Working postures and activities of lorry drivers: a reliability study of on-site observation and recording on a pocket computer. Appl Ergon. 1992;23(5):331–336.
121. Kilbom Å, Persson J, Jonsson B. Risk factors for work related disorders of the neck and shoulder–with special emphasis on working postures and movements. In: Corlett N, Wilson J, Manenica I, editors. The ergonomics of working postures: models, methods and cases. London (UK): Taylor & Francis; 1986. p. 44–53.
122. Yen TY, Radwin RG. A Video-Based System for Acquiring Biomechanical Data Synchronized with Arbitrary Events and Activities. IEEE Trans Biomed Eng. 1995;42(9):944-948.
123. Magnusson M, Örtengren R. Investigation of optimal table height and surface angle in meatcutting. Appl Ergon. 1987;18(2):146–152.
124. Chen JG, Peacock JB, Schlegel RE. An observational technique for physical work stress analysis. Int J Ind Ergon. 1989;3(3):167–176.
125. Winter G, Schaub K, Landau K. Stress screening procedure for the automotive industry: Development and application of screening procedures in assembly and quality control. Occup Ergon. 2006;6(2):107–120.
126. Arbouw Foundation. Guidelines on Physical Workload for the Construction Industry. Amsterdam (NL): Arbouw; 1997.
127. Holzmann P. ARBAN: A new method for analysis of ergonomic effort. Appl Ergon. 1982;13(2):82–86.
128. Armstrong TJ. The American Conference of Governmental Industrial Hygienists threshold limit value for hand activity level. In: Marras WS, Karwowski W, editors. Fundamentals and Assessment Tools for Occupational Ergonomics. Boca Raton (FL): CRC Press; 2006. p. 41.1–41.14.
129. Marras WS, Hamrick C. The ACGIH TLV for Low Back Risk. In: Marras WS, Karwowski W, editors. Fundamentals and Assessment Tools for Occupational Ergonomics. Boca Raton (FL): CRC Press; 2006. p. 50.1–50.15.
130. Ferreira J, Gray M, Hunter L, Birtles M, Riley D. Development of an assessment tool for repetitive tasks of the upper limbs (ART). Derbyshire (UK): Health and Safety Laboratory; 2009. (HSE publication; No. RR707).
131. Palm P, Josephson M, Mathiassen SE, Kjellberg K. Reliability and criterion validity of an observation protocol for working technique assessments in cash register work. Ergonomics. 2016;59(6):829–839.
132. Kjellberg K, Palm P, Josephson M. Development of an instrument for assessing workstyle in checkout cashier work (BAsIK). Work. 2012;41(Suppl. 1):663–668.
133. Chung MK, Lee I, Kee D. Quantitative postural load assessment for whole body manual tasks based on perceived discomfort. Ergonomics. 2005;48(5):492–505.

134. Seth V, Lee Weston R, Freivalds A. Development of a cumulative trauma disorder risk assessment model for the upper extremities. Int J Ind Ergon. 1999;23(4):281–291.

135. Damlund M, Gøth S, Hasle P, Munk K. Low back strain in Danish semi-skilled construction work. Appl Ergon. 1986;17(1):31–39.

136. DUTCH. TNO, the Netherlands Organisation for Applied Scientific Research (NL). 2017 [Cited 2017 April 15]. https://www.fysiekebelasting.tno.nl/en/page/dutch.

137. Douwes M, Könemann R, Krause F, Bosch T, Hoozemans M. A new risk assessment method for push and pull tasks for practitioners. In Rogers M, Moser C, editors. Proceedings of the 9th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders (PREMUS). Toronto (CA); Institute for Work & Health: 2016. p. 142.

138. Washington State Department of Labor & Industries. Caution Zone Checklist. Cited 2017 April 15. Available from: http://www.lni.wa.gov/safety/SprainsStrains/evaltools/CautionZones2.pdf.

139. Washington State Department of Labor & Industries. Hazard Zone Checklist. Cited 2017 April 15. Available from: http://www.lni.wa.gov/safety/SprainsStrains/evaltools/HazardZoneChecklist.PDF.

140. Johnsson C, Kjellberg K, Kjellberg A, Lagerström M. A direct observation instrument for assessment of nurses' patient transfer technique (DINO). Appl Ergon. 2004;35(6):591–601.

141. Sharan D. Ergonomic workplace analysis (EWA). Work. 2012;41(Suppl. 1):5366–5368.

142. Ahonen M, Launis M, Tuulikki K. Ergonomic workplace analysis. Helsinki (FI); Finnish Institute of Occupational Health. Institute of Occupational Health. 1989.

143. Rodríguez Y, Viña S, Montero R. ERIN: A practical tool for assessing work-related musculoskeletal disorders. Occup Ergon. 2013;11(2–3):59–73.

144. Jarebrant C, Öjmertz B. Ergonova. Arbetsbok. IVF. Mölndal (SE). IVF 050802. 2005.

145. Jarebrant C, Winkel J, Johansson Hanse J, Mathiassen SE, Öjmertz B. ErgoVSM: A Tool for Integrating Value Stream Mapping and Ergonomics in Manufacturing. Hum Factors Ergon Manuf. 2016;26(2):191–204.

146. Nunes IL. ERGO X – The Model of a Fuzzy Expert System for Workstation Ergonomic Analysis. In: Karwowski W, editor. International Encyclopedia of Ergonomics and Human Factors. Boca Raton (FL): CRC Press; 2004. p. 3114–3121.

147. Nunes IL. FAST ERGO-X - A tool for ergonomic auditing and work-related musculoskeletal disorders prevention. Work. 2009;34(2):133–148.

148. Van Lingen P, Van Rhijn G, De Looze M, Vink P, Koningsveld E, Tuinzaad G, Leskinen T. ERGOtool for the integral improvement of ergonomics and process flow in assembly. Int J Prod Res. 2002;40(15):3973–3980.

149. Schaub K, Caragnano G, Britzke B, Bruder R. The European Assembly Worksheet. Theor Issues Ergon Sci. 2013;14(6):616–639.

150. Keyserling WM, Stetson DS, Silverstein BA, Brouwer ML. A checklist for evaluating ergonomic risk factors associated with upper extremity cumulative trauma disorders. Ergonomics. 1993;36(7):807–831.

151. Keyserling WM, Brouwer M, Silverstein BA. A checklist for evaluating ergonomic risk factors resulting from awkward postures of the legs, trunk and neck. Int J Ind Ergon. 1992;9(4):283–301.

152. Douwes M, de Kraker H. Development of a non-expert risk assessment method for hand-arm related tasks (HARM). Int J Ind Ergon. 2014;44(2):316–327.

153. Ketola R, Toivonen R, Viikari-Juntura E. Interobserver repeatability and validity of an observation method to assess physical loads imposed on the upper extremities. Ergonomics. 2001;44(2):119–131.

154. Mattila MK. Job load and hazard analysis: A method for the analysis of workplace conditions for occupational health care. Br J Ind Med. 1985;42(10):656–666.

155. Pehkonen I, Ketola R, Ranta R, Takala EP. A video-based observation method to assess musculoskeletal load in kitchen work. Int J Occup Saf Ergon. 2009;15(1):75–88.

156. Steinberg U, Caffier G, Liebers F. Assessment of manual material handling based on key indicators – German guidelines. In: Karwowski W, editor. Handbook of standards in ergonomics and human factors. Boca Raton (FL): CRC Press; 2006. p. 317–335.

157. Swedish Work Environment Authority (SWEA). KIM 1. Bedöm risker vid manuell hantering – lyfta/bära [KIM 1. Assess risks in manual handling – lifting/carrying]. Stockholm (SE): SWEA; 2012. (SWEA publication; no. ADI 627). Swedish.

158. Swedish Work Environment Authority (SWEA). KIM 2. Bedöm risker vid manuell hantering – skjuta/dra [KIM 2. Assess risks in manual handling – pushing/pulling]. Stockholm (SE): SWEA; 2012. (SWEA publication; no. ADI 668). Swedish.

159. Klussmann A, Steinberg U, Liebers F, Gebhardt H, Rieger MA. 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. 2010;11(272):1–8. DOI:10.1186/471-2474-11-272.DOI:10.1186/471-2474-11-272.

