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MARI-ANNE WALLIUS

REDUCTION OF UPPER EXTREMITY LOAD IN FLOOR MOPPING WORK

With the special reference of the height of the upper mop handle

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Mari-Anne Wallius

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ABSTRACT

Work-related musculoskeletal disorders (WMSDs) commonly occur among cleaners. The aim of this study was to obtain knowledge regarding ergonomic strategies and measures for reducing risk factors of WMSDs of the upper extremities in floor mopping work, and to guide future ergonomic development of cleaning tools and methods. The aim of the experimental portion of the study was to determine the optimal height of the upper handle of the mop, a height which would particularly affect the musculoskeletal strain of the upper arms without having adverse effects on the wrists and forearms.

This dissertation consists of three separate studies. Study I is a systematic review assessing effects on the upper extremities´ load of the performed technical (e.g., tools and methods) measures on mopping work (1/1987 to 2/2017). Data from 11 included studies were assessed and organized into categories representing ergonomic strategies. The data were then synthesized by using a specific criterion for combining the findings. Levels of evidence were determined in order to propose recommendations for strategies and measures for reducing musculoskeletal load.

Data (n=13) for Study II and III were collected by experimental study and analyzed by statistical methods. Study II examined the effects of upper mop handle height on the surface electromyographic (EMG) activities of the shoulder muscles and perceived strain during mopping measured on Borg´s Category-Ratio Scale (CR-10). Study III investigated the effects of mop height on the EMG activities of the forearm muscles, and on the upper arm and wrist positions and movements using an inertial motion capture system.

This study indicates that strong evidence-based recommendations regarding any ergonomic strategy or measure for reducing risk factors cannot be made for cleaning practice. The reviewed studies provided mixed evidence that musculoskeletal load is reduced by the use of mop materials and methods, including the smallest possible amount of water, and pre-actions ensuring a clear floor surface. There was insufficient evidence for the adoption of any specific mopping technique resulting in less musculoskeletal strain. There is a moderate level of evidence for the use of individually adjustable tools as an effective strategy for reducing musculoskeletal load on the upper extremities. The results of this study suggest that correct use of the height of the mop, in which the upper mop handle is set at about at the chin level, enables allevation of strain of the shoulder muscles and also minimizes its possible negative effects on strain of the wrists and forearm muscles.

The preliminary framework for future ergonomic development of cleaning tools and methods proposed in this study emphasizes a more comprehensive approach that takes into consideration user- and task-related factors in tool design. Future research is needed to enlarge this framework to also include aspects of organizational ergonomics.

National Library of Medicine Classification: TA 166-167; WE 805
Medical Subject Headings: *Ergonomics; Musculoskeletal System; Physical Exertion; Posture; Risk Factors; Upper Extremity; Electromyography, Equipment Design; Biomechanical Phenomena*

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TIIVISTELMÄ

Työperäiset tuki- ja liikuntaelinsairaudet ovat yleisiä siivoojilla. Tutkimuksen tarkoituksena oli saada tietoa ergonomiaan liittyvistä strategioista ja toimenpiteistä, joilla voidaan vähentää riskitekijöitä yläraajasairauksille siivoustyön keskeisessä moppaustyössä sekä ohjata siivoustyövälineiden ja -menetelmien ergonomiakehitystä. Tutkimuksen kokeellisessa osassa määritettiin olkapäiden kuormittumisen näkökulmasta optimaalinen säätökorkeus moppaustyövälineelle aiheuttamatta haitallisia vaikutuksia ranteisiin ja kyynärvarsiin.

Väitöskirja koostuu kolmesta osatutkimuksesta. Tutkimus I on systemaattinen kirjallisuuskatsaus, jossa selvitettiin moppaustyövälineisiin ja -menetelmiin kohdistettujen teknisten toimenpiteiden vaikutuksia yläraajakuormitukseen (1/1987-2/2017). Aineisto (n=11) arvioitiin ja jäsenneltiin ryhmiin ergonomiastrategioiden muodostamiseksi sekä syntetisoitiin laaditun kriteeristön avulla. Ergonomiastrategioille määritettiin näytön aste moppaustyön kuormittavuutta vähentävien suositusten laatimiseksi.

Tutkimusten II-III aineisto (n=13) kerättiin kokeellisella tutkimuksella ja analysoitiin tilastomenetelmin. Tutkimuksessa II selvitettiin mopinvarren korkeuden vastetta moppauksenaikaiseen hartian ja olkavarren lihasten sähköiseen aktiviteettiin pinta-elektromyografialla (EMG) sekä koettuun kuormittumiseen CR-10 -menetelmällä. Tutkimuksessa III selvitettiin mopinvarren korkeuden vaikutuksia olkapäiden ja ranteiden asentoihin ja liikkeisiin inertiapohjaisella liikeanalyysimenetelmällä sekä kyynärvarsien lihasaktiviteettiin EMG:lla.

Tutkimus osoitti, että fyysisiä riskitekijöitä vähentävistä ergonomiastrategioista ja toimenpiteistä ei ole riittävää tieteellistä näyttöä suositusten antamiseksi siivoustyöhön. Vähäistä vedenkäyttöä suosivien moppimateriaalien käytöstä sekä puhdistettavien lattiapintojen esivalmistelutoimista on ristiriitaista näyttöä yläraajakuormituksen keventämisessä. Työskentelytekniikoiden myönteisistä vaikutuksista kuormitukseen on riittämätön näyttö. Yksilöllisesti säädettävien työvälineiden hyödyntämisestä on kohtalaista näyttöä yläraajakuormituksen keventämisessä. Tulosten perusteella mopinvarren säätökorkeus lähellä leukatasoa mahdollistaa moppauksenaikaisen hartian ja olkavarren lihasten kuormittumisen keventymisen, sekä minimoi epäsuotuisia vaikutuksia ranteen ja kyynärvarren lihasten kuormittumiseen.

Tutkimus tuotti alustavan viitekehyksen siivoustyövälineiden ja -menetelmien ergonomian kehittämiseen korostaen kokonaisvaltaista, käyttäjät ja toimintaympäristön huomioivaa työvälinesuunnittelua. Jatkotutkimuksia tarvitaan viitekehyksen laajentamiseksi sisältämään myös organisatorisen ergonomian näkökulmat.

Luokitus: TA 166-167; WE 805
Yleinen suomalainen asiasanasto: *ergonomia; siivousvälineet; siivoojat; tuki- ja liikuntaelimet; olkapäät; ranteet; kyynärvarret; riskitekijät; kuormitus; fyysinen kuormittavuus; liikeanalyysi; elektromyografia*

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Lemu, October 2019

Mari-Anne Wallius

LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications:

I Wallius, M-A., Järvelin-Pasanen, S., Rissanen, S. M., Karjalainen, P. A, & Räsänen, K. (2019). An overview of strategies for reducing upper extremity physical exposure associated with floor mopping: A systematic review. *Human Factors, 61*(1), 43-63.

II Wallius, M. A., Rissanen, S. M., Bragge, T., Vartiainen, P., Karjalainen, P. A., Räsänen, K., & Järvelin-Pasanen, S. (2016). Effects of mop handle height on shoulder muscle activity and perceived exertion during floor mopping using a figure eight method. *Industrial Health, 54*(1), 58-67.

III Wallius, M-A., Bragge, T., Karjalainen, P. A., Järvelin-Pasanen, S., Rissanen, S. M., Vartiainen, P., & Räsänen, K. (2018). Effects of mop handle height on forearm muscle activity, wrist and upper arm posture and movement during floor mopping. *IISE Transactions on Occupational Ergonomics and Human Factors, 6*(2), 84-97.

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The summary of the study also includes unpublished material.

CONTENTS

ABBREVIATIONS

AD	Anterior deltoid muscle
APDF	Amplitude probability distribution function
BMI	Body mass index
CI	Confidence interval
CR-10	Category-Ratio Scale
ECR	Extensor carpi radialis muscle
EMG	Surface electromyography, electromyographic
FCU	Flexor carpi ulnaris muscle
IMU	Inertial measurement unit
IP	Infraspinatus muscle
log(APDF)	Logarithmically transformed EMG parameter
LP	Lower position (hand)
MD	Middle deltoid muscle
MSDs	Musculoskeletal disorders
MVC	Maximal voluntary contraction
%MVC	Percentage of maximal voluntary contraction
MVIC	Maximal voluntary isometric contraction
NRS-11	Numeric Rating Scale
OHC	Occupational health care
OWAS	Ovako Working posture Analysis System

REBA	Rapid Entire Body Assessment
RMS	Root mean square
RPE	Rating of perceived exertion
RULA	Rapid Upper Limb Assessment
RVC	Reference voluntary contraction
%RVC	Percentage of reference voluntary contraction
SD	Standard deviation
SEM	Standard error of the mean
SIS	Shoulder impingement syndrome
UEMSDs	Upper-extremity musculoskeletal disorders
UP	Upper position (hand)
UT	Upper trapezius muscle
VAS	Visual Analogue Scale
WMSDs	Work-related musculoskeletal disorders

1 INTRODUCTION

The progressive development of technology has rapidly changed the nature of work and the demands on the worker. Despite the fact that manufacturing (Liukkonen & Korhonen, 2013) and work involving heavy labour has declined, employment in the service sector has increased (Väänänen, Toivanen, & Kokkinen, 2013), and physically demanding occupations such as cleaning work, still exist. In Finland, the number of professional cleaners was approximately 70 000 in 2016 (Statistics Finland). The labour force in the cleaning sector is predominantly female, multinational and employed part-time (Hopsu, Konttinen, & Louhevaara, 2007). Although the technology of cleaning tools, equipment and machines has developed in recent decades (Hopsu, Toivonen, Louhevaara, & Sjøgaard, 2000; Hopsu, Degerth, & Toivonen, 2004; Kumar & Kumar, 2008), manual cleaning tasks are still common in cleaning work (the European Agency for Safety and Health at Work [EU-OSHA], 2008a; Hopsu et al., 2004; Hopsu et al., 2007; Pekkarinen, 2009; Tantuco, Mirasol, Oleta, & Custodio, 2016).

Cleaning is a high-risk occupation for developing musculoskeletal disorders (EU-OSHA, 2009; Kumar & Kumar, 2008; Nordander et al., 2000; Nordander et al., 2009; Woods & Buckle, 2000; Woods & Buckle, 2006) due to a high frequency of awkward working postures (Bell & Steele, 2012; EU-OSHA, 2009; Kumar, Chaikumarn, & Kumar, 2005a; Samani, Holtermann, Søgaard, Holtermann, & Madeleine, 2012), repetitive movements (Hägg, Schmidt, Kumar, Lindbeck, & Öhrling, 2008a), high muscular load (Louhevaara, Hopsu, & Søgaard, 1998; Søgaard, Fallentin, & Nielsen, 1996) and lack of muscle rest (Nordander et al., 2000). Work-related musculoskeletal disorders among cleaning professionals are a worldwide concern. The musculoskeletal disorders (MSDs) in neck-shoulder region (Chang, Wu, Liu, & Hsu, 2012; Jørgensen et al., 2011; Lasrado, Møllerløkken, Moen, & Van den Bergh, 2017; Unge et al., 2007; Woods & Buckle, 2006), wrist and lower back (Lasrado et al., 2017; Woods & Buckle, 2005) are commonly reported among cleaners.

Cleaners suffer from plenty of MSDs that negatively affect their work ability (EU-OSHA, 2009). The incidence rate of disability is higher in the cleaning sector than in other workers' groups (EU-OSHA, 2009). It has been reported that disability pension rates are higher among cleaning workers than among other women in unskilled occupations (Gamperiene, Nygård, Brage, Bjerkedal, & Bruusgaard, 2003). Persistent shoulder pain is an important predictor of a cleaner´s likelihood of receiving a disability pension (Jensen, Bonde, Christensen, & Maribo, 2016). In Finland, according to the Finnish 10-Town study, the amount of sickness absence was 30.4 days per one man-year for cleaning workers, which was several times higher than in low morbidity occupations (Oksanen, Pentti, Vahtera, & Kivimäki, 2012). The disability pension due to MSDs is also high among cleaning workers (Pensola, Gould, & Polvinen, 2010).