160. Kee D, Karwowski W. LUBA: An assessment technique for postural loading on the upper body based on joint motion discomfort and maximum holding time. Appl Ergon. 2001;32(4):357–366.

161. Monnington SC, Pinder ADJ, Quarrie C. Development of an inspection tool for manual handling risk assessment. Sheffield (UK): Health & Safety Laboratory; 2002. (HSL publication; no. 2002/30).

162. Burgess-Limerick L, Straker L, Pollock C, Egeskov R, McGorry R. Manual Risk Assessment Tool (ManTRA) V2.0. School of Human Movement Studies, The University of Queensland (AU). 2004 [Cited 2017 April 15]. http://ergonomics.uq.edu.au/download/mantra2.pdf.

163. Battevi N, Menoni O, Ricci MG, Cairoli S. MAPO index for risk assessment of patient manual handling in hospital wards: A validation study. Ergonomics. 2006;49(7):671–687.
164. Health and Safety Executive (HSE). Manual Handling Manual Handling Operations Regulations 1992. Guidance on Regulations. Sudbury (UK): HSE Books; 2004.
165. Health and Safety Executive (UK). Risk assessment of pushing and pulling (RAPP) tool. HSE; 2016. (HSE publication; no. INDG478).
166. Okunribido O. Further work for the development of an inspection tool for risk assessment of pushing and pulling force exertion. Derbyshire (UK): HSE; 2013. (HSE publication; no. RR998).
167. Health and Safety Executive (HSE). Upper Limb Disorders in the Workplace HSG60. Guidance on Regulations. Sudbury (UK): HSE Books; 2002.
168. Ashby L, Tappin D, Bentley T. Evaluation in industry of a draft code of practice for manual handling. Appl Ergon. 2004;35(3):293–300.
169. Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics. 1993;36(7):749–776.
170. National Institute for Occupational Safety and Health (US). Work practices guide for manual lifting. Cincinnati (OH): NIOSH; 1981. (NIOSH publication; no. 81–122).
171. Occhipinti E. OCRA: a concise index for the assessment of exposure to repetitive movements of the upper limbs. Ergonomics. 1998;41(9):1290–1311.
172. Colombini D, Occhipinti E, Alvarez-Casado E. The revised OCRA checklist method. Barcelona (ES): Editorial Factors Humans; 2013.
173. Karhu O, Kansi P, Kuorinka I. Correcting working postures in industry: A practical method for analysis. Appl Ergon. 1977;8(4):199–201.
174. Kemmlert K. A method assigned for the identification of ergonomic hazards - PLIBEL. Appl Ergon. 1995;26(3):199–211.
175. David G, Woods V, Li G, Buckle P. The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. Appl Ergon. 2008;39(1):57–69.
176. Hignett S, McAtamney L. Rapid Entire Body Assessment (REBA). Appl Ergon. 2000;31(2):201–205.
177. Garg A, Moore JS, Kapellusch JM. The Revised Strain Index: an improved upper extremity exposure assessment model. Ergonomics. 2016:1–11. doi:10.1080/00140139.2016.1237678.
178. Sonne M, Villalta DL, Andrews DM. Development and evaluation of an office ergonomic risk checklist: ROSA - Rapid office strain assessment. Appl Ergon. 2012;43(1):98–108.
179. Villarroya A, Arezes P, Díaz-Freijo S, Fraga F. Comparison between five risk assessment methods of patient handling. Int J Ind Ergon. 2016;52:100–108.
180. Karhula K, Rönnholm T, Sjögren T. A method for evaluating the load of patient transfers. Occupational Safety and Health Administration. Occupational safety and health publications 83. 2009. ISBN 978-952-479-089-5. ISSN 1455-4011.
181. McAtamney L, Corlett EN. RULA: A survey method for the investigation of work-related upper limb disorders. Appl Ergon. 1993;24(2):91–99.
182. Stetson DS, Keyserling WM, Silverstein BA, Leonard JA. Observational analysis of the hand and wrist: A pilot study. Appl Occup Environ Hyg. 1991;6(11):927–937.
183. Moore JS, 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(5):443–458.
184. Swedish Work Environment Authority (SWEA). Belastningsergonomi [Physical Ergonomics]. Stockholm (SE): SWEA; 1998. (SWEA publication; no. AFS 1998:1). Swedish.
185. Roman-Liu D. Upper limb load as a function of repetitive task parameters: Part 1—a model of upper limb load. Int J Occup Saf Ergon. 2005;11(1):93–102.
186. Rahman MNA, Rani MRA, Rohani JM. WERA: an observational tool develop to investigate the physical risk factors associated with WMSDs. J Hum Ergol (Tokyo). 2011;4(1–2):19–36.
187. Kadefors R, Forsman M. Ergonomic evaluation of complex work: A participative approach employing video-computer interaction, exemplified in a study of order picking. Int J Ind Ergon. 2000;25:435-45.
188. Karling M, Brohammer G. Work environment screening tool: en metod som bedömer hela arbetsmiljön. Metodbeskrivning. Mölndal (SE): Institutet för verkstadsteknisk forskning (IVF); 2002. (IVF publication; 0349-0653).
189. Pinzke S. A computerised system for analysing working postures in agriculture. Int J Ind Ergon. 1994;13(4):307–315.
190. de Kraker H, Douwes M. New risk assessment tools in The Netherlands. Work. 2012;41(suppl. 1):3984–3989.
191. Swat K, Krzychowicz G. ERGONOM: Computer-aided working posture analysis system for workplace designers. Int J Ind Ergon. 1996;18(1):15–26.
192. Schaub K, Wakula J, Berg K, Kaiser B, Bruder R, Glitsch U, Ellegast RP. The assembly specific force atlas. Hum Factors Ergon Manuf. 2015;25(3):329–339.
193. Pascual SA, Naqvi S. An investigation of ergonomics analysis tools used in industry in the identification of work–related musculoskeletal disorders. Int J Occup Saf Ergon. 2008;14(2):237–245.
194. Arezes PM, Miguel AS, Colim AS. Manual materials handling: knowledge and practices among Portuguese health and safety practitioners. Work. 2011;39(4):385–395.
195. Winkel J. On the manual handling of wide-body carts used by cabin attendants in civil aircraft. Appl Ergon. 1983;14(3):162–168.