A high prevalence of work-related MSDs of the upper extremities amongst cleaners exposes a great need for research into the risk factors associated with the most frequently used cleaning methods. Floor mopping is a frequently performed and strenuous cleaning task (Hägg et al., 2008b; Weigall, Simpson, Bell, & Kemp, 2005; Woods & Buckle 2005; Woods & Buckle 2006) that is associated with high levels of risk for the upper extremities due to the combination of many physical risk factors (Weigall et al., 2005). In most cleaning jobs, approximately 35-70% of working time is spent on floor mopping (Hägg et al., 2008b). In Finland, floor mopping is the most common cleaning task (Pekkarinen, 2009), and 32 % of cleaners perform mopping more than four hours a day (Hopsu et al., 2004). Mopping has been classified as harmful for the shoulders due to its prolonged exposure times with arms elevated (Hägg et al., 2008b; Tantuco et al., 2016). The greater shoulder abduction angles (Søgaard et al., 1996) and higher shoulder muscular strain are especially related to the hand placed in the upper position on the mop handle (Hagner & Hagberg, 1989; Hopsu et al., 2000; Søgaard, Laursen, Jensen, & Sjøgaard, 2001). In addition, mopping is characterised by repetitive motions of the upper extremities (Hägg et al., 2008a; Pekkarinen, 2009) and awkward postures of the wrist (Chang et al., 2012; Woods & Buckle, 2005), the neck (Woods & Buckle, 2005) and the trunk (Kumar et al., 2005a; Woods & Buckle, 2005). Musculoskeletal pain and discomfort have also been attributed to the use of a mop (Woods & Buckle, 2005; Woods & Buckle, 2006). The high prevalence of carpal tunnel syndrome among floor cleaners is assumed to be caused by repetitive forced movements of the wrists (Mondelli et al., 2006).

Major technical advancements have been made in mop materials and in the design of hand tools, such as the adjustability of mop handles and development of all-round joints (Pekkarinen, 2009). Based on extensive equipment evaluations, design modifications to mopping tools and equipment have been recommended by researchers (Woods & Buckle, 2005). Although there has been a great deal of interest in the gradual improvement of mop design and the increasing effectiveness of new floor cleaning methods, it is unclear whether these advances have changed cleaners' workloads. It is also unclear which preventive strategies and measures are successful in reducing upper extremity load and strain in mopping. Knowledge of the impacts of developments on musculoskeletal strain is limited (Blangsted, Vinzents, & Søgaard, 2000; Søgaard, Blangsted, Herod, & Finsen, 2006). In addition, safe use of cleaning tools depends not only on their design, but also on instruction about how the tool is used and adapted to the characterics of the users and the work setting (Jensen, Frydendall, & Flyvholm, 2011).

The present author´s 15 years of experience in occupational health care (OHC) in cooperation with cleaning companies confirms that challenges exist in the implementation of new tools into cleaning practice. First, many cleaning tools advertised as ´ergonomic´ do not guarantee that they fit to workers. This situation challenges OHC practioners, whose resources are often limited, in assessing the musculoskeletal strain associated with the use of different tools in order to support cleaning managers' decision-making in selecting tools that will best benefit their workers. Second, challenges exist regarding how the new tehniques are to be integrated into practice. Nowadays, a telescopic type of mop handle is commonly used by cleaners. However, information is lacking on the appropriate length of mop handle. Thus, controversies around the advice given to cleaners exists. An unsuitable mop handle length has also been recognized in the research literature as an important issue of concern (Jensen et al., 2011; Weigall, Bell, & Simpson, 2006; Woods & Buckle, 2005). Cleaning managers, supervisors and OHC need guidelines for reducing musculoskeletal load in order to facilitate implementation of healthy working techniques into practice, thereby also ensuring that the benefits of the technical advancements are taken advantage of.

New technologies in floor cleaning may offer opportunities for reducing the risk of MSDs. There is a need for filling the gap in knowledge about the impacts of the height of the mop adjustment on the upper extremities' strain in mopping in order to determine the optimum height for the upper mop handle. Further, obtaining knowledge about ergonomic strategies and measures for decreasing risk factors of work-related musculoskeletal disorders (WMSDs) of the upper extremities in floor mopping work is needed for the support of health cleaning practices. This doctoral thesis comprises the main findings and summaries of three original articles. Through its findings, it constructs a framework for guiding future development of cleaning tools and methods from the viewpoint of reduction of musculoskeletal load. This study consists of a systematic review of the literature and an experimental study conducted among Finnish cleaning professionals.

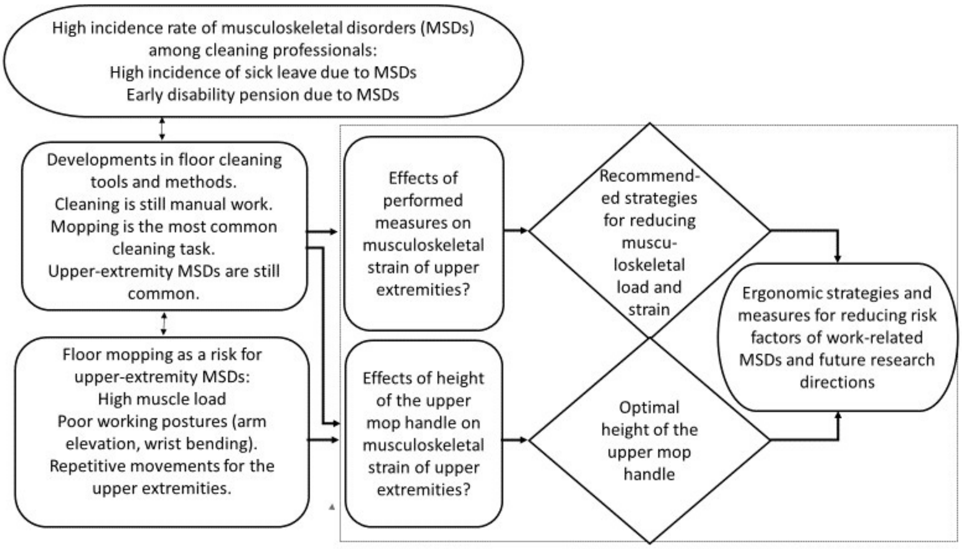


Figure 1. Background and purpose of the present study, plus strategies and measures, one of which is the optimization of the level of the upper mop handle

2 REVIEW OF THE LITERATURE

This literature review provides an overview of the existing literature on physical risk factors for MSDs of the upper extremities associated with floor mopping work and methods for assessing physical load factors and strain. A detailed systematic review on strategies for reducing the upper extremities´ load and strain associated with floor mopping is presented in Original publication I.

2.1 FLOOR MOPPING WORK

Floor cleaning consists of different types of cleaning tasks, such as mopping, buffing and vacuuming (Woods & Buckle, 2005; Woods & Buckle, 2006). Use of electrically powered machines that clean and polish floors still constitutes a minor portion of a cleaner's working day. Cleaning is mostly carried out by manual methods (Blangsted et al., 2000; EU-OSHA, 2008a; Hopsu et al., 2007; Kumar & Kumar, 2008; Tantuco et al., 2016). In this thesis, floor mopping denotes floor cleaning work that is conducted manually with long-handled tools and various types of mop heads, such as long tail (i.e., string) mops, round head mops and flat mops (see Figure 2).

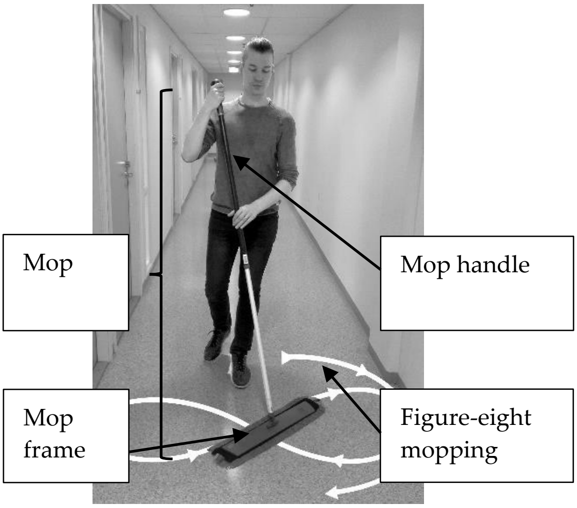


Figure 2. A mop is a tool that consists of three basic parts: a mop head including a frame, a mechanical attachment (linking the head and handle), and the handle. Mopping systems differ with regard to mop head design, mopping methods (i.e., mop head materials and the associated dampening methods), as well as type of bucket and handle or mopping technique used.

Floor mopping is a frequent working method in cleaning work (Hopsu et al., 2000; Hopsu et al., 2007; Hägg et al., 2008a; Hägg et al., 2008b; Kumar & Kumar, 2008; Tantuco et al., 2016; Woods & Buckle, 2006) and it is also described as the most used cleaning task (Pekkarinen, 2009). Floor mopping takes up 35% - 40% of working time in most cleaning jobs, in office cleaning, up to 70% of working time is spent on mopping (Hägg et al., 2008b). Floor mopping is commonly performed by pushing the mop or by using a wiping motion in either in a back-and-forth pattern or using method resembling a figure-eight (i.e., a method of mopping in which the mop is moved in an arc or in butterfly shape; see Figure 2). The term ´figure-eight technique´ is used when it focuses on examining an individual´s working technique, that is, the manner the mopping is performed. The term ´figure-eight mopping´ describes the use of this mopping method in general.

The task of floor mopping has been identified as strenuous and demanding for the cardio-respiratory (Louhevaara et al., 1998; Louhevaara, Hopsu, & Sjøgaard, 2000) and musculoskeletal systems, especially for the upper extremities (Hagner & Hagberg 1989; Hopsu et al., 2000; Hopsu et al., 2004; Søgaard et al., 1996; Søgaard et al., 2001; Weigall et al., 2005; Woods & Buckle 2005; Öhrling, Kumar, & Abrahamsson, 2012). According to a Finnish survey (n=48), one-third of the cleaners surveyd experienced mopping as a strenuous task and experienced that they needed more training in the working technique involved in mopping (Hopsu et al., 2004).

2.1.1 Floor mopping as a risk task for upper extremities

A recent study reported that mopping is one of the two cleaning tasks that pose the highest risk to cleaners (Tantuco et al., 2016). Mopping is an identified high risk task for the shoulders due to the work with prolonged arm elevation it involves (Hägg et al., 2008b; Tantuco et al., 2016). The task of mopping resulted in the maximum scores of the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) methods due to the elevated arm postures involved (Tantuco et al., 2016).

Prior studies using electromyography (EMG) have shown high static and median shoulder muscle load levels associated with mopping (Hagner & Hagberg, 1989; Søgaard et al., 1996). The static levels exceeded the level of 2%-5% of the maximal voluntary contraction (MVC) which was earlier suggested as a risk level for an 8-hour workshift (Jonsson, 1982). In addition, mopping involves high movement velocities (Søgaard et al., 1996) and repetitiveness of the arms (Søgaard et al., 1996; Søgaard et al., 2001). For instance, mean mopping cycle time 1.4 (range 1.1-1.8) s and peak abduction velocity of 114°/s (UP-arm) and 117°/s (LP-arm) have been recorded (Søgaard et al., 1996). Further, high muscular loading for the wrist extensors has also been recorded (Öhrling et al., 2012). A high degree of hand force is also required when wringing out excess water from a mop (Woods & Buckle, 2005). Weigall et al. (2005) reported that when involved in wet mopping and static mopping, the upper limb is at risk of developing MSDs due to the combination of repetition with other risk factors.

Figure-eight technique involves high shoulder muscle load and repetitive motion of highly abducted arms (Hagner & Hagberg, 1989; Søgaard et al., 1996). Previous research has indicated that perceived strain and the local muscle strain for the trapezius were higher with the figure-eight technique compared to the ´push´

technique (Hagner & Hagberg, 1989). The figure-eight mopping (termed as ´butterfly motion′ in the original study) is composed of a push phase (i.e., the mop is pushed away from the body) and a pull phase (i.e., the mop is pulled towards the body) (Søgaard et al., 2001). According to Chang et al. (2012), the lower-position (LP) hand performed the propelling movement and the upper-position (UP) hand steered the mop. This differs from the study of Woods and Buckle (2005), who stated that the LP-hand steered the mop while the UP-hand applied force. Further, a notable proportion of mopping time is spent in harmful flexion-extension of the wrist or deviation postures (Chang et al., 2012; Woods & Buckle, 2005) due to the rotation motion of the mop controlled by the wrists (Hägg et al., 2008b). Wrist bending has also been reported as an important risk factor for developing wrist discomfort during mopping (Chang et al., 2012).

Previous studies using EMG have also reported that the shoulder muscle strain was higher for the UP-arm than for the LP-arm (Hagner & Hagberg, 1989; Hopsu et al., 2000; Søgaard et al., 2001), in spite of the dampness of the mop and mopping direction (Hopsu et al., 2004). Further, while using figure-eight technique, the UP-arm is more abducted than the LP-arm (Hagner & Hagberg, 1989). Nevertheless, none of these studies assessed whether the mop handle length affected the shoulder muscle strain and arm abduction angles. According to a Finnish survey by Hopsu et al. (2004), only 2% of cleaners mopped by alternating the place of the hands on the upper mop handle. Therefore, UP-arm particularly may be at increased risk for MSDs.

Taken together, this review of the literature confirms that floor mopping involves several physical risk factors of the upper extremities and therefore poses a risk of upper extremity musculoskeletal disorders for cleaning workers. A survey (Woods & Buckle, 2006) of 1216 cleaners (31% response rate) also demonstrated that mopping was one of the three cleaning tasks most frequently causing pain and discomfort. These studies highlight the need for further research in order to improve conditions for cleaning workers.

2.1.2 Modern tools and techniques

New floor cleaning equipment and methods have been developed which are designed to improve cleaning efficiency. Advanced mopping technologies such as microfiber mops that use flat mop heads, require less water as well as the need for handling heavy buckets of water (Goggins, 2007; Lehman, 2004) as well as wringing out wet, braided mops (Irwin, Farfan, & Conner, 2012; Weigall et al., 2005). Nevertheless, the traditional mop- and-bucket floor cleaning method is still used in many workplaces.

The use of ergonomic cleaning equipment and methods has been suggested as a means of reducing harmful physical load (Kumar, 2006; Louhevaara et al., 1998). Poor ergonomic design of equipment and equipment handles is a common ergonomic risk factor associated with cleaning tasks that may lead to MSDs (EU-OSHA, 2009). Based on an extensive assessment of cleaning equipment, ergonomic concerns in the design of mops have also been highlighted and a set of practical design modifications to mopping systems has been suggested (Woods & Buckle, 2000; Woods & Buckle, 2005). Nevertheless, it is uncertain whether the musculoskeletal load and strain of the upper extremities have decreased in floor mopping work over the past decades due to improvements in mop equipment and mopping methods. Only a limited number of studies have compared new methods with those previously in use and evaluated the possible change in workload. A literature review by Blangsted et al. (2000) and Søgaard et al. (2006) showed that floor cleaning is a strenuous work task for the shoulder muscles regardless of the method or tool used. However, no systematic evaluation exists that explores the relationship between floor mopping and upper-extremity load and strain. Such information is scattered throughout the scientific literature. On the one hand, information is needed in order to define which preventive strategies and measures could be used as good examples for reducing upper extremity workload for cleaners. On the other hand, such information is needed for identifying gaps in knowledge and guiding future research for developing floor cleaning tools and methods from an ergonomics perspective. Ergonomic strategies and measures for reducing musculoskeletal load and strain may contribute to a decrease in WMSDs.

2.1.3 Mop handle height adjustment

Modern tools and equipment per se do not benefit cleaners; rather, successful implementation is required for optimization of the workload. At present, modern telescopic types of mop handles are used by cleaners in many workplaces in Finland and hold promise for reducing ergonomic risks. However, unsuitable mop handle height has been a significant issue of concern for cleaners (EU-OSHA, 2008b; Goggins, 2007; Weigall et al., 2006; Woods & Buckle, 2005). Despite the possibility of adjusting long-handled cleaning tools, according to Hopsu et al. (2007) cleaners spent one-third of their working time with one arm above the shoulder level. One possible explanation for elevated arms in this situation is the use of too-long mop handles (Goggins, 2007). It has been reported that for female cleaners the top of the mop was situated between standing eye and shoulder height (Woods & Buckle, 2005). A Finnish survey (n=48) found that 35% of cleaners hold the mop at shoulder level, 33% at chin level, 21% at nose level, and the remaining 12% at some other level (Hopsu et al., 2004). It has been recognized that cleaning workers position their UP-hand too high when they perform mopping (Jensen et al., 2011). On the other hand, a shorter mop handle may lead to reaching while mopping (EU-OSHA, 2008a; Goggins, 2007).

Only a limited number of studies have assessed the effects of mop height adjustment on musculoskeletal strain of the upper extremities. A study of Öhrling et al. (2012) found that in staircase mopping the electrical activities for the shoulder muscles were lower when an easily adjustable mop handle was used compared to a non-adjustable mop. There is still no evidence that the level of arm elevation can be reduced by adjusting the mop. In addition, minimizing the load on the shoulders could shift the load to other parts of the upper limb: for example, to the wrists and forearms. Tailoring a suitable mop height for an individual is challenging, because floor mopping is a two-handed and asymmetric task for the upper limbs and requires control of simultaneous multi-joint movements of the upper limbs. Currently, no recommendation exists in the literature for optimal mop handle height for figure-eight mopping based on evaluation of the upper limb positions, movements and muscular loading. In order to prevent physical hazards, information on how to use a mop safely should be available. Therefore, the present study evaluates the impact of the height of the upper mop handle on upper arm and wrist positions and movements as well as shoulder and forearm electrical activities involved in the task of floor mopping.

2.2 WORK-RELATED FACTORS FOR MUSCULOSKELETAL DISORDERS

MSDs are conditions that affect the tendons, muscles, nerves and supporting structures of the body (Punnett, 2014; Stack, Ostrom, & Wilhelmsen, 2016). MSDs that arise from occupational exposures are termed work-related MSDs (WMSDs) (Forde, Punnett, & Wegman, 2002). Work-related upper-limb musculoskeletal disorders include a variety of upper-limb degenerative and inflammatory diseases and disorders (Hagberg, 2000).

Many MSDs are characterized as multifactorial in nature (van der Beek & Frings-Dresen, 1998; Bernard, 1997; da Costa & Viera, 2010; Roquelaure et al., 2009). Risk factors for upper extremity musculoskeletal disorders (UEMSDs) can be grouped into three main categories: (i) physical; (ii) psychosocial; and (iii) individual (Bernard, 1997). Physical factors such as repetition, force, posture and vibration are widely recognized as work-related physical risk factors for UEMSDs (Bernard, 1997), and for neck and upper limb disorders (Hagberg, 2000).

Many workplace risk factors such as exertions involving flexed, extended or deviated wrist or repetitive hand exertions and wrist acceleration, are associated with the increased risk of upper-extremity disorders (Keyserling, 2000). Further, adverse psychosocial factors at work, such as low social support (Hauke, Flintrop, Brun, & Rugulies, 2011), low job control (Bernard, 1997; da Costa & Viera, 2010; Hauke et al., 2011) and low decision authority, have been shown to increase the risk of MSDs (Hauke et al., 2011). Many personal factors such as advancing age and pre-existing musculoskeletal disorders, are strongly associated with UEMSDs (Roquelaure et al., 2009). In cleaning work, upper extremity MSDs develop out of the complex interaction of many risk factors (Weigall et al., 2005).

Although the importance of individual factors and work organizational and psychosocial factors should not be underestimated, this thesis discusses only physical risk factors. The risk of upper limb MSDs is high for manual workers (i.e., those exposed to forceful and repetitive movements) in particular (Melchior et al., 2006). Strategies and measures for limiting physical exposures have been presented for those factors that increase the risk of MSDs (Barcenilla, March, Chen, &

Sambrook, 2012; Charles, Ma, Burchfiel, & Dong, 2018; Keyserling, 2000; Melchior et al., 2006). Therefore, accurate measurement of exposure to factors that may contribute to the development of WMSDs is essential (David, 2005). Early ergonomic workplace interventions to improve ergonomics have been shown to reduce absence due to sickness (Shiri et al., 2011), as well as self-reported productivity loss caused by upper extremity disorders (Martimo et al., 2010).

2.2.1 Physical risk factors for neck/shoulder pain and disorders

Despite the fact that shoulder pain is common in both the general population and in different occupational groups, there is no universally accepted way to define MSDs of the neck and/or shoulder (Linaker & Walker-Bone, 2015). A wide variety of classification systems are used, and consensus has not been reached on terminology and diagnostic criteria for shoulder pain (Huisstede, Miedema, Verhagen, Koes, & Verhaar, 2007; Linaker & Walker-Bone, 2015). The term ´neck-shoulder disorders´ covers among other things self-reported pain and variety of clinical diagnoses of neck and shoulder disorders (Larsson, Søgaard, & Rosendal, 2007). Physical risk factors for both specific shoulder disorders and non-spesific shoulder pain are discussed in this section briefly.

According to the systematic review of longitudinal studies by da Costa and Viera (2010), heavy physical work and repetitive work are biomechanical risk factors for shoulder disorders. Further, the prospective studies by Harkness, Macfarlane, Nahit, Silman, & Mcbeth (2003) and Hoozemans, van der Beek, Fring-Dresen, van der Woude, & van Dijk (2002) reported that manual handling activities such as pulling and pushing are risk factors for shoulder complaints. Similarly, the cross-sectional survey by Pope, Silman, Cherry, Pritchard, & Macfarlane (2001) and the case-reference study by Beach, Senthilselvan, & Cherry (2012) found that occupational factors such as lifting are associated with shoulder pain or injury, particularly in the lifting of weights above shoulder level (Beach et al., 2012). Van der Windt et al. (2000) concluded in their systematic review that heavy physical work load, repetitive movements, awkward postures and vibration are physical risk factors for shoulder pain. Similar findings were found in a review by Charles et al. (2018) showing that exposure to awkward posture and vibration are associated with MSDs of the neck and shoulder.

A prospective population-based study by Miranda, Punnett, Viikari-Juntura, Heliövaara, & Knekt (2008) also showed that repetitive movements and vibration increase risk for shoulder disorders. It has been shown that repetitive movements of the wrists and arms for continuos periods exceeding 10 minutes are associated with disabling shoulder pain (Pope et al., 2001). Nordander et al. (2016) have demonstrated that a higher velocity of the wrist or upper arm is associated with shoulder complaints. A prospective cohort study by Andersen at al. (2003) showed that work exposure to repetitive movements of the shoulder is an important risk factor in the onset of neck/shoulder pain.

Exposure to excessive force, repetitive movements and continuous arm elevation increase the risk of tendon disorders of the shoulder (Current Care Guidelines, 2014). A cross-sectional study by Frost et al. (2002) reported that manual repetitive work with a lack of micropauses in arm elevation (i.e., lack of recovery time) when combined with high force requirements increase the risk of shoulder tendinitis. Van Rijn, Huisstede, Koes, & Burdorf (2010) concluded in their systematic review that repetitive movements of the wrist/hand or shoulder, high force requirements, working with arm elevated and use of vibrating hand tools are work-related physical risk factors for shoulder impingement syndrome (SIS). The risk for developing SIS increases when the use of hand force exceeds 10% of maximal voluntary contraction (MVC) (van Rijn et al., 2010).

Exposure to work with arms elevated is an important risk factor for shoulder pain/disorders (Coenen, Douwes, van den Heuvel, & Bosch, 2016; Mayer, Kraus, & Ochsmann, 2012; van Rijn et al., 2010; Viikari-Juntura, 2010). Similarly, working with the hand above shoulder level is associated with shoulder pain (Harkness et al., 2003; Leclerc, Chastang, Niedhammer, Landre, & Roquelaure, 2004; Pope et al., 2001). A prospective study by Miranda, Viikari-Juntura, Hartikainen, Takala, & Riihimäki (2001) also showed that heavy physical workload and working with trunk forward bended or arm above shoulder level increase risk for shoulder pain. Further, a cross-sectional study by Miranda, Viikari-Juntura, Heistaro, Heliövaara, & Riihimäki (2005) showed that cumulative exposure of working with a hand above shoulder level increase the risk of chronic rotator cuff tendinitis. Similarly, a case-referent study by Punnett, Fine, Keyserling, Herrin, & Chaffin (2000) showed that increasing duration of severe shoulder flexion or abduction predicted shoulder disorders and the use of hand-held tools also increase the risk of shoulder disorders. An increase in the percentage of time in upper arm flexion, and high hand force have been identified as significant risk factors for rotator cuff syndrome (Silverstein et al., 2008). A systematic review and meta-analysis by Molen, Foresti, Daams, Frings-Dresen, & Kuijer (2017) reported that elevation of the arm and shoulder load doubled the risk of specific shoulder disorders. The evidence is most convincing for a combined exposure to several physical factors increasing the risk of shoulder disorders (Bernard, 1997; Miranda et al., 2008; Silverstein et al., 2008).

Although it has been widely recognized that frequent or sustained shoulder flexion or abduction are associated with specific shoulder disorders and nonspecific shoulder pain, no consensus exists in the literature on a definite safe limit for the elevation of the arm when it is performing work. 60° and 90° cut-off points for severe flexion/abduction or elevation of the arm have been used in several studies (Bernard, 1997; Coenen et al., 2016; Hanvold, Waersted, Mengshoel, Bjertness, & Veiersted, 2015; Punnett et al., 2000). Magnetic-resonance imaging-diagnosed alterations in the supraspinatus tendon have been detected in those working with their arms in highly elevated (90°) postures (Svendsen et al., 2004). Hanvold et al. (2015) demonstrated that work with prolonged upper arm elevation >60° and >90° is associated with shoulder pain, particularly among women. However, lower angles (≥45°) of upper arm flexion at least 15% of working time, as well as forceful exertion, also are associated specific shoulder disorders such as shoulder impingement syndrome (van Rijn et al., 2010) and rotator cuff syndrome (Silverstein at al., 2008).