196. Jung MC, Haight JM, Freivalds A. Pushing and pulling carts and two-wheeled hand trucks. Int J Ind Ergon. 2005;35(1):79–89.
197. Jäger M, Sawatzki K, Glitsch U, Ellegast R, Ottersbach HJ, Schaub K, Franz G, Luttmann A. Load on the lumbar spine of flight attendants during pushing and pulling trolleys aboard aircraft. Int J Ind Ergon. 2007;37(11–12):863–876.
198. Bennett A, Desai S, Todd A, Freeland H. The effects of load and gradient on hand force responses during dynamic pushing and pulling tasks. Ergonomics SA: Journal of the Ergonomics Society of South Africa. 2008; 20(1):3–15.
199. Garg A, Waters T, Kapellusch J, Karwowski W. Psychophysical basis for maximum pushing and pulling forces: a review and recommendations. Int J Ind Ergon. 2014;44(2):281–291.
200. Al-Eisawi KW, Kerk CJ, Congleton JJ, Amendola AA, Jenkins OC, Gaines W. Factors affecting minimum push and pull forces of manual carts. Appl Ergon. 1999;30(3):235–245.
201. Jung MC, Haight JM, Hallbeck MS. Biomechanical and physiological analyses of a luggage-pulling task. Ind Health. 2007;45(6):756–765.
202. Swedish Work Environment Authority (SWEA). Vibrationer [Vibrations]. Stockholm (SE): SWEA; 2005. (SWEA publication; no. AFS 2005:5). Swedish.
203. Hamberg-van Reenen HH, van der Beek AJ, Blatter B, van der Grinten MP, van Mechelen W, Bongers PM. Does musculoskeletal discomfort at work predict future musculoskeletal pain? Ergonomics. 2008;51(5):637–648.
204. Werner RA, Franzblau A, Gell N, Ulin SS, Armstrong TJ. A longitudinal study of industrial and clerical workers: predictors of upper extremity tendonitis. J Occup Rehabil. 2005;15(1):37–46.
205. Werner RA, Franzblau A, Gell N, Ulin SS, Armstrong TJ. Predictors of upper extremity discomfort: a longitudinal study of industrial and clerical workers. J Occup Rehabil. 2005;15(1):27–35.
206. Mital A, Nicholson AS, Ayoub MM. A guide to manual materials handling. 2nd ed. London (UK): Taylor & Francis; 1997.
207. Chaffin DB. A computerized biomechanical model – Development of and use in studying gross body actions. J Biomech. 1969;2(4):429–441.
208. Chaffin DB, Baker WH. A Biomechanical Model for Analysis of Symmetric Sagittal Plane Lifting. AIIE Trans. 1970;2(1):16–27.
209. Garg A, Chaffin DB. A biomechanical computerized simulation of human strength. AIIE Transactions.1975;7(1):1–15.
210. Drury CG, Pfeil RE. A task-based model of manual lifting performance. Int J Prod Res. 1975;13(2):137–148.
211. Garg A, Chaffin DB, Herrin GD. Prediction of metabolic rates for manual materials handling jobs. Am Ind Hyg Assoc J. 1978;39(8):661–674.
212. Liles DH, Deivanayagam S, Ayoub MM, Mahajan P. A job severity index for the evaluation and control of lifting injury. Hum Factors. 1984;26(6):683–693.
213. Ayoub MM, Selan JL, Liles DH. An ergonomics approach for the design of manual materials-handling tasks. Hum Factors. 1983;25(5):507–515.
214. Taboun SM, Dutta SP. Prediction models for combined tasks in manual materials handling (CTMMH). In: Attwood DA, Mccann C, editors. Proceedings of the 1984 International Conference on Occupational Ergonomics; Toronto, ON; 1984. p. 551–555.
215. Mital A. Analysis of multiple activity manual materials handling tasks using A Guide to Manual Materials Handling. Ergonomics. 1999;42(1):246–257.
216. Ayoub MM, Mital A. Manual materials handling. London (UK): Taylor & Francis; 1989.
217. Shoaf C, Genaidy A, Karwowski W, Waters T, Christensen D. Comprehensive manual handling limits for lowering, pushing, pulling and carrying activities. Ergonomics. 1997;40(11):1183–1200.
218. Hidalgo J, Genaidy A, Karwowski W, Christensen D, Huston R, Stambough J. A comprehensive lifting model: beyond the NIOSH lifting equation. Ergonomics. 1997;40(9):916–927.
219. Dempsey PG, Ciriello VM, Maikala RV, O'Brien NV. Oxygen consumption prediction models for individual and combination materials handling tasks. Ergonomics. 2008;51(11):1776–89.
220. Genaidy A, Karwowski W, Ravelo E, Abdallah S, Shell R, Holley MB. Theoretical basis for general mixed object handling equations based on mechanical work required. Theor Issues Ergon Sci. 2006;7(5):469–490.
221. Abdallah S, Genaidy A, Karwowski W, Shell R, Sonbol A, Ravelo E, Holley MB. Theoretical basis for general lifting equations based on mechanical work performed during manual lifting. Theor Issues Ergon Sci. 2005;6(6):551–564.
222. Waters TR, Garg A. Two-dimensional biomechanical model for estimating strength of youth and adolescents for manual material handling tasks. Appl Ergon. 2010;41(1):1–7.
223. La Delfa NJ, Potvin JR. The ‘Arm Force Field’ method to predict manual arm strength based on only hand location and force direction. Appl Ergon. 2017;59:410–421.
224. Straker LM, Stevenson MG, Twomey LT. A comparison of risk assessment of single and combination manual handling tasks: 1. Maximum acceptable weight measures. Ergonomics. 1996;39(1):128–140.
225. Li KW, Yu Rf, Gao Y, Maikala RV, Tsai HH. Physiological and perceptual responses in male Chinese workers performing combined manual materials handling tasks. Int J Ind Ergon. 2009;39(2):422–427.:422-7.
226. Lortie M, Baril-Gingras G. Box Handling in the Loading and Unloading of Vans. Int J Occup Saf Ergon. 1998;4(1):3–18.

227. Straker LM. Combination Manual Handling Tasks In: Karwowski W, editor. International Encyclopedia of Ergonomics and Human Factors. 2nd ed. Boca Raton (FL): CRC Press; 2006.

228. Fallentin N, Viikari-Juntura E, Wærsted M, Kilbom Å. Evaluation of physical workload standards and guidelines from a Nordic perspective. Scand J Work Environ Health. 2001;27(Suppl. 2):1–52.

229. Eklund J, Lindbeck L, Riquelme P, Törnström L. Arbetsmiljöarbete med företagsbaserade modeller – effekter av belastningsergonomiska insatser. Arbetslivsrapport 2007:17, Stockholm (SE): Arbetslivsinstitutet. 2007.

230. Amprazis J. BME. Beräknings Modell Ergonomi Volvo Car Torslanda, utg. 03. 2005-01-10 (internal Volvo BME education material, in Swedish). 2005.

231. Moreau M. Corporate ergonomics programme at automobiles Peugeot-Sochaux. Appl Ergon. 2003;34(1):29–34.

232. Ratti N, Pilling K. Back pain in the workplace. Br J Rheumatol. 1997;36(2):260–264.:260-4.

233. Scania CV. SES - Scania ergonomistandard för produktion [SES - Scania Ergonomic Standard for Assembly]. Södertälje (SE); 2009. (publication; no. STD4324sv). Swedish.

234. Roche J-M. Ergonomics Memorandum. Principle recommendations. Renault Trucks. User guide. 2008.

235. Saab Automobile. SARA. Samlad Riskbedömning Arbetsplatser. SaabHälsan: Trollhättan (SE); 2007. (publication; version 4). Swedish.

236. Lundahl C. WERA - ny modell för riskbedömning vid Scania CV AB [master's thesis]. Luleå (SE): Luleå University of Technology; 2010. Swedish.

237. Buckle P, Li G. User needs in exposure assessment for musculoskeletal risk assessment. In Straker L, Pollock C, editors. Proceedings of CybErg 1996: The First International Cyberspace Conference on Ergonomics. Perth (AU): IEA Press;1996.

238. Diego-Mas JA, Poveda-Bautista R, Garzon-Leal DC. Influences on the use of observational methods by practitioners when identifying risk factors in physical work. Ergonomics. 2015;58(10):1660–1670.

239. Dempsey PG, Burdorf A, Fathallah FA, Sorock GS, Hashemi L. Influence of measurement accuracy on the application of the 1991 NIOSH equation. Appl Ergon. 2001;32(1):91–99.

240. Snook SH, Ciriello VM. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. Ergonomics. 1991;34(9):1197–1213.

241. Nordlander C. Metoder för att bedöma belastningsergonomiska risker – en inventering av de idag vanligast förekommande metoderna inom företagshälsovården. Arbetslivsinstitutet. Stockholm (SE). 2006; as reported by Andersson I-M, Laring J, Åteg M & Rosén G.Arbetsmiljöfrågans väg. Samverkan mellan kundföretag och företagshälsovård. Arbete och Hälsa 2006:20, Arbetslivsinstitutet, Stockholm (SE). 2006.

242. Sturesson S. Metoder och effekter i tillämpat arbetsmiljöarbete [master's thesis]. Linköping (SE): Linköping University; 2006. Swedish.

243. Laring J, Neumann P, Nagdee T, Wells R, Theberge N. Human factors tool use among Swedish ergonomists - an interview study. Proceedings of the 38th Annual Conference of the Association of Canadian Ergonomists (ACE). Toronto (CA). 2007.

244. Rose L, Lind C, Franzon H, Nord-Nilsson L, Clausén A. Development, implementation and dissemination of RAMP: Risk management Assessment tool for Manual handling Proactively. In: Lindfors J, Savolainen M, Väyrynen S. Proceedings of the Nordic Ergonomics Society 43rd Annual Conference. Oulu (FI): 2011. p. 255–260. ISBN 978-951-42-9541-6.

245. Rose L, Franzon H, Nord-Nilsson L. Utveckling, implementering och spridning av belastningsergonomiskt bedömningsverktyg och åtgärdsprocess. Projektbeskrivning av projektet i bilaga till afa - ansökan i programmet 'Från ord till handling'. KTH STH. September 30, 2009.