2.2.2 Physical risk factors for wrist, hand and elbow pain or disorders

Repetitive strain injuries of the hand and forearm are caused by excessive strain. The most common disorders in the distal upper extremity are: hand/wrist tenosynovitis, epicondylitis and carpal tunnel syndrome (Current Care Guidelines, 2013.) A number of physical risk factors for wrist, hand and elbow pain have been established in the literature. Many reviews have concluded that use of high hand force, highly repetitive work with the hands, and especially the combination of these two factors, increase the risks of wrist, hand or elbow disorders (Bernard, 1997; Kozak et al., 2015; Palmer, Harris, & Coggon, 2007; van Rijn, Huisstede, Koes, & Burdorf, 2009a; van Rijn, Huisstede, Koes, & Burdorf, 2009b).

The overview of systematic reviews and meta-analysis by Kozak et al. (2015) indicated that activities requiring a high degree of repetition, forceful exertion or combined exposures increase the risk of carpal tunnel syndrome (CTS), and that the evidence for association for non-neutral postures of the wrist and CTS is low. A meta-analysis by Barcenilla et al. (2012) concluded that occupational exposure to increased hand force, repetition and excess vibration increase the risk of developing CTS. The systematic review by Palmer et al. (2007) also showed that, in addition to the use of hand-held vibratory tools, highly repetitious or prolonged flexion and extension of the wrist was found to increase the risk of CTS, especially when combined with a forceful grip. Similarly, the systematic review by van Rijn et al. (2009a) showed that CTS is associated with prolonged work with: the wrist in flexed or extended position, hand-arm vibration, high requirements for hand force and high repetitiveness, and with their combinations. Further, repetitive movements (>2 hours per day), handling tools (>1kg) and handling of loads (>20kg) increase the risk of lateral epicondylitis (van Rijn et al., 2009b). In addition to repetitive movements and handling loads of over 20kg, work factors such as handling loads of over 5kg (two times per minute at least two hours a day), high hand grip forces and working with vibrating tools increased the risk of medial epicondylitis (van Rijn et al., 2009b). An increase in wrist angular velocity has also been shown to be an important factor in increasing the risk of wrist/elbow disorders (Nordander at al., 2013) or specific disorders at the elbow (Seidel, Ditchen, Hoehne-Hückstädt, Rieger, & Steinhilber, 2019). Exposure to physical risk factors such as repetition, force, posture and movement, as well as combinations of these factors, is significantly associated with the development of specific disorders at the elbow (i.e., lateral and medial epicondylitis or ulnar neuropathy) (Seidel et al., 2019).

2.3 ASSESSMENT OF PHYSICAL LOAD AND STRAIN

2.3.1 Exposure

Physical job demands, that is, muscular work load, can also be referred to using terms such as ′stress′ and ′exertion′ (Louhevaara, 1999). The term ′physical exposure′ is often used as a substitute for, or in connection with the term ′physical load′. The term ′physical exposure′ is commonly used when measuring physical work load (Li & Buckle, 1999), or in studies quantifying an exposure-response relationship between exposure to physical risk factors and MSDs (Kapellusch et al., 2013; Nordander et al., 2013). On the contrary, according to Westgaard and Winkel (1997), the term ′physical exposure′ refers to environmental physical exposure factors such as noise and lighting and excludes mechanical exposure. The term ′mechanical exposure′ is used in connection with the term ′physical work load′ (Winkel & Mathiassen, 1994), in assessment of physical work load in ergonomic epidemiology studies (van der Beek & Frings-Dresen, 1998; Winkel & Mathiassen, 1994).

In this thesis, musculoskeletal load factors (e.g., postures of the upper extremities) and strain responses (e.g., joint angles) were assessed. Further, the term ′physical exposure′ is used in this thesis as a synonym for ′exposure at work′, and particularly to describe exposure to physical risk factors for MSDs of the upper extremities. Exposure assessment should include three principal dimensions: exposure level (intensity/amplitude), temporal pattern of exposure (repetitiveness or frequency) and exposure duration (van der Beek & Frings-Dresen, 1998; David, 2005; Westgaard & Winkel, 1996; Westgaard & Winkel, 1997; Winkel & Mathiassen, 1994).

Ergonomics and exposure assessment methods

Ergonomics is an applied science combining various disciplines that investigate strategies for reducing harmful exposures (Stack et al., 2016). The objective of an ergonomics approach is to achieve an effective match between the user and the work system (i.e., equipment, task, environment, organization and personnel; Stubbs, 2000). Ergonomics is used to evaluate and design work environments to fit the physical and cognitive capabilities of individuals operating within the work system, in order to reduce occupational injury and illness and to improve productivity (Stack et al., 2016). This thesis utilizes an occupational biomechanics (i.e., industrial ergonomics) approach. Industrial ergonomics is a discipline that is oriented to the physical aspects of work and human capabilities such as posture, force and repetition (Stack et al., 2016). Another branch of ergonomics, known as ′human factors′, concentrates on psychological aspects of work (e.g., mental loading). This approach falls outside the scope of this thesis.

The methods by which ergonomic goals are achieved commonly involve evaluation and control of work site risk factors as well as identification and quantification of existing work site risk conditions (Stack et al., 2016). Quantification of physical exposures commonly involve combined kinematics (e.g., three-dimensional joint angles, angular velocities) or kinetics (moments at different body parts). These exposures are often substituted for or supplemented by subjective (e.g., perceived exertion) or physiological (e.g., electromyography) measurements (Kim & Nussbaum, 2013.)

Numerous methods have been developed for assessment of physical work load and strain. Exposure assessment methods can be divided in three main categories: subjective judgements, systematic observations (i.e., direct observations or video-based observations) and direct measurements (van der Beek & Frings-Dresen, 1998; David, 2005; Li & Buckle, 1999; Spielholz, Silverstein, Morgan, Chechoway, & Kaufman, 2001). Subjective judgement methods include both expert judgements (van der Beek & Frings-Dresen, 1998; Spielholz et al., 2001) and self-report methods, such as rating scales (Borg, 1982), worker diaries and questionnaires and interviews (van der Beek & Frings-Dresen, 1998; David, 2005; Kilbom, 1994). Direct measurements (i.e., technical measurements) can be used to collect data on workplace exposure by: electromyographic (EMG) recordings, inclinometers, goniometers, electromagnetic devices, accelerometers, and optoelectronic devices (van der Beek & Frings-Dresen, 1998; Kilbom, 1994; Li & Buckle, 1999). The measurements can be obtained at the workplace itself, simulated in the laboratory (van der Beek & Frings-Dresen, 1998; David, 2005), or in settings simulating field use (Bao & Silverstein, 2005; Koppelaar & Wells, 2005). The number of available observational methods is large. The systematic review by Takala et al. (2010) identified a total of 30 eligible observational methods assessing biomechanical exposures in occupational settings.

Although various methods are available for exposure assessment, no standard exists for the evaluation of methods assessing biomechanical exposures. Even if the choice of exposure assessment method is dependent on feasibility, cost and resources (Spielholz et al., 2001), the choice of a specific method should depend upon the application concerned, the purposes of the study and the level of accuracy required of the data (David, 2005; Spielholz et al., 2001; Takala et al., 2010).

The advantages and disadvantages, or limitations of the measurement techniques, are widely recognized. Many studies agree that direct measurements are quantitative and highly accurate methods for quantifying physical exposure (van der Beek & Frings-Dresen, 1998; Hansson et al., 2001; Kilbom 1994; Spielholz et al., 2001). Direct measurement methods have been shown to be useful (in terms of accuracy and applicability) in assessing exposure dimensions with regard to postures, movements and exerted forces (van der Beek & Frings-Dresen, 1998). Because technical measurements provide objective data on physical risk factors of work-related UEMSDs, these are regarded as applicable to risk estimation (Hansson et al., 2010; Nordander et al., 2016). However, in the early 2000s the disadvantages of these measurements were that they were often limited to a small number of persons (Spielholz et al., 2001) and accompanied by high costs for instruments and accompanying analysis software (David, 2005; Spielholz et al., 2001). In addition, it has been noted that the attachment of measurement devices and their calibration is time-consuming and can also be sources of systematic error (Kilbom, 1994).

Measurement equipment carried by the worker can also hinder the worker and thereby restrict his/her natural movements (David, 2005; Kilbom, 1994). Nowadays, the costs for instruments are lower and analyses allow long-term field recordings of many participants. Thus, technical measurements can be included in epidemiological studies (Jørgensen et al., 2019.) However, in field recordings, instruments used for collecting data may be compromised by environmental interferences such as strong electromagnetic fields (Li & Buckle, 1999; Schall, Fethke, Chen, Ovama, & Douphrate, 2016).

Comparison of direct measurements methods to self-report questionnaires and observational video analysis methods has indicated that direct measurements were the preferred measurement method for various exposure metrics, including hand force, forearm rotation and wrist flexion/extension. Self-reports were shown to be the least-precise method of exposure assessment as compared to direct measurements and observational video analysis (Spielholz et al., 2001.) Similarly, questionnaire-assessed exposure data on work postures and movements had low validity in comparison to direct technical measurements (Hansson et al., 2001). In particular, low validity with respect to exposure level assessments has been indicated (Wiktorin, Karlqvist, & Winkel, 1993). Sources of error in self-reports may be due to report scale, formulation of questions (Wiktorin et al., 1993) or the subjects themselves (e.g., worker literacy and comprehension; Spielholz et al., 2001). However, self-reports have the advantages of being applicable to various working situations and of being capable of observing exposure to both physical and psychophysical factors at work (David, 2005).

Simpler observational techniques have advantages of being inexpensive and appropriate for use in a wide range of workplaces, while the video-based observational technique allows analyses of several joint segments simultaneously (David, 2005). However, the internal and external validity of observational methods has been found to be questionable (Juul-Kristensen, Fallentin, & Ekdahl, 1997; Li & Buckle, 1999). Although trained observers are able to estimate body angles of static postures accurately and precisely, observation validity proved to be inadequate for highly dynamic activities (van der Beek & Frings-Dresen, 1998). Visual observation of fast movements of the wrist and hand seemed to be less reliable (Takala et al., 2010). Further, assessment of risk factors such as force, angular velocity and acceleration are not included in observational methods (Juul-Kristensen et al., 1997). A recent systematic review by Seidel et al. (2019) indicated that objective quantitative measures of exposure assessment were important for increasing understanding of the impacts of physical risk factors on MSDs.

2.3.2 Postures, movements and repetition

Posture is generally defined as the position of one or more joint or position of the body while performing work activities. In this thesis, the term ´position´ is used to represent the angle measured from a joint. Further, movement is defined as angular change per second (°/s). In other words, a low angular velocity of the wrist indicates slow wrist movement and also low motion repetitiveness. Repetition is the frequency with which upper limb motion is repeated (i.e, frequency measure) and is defined as the time quantification of a similar exertion conducted during a task (e.g., cycle time measure).

Measurement techniques in upper-limb motion analyses

In ergonomic research, postures/positions have been assessed by analysing the magnitude of joint angles, frequency of extreme joint movements, and duration in a specific posture angular sector (Kilbom, 1994). Traditionally, research on the upper extremities' postures have primarily relied on observational methods (Kilbom, 1994; Li & Buckle, 1999). Posture analyses tools such as the Ovako Working posture Analysis System (OWAS) (Karhu, Kansi, & Kuorinka, 1977), Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993) and Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000) utilize a set of discrete posture categories for classifying and representing upper-limb postures.

Range of movement has been most commonly measured using instruments such as goniometers that provide information only in single plane and in static posture. Biomechanical models have been developed from simple static models to dynamic three-dimensional models (Cuesta-Vargas, Galán-Mercant, & Williams, 2010.) Electrogoniometers and inclinometers are able to depict motions in more than one plane simultaneously. Electromagnetic systems and video-based optoelectronic systems are two commonly used laboratory systems that allow for visualization of several body regions. Video-based optoelectronic motion analysis systems utilizing multiple video-cameras to track the image of coordinates of retro-reflective markers attached to anatomical landmarks, have been considered to be the laboratory gold standard for the collection of human kinematics (Cuesta-Vargas et al., 2010). However, laboratory systems can be complex and time-consuming to operate (Cuesta-Vargas et al., 2010; Wong, Wong, & Lo, 2007). Electromagnetic sensors often have a limited workspace, and they are sensitive to electromagnetic interference (Wong et al., 2007).