246. Wilson JR. Fundamentals of ergonomics in theory and practice. Appl Ergon. 2000;31(6):557–567.

247. International Ergonomics Association. Definition and Domains of Ergonomics. http://www.iea.cc/whats/ (cited Feb 28 2017). .

248. European Committee for Standardization (CEN). Ergonomics – General approach, principles and concepts. Brussels: CEN; 2011. Standard No. EN ISO Brussels: CEN; 2011. Standard No. 26800;2011.

249. Magora A. Investigation of the relation between low back pain and occupation. 3. Physical requirements: sitting, standing and weight lifting. IMS Ind Med Surg. 1972;41(12):5–9.

250. Kilbom Å. Short- and long-term effects of extreme physical inactivity: a brief review. In: Knave B, Wideback PG, editors. Work with display units. Amsterdam (NL): North-Holland; 1987. p. 219–228.

251. Winkel J. Varför ökar belastningsskadorna? Nordisk Medicin. 1989;104(12):324–327.

252. Winkel J, Westgaard R. Occupational and individual risk factors for shoulder-neck complaints: Part II - The scientific basis (literature review) for the guide. Int J Ind Ergon. 1992;10(1–2):85–104.

253. Marras WS. Occupational low back disorder causation and control. Ergonomics. 2000;43(7):880–902.

254. Marras WS. The working back: A systems view. Hoboken (NJ): Wiley-Interscience; 2008.

255. Heneweer H, Vanhees L, Picavet HSJ. Physical activity and low back pain: A U-shaped relation? Pain. 2009;143(1–2):21–25.

256. Heuch I, Hagen K, Zwart JA. Is there a U-shaped relationship between physical activity in leisure time and risk of chronic low back pain? A follow-up in the HUNT Study. BMC Public Health. 2016;16(1).

257. Winkel J, Westgaard R. Belastningsergonomiska förändringsstrategier. In: Holmström E, Ohlsson K, editors. Människan i arbetslivet: Teori och praktik. Lund (SE): Studentlitteratur; 2014. p. 137–162.

258. Silverstein B. Work-Related Musculoskeletal Disorders (WMSD): General Issues. In: Karwowski W, Marras WS, editors. International Encyclopedia of Ergonomics and Human Factors, 2nd ed. Boca Raton (FL): CRC Press; 2003. Ch 548.

259. Kuorinka I, Forcier L, editors. Work related musculoskeletal disorders (WMSDs): a reference book for prevention. London (UK): Taylor & Francis; 1995.

260. Miranda H, Viikari-Juntura E, Heistaro S, Heliövaara M, Riihimäki H. A population study on differences in the determinants of a specific shoulder disorder versus nonspecific shoulder pain without clinical findings. Am J Epidemiol. 2005;161(9):847–855.

261. Ferguson SA, Marras WS. A literature review of low back disorder surveillance measures and risk factors. Clin Biomech (Bristol, Avon). 1997;12(4):211–226.

262. Lötters F, Burdof A. Are changes in mechanical exposure and musculoskeletal health good performance indicators for primary interventions? Int Arch Occup Environ Health. 2002;75(8):549–561.

263. Straker LM. Body Discomfort Assessment Tools. In: Karwowski W, Marras WS, editors. Occupational Ergonomics: Engineering and Administrative Controls. Boca Raton (FL): CRC Press; 2003. p. 26.1–26.14.

264. Chaffin DB, Park KS. A longitudinal study of low back pain as associated with occupational weight lifting factors. Am Ind Hyg Assoc J. 1973;34(12):513–525.

265. Herrin GD, Jaraiedi M, Anderson CK. Prediction of overexertion injuries using biomechanical and psychophysical models. Am Ind Hyg Assoc J. 1986;47(6):322–330.

266. Chaffin DB, Herrin GD, Keyserling WM. Preemployment strength testing. An updated position. J Occup Med. 1978;20(6):403–408.

267. Boda S, Garg A, Campbell-Kyureghyan N. Can the Revised NIOSH Lifting Equation predict low back pain incidence in a '90-day-pain-free-cohort'? Proceedings of the Human Factors Society Annual Meeting. 2012;56(1):1178–1182.

268. Lu ML, Waters TR, Krieg E, Werren D. Efficacy of the revised NIOSH lifting equation to predict risk of low-back pain associated with manual lifting: a one-year prospective study. Hum Factors. 2014;56(1):73–85.

269. Lu ML, Putz-Anderson V, Garg A, Davis KG. Evaluation of the Impact of the Revised National Institute for Occupational Safety and Health Lifting Equation. Human Factors. 2016;58(5):667–682.

270. Eklund JAE. Relationships between ergonomics and quality in assembly work. Appl Ergon. 1995;26(1):15 –20.

271. Falck AC, Örtengren R, Högberg D. The impact of poor assembly ergonomics on product quality: A cost-benefit analysis in car manufacturing. Hum Factors Ergon Manuf. 2010;20(1):24 –41.

272. Erdinç O, Yeow PHP. Proving external validity of ergonomics and quality relationship through review of real-world case studies. Int J Prod Res. 2011;49(4):949–962.

273. Eklund J, Yeow P. Integrating Ergonomics and Quality Concepts. In: Wilson JR, Sharples S, editors. Evaluation of Human Work. 4th ed. Boca Raton (FL). CRC Press. 2015. p. 931–956. .

274. Ivarsson A, Eek F. The relationship between physical workload and quality within line-based assembly. Ergonomics. 2016;59(7):913–923.

275. Steele T, Merryweather A, Bloswick D. Manual material handling guidelines for the shoulder: Biomechanical support for the Liberty Mutual Tablesas developed by Snook and Ciriello. Int J Ind Ergon. 2014;44(2):275–280.

276. Fischer SL, Dickerson CR. Applying psychophysics to prevent overexposure: on the relationships between acceptable manual force, joint loading, and perception. Int J Ind Ergon. 2014;44(2):266–274.

277. Leamon TB. Research to reality: A critical review of the validity of various criteria for the prevention of occupationally induced low back pain disability. Ergonomics. 1994;37(12):1959–1974.

278. Leamon TB. L5/S1: So who is counting? Int J Ind Ergon. 1994;13(3):259–265.

279. Jäger M, Luttmann A. Critical survey on the biomechanical criterion in the NIOSH method for the design and evaluation of manual lifting tasks. Int J Ind Ergon. 1999;23(4):331–337.

280. Jäger M, Luttmann A. Belastbarkeit der Lendenwirbelsäule bei manueller Lastenhandhabung – Ableitung der „Dortmunder Richtwerte" auf Basis der lumbalen Kompressionsfestigkeit. Zbl. Arbeitsmed. 2001;51:354–372.

281. McGill SM, Norman RW, Yingling VR, Wells RW, Neumann P. Shear Happens! Suggested Guidelines for Ergonomists to Reduce the Risk of Low Back Injury from Shear Loading. Proceedings of the 30th Annual Conference of the Human Factors Association of Canada (HFAC), Mississauga (CA); HFAC: 1998. p. 157–161.

282. Gallagher S, Marras WS. Tolerance of the lumbar spine to shear: A review and recommended exposure limits. Clin Biomech. 2012;27(10):973–978.

283. Dempsey PG, Ayoub MM, Westfall PH. Evaluation of the ability of power to predict low frequency lifting capacity. Ergonomics. 1998;41(8):1222–1241.

284. Mital A, Kumar S. Human muscle strength definitions, measurement, and usage: Part I - Guidelines for the practitioner. Int J Ind Ergon. 1998;22(1–2):101–121.

285. Mital A, Kumar S. Human muscle strength definitions, measurement, and usage: Part II - The scientific basis (knowledge base) for the guide. Int J Ind Ergon. 1998;22(1–2):123–144.

286. Jørgensen K. Permissible loads based on energy expenditure measurements. Ergonomics. 1985;28(1):365–369.

287. Garg A, Rodgers SH, Yates JW. The physiological basis for manual lifting. In: Kumar S, editor. Advances in industrial ergonomics and safety IV. London (UK): Taylor & Francis; 1992. p. 867–874.