In recent decades, there has been a growing interest in using three-dimensional (3D) motion analysis systems to assess the biomechanics of upper-extremity motions during occupational activities. The benefit of 3D motion analysis lies in its exact, simultaneous tracking of dynamic and multi-planar movements of multiple body segments (Àlvarez, Alvarez, González, & Lòpez, 2016.) Recently, new technology appears to be a promising development in the field of upper-limb motion analysis (Àlvarez et al., 2016; Schall et al., 2016). Inertial and magnetic measurement systems have been applied in research to the measurement of the 3D orientation of different body segments and upper limb joint angles (Cutti, Giovanardi, Rocchi, Davalli, & Sacchetti, 2008; van den Noort et al., 2014). Small-sized and lightweight electromechanical sensors utilizing technologies such as gyroscopes, accelerometers and magnetometers provide the potential for dynamic 3D motion analysis (Àlvarez et al., 2016; Cuesta-Vargas at al., 2010; Schall et al., 2016). Nowadays, wireless sensors are also available that increase the applicability of field motion analysis (Cuesta-Vargas et al., 2010).

Inertial sensors have been employed in previous studies for measuring the 3D shoulder and elbow kinematics (Cutti et al., 2008) as well as scapular kinematics (van den Noort et al., 2014; Parel et al., 2012). Inertial sensors have also been used in ergonomic analyses in fieldsettings, for example, in the evaluation of 3D trunk motion in nurses´ work tasks (Szeto, Wong, Law, & Lee, 2013) and for upper arm elevation measurements in activities involving picking and placing (Könemann, Bosch, Kingma, Van Dieën, & De Looze, 2015) as well as hand planting (Granzow et al., 2018). To the best knowledge of the present author, no study has utilized an inertial motion capture system utilizing inertial measurement units (IMU) for assessment of musculoskeletal strain of the upper extremities in ergonomics analyses concerning floor mopping.

The validation study of Taylor, Miller, & Kaufman (2017) showed that commercially available IMUs provided accurate and precise measurement of both static sensor orientation and angular velocities. Many IMU systems have been observed to accurately estimate joint kinematics of the upper limb (Cutti et al., 2008; El-Gohary & McNames, 2012; Schall et al., 2016; Zhou & Hu, 2010; Zhou, Stone, Hu, & Harris, 2008). The review by Cuesta-Vargas et al. (2010) concluded that inertial sensors could provide an accurate and reliable measurement method to examine human movements, although the degree of accuracy and reliability depended on the site and task. Upper limb movement errors for the inertial sensors utilized in this review ranged from 2.3° to 4.83°. The accuracy of inertial sensors (such as the MT9b sensor unit) has been shown to be adequate for clinical applications (Cutti et al., 2008), and good intra- and inter-operator agreement has also been shown for inertial sensors (such as the Mtx sensor unit; Parel et al., 2012). Further, the IMU system can be regarded as an acceptable instrument for occupational exposure assessment studies for directly measuring upper arm postures in field settings over the course of a working day (Schall et al., 2016). However, soft tissue artefact is a known source of error which should be taken into consideration in inertial sensor positions (Bouvier, Duprey, Claudon, Dumas, & Savescu, 2015; Cutti et al., 2008; Schall et al., 2016). Further, calibration of IMUs is regarded as an essential step in the use of such devices. However, the study by Bouvier et al. (2015) used inertial sensors (an MTw sensor unit) in comparisons of three different technique of calibration (i.e., static pose, functional movements and technical calibration) and indicated that the accuracy of upper limb joint angle data measured by inertial sensors was more dependent on the rigor of the experimental procedure (e.g., awareness of soft tissue artefacts effect and operator training), than on the selection of calibration techniques itself. Measurement drift in segment orientation is another potential source of error to consider (Zhou & Hu, 2010).

Technical measurements provide objective data on the physical risk factors for upper-extremity MSDs (Hansson et al., 2010). In quantifying posture and movement parameters, many studies have used the percentiles of angular and angular velocity distributions for characterising upper-arm positions and movements (Hansson et al., 2010; Nordander et al., 2016; Rislund, Hemphälä, Hansson, & Balogh, 2013; Veiersted, Gould, Osterås, & Hansson, 2008; Wahlström et al., 2010). In addition, the fraction of time spent in predefined angular zones has also been used to describe postures (Veiersted et al., 2008; Wahlström et al., 2010), as well as predefined angular velocity zones for describing movements (Wahlström et al., 2010). In field-based occupational assessments, angular displacement variation (i.e., the difference between the 90th and 10th posture percentiles) has also been utilized for estimating the variation in exposure (Kazmierczak, Mathiassen, Forsman, & Winkel, 2005; Wahlström et al., 2010).

2.3.3 Electrical activity of muscles and force

Electromyographic activity

The functioning muscle produces electrical activity which can be measured by electromyography (EMG), either by means of surface electrodes or intramuscular electrodes (Kroemer & Grandjean, 1997; Sella, 2007). Surface electrodes are placed on the skin superimposed upon the muscles involved, and these record the sum of action potentials of motor units reaching the electrode (Cram & Kasman, 2011). An electrical signal can also be detected using a fine wire or needle electrodes inserted into the muscle to be studied, in order to estimate deep muscle activity (Kroemer & Grandjean, 1997).

The method of measuring surface muscular activity has been used for decades in ergonomic research. EMG has been used in occupational activities for many purposes: comparison of alternative working methods (Szeto, Chan, Chan, Lai, & Lau, 2014), selection of the most appropriate tool or equipment (Søgaard et al., 2001), and detection of signs of changes in muscle behavior, for example fatigue (De Luca, 1997; Hägg, Luttmann, & Jäger, 2000; Hägg, Melin, & Kadefors, 2004). Depending on the research question, two surface EMG approaches have been adopted in ergonomic studies: (1) the biomechanical approach (interest in force and torques) and (2) the physiological approach (studies of general muscle activation and fatigue; Hägg et al., 2000).

Changes in the amplitude and frequency content of the EMG signal can be analysed (Cram & Kasman, 2011; Kroemer & Grandjean, 1997; Petrofsky, Glaser, Phillips, Lind, & Williams, 1982). Median frequency and mean power frequency, derived from the spectral analysis, are commonly used spectral parameters for the assessment of muscle fatigue in surface EMG signals (Hägg et al., 2000; Hägg et al., 2004). The amplitude of the EMG signal provides an estimate of the muscle contraction level and can be regarded as an indicator of muscle force (Disselhorst-Klug, Schmitz-Rode, & Rau, 2009; Hoozeman & Dieën, 2005). Although muscle force cannot be directly calculated via EMG, EMG-based muscle force estimation is frequently used (Staudenmann, Roeleveld, Stegeman, & van Dieën, 2010).

The major limiting factor associated with the surface EMG technique is its susceptibility to crosstalk from adjacent muscles: that is, detection of signals from neighboring muscles (Cram & Kasman, 2011; Disselhorst-Klug et al., 2009; Talib, Sundaraj, Lam, Hussain, & Ali, 2019). Although many reliable methods have been developed for crosstalk identification, a recent study showed that further research is needed in exploration of crosstalk quantification and reduction techniques (Talib et al., 2019). Appropriate size of the electrode (Zipp, 1982; Hermens et al., 1999), electrode placement (Cram & Kasman, 2011; Hermens et al., 1999) and inter-electrode distance (Cram & Kasman, 2011; Farina, Madeleine, Graven-Nielsen, Merletti, & Arendt-Nielsen, 2002) have been proposed as important factors in avoiding crosstalk.

Normalization

Due to the large inter-individual differences in the amplitude of the signal, in most studies EMG data is normalized to a reference contraction (Cram & Kasman, 2011; Mathiassen, Winkel, & Hägg, 1995). Normalization of EMG allows comparisons within the subject on different days (without electrode detachment from the skin) or concerning different muscles, between individuals and between studies (Halaki & Ginn, 2012; Soderberg & Knutson, 2000). Several different normalization methods are found in the literature. In order to obtain a reference contraction, both maximal voluntary contraction (MVC) and sub-maximal reference voluntary contraction (RVC) are commonly employed in a variety of postures (Burnett, Green, Netto, & Rodriques, 2007; Cram & Kasman, 2011; Mathiassen et al., 1995; Soderberg & Knutson, 2000), as well as both unilaterally and bilaterally (Bao, Mathiassen, & Winkel, 1995). Sub-maximal contraction may be performed at various load levels (Yang & Winter, 1983). In addition, both static and dynamic effort can be used as a reference contraction (Burden, 2010; Soderberg & Knutson, 2000).

Although a consensus on the choice of normalization methods has not been reached (Burden, 2010), the maximal voluntary reference contraction (MVC) has been used as a common method for obtaining reference amplitude (Halaki & Ginn, 2012). Different methods such as maximal voluntary isometric contraction (MVIC), maximum voluntary dynamic concentric contraction and maximum contractions collected during the experimental task, have been used to obtain maximum muscle excitation (Hodder & Keir, 2013). Normalization technique selection should depend on the task and muscle studied (Cram & Kasman, 2011). Many studies have endorsed MVIC as a normalization reference value (Boettcher, Ginn, & Cathers, 2008; Burden, 2010; Soderberg & Knutson, 2000). However, as a prerequisite for a valid normalization, the maximum neural activation should be achieved in each muscle tested (Halaki & Ginn, 2012; Kelly, Kadrmas, Kirkendall, & Speer, 1996).

Prior studies have aimed at defining standardized MVC tests for the shoulder normalization (Boettcher et al., 2008; Ginn, Halaki, & Cathers, 2011; Kelly et al., 1996). No single test has generated maximal activation for the muscle studied in all subjects. However, many of the examined tests maximally activated more than one shoulder muscle simultaneously (Kelly et al., 1996; Boettcher et al., 2008.) It has been suggested to perform more than one MVC test in order to determine the optimal reference value for the shoulder muscles examined (Ekstrom, Soderberg, & Donatelli, 2005; Kelly et al., 1996).

It seems that a lack of consensus exists in the ergonomics literature regarding the terminology for normalized output variables. According to Mathiassen et al. (1995), the terms MVE and RVE refer in normalization to bioelectrical variables. Accordingly, in normalization MVC and RVC refers to the force or torque performance during a maximal and reference contraction (Mathiassen et al., 1995). One example of such a method is the so-called ramp procedure, in which EMG amplitude is converted into force and torque (Bao et al., 1995; Hägg et al., 2000). However, the terminology for normalized output variables remains varied. In the experimental part of this thesis, the term '%MVC values' refers to the maximum voluntary contraction values: that is, as a percentage of the electrical activity produced during a static maximal voluntary contraction.

Characterization of electromyographic data

The characterization of muscular activity in quantitative terms may be performed in a number of ways. In ergonomics, calculation on time average of the root-mean-square (RMS) of EMG total recording time (e.g., mean exposure level) is the simplest approach for data reduction (Hägg et al., 2000; Hägg et al., 2004). This measure has also been applied in many floor cleaning analyses (Hopsu et al., 2000; Kumar, Hägg, & Öhrling, 2008; Öhrling et al., 2012). Other measures include the amplitude distribution of muscular activity and muscular rest characterized by frequency of periods in muscular rest, or the time fraction of EMG amplitude below a certain threshold (Hansson et al., 2000; Nordander et al., 2000; Veiersted, Westgaard, & Andersen, 1993). Some studies have found that a lack of periods of completely relaxed muscles (EMG gaps) (Hägg & Åström, 1997; Veiersted, Westgaard, & Andersen, 1990; Veiersted et al., 1993) or higher levels of muscle activity may also be a risk factor for neck/shoulder disorders (Aarås, 1994; Veiersted et al., 1990; Veiersted et al., 1993). However, other studies have found no evidence for such a relationship (Takala & Viikari-Juntura, 1991; Westgaard, Vasseljen, & Holte, 2001).

The relevance of EMG results can be evaluated using the amplitude probability distribution function (APDF) introduced by Jonsson (1982). Muscular load limit values based on the 10th (static load), 50th (median load), and 90th (peak load) percentiles of the amplitude distribution have been proposed for quantifying EMG data in relation to MSDs risk. According to Jonsson (1982), the static load level should not exceed 2% of the maximal electrical activity (%MVC) obtained during MVC, and it must not exceed 5% of the MVC. Further, the median load level should not exceed 10% of the MVC and must not exceed 14% of the MVC. Finally, the peak load level should not exceed 50% of the MVC and must not exceed 70% of the MVC. Many studies have evaluated muscular strain in floor cleaning by analysing amplitude probability distribution of the myoelectric signals (Hagberg & Hagner, 1989; Søgaard et al., 1996; Søgaard et al., 2001; Søgaard et al., 2006). Further, the variable of the APDF range (i.e., the difference between the 90th and 10th percentile APDF) has also been utilized to evaluate the variation in mucle activity amplitudes involved in performing different occupational tasks (Szeto, Straker, & O'Sullivan, 2009).