288. Søgaard K, Sjøgaard G. Physiological Bases of Work Assessment. In: Wilson JR, Sharples S, editors. Evaluation of Human Work. 4th ed. Boca Raton (FL). CRC Press. 2015. p. 419–445. .

289. Aminoff T, Smolander J, Korhonen O, Louhevaara V. Physiological strain during kitchen work in relation to maximal and task-specific peak values. Ergonomics. 1999;42(4):584–592.
290. Louhevaara V, Kilbom Å. Dynamic work assessment. In: Wilson JR, Corlett N, editors. Evaluation of Human Work. 3rd ed. Boca Raton (FL). CRC Press. 2005. p. 429–451. .
291. Genaidy AM, Asfour SS, Khalil TM, Wal SM. Physiological Issues in Manual Materials Handling. In Eberts R, Eberts CG, editors. Trends in Ergonomics/Human Factors II. Amsterdam (NL): Elsevier Science Publishers; 1985. p. 571–576.
292. Asfour SS, Genaidy AM, Mital A. Physiological guidelines for the design of manual lifting and lowering tasks: The state of the art. Am Ind Hyg Assoc J. 1988;49(4):150–160.
293. Holtermann A, Marott JL, Gyntelberg F, Søgaard K, Mortensen OS, Prescott E, Schnohr P. Self-reported occupational physical activity and cardiorespiratory fitness: Importance for cardiovascular disease and all-cause mortality. Scand J Work Environ Health. 2016;42(4):291–298.
294. Stevens SS. Psychophysics: Introduction to its perceptual, neural, and social prospects. Stevens G, editor. New Yok (US): Wiley; 1975.
295. Ayoub MM, Dempsey PG. The psychophysical approach to manual materials handling task design. Ergonomics. 1999(1);42:17–31.
296. Fernandez JE, Marley RJ. The development and application of psychophysical methods in upper-extremity work tasks and task elements. Int J Ind Ergon. 2014;44(2):200–2006.
297. Emanuel I, Chaffee JW, Wing J. A study of human weight lifting capabilities for loading ammunition into the F-86H aircraft.Wright Air Development Center. Ohio: WADC; 1956. (WADC Technical Report 56-367).
298. Switzer SA. Weight-lifting capabilities of a selected sample of human subjects. Aerospace Medical Research Laboratories. Ohio; 1962. (Technical Report No. MRL-TDR-62-57).
299. Snook SH, Irvine CH. The evaluation of physical tasks in industry. Am Ind Hyg Assoc J. 1966;27(3):228–233.
300. Snook SH, Irvine CH, Bass SF. Maximum weights and work loads acceptable to male industrial workers. A study of lifting, lowering, pushing, pulling, carrying, and walking tasks. Am Ind Hyg Assoc J. 1970;31(5):579–586.
301. Snook SH, Ciriello VM. Maximum weights and work loads acceptable to female workers. J Occup Med. 1974;16(8):527–534.
302. Ciriello VM, Snook SH. A study of size, distance, height, and frequency effects on manual handling tasks. Hum Factors. 1983;25(5):473–483.
303. Ciriello VM. The effects of box size, vertical distance, and height on lowering tasks. Int J Ind Ergon. 2001;28(2):61–67.
304. Ciriello VM. The effects of box size, vertical distance, and height on lowering tasks for female industrial workers. Int J Ind Ergon. 2005;35(9):857–863.
305. Ciriello VM, Dempsey PG, Maikala RV, O'Brien NV. Secular changes in psychophysically determined maximum acceptable weights and forces over 20 years for male industrial workers. Ergonomics. 2008;51(5):593–601.
306. Ciriello VM, Maikala RV, Dempsey PG, O'Brien NV. Gender differences in psychophysically determined maximum acceptable weights and forces for industrial workers observed after twenty years. Int Arch Occup Environ Health. 2011;84(5):569–575.
307. Legg SJ, Myles WS. Maximum acceptable repetitive lifting workloads for an 8-hour work-day using psychophysical and subjective rating methods. Ergonomics. 1981;24(12):907–916.
308. Mital A. Psychophysical capacity of industrial workers for lifting symmetrical and asymmetrical loads symmetrically and asymmetrically for 8 h work shifts. Ergonomics. 1992;35(7–8):745–754.
309. Mital A. Comprehensive maximum acceptable weight of lift database for regular 8-hour work shifts. Ergonomics. 1984;27(11):1127–1138.
310. Garg A, Badger D. Maximum acceptable weights and maximum voluntary isometric strengths for asymmetric lifting. Ergonomics. 1986;29(7):879–892.
311. Nicholson LM, Legg SJ. A psychophysical study of the effects of load and frequency upon selection of workload in repetitive lifting. Ergonomics. 1986;29(7):903–911.
312. Garg A, Banaag J. Maximum acceptable weights, heart rates and RPEs for one hour’s repetitive asymmetric lifting. Ergonomics. 1988;31(1):77–96.
313. Wu SP. Maximum acceptable weights for asymmetric lifting of Chinese females. Appl Ergon. 2003;34(3):215–224.
314. Lee TH. Psychophysically determined asymmetrical lifting capabilities for different frequencies and containers. Ind Health. 2005;43(2):337–340.
315. Founooni-Fard H, Mital A. A psychophysiological study of high and very high frequency manual materials handling: Part I - Lifting and lowering. Int J Ind Ergon. 1993;12(1–2):127–141.
316. Ciriello VM, Dempsey PG, Maikala RV, O'Brien NV. Revisited: comparison of two techniques to establish maximum acceptable forces of dynamic pushing for male industrial workers. Int J Ind Ergon. 2007;37(11–12):877–882.
317. Maikala R, Dempsey PG, Ciriello VM, O'Brien NV. Dynamic pushing on three frictional surfaces: maximum acceptable forces, cardiopulmonary and calf muscle metabolic responses in healthy men. Ergonomics. 2009;52(6):735–746.

318. Ciriello VM, Maikala RV, Dempsey PG, O'Brien NV. Psychophysically determined forces of dynamic pushing for female industrial workers: comparison of two apparatuses. Appl Ergon. 2010;41(1):141–145.

319. Founooni-Fard H, Mital A. A psychophysiological study of high and very high frequency manual materials handling: Part II - Carrying and turning. Int J Ind Ergon. 1993;12(1–2):143–152.

320. Wu SP, Chen CC. Psychophysical determination of load carrying capacity for a 1-h work period by Chinese males. Ergonomics. 2001;44(11):1008–1023.

321. Andrews DM, Potvin JR, Christina Calder I, Cort JA, Agnew M, Stephens A. Acceptable peak forces and impulses during manual hose insertions in the automobile industry. Int J Ind Ergon. 2008;38(2):193–201.

322. La Delfa NJ, Potvin JR. Multidirectional manual arm strength and its relationship with resultant shoulder moment and arm posture. Ergonomics. 2016;59(12):1625–1636.

323. Snook SH, Vaillancourt DR, Ciriello VM, Webster BS. Psychophysical studies of repetitive wrist flexion and extension. Ergonomics. 1995;38(7):1488–1507.

324. Snook SH, Vaillancourt DR, Ciriello VM, Webster BS. Maximum acceptable forces for repetitive ulnar deviation of the wrist. Am Ind Hyg Assoc J. 1997;58(7):509–517.

325. Snook SH, Ciriello VM, Webster BS. Maximum acceptable forces for repetitive wrist extension with a pinch grip. Int J Ind Ergon. 1999;24(6):579–590.

326. Marley RJ, Thomson MR. Isokinetic strength characteristics in wrist flexion and extension. Int J Ind Ergon. 2000;25(6):633-643.

327. Ciriello VM, Webster BS, Dempsey PG. Maximal acceptable torques of highly repetitive screw driving, ulnar deviation, and handgrip tasks for 7-hour workdays. Am Ind Hyg Assoc J. 2002;63(5):594–604.

328. Ciriello VM, Maikala RV, O'Brien NV. Maximal acceptable torques of six highly repetitive hand-wrist motions for male industrial workers. Hum Factors. 2013;55(2):309–322.

329. Sonne MW, Potvin JR. A psychophysical study to determine maximum acceptable efforts for a thumb abduction task with high duty cycles. Ergonomics. 2015;58(1):118–127.

330. Cort JA, Potvin JR. Maximum isometric finger pull forces. Int J Ind Ergon. 2011;41(2):91–95.

331. Karwowski W, Lee WG, Jamaldin B, Gaddie P, Jakg RL, Alqesaimi KK. Beyond psychophysics: The need for a cognitive engineering approach to setting limits in manual lifting tasks. Ergonomics. 1999;42(1):40–60.

332. Snook SH, Ciriello VM. The effects of heat stress on manual handling tasks. Am Ind Hyg Assoc J. 1974;35(11):681–685.

333. Gamberale F. Perceived exertion, heart rate, oxygen uptake and blood lactate in different work operations. Ergonomics. 1972;15(5):545–554.

334. Karwowski W. A pilot study on the interaction between physiological, biomechanical, and the psychophysical stresses involved in manual lifting tasks. In Coombe K, editor. Proceedings of the Ergonomics Society's Annual Conference. London (UK): Taylor & Francis; 1983. p. 95–100.

335. Fischer SL, Brenneman EC, Wells RP, Dickerson CR. Relationships between psychophysically acceptable and maximum voluntary hand force capacity in the context of underlying biomechanical limitations. Appl Ergon. 2012;43(5):813–820.

336. Kumar S, Mital A. Margin of safety for the human back: A probable consensus based on published studies. Ergonomics. 1992;35(7–8):769–781.

337. Asfour SS, Genaidy AM, Khalil TM, Greco EC. A combined approach for determination of lifting capacity. In: Eberts RE, Eberts CG, editors. Trends in Ergonomics/Human Factors II. Amsterdam (NL): Elsevier;1985. p. 617–623.

338. Ayoub MM, Woldstad JC. Models in Manual Materials Handling. In: Kumar S, editor. Biomechanics in Ergonomics. London (UK): Taylor & Francis; 1999. p. 267–305.

339. Potvin JR. Comparing the revised NIOSH lifting equation to the psychophysical, biomechanical and physiological criteria used in its development. Int J Ind Ergon. 2014;44(2):246–252.

340. Davis KG, Jorgensen MJ, Marras WS. An investigation of perceived exertion via whole body exertion and direct muscle force indicators during the determination of the maximum acceptable weight of lift. Ergonomics. 2000;43(2):143–159.

341. Le P, Dufour J, Monat H, Rose J, Huber Z, Alder E, Radin Umar RZ, Hennessey B, Dutt M, Marras WS. Association between spinal loads and the psychophysical determination of maximum acceptable force during pushing tasks. Ergonomics. 2012;55(9):1104–1114.

342. Thompson DD, Chaffin DB. Can biomechanically determined stress be perceived? Proceedings of the Human Factors and Ergonomics Society. 1993;37(10):489–492.

343. Chaffin DB, Page GB. Postural effects on biomechanical and psychophysical weight-lifting limits. Ergonomics. 1994;37(4):663–676.

344. Granata KP, Marras WS. Relation between spinal load factors and the high-risk probability of occupational low-back disorder. Ergonomics. 1999;42(9):1187–1199.

345. Kuijer PPFM, van Oostrom SH, Duijzer K, van Dieën JH. Maximum acceptable weight of lift reflects peak lumbosacral extension moments in a functional capacity evaluation test using free style, stoop and squat lifting. Ergonomics. 2012;55(3):343–349.

346. Kuijer PPFM, Hoozemans MJM, Frings–Dresen MHW. A different approach for the ergonomic evaluation of pushing and pulling in practice. Int J Ind Ergon. 2007;37(11–12):855–862.

347. Garg A. An evaluation of the NIOSH guidelines for manual lifting, with special reference to horizontal distance. Am Ind Hyg Assoc J. 1989;50(3):157–164.

348. Snook SH. The ergonomics society. The society's lecture 1978. The design of manual handling tasks. Ergonomics. 1978;21(12):963–985.

349. Ferreira J, Smith M. Evaluating the feasibility of developing assessment charts for high risk pushing and pulling operations. Derbyshire (UK): HSE; 2007. (HSE publication; no. RR562).

350. Tool [Def. 1a, 2a]. Merriam-Webster Online. In Merriam-Webster. Retrieved February 25, 2017, from https://www.merriam-webster.com/dictionary/tool.

351. Method [Def. 1, 1a(1)]. Merriam-Webster Online. In Merriam-Webster. Retrieved February 25, 2017, from https://www.merriam-webster.com/dictionary/method.

352. Technique [Def. 2a, 2b]. Merriam-Webster Online. In Merriam-Webster. Retrieved February 25, 2017, from https://www.merriam-webster.com/dictionary/technique.

353. Åteg M, Andersson I-M, Rosén G. Moveit. Motivations- och engagemangsskapande metoder i arbetsmiljöarbetet. Arbetslivsinstitutet (SE); 2006. Arbete och Hälsa 2005:8.

354. Hansson SO. Dimensions of Risk. Risk Anal. 1989;9(1):107–112.

355. European Committee for Standardization (CEN). Safety of machinery - General principles for design - Risk assessment and risk reduction. Brussels: CEN; 2010. Standard No. EN ISO 12100:2010.

356. International Organization for Standardization. Ergonomic requirements for office work with visual display terminals (VDTs) — Part 11: Guidance on usability. Geneva: ISO; 1998. Standard No. ISO 9241-11:1998(E).

357. International Organization for Standardization. Ergonomics of human-system interaction – part 210: Human-centred design for interactive systems. Geneva: ISO; 2010. Standard No. ISO 9241-210:2010.

358. Jordan PW. Designing Pleasurable Products: An Introduction to the New Human Factors. London (UK): Taylor & Francis; 2000. ISBN 0-203-34210-0.

359. Jordan PW. Pleasure with Products: Human Factors for Body, Mind and Soul. In Green WS, Jordan PW, editors. Human Factors in Product Design: Current Practice and Future Trends. London (UK): Taylor & Francis; 1999. p. 206–217.

360. Maslow AH. A theory of human motivation. Psychol Rev. 1943;50(4):370–396.

361. Hancock PA, Pepe AA, Murphy LL. Hedonomics: The Power of Positive and Pleasurable Ergonomics. Ergon Des. 2005;13(1):8–14.

362. International Organization for Standardization, International Electrotechnical Commission. Systems and software engineering – Systems and software Quality Requirements and Evaluation (SQuaRE) – System and software quality models. Geneva: ISO/IEC; 2011. Standard No. ISO/IEC 25010:2011(E).

363. Högberg D. Ergonomics integration and user diversity in product design [dissertation]. Skövde (SE): University of Skövde & Loughborough University; 2005.

364. Shackel B. Usability - Context, framework, definition, design and evaluation. Interact Comput. 2009;21(5–6):339–346.

365. Nielsen J. Usability Engineering. London (UK): Academic Press; 1993. ISBN 0-12-518406-9.

366. Blessing LTM, Chakrabarti A. DRM, a Design Research Methodology. London (UK): Springer; 2009. ISBN 978-1-84882-586-4.

367. Mattes J, Ternblad M. Riskbedömningsmetoder för fysisk belastning – vilka används och varför? [master's thesis]. Stockholm (SE): KTH Royal Institute of Technology; 2012. Swedish.

368. Eklund J, Liew M, Odenrick P. Kompendium i Antropometri, Lyftrekommendationer, Biomekanik och Arbetsobservation. Stockholm (S); KTH Royal Institute of Technology Unit of Ergonomics; 2015 [updated 2013 Oct 11; cited 2017 Feb 27]. Available from: https://www.kth.se/sth/forskning/halso-och-systemvetenskap/ergonomi/framtagna-verktyg/alba/manualer-1.54610

369. Bongers PM, De Winter CR, Kompier MAJ, Hildebrandt VH. Psychosocial factors at work and musculoskeletal disease. Scand J Work Environ Health. 1993;19(5):297–312.

370. Bongers PM, Kremer AM, Laak JT. Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist?: A review of the epidemiological literature. Am J Ind Med. 2002;41(5):315–342.

371. Bos J, Kuijer PPFM, Frings-Dresen MHW. Definition and assessment of specific occupational demands concerning lifting, pushing, and pulling based on a systematic literature search. Occup Environ Med. 2002;59(12):800–806.