Measurements of force in ergonomics

Force can be measured or estimated in a number of ways. Various measurement methods have been utilized by different researchers in quantifying force levels (Bao, Spielholz, Howard, & Silverstein, 2006a; Bao, Howard, Spielholz, & Silverstein, 2006b; Koppelaar & Wells, 2005). In the field of ergonomics, evaluation of force has been made by means of direct and indirect methods (Koppelaar & Wells, 2005). In floor mopping work, direct force measurements for both the upper and lower hand positions have been performed with custom-made force transducers embedded in the mop handle (Søgaard et al., 2001).

Evaluation of handgrip forces constitutes an essential component of ergonomic assessments. The definition of hand force can be divided into the following main approaches: (a) identifying the weight of the object handled; (b) describing the contact force between the hand and the object handled; (c) obtaining a perception of effort; and (d) utilizing surface electromyographic activity to estimate muscular loading (Koppelaar & Wells, 2005). Force transducers and strain gauges are commonly used direct measurement methods for quantifying hand force (DiDomenico & Nussbaum, 2008; Koppelaar & Wells, 2005). In addition, push/pull forces can be measured using a force gauge (Bao et al., 2006a; Bao et al., 2006b). Further, hand force has been measured by mimicking (so-called force matching method) by workers using a hand dynamometer (Koppelaar & Wells, 2005; Bao & Silverstein, 2005; Bao et al., 2006a). For instance, power grip force has been measured by asking the subjects to replicate on a force dynamometer the hand force that they used in the task, using similar postures of their wrists (Bao & Silverstein, 2005; Bao et al., 2006a).

The use of hand force is also evaluated by the means of the observation of tasks (Bao et al., 2006a; Koppelaar & Wells, 2005), or by means of self-reporting by workers (Bao et al., 2006b). The level of forces has often been rated by subjects using the Borg scale of perceived exertion (Bao et al., 2006a) or by means of self-report using a visual analogue scale (VAS) (Koppelaar & Wells, 2005). Experienced ergonomists have also estimated forces using rating scales (Bao et al., 2006a; Bao et al., 2006b). In comparison of different measurement approaches in force quantification, correlation between the directly measured forces, self-reported levels of force, and the ergonomist's estimates of force level for lifting and push/pull forces were reported to be higher than those for the pinch grip and power grip forces measurements (Bao et al., 2006b).

It has been found that direct measurements can be cumbersome in evaluation of hand-intensive tasks. The limitations of these measurements have led to the development of alternative indirect methods for determining hand force. The relationship between EMG activity in the forearm muscles and exerted hand grip forces has been explored in many studies (DiDomenico & Nussbaum, 2008; Greig & Wells, 2008; Hoozemans & van Dieën, 2005). Force requirements have been indirectly estimated by developed predictive models, such as models for predicting handgrip or finger forces from surface EMG data of the forearm (DiDomenico & Nussbaum, 2008; Duque, Masset, & Malchaire, 1995; Hoozemans & van Dieën, 2005). In many studies, electromyographic signal amplitudes have been used to estimate hand force during gripping, such as when squeezing a hand grip dynamometer (Duque et al., 1995; Keir & Mogk, 2005). For instance, in the study by Duque et al. (1995), a mathematical-empirical model has been developed in which handgrip force has been estimated with great accuracy (correlation coefficient R=0.895) from the electrical activity of the forearm muscles. However, this method was shown to be highly context-related. Unreliable estimates of force could result from dynamic working conditions: that is, when non-neutral forearm postures are involved (Duque et al., 1995). In addition to type of task and forearm posture, the location of surface electrodes have an impact on forearm EMG activity, a factor that should be taken into account in assessments of forearm loading (Takala & Toivonen, 2013).

Although an increase in muscle tension is parallel to an increase in myoelectric activity, the relationship is shown to be non-linear under many circumstances (Duque et al., 1995; Greig & Wells, 2008; Staudenmann et al., 2010). For instance, changes in posture alters the length of a muscle, thereby changing the force-EMG relationship (Duque et al., 1995; Staudenmann et al., 2010). Moreover, electromyographic amplitudes of eccentric contraction are lower than those measured during concentric contraction (Cram & Kasman, 2011). The effect of muscle fatigue has also been considered as a confounding factor, since it changes the EMG–force relationship (Hägg et al., 2000). Nevertheless, EMG has been used to estimate force in many applications (Staudenmann et al., 2010). Spielholz et al. (2001) showed that in comparison to observational and self-reported techniques, direct measurement using electromyography (as RMS amplitude) appeared to be a better method for quantifying grip force.

2.4 SUMMARY OF THE LITERATURE AND THEORETICAL FRAMEWORK OF THIS STUDY

Despite the technological developments, cleaning work is still mostly conducted manually. Poor ergonomic design of cleaning tools and equipment is a common ergonomic risk factor associated with cleaning tasks that may lead to MSDs (EU-OSHA, 2009; Weigall et al., 2006). Physical hazards in cleaning work are also related to challenges concerning the physical work environment and improper use of tools (EU-OSHA, 2008b; Weigall et al., 2006).

Floor mopping is a frequently performed cleaning task (Pekkarinen, 2009; Tantuco et al., 2016) that is an identified high risk task for the the upper extremities. This is due to the work performed with arms elevated (Hägg et al., 2008b) under high muscle load, and due as well to the repetitive movements involved (Søgaard et al., 1996). In mopping, cleaners are exposed to multiple risk factors that may contribute to the development of UEMSDs (Weigall et al., 2005). Therefore, efforts to prevent UEMSDs should include reduction of these occupational risk factors.

Although there has been a great deal of interest in the gradual evolution of mop design and methods in recent decades, much less is known about the new technology's role in offering a solution for decreasing risk factors for WMSDs of the upper extremities. There is only a limited amount of information about the impact of technical improvements on musculoskeletal strain of the shoulders (Blangstedt et al., 2000; Søgaard et al., 2006). One such technical advancement is modern telescopic mops, which are nowadays commonly used by cleaners, and which hold promise for reducing ergonomic risks. However, the optimal height for the upper mop handle is still unknown because the effects of mop adjustability on musculoskeletal strain of the upper extremities is unclear.

The main theoretical framework of this thesis (Figure 3) is based on the stress-strain concept developed by Rutenfranz (1981). This model has been expanded by Louhevaara and Kilbom (2005) to many applications in dynamic work assessment. According to the stress-strain model, occupational stress creates strain within the individual. The stress-strain concept hypothesizes that a given work load (stress) does not result in the same level of strain for all persons. The level of strain depends to a very high degree on the individual characteristics of the worker. These characteristics are considered to be intervening factors modifying strain responses due to physical work load. Thus, the strain can be optimal, acceptable, suitable, or over-/ underloading for the worker.

Along with the load-strain model applied in this study, the load variables include technical load factors due to mopping tools and methods used which cause physiological and subjective strain responses in which a cleaner´s characteristics such age, gender and body mass index (BMI) intervene. In the experimental part of the study, musculoskeletal strain of the upper extremities associated with floor mopping was evaluated by means of posture, intensity and duration of static and dynamic force, as well as repetition. Strain responses were assessed by physiological measurements such EMG and motion analysis, as well as ratings of perceived exertion. Considering that the quantification of exposure to physical risk factors should consider three factors: level, repetitiveness and duration of the load (David 2005; Westgaard & Winkel, 1997; Winkel & Mathiassen, 1994), musculoskeletal strain associated with mopping was assessed in terms of exposure dimensions. Exposure level has been estimated by e.g., EMG and posture recordings, and repetitiveness by angular velocity. Duration has been estimated by percentage of time spent in given posture. In the systematic review, assessment of effects of the performed technical measures on mopping work on musculoskeletal load and strain was done by evaluating and synthesizing the literature.

This study concentrates only on musculoskeletal load factors and musculoskeletal strain responses. Therefore, musculoskeletal health outcome variables were not included. However, it is assumed that, as the physical demand (e.g., output of force) of the mopping task decreases, the risk for WMSDs probably decreases.

Knowledge about ergonomic strategies and measures for reducing risk factors of WMSDs of the upper extremities in mopping, including optimization of the height of the upper mop handle, may facilitate implementation of proper working techniques into the cleaner's work routines. Ergonomics strategies may contribute to a decrease in UEMSDs. This study can also provide important information for guiding development of cleaning tools and methods from an ergonomics point of view.

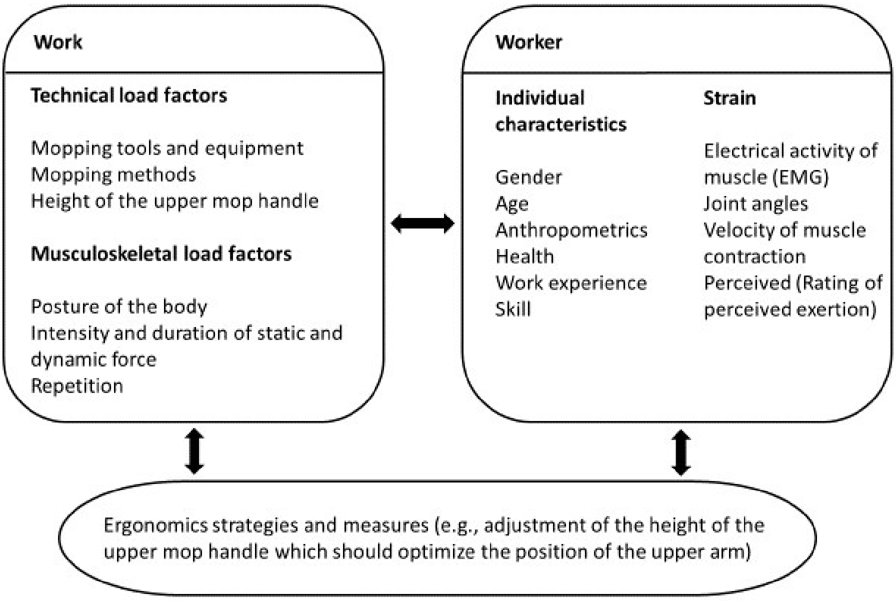


Figure 3. Modified load-strain model (after model by Rutenfranz 1981, Louhevaara & Kilbom, 2005).

3 AIMS OF THE STUDY

The main aim of the study was to obtain knowledge of ergonomic strategies and measures for reducing risk factors of work-related musculoskeletal disorders (WMSDs) of the upper extremities in floor mopping, which is the most common task in professional cleaning work, and to guide future ergonomic development of cleaning tools and methods. The experimental part of the main aim was to determine the optimal height of the upper handle of the mop and the position of the upper arm particularly affecting musculoskeletal strain of the upper arms without adverse effects on wrists and forearms.

The specific aims were as follows:

1. To systematically evaluate and synthesize relevant scientific literature regarding the musculoskeletal load and strain of upper extremities in floor mopping in order to assess effects of the performed technical (e.g., tools and methods) measures on mopping work, and to propose recommendations for strategies and measures for reducing musculoskeletal load (Study I).

2. To examine effects of the height of the upper mop handle on electrical activities of the shoulder muscles of the upper arm steering the mop, and perceived exertion during floor mopping using the mopping method resembling a figure-eight (Study II).

3. To examine effects of the height of the upper mop handle on the bilateral upper arm and wrist positions and movements, and the electrical activities of the forearm muscles (Study III).

4 PARTICIPANTS AND METHODS

4.1 STUDY DESIGN AND PARTICIPANTS

This thesis comprises a cross-sectional quantitative study design and a systematic review. Study I is a systematic review of research literature (n=11) that evaluates the impacts of the performed technical measures on floor mopping work over the past 30 years, and proposes recommendations for strategies and measures for reducing musculoskeletal load.

Study II and III employed a quasi-experimental design with repeated measures for within-subject comparisons to evaluate upper extremity muscle activity (II-III), position (III), angular velocity (III) and perceived exertion (II) among cleaners while mopping with four different mop handle heights. The parameters of the study are presented in chapter 4.3 (p. 51).

Experimental measurements were carried out during October-November 2014 at the Department of Applied Physics, University of Eastern Finland, Kuopio, Finland. The study population in Study II and III consisted of 13 (12 female and 1 male) experienced professional cleaners recruited voluntarily from Kuopio and the surrounding area from a international facility services company. The inclusion criteria required that the cleaners were Finnish-speaking, had at least six months of work experience, and that floor mopping was a part of their daily routine. The exclusion criterion was disorder in the upper limb or shoulder region at time of the experiment.

4.2 SYSTEMATIC REVIEW: DATA COLLECTION AND EVALUATION

Preliminary literature searches were carried out during spring 2014 in order to assess the volume of potentially relevant studies and to identify key terms used to describe floor mopping and the exposure of the upper extremity to physical risk factors. These informed the content and structure of the search strategy used in the primary literature seach.