372. Colombini D, Kilbom A, Delleman N, bbb. Exposure assessment of upper limb repetitive movements: a consensus document. In: Karwowski W, editor. International Encyclopedia of Ergonomics and Human Factors. 2nd ed. Boca Raton (FL): CRC Press; 2006.

373. Delleman NJ, CM H, DM C. Working postures and movements: tools for evaluation and engineering. Boca Raton (FL): CRC Press; 2004.

374. Chaffin DB, Andersson GBJ, Martin BJ. Occupational biomechanics. 4th ed. New York (NY): Wiley; 2006.

375. Perez J, Neumann WP. Ergonomists' and engineers' views on the utility of virtual human factors tools. Human Factors and Ergonomics In Manufacturing. 2015;25(3):279–293.

376. Portney LG, Watkins MP. Foundations of Clinical Research: Applications to Practice. 3rd ed. Upper Saddle River (NJ): Pearson Education; 2009.

377. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–174.

378. International Organization for Standardization. Ergonomics of human-system interaction — Usability methods supporting human-centred design. Geneva: ISO; 2002. Technical report No. ISO/TR 16982:2002(E).

379. Svensk författningssamling. Lag (2003:460) om etikprövning av forskning som avser människor.
380. Svensk författningssamling. Lag om ändring i lagen (2003:460) om etikprövning av forskning som avser människor. 2008.
381. Svensk författningssamling. Personuppgiftslag (1998:204). .
382. Vetenskapsrådet. Forskningsetiska principer inom humanistisk-samhällsvetenskaplig forskning. Vetenskapsrådet. Stockholm (SE). 2002. ISBN:91-7307-008-4.
383. Knapik GG, Marras WS. Spine loading at different lumbar levels during pushing and pulling. Ergonomics. 2009;52(1):60–70.
384. Ariëns GAM, Bongers PM, Hoogendoorn WE, van der Wal G, van Mechelen W. High physical and psychological load at work and sickness absence due to neck pain. Scand J Work Environ Health. 2002;28(4):222–231.
385. Kroemer K, Grandjean E. Fitting the task to the human. 5th ed. London (UK): Taylor & Francis; 1997.
386. Delleman NJ. Head and Neck. In: Delleman NJ, Haslegrave CM, Chaffin DM, editors. Working postures and movements: tools for evaluation and engineering. Boca Raton (FL): CRC Press; 2004. p. 85–107.
387. Harms-Ringdahl K, Ekholm J. Intensity and character of pain and muscular activity levels elicited by maintained extreme flexion position of the lower–cervical–upper-thoracic spine. Scand J Rehabil Med. 1986;18(3):117–126.
388. Chaffin DB. Localized muscle fatigue – definiton and measurement. J Occup Med. 1973;15(4):346–354.
389. Hunting W, Laubli T, Grandjean E. Postural and visual loads at VDT workplaces. I. Constrained postures. Ergonomics. 1981;24(12):917–931.
390. Dartigues JF, Henry P, Puymirat E, Commenges D, Peytour P, Gagnon M. Prevalence and risk factors of recurrent cervical pain syndrome in a working population. Neuroepidemiology. 1988;7(2):99–105.
391. Miranda H, Viikari-Juntura E, Martikainen R, Takala EP, Riihimäki H. A prospective study of work related factors and physical exercise as predictors of shoulder pain. Occup Environ Med. 2001;58(8):528–534.
392. Heuvel SG, Beek AJ, Blatter BM, Bongers PM. Do work–related physical factors predict neck and upper limb symptoms in office workers? Int Arch Occup Environ Health. 2006;79(7):585–592.
393. Wikström BO. Effects from twisted postures and whole-body vibration during driving. Int J Ind Ergon. 1993;12(1–2):61–75.
394. Snijders CJ, Hoek van Dijke GA, Roosch ER. A biomechanical model for the analysis of the cervical spine in static postures. J Biomech. 1991;24(9):783–792.
395. Bernhardt P, Wilke HJ, Wenger KH, Jungkunz B, Böhm A, Claes LE. Multiple muscle force simulation in axial rotation of the cervical spine. Clin Biomech (Bristol, Avon). 1999;14(1):32–40.
396. Genaidy AM, Karwowski W. The effects of neutral posture deviations on perceived joint discomfort ratings in sitting and standing postures. Ergonomics. 1993;36(7):785–792.
397. Sakakibara H, Miyao M, Kondo TA, Yamada S. Overhead work and shoulder-neck pain in orchard farmers harvesting pears and apples. Ergonomics. 1995;38(4):700–706.
398. Sakakibara H, Miyao M, Kondo T, Yamada S, Nakagawa T, Kobayashi F. Relation between overhead work and complaints of pear and apple orchard workers. Ergonomics. 1987;30(5):805–815.
399. Takamiya Y, Nagata K, Fukuda K, Shibata A, Ishitake T, Suenaga T. Cervical spine disorders in farm workers requiring neck extension actions. J Orthop Sci. 2006;11(3):235–240.
400. Marcus M, Gerr F, Monteilh C, Ortiz DJ, Gentry E, Cohen S, Edwards A, Ensor C, Kleinbaum D. A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. Am J Ind Med. 2002;41(4):236–249.
401. Carlsöö S, Hammarskjöld E. Kroppsställningar och belastning [Postures and strain]. Bygghälsans forskningsstiftelse. Stockholm (SE): Byggförlaget; 1985. Swedish.
402. van der Grinten MP. Test-retest reliability of a practical method for measuring body part discomfort. In: Quennec Y, Daniellou R, editors. Design for Everyone. London (UK): Taylor & Francis; 1991. p. 54–57.
403. van der Grinten MP, Smitt P. Development of a practical method for measuring body part discomfort. In: Kumar S, editor. Advances in industrial ergonomics and safety IV. London (UK): Taylor & Francis; 1992. p. 311–318.
404. Kumar S. A computer desk for bifocal lens wearers, with special emphasis on selected telecommunication tasks. Ergonomics. 1994;37(10):1669–1678.
405. Genaidy A, Barkawi H, Christensen D. Ranking of static non-neutral postures around the joints of the upper extremity and the spine. Ergonomics. 1995;38(9):1851–1858.
406. Kee D, Karwowski W. Ranking systems for evaluation of joint and joint motion stressfulness based on perceived discomforts. Appl Ergon. 2003;34(2):167–176.
407. European Committee for Standardization (CEN). Safety of machinery – human physical performance – part 2: manual handling of machinery and component parts of machinery. Brussels: CEN; 2008. Standard No. EN 1005-2:2003+A1:2008
408. International Organization for Standardization. Ergonomics – manual handling – part 1: lifting and carrying. Geneva: ISO; 2003. Standard No. ISO 11228-1:2003.
409. Whysall ZJ, Haslam RA, Haslam C. Processes, barriers, and outcomes described by ergonomics consultants in preventing work-related musculoskeletal disorders. Appl Ergon. 2004;35(4):343–351.
410. Saab Automobile. BUMS Belastningsergonomisk utvärderingsmall [BUMS Physical ergonomics assessment sheet]. SaabHälsan: Trollhättan (SE); 2001. (publication; version 10). Swedish.