Structured procedure is a principle of methodology of systematic review (Leucht, Kissling, & Davis, 2009). This systematic review was conducted using a systematic approach in retrieving, analysing and interpreting the evidence (Grant & Booth, 2009). The review was performed using the standard stages involved in a systematic review (Harden & Thomas, 2005), see Figure 4. First, research questions from the topic were identified. Second, the review protocol was developed and study eligibility criteria appropriate for the research questions were defined (see Table 1). A senior researcher was consulted to determine the eligibility criteria.

Third, data from the relevant literature were systematically searched and selected. This systematic review was performed in compliance with the Preferred Reporting

Items for Systematic Reviews and Meta-Analyses (PRISMA**)** guidelines (Moher, Liberati, Tetzlaff & Altman, 2009). The results of the search strategy were summarized in a flowchart including study identification, screening, eligibility, inclusion and analysis (see Figure 2 in Original Publication I). Fourth, the study quality was assessed by independent reviewers. Lastly, the data were extracted (e.g., on study characteristics and findings), analysed and finally reported.

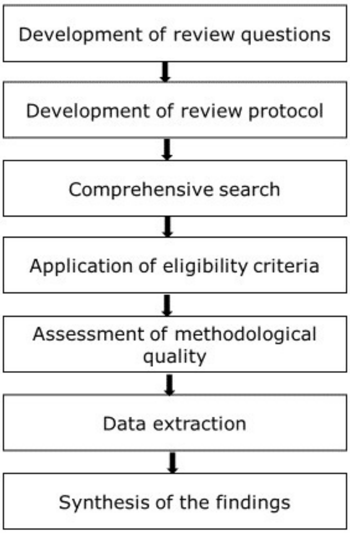


Figure 4. Stages of this systematic review.

Table 1. Inclusion and exclusion criteria for systematic review

Inclusion criteria	Exclusion criteria
Original studies investigating floor mopping and upper extremity physical exposure in cleaners (or in those from related professions).	Studies that examine only the usability of equipment or mopping in a household environment.
Published articles in English in peer-reviewed journals, conference proceedings (i.e., full text) or technical reports (years from 1987 to 2017).	Reviews, book chapters, doctoral thesis and conference abstracts (i.e., brief summary of a conference paper).
Multiple study types.	
Upper extremities' load and strain were quantified in the workplace or laboratory settings by exposure assessment techniques such as direct measurements, observation-based assessments or self-reported methods. Electronically available.	Data presented as general observations (no systematic assessment of physical load). Double issue. Multiple publications based on the same study population were retained if the analyses were conducted for different exposures or outcomes.

Search strategy

The literature search was performed in order to identify all relevant studies related to exposure to physical risk factors for MSDs of the upper extremities associated with floor mopping. First, an electronic database search was conducted in the PubMed, Scopus, CINAHL (EBSCO), Web of Science and ProQuest (Health & Safety Science

Abstracts) databases for the years from 1987 to February 2017. The identification of studies was performed by two reviewers following a priori established eligibility criteria. After having removed duplicate articles across databases, all the remaining study titles were screened against inclusion criteria by two independent reviewers and all potentially eligible titles were included for abstract screening. Based on abstract screening, the full texts of studies were obtained for those that appeared to be potentially eligible or those that could not be excluded on the basis of the information provided in the abstract alone. The full texts were screened, and those that did not meet the initial criteria were excluded from the final review. There was a third researcher available to resolve disagreements if they arose. The inter-rater agreement for final article inclusion was calculated using a measure of percent agreement. Second, hand searching was performed on the reference list of the included papers and relevant reviews. Third, grey literature from the Google Scholar database was searched by searching the included article titles.

The comprehensive search terms were generated with the assistance of an information specialist. Search strings were modified for each individual database using combinations of keywords, synonyms and thesaurus (MeSH) terms. Three groups of seach terms and two groups of MeSH terms are described in the original article (see Original Publication I, Appendix A). All relevant search terms were searched for in their singular, plural and genitive forms, and modified for the specific databases searched. The terms belonging to group 1 (´floor mopping´) were combined with the Boolean search operator ´AND´ with the terms belonging to group 2 (´upper extremity´) and group 3 (´physical exposure´). The last (i.e., group 3) represents the terms regarding musculoskeletal load and strain. In addition, the terms belonging to group 1 were combined with ´AND´ with thesaurus (MeSH) terms (group 4 and group 5). See Figure 5. The search was limited to Humans and the English language. A time limit (years 1987-2017) was used. Medline records were excluded in the Scopus and CINAHL searches.

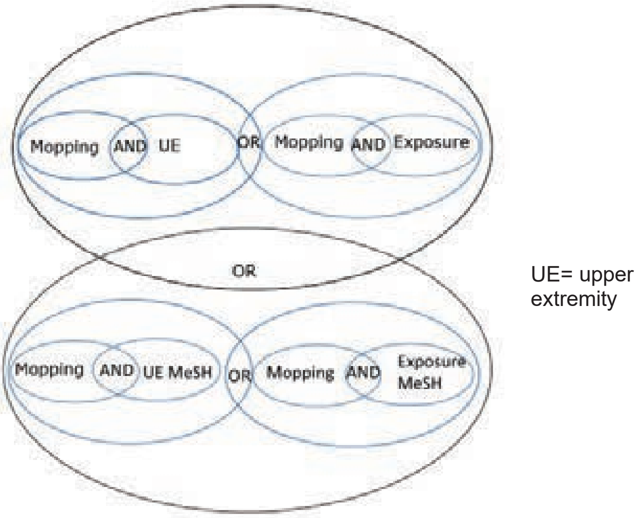


Figure 5. Combination of search terms and operators (literature search in PubMed)

Methodological quality assessment

In systematic reviews, the appraisal of study quality is an essential part of a review process aiming to assess the potential for bias in individual studies (Katrak et al., 2004; Oxman, 1994; Porritt, Gomersall, & Lockwood, 2014). The quality of a systematic review depends on the quality of studies included; therefore, evaluation of methodological quality of each study is crucial. The assessment of the risk of bias is utilized in systematic reviews with a variety of approaches (Lundh & Gøtzsche, 2008). The aim of the critical appraisal in this review was to assess the methodological quality (internal and external validity) of included studies and the extent to which each study addressed the possibility of bias in its design, conduct and analysis. This evaluation process identifies the limitations and strengths of the studies and is essential for assessing the interpretation of the original studies´ results. Thus, it decreases the possibility of including biased or misleading results (Porrit et al., 2014). However, the quality assessment was not used as threshold for inclusion of studies; all studies were included regardless of their methodological quality. Study quality ratings were utilized when establishing evidence synthesis guidelines for the recommendations for practice. In addition, critical appraisal of the studies assists reviewers in determining which methodological study features requires documentation (Meade & Richardson, 1997). In this review, the goal was to provide sufficient information for readers to be able to judge for themselves the applicability of the review to their practice.

No one correct way of assessing a risk of bias exists (Katrik et al., 2004), different study designs may require different instruments (Murad et al., 2014). Before the actual quality assessment, two reviewers pretested the critical appraisal checklists to ensure the applicability of the assessment tool. The methodological quality of the included studies was assessed by two independent reviewers using the Joanna Briggs Institute (JBI, 2016) critical appraisal checklists for Analytical Cross-Sectional Studies or Quasi-Experimental Studies, depending on the type of study. JBI tools do not specify a cut-off value in order to differentiate the study quality levels. Therefore, in this systematic review the methodological quality was scored as ´low´ (<4), ´medium´ (≥4) and ´high´ (>6) in both the observational and the quasi-experimental studies. Appraisal criteria were also applied to the conference proceedings even if their brevity limited the provision of methodological detail. The results of the methodological quality assessment of the included studies were tabulated. The inter-rater agreement for critical appraisal was calculated using measure of percent agreement. As for credibility of review, according Murad et al. (2014) reporting the measure of agreement of the reviewers may strengthen the confidence of the review process. Any discrepancies regarding the quality assessment were resolved by consensus, and if necessary, a third reviewer was consulted. Finally, the overall quality of the studies was evaluated under the heading of bias and strength of the results.

Data extraction and synthesis

The data extraction and synthesis processes were designed to address the research questions. One reviewer extracted and tabulated the following predetermined information related to the research questions and outcomes of interest from each study: author(s), study design, type of mop used, sample characteristics, exposure assessment methods, outcome measures used and relevant research results. A second reviewer checked the accuracy of the data extraction. This was followed by organizing the evidence into the following items: identification of studies (literature search and screening), study characteristics and quality. Then, evidence synthesis was conducted.

The nature of the evidence to be synthesized (Voils, Sandelowski, Barroso, & Hasselblad, 2008), and the purpose of synthesis (Snilstveit, Oliver & Vojtkova, 2012) guided the choice of synthesis method. Owing to the heterogeneity of study methodologies encountered, a best-evidence synthesis approach was used to synthesize the results of the included studies (Slavin, 1995). Best-evidence synthesis has previously been used in occupational health research (Brewer et al., 2006; Cullen et al., 2017; Rivilis et al., 2008; Tompa, Trevithic, & McLeod, 2007; Van Eerd et al., 2016).

First, the performed technical measures on mopping work were identified from the studies reviewed. These measures consider different physical ergonomics measures associated with mopping (i.e., items concerning tools, equipment, methods or working environment). This was followed by organizing the performed technical measures into categories that represented different strategies for reducing musculoskeletal load. These categories are termed ´ergonomic strategies´.

Second, the effects of each particular measure on musculoskeletal outcomes of the upper extremity was assessed. Given the heterogeneity in the studies in terms of design, outcome measures used and reported data, results were synthesized by using a specific criterion for combining the findings. Findings were then aggregated in tabular form. This criterion included the requirement that the technical measure have a positive effect on the musculoskeletal outcomes (that is, exposure to physical risk factors such as posture, force, muscle load, repetition and perceived exertion). To determine the effects in individual studies, the following rules were applied: the positive effect was classified as (+) when the measure resulted in reduction in musculoskeletal outcomes (i.e., reduction in exposure level, duration or frequency), (—) when no effect was observed, and (n/a) when the effect was not measured. A study with both positive effect and no effects on musculoskeletal outcomes was classified as a positive effect study. These evaluations of the directions of the effects were utilized in determining the evidence levels for the ergonomic strategies.

Third, evidence synthesis for each category was determined. Five levels of evidence (i.e., strong, moderate, mixed, partial and insufficient) were defined based on evidence synthesis guidelines adapted from the systematic review by Brewer et al. (2006). The overall strength of evidence for each category (ergonomic strategy) was appraised according to the three factors of quality, quantity and consistency (see evidence synthesis guidelines in Original Publication I, Table 2). ‘Quantity’ refers to the number of studies, ‘quality’ refers to the methodological quality of pertinent studies and ‘consistency’ refers to the similarity of results across studies.

Finally, based on the evidence synthesis, accompanying messages were generated to support evidence-based practice (Cullen et al., 2017; Van Eerd et al., 2016). That is, a strong level of evidence leads to recommendations whereas a moderate level of evidence leads to ´practice considerations´. For all evidence below a moderate level, there was not enough evidence from the scientific literature to make recommendations or practice considerations.

4.3 EXPERIMENTAL DATA COLLECTION

The parameters for Study II and Study III are presented in Table 2.

Table 2. Upper arm, wrist, EMG and perceived exertion parameters (Study II and III)

Study	**Definition of parameters**	**unit**
Study II	*Electromyographic activities (upper-position shoulder)* 10th, 50th and 90th percentiles of amplitude distributions for the upper trapezius, infraspinatus, middle and anterior deltoid muscles[#]. Parameters denoted as APDF10, APDF50 and APDF90.	percentage of maximal voluntary contraction (MVC)
	Perceived exertion Rating of perceived exertion	rating from 0 to 10
Study III	*Upper arm* 50th and 99th percentiles of the arm elevation distribution (regardless of plane)	angles (°)
	Upper arm elevation zone ´neutral´ <20°[a]	percentage of mopping cycle time
	Upper arm elevation zone ´moderate´ between 20° and 60°[a]	percentage of mopping cycle time
	Upper arm elevation zone ´severe´ >60°[a]	percentage of mopping cycle time
	50th percentile of arm elevation angular velocity	°/s
	The ´rest´: upper arm elevation <20° and velocity <5°/s[b]	percentage of mopping cycle time
	Wrist	
	10th, 50th and 90th percentiles of flexion/extension[c]	angles (°)
	10th, 50th and 90th percentiles of ulnar/radial deviation[d]	angles (°)
	50th percentile of the flexion/extension angular velocity of the wrist	°/s
	´Rest´: inside an ellipse with major flexion axis -20 to 20° *and* minor deviation axis -10 to 10°, *and* velocity <5°/s[b]	percentage of mopping cycle time
	´Extreme´: flexion >45° *or* extension >45° *or* ulnar deviation >20° *or* radial deviation >15°.[e]	percentage of mopping cycle time
	Electromyographic activities (forearm) 10th, 50th and 90th percentiles of amplitude distributions for the flexor carpi ulnaris (FCU) and the extensor carpi radialis longus and brevis (ECR) muscles[#]. Parameters denoted as APDF10, APDF50 and APDF90.	percentage of maximal voluntary contraction (MVC)

[#] Jonsson 1982. [a] Limits for the zones were set by modifying the European Standard (2005).
[b] Kazmierczak et al., 2005; Wahlström et al., 2010. [c] Positive angles denote flexion and negative extension. [d] Positive angles denote ulnar deviation and negative radial deviation.
[e] modified from the European Standard (2007).