411. Graves RJ, Way K, Riley D, Lawton C, Morris L. Development of risk filter and risk assessment worksheets for HSE guidance - 'Upper limb disorders in the workplace' 2002. Appl Ergon. 2004;35(5):475–484.
412. Gallagher S, Heberger JR. Examining the interaction of force and repetition on musculoskeletal disorder risk: A systematic literature review. Hum Factors. 2013;55(1):108–124.
413. Yeung SS, Deddens J, Genaidy AM, Karwowski W, Leung PC. Theoretical and experimental evaluation of the multiplicative lifting equation and the general lifting index. Occup Ergon. 2006;6(1):13–24.
414. Karwowski W. Comments on the assumption of multiplicity of risk factors in the draft revisions to NIOSH Lifting Guide. In Kumar S, editor. Advances in Industrial Ergonomics and Safety IV. London (UK): Taylor & Francis; 1992. p.906–910.
415. Waters TR, Putz-Anderson V, Garg A, aaa. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics. 1993;36(7):749–776.
416. Davis K, Marras W. Load spatial pathway and spine loading: How does lift origin and destination influence low back response? Ergonomics. 2005;48(8):1031–1046.
417. Ciriello VM, Snook SH, Hashemi L, Cotnam J. Distributions of manual materials handling task parameters. Int J Ind Ergon. 1999;24(4):379–388.
418. Taboun SM, Dutta SP. Psychophysical assessment of combined manual lifting and carrying tasks. In: Karwowski W, Yates JW, editors. Advances in industrial ergonomics and safety III. London (UK):Taylor & Francis; 1991. p. 209–216.
419. Morrissey SJ, Liou YH. Maximum acceptable weights in load carriage. Ergonomics. 1988;31(2):217-226.
420. Keyserling WM, Herrin GD, Chaffin DB, Armstrong TJ, Foss ML. Establishing an industrial strength testing program. Am Ind Hyg Assoc J. 1980;41(10):730–736.
421. Karwowski W, Ayowb MM. Fuzzy modelling of stresses in manual lifting tasks. Ergonomics. 1984;27(6):641–649.
422. Slavin RE. Best evidence synthesis: An intelligent alternative to meta-analysis. J Clin Epidemiol. 1995;48(1):9–18.
423. SBU. Occupational exposures and neck and upper extremity disorders. A systematic review. Stockholm (SE): Swedish Council on Health Technology Assessment (SBU); 2012. (SBU publication; no. 210). Swedish.
424. SBU. Occupational exposures and back disorders. A systematic review. Stockholm (SE): Swedish Council on Health Technology Assessment (SBU); 2014. (SBU publication; no. 227). Swedish.
425. Wai EK, Roffey DM, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational lifting and low back pain: results of a systematic review. Spine J. 2010;10(6):554–566.
426. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational pushing or pulling and low back pain: results of a systematic review. Spine J. 2010;10(6):544–553.
427. Wai EK, Roffey DM, Bishop P, Kwon BK, Dagenais S. Causal assessment of occupational bending or twisting and low back pain: results of a systematic review. Spine J. 2010;10(1):76–88.
428. Roffey DM, Wai EK, Bishop P, Kwon BK, Dagenais S. Causal assessment of awkward occupational postures and low back pain: results of a systematic review. Spine J. 2010;10(1):89–99.
429. Punnett L. Musculoskeletal disorders and occupational exposures: How should we judge the evidence concerning the causal association? Scand J Public Health. 2014;42(13):49–58.
430. Hill AB. The environment and disease: association or causation? Proc R Soc Med. 1965;58:295–300.
431. Takala EP. Lack of “statistically significant” association does not exclude causality. Spine J. 2010;10(10):944.
432. Kuijer PP, Takala EP, Burdorf A, Gouttebarge V, van Dieen JH, van der Beek AJ, Frings-Dresen MH. Low back pain: Doesn't work matter at all? Occup Med (Lond). 2012;62(2):152–153.
433. Straker L, Mathiassen SE. Increased physical work loads in modern work - A necessity for better health and performance? Ergonomics. 2009;52(10):1215–1225.
434. Mathiassen S, Lewis C. Fysisk variation och belastningsbesvär i arbetet. Stockholm (SE): SWEA; 2016. (Kunskapssammanställning 2016:1). ISSN: 1650-3171. Swedish.
435. Marras WS, Lavender SA, Leurgans SE, Rajulu SL, Gary Allread W, Fathallah FA, Ferguson SA. The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders: The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. Spine (Phila Pa 1976). 1993;18:617–628.
436. Light RJ. Measures of response agreement for qualitative data: Some generalizations and alternatives. Psychol Bull. 1971;76(5):365–377.
437. Conger AJ. Integration and generalization of kappas for multiple raters. Psychol Bull. 1980;88(2):322–328.
438. Waters TR, Baron SL, Kemmlert K. Accuracy of measurements for the revised NIOSH lifting equation. Appl Ergon. 1998;29(6):433–438.
439. Dartt A, Rosecrance J, Gerr F, Chen P, Anton D, Merlino L. Reliability of assessing upper limb postures among workers performing manufacturing tasks. Appl Ergon. 2009;40(3):371–378.
440. Dahlqvist C, Hansson GT, Forsman M. Validity of a small low-cost triaxial accelerometer with integrated logger for uncomplicated measurements of postures and movements of head, upper back and upper arms. Appl Ergon. 2016;55:108–116.

441. Lind C, Forsman M. Accuracy of a posture measurement system for practitioners. In: Fostervold KI, Kjøs Johnsen SÅ, Rydstedt L, Watten, EG, editors. Proceedings of the Nordic Ergonomics Society 47th Annual Conference. Lysaker (NO); NEHF: 2015. p. D6.1–D6.5. ISBN 978-82-995747-5-4.

442. Mathiassen SE, Liv P, Wahlström J. Cost-efficient observation of working postures from video recordings - More videos, more observers or more views per observer? Work. 2012;41(Suppl. 1):2302–2306.

443. Mathiassen SE, Liv P, Wahlström J. Cost-efficient measurement strategies for posture observations based on video recordings. Appl Ergon. 2013;44(4):609–617.

444. Fan ZJ, Harris-Adamson C, Gerr F, Eisen EA, Hegmann KT, Silverstein B, Evanoff B, Dale AM, Thiese MS, Garg A, Kapellusch J, Burt S, Merlino L, Rempel D. Associations between workplace factors and carpal tunnel syndrome: A multi-site cross sectional study. Am J Ind Med. 2015;58(5):509–518.

445. Andrews DM, Arnold TA, Weir PL, Van Wyk PM, Callaghan JP. Errors associated with bin boundaries in observation-based posture assessment methods. Occup Ergon. 2008;8(1):11–25.

446. Helander MG. Forget about ergonomics in chair design? Focus on aesthetics and comfort! Ergonomics. 2003;46(13–14):1306–1319.

447. Brooke J. SUS: ‘a quick and dirty usability’ scale. In Jordan PW, Thomas B, Weerdmeester BA, McClelland AL. Usability Evaluation in Industry. London (UK): Taylor & Francis; 1996. p. 189–194.

448. Eliasson K, Nyman T, Forsman M. Usability of six observational risk assessment methods. In: Lindgaard G, Moore D, editors. Proceedings of the 19th Triennial Congress of the International Ergonomics Association. Melbourne (AU); International Ergonomics Association: 2015. p. 971.1–971.2. http://www.iea.cc/congress/2015/971.pdf.

449. Sharples S, Cobb S. Methods for Collecting and Observing Participant Responses. In: Wilson JR, Sharples S, editors. Evaluation of Human Work. 4th ed. Boca Raton (FL). CRC Press. 2015. p. 83–118. .

450. Gunnarsson A-B, Wersäll M. Hand Arm Risk Assessment Method (HARM) - evaluation of a method for assessment of biomechanical exposure of the upper limbs when performing manual tasks as well as its suitability within work environment inspection. [master’s thesis]. Stockholm (SE): KTH Royal Institute of Technology; 2011. Swedish.

451. Sandahl B. An evaluation of the development of the ergonomic risk assessment method risk management assessment tool for manual handling proactively (RAMP) [master’s thesis]. Stockholm (SE): Karolinska Institutet; 2013. Swedish.

452. Drury CG, C. Patel S, Prabhu PV. Relative advantage of portable computer-based workcards for aircraft inspection. Int J Ind Ergon. 2000;26(2):163–176.

453. Baril-Gingras G, Lortie M. The handling of objects other than boxes: Univariate analysis of handling techniques in a large transport company. Ergonomics. 1995;38(5):905–925.

454. Mathiassen SE, Möller T, Forsman M. Variability in mechanical exposure within and between individuals performing a highly constrained industrial work task. Ergonomics. 2003;46(8):800–824.

455. Trask CM, Teschke K, Morrison J, Wallacejohnson P, Village J, Koehoorn M. How long is long enough? Evaluating sampling durations for low back emg assessment. J Occup Environ Hyg. 2008;5(10):664–670.

456. Halpern M, Hiebert R, Nordin M, Goldsheyder D, Crane M. The test-retest reliability of a new occupational risk factor questionnaire for outcome studies of low back pain. Appl Ergon. 2001;32(1):39–46.

457. Burdorf A, Van der Beek A, Waters TR. Letter to the Editor. Appl Ergon. 1999;30(4):369–370.