4.3.1 Electromyography

A Biomonitor ME6000 (Mega Electronics Ltd, Kuopio, Finland) was used for recording surface electromyographic activity from the upper trapezius (UT), infraspinatus (IP), middle (MD) and anterior of the deltoid (AD) muscles, from the arm that the participant preferred to use in a higher position on the mop handle (Study II). In Study III, electromyographic activity was recorded bilaterally from the flexor carpi ulnaris (FCU) and the extensor carpi radialis longus and brevis (ECR) muscles. These muscles were chosen for their relevance to wrist (Chang et al., 2012; Woods & Buckle, 2006; Öhrling et al., 2012) and shoulder function during mopping (Hagner & Hagberg, 1989; Kumar, Hägg, & Öhrling, 2008; Søgaard et al., 1996; Søgaard et al., 2001). The selection of the UT muscle was also based on previous studies, which reported that high trapezius muscle loading might predict disorders in the neck and shoulder region (Aarås, 1994).

Electrode placements and normalization

Prior to electrode placement, the skin was shaved (if required) and rubbed with alcohol over the recording sites in order to reduce impedance levels. A skin impedance of less than 10 KΩ measured using an ohm meter (Fluke 183, True RMS multimeter) was considered acceptable. Surface electrodes were applied over the muscle bellies so that they ran parallel to the muscle fibers (Cram, Kasman, & Holz, 2011). Reference electrodes were placed on an electrically inactive area, in accordance with SENIAM guidelines (Hermens et al., 1999). EMG signals were recorded bipolarly using disposable Ag/AgCl-surface electrodes (Ambu Neuroline 720, Denmark), a gel area diameter of 10 mm and an inter-electrode distance of 20 mm. Table 3 shows placements of the surface electrodes. For the UT muscle, electrodes were placed according to McLean, Chislett, Keith, Murphy, & Walton (2003). For the IP, AD and MD muscles, electrode placement guidelines of Cram et al. (2011) were adopted. For the wrists, muscle mass locations prior to electrode application were confirmed by palpation during muscle-specific movements of the wrist (Cram et al., 2011). For the FCU, electrodes were placed according to the guidelines proposed by Perotto (1994). For the ECR, electrode placement guidelines of Cram et al. (2011) were adopted. The reference electrodes were placed on electrically inactive sites: C7 vertebra, the clavicle, on the acromion, the lateral part of the acromion, as well as the medial and lateral epicondyles.

Table 3. Electrode placements (Study II and III)

Muscle	Electrode placement
Upper trapezius	2 cm lateral to the midpoint of the lead line between the spinous process of C7 and posterolateral border of acromion
Middle deltoid	Lateral aspect of the upper arm, approximately 3 cm below the acromion
Anterior deltoid	Anterior aspect of the upper arm, approximately 4 cm below the clavicle.
Infraspinatus	Approximately 4 cm below the spine of the scapula on the lateral aspect, over the infrascapular fossa of the scapula.
Flexor carpi ulnaris	Two fingerbreadths from the ulna at a distance of one-third the forearm length from the elbow crease
Extensor carpi radialis	Approximately 5 cm distal from the lateral epicondyle, on the dorsal side of the arm slightly lateral to the brachioradialis muscle

In order to normalize shoulder EMG data, it is recommended to use more than one maximal voluntary contraction (MVC) test to facilitate ascertaining the maximal levels of EMG activity (Boettecher et al., 2008; Ekstrom et al., 2005; Ginn et al., 2011). For shoulder muscle normalization, participants performed isometric MVC in three test positions. ′Flexion 125°′, ′empty can′ and ′external 0°′ tests were selected, because it has been reported that the ′flexion 125°′ test maximally activates the UT, AD, MD and IP muscles, whereas the ′empty can′ test maximally activates the UT, AD and MD muscles, and the ′external 0°′ test highly activates the IP muscle (Boettcher et al., 2008). The MVC test positions are described in Table 4. Each contraction was performed against manual resistance for 5 s: 1 s to reach maximum, sustained maximum for 3 s and 1 s to gradual release contraction. Three repetitions of each test were performed, with a rest interval of 30 s between repetitions (Boettcher et al., 2008; Ginn et al., 2011). A rest period of 2 min was held prior to each new test. During tests, standardized verbal encouragement was given to the participants.

Table 4. Description of the maximal isometric voluntary contractions tests (Study II and III)

Normalisation test for the shoulder and forearm muscles	Test position*
Flexion 125°	Shoulder flexed to 125° as resistance applied above elbow and at the inferior angle of scapula attempting to de-rotate scapula.[a]
Empty can	Shoulder abducted 90° in plane of scapula, internally rotated and elbow extended. Arm abducted as resistance applied at wrist.[a]
External 0°	Shoulder kept in pendant position in neutral rotation with elbow flexed 90° and arm externally rotated as resistance applied at wrist.[a]
Extensor carpi radialis	Forearm in pronation, extended and deviated the wrist toward the radial side against manual resistance. [b]
Flexor carpi ulnaris	Forearm in supination, flexed and deviated the wrist toward ulnar side against manual resistance. [b]

*Participants were seated in erect posture without back support. [a]Boettcher et al., (2008), [b]Kendall et al., (2005)

Similarly, three repetitions of 5-second maximal voluntary contractions were performed for the forearm muscles. The participant was seated with the forearm supported on the armrest of the chair. Manual resistance was applied to the FCU and ECR muscles as suggested by Kendall, McCreary, & Provance (2005). See Table 4.

EMG data were collected at a sampling rate of 1000Hz, raw EMG signals were analogically band-pass filtered with an anti-aliasing filter (signal band-pass 8-500 Hz) and preamplified (gain: 1000, a common-mode rejection ratio CMRR of > 130dB, noise < 1 μV).

EMG data processing and analyses

At first, the EMG signals were band-pass filtered (5th order Butterworth, 20-400 Hz pass-band), and the few high-amplitude artefacts were removed using spline interpolation. Root mean square (RMS) amplitudes were calculated using a 250 ms window (Figure 6).

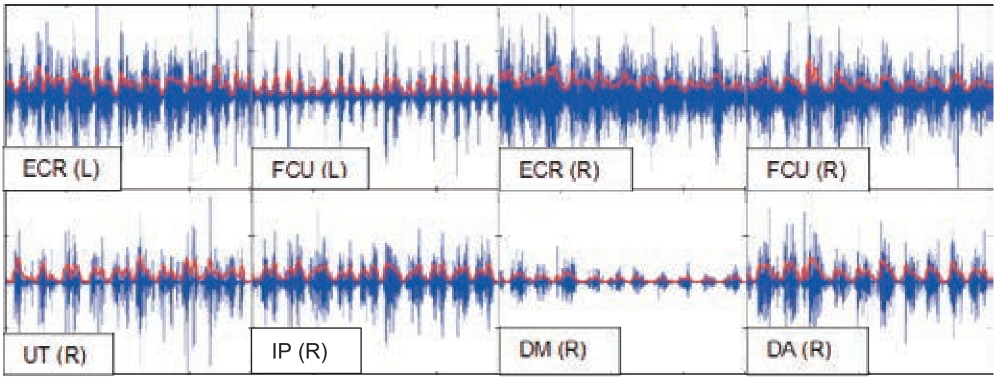


Figure 6. EMG data (arbitrary units) of one participant´s shoulder and forearm muscles in mopping with eye-level mop adjustment (incl. data collected over the course of five mopping cycles). The red line describes calculation of RMS amplitudes (arbitrary units). L= left; R= right. ECR= extensor carpi radialis; FCU= flexor carpi ulnaris; UT= upper trapezius; IP= infraspinatus; DM= middle deltoid, DA= anterior deltoid.

Next, the RMS amplitudes of the mopping trials were normalized according to isometric MVC tests such that a 100 %MVC value corresponds to the highest value obtained during the three shoulder MVC tests, individually for each shoulder muscle and each participant (see Figure 7). Similarly, the signals were normalized to the maximum amplitude obtained during MVC tests of the FCU and the ECR muscles.

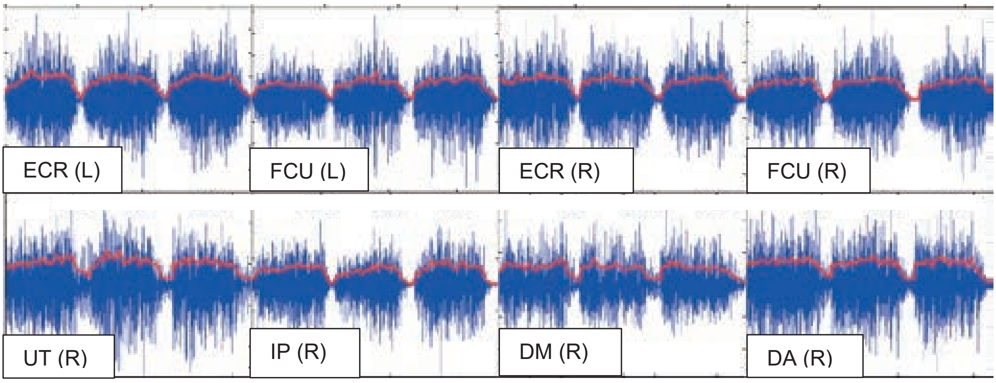


Figure 7. EMG and RMS (arbitrary units) of three repetitions of maximal voluntary contractions for eight muscles: ECR= extensor carpi radialis; FCU= flexor carpi ulnaris; UT= upper trapezius; IP= infraspinatus; DM= middle deltoid, DA= anterior deltoid. L= left; R= right.

Then, the amplitude probability distribution function (APDF) of RMS amplitudes was assessed for each time period when the actual mopping of a 20 m long corridor took place. The APDF of RMS amplitude values (expressed as %MVC) was calculated as follows: a probability density function of the amplitudes was created; from this, a cumulative distribution function was computed. Then, this cumulative distribution function was used to determine the 10th, 50th and 90th percentile values for the RMS amplitudes. The 10% percentile of the function was defined as the static activity level, the median (50% percentile) as the median activity level and the 90% percentile as the peak activity level. Thus, the amplitude probability at certain level was expressed as a fraction of total duration of time that the RMS amplitude (%MVC) was lower than equal to that particular level.

Thus, the 10th, 50th and 90th percentiles of the APDF, expressed as %MVC, for the six muscles (UT, MD, AD, IP, FCU, ECR) were calculated for each participant and for each mopping trial. For the forearm (FCU and ECR) muscles, the APDF was calculated for both hands, whereas for the shoulder (UT, MD, AD and IP) muscles, the APDF was calculated for the upper position arm only. These percentiles were denoted by APDF10, APDF50 and APDF90 and represent static, median and peak activity levels respectively (Jonsson, 1982). In other words, the 10th percentile of the APDF indicates that during only 10% of the measuring time the muscle is under this activity level and 90% above this level. Similarly, the 90th percentile of the APDF indicates that during 90% of the measuring time the muscle is under this activity level and only 10% on time above this level.

Due to poor signal quality, the data for the FCU muscle of the upper hand of one participant were excluded from the analysis. All signal processing and analysis was performed using the MATLAB R2014a environment (The MathWorks Inc., Natick, MA, USA).

4.3.2 Motion analysis

Three-dimensional kinematic data were collected for the wrists and upper arms using a wireless inertial motion capture system (Xsens Technologies, Enschede, Netherlands). Inertial motion capture utilizes IMU to describe human motion. Each IMU (model MTw) comprises three-dimensional (3D) accelerometers, 3D gyroscopes and 3D magnetometers (35 x 58 x 15 mm, 27 g). Data supplied by the IMUs are calculated by a sensor-fusion scheme to measure the orientation of IMUs at each instant of time. Raw data were transmitted by a Bluetooth connection to a laptop computer on which data were processed and further analysed (i.e., calculated and visualised) utilizing MATLAB software.

The 3D orientation of each IMU (hereinafter ´sensor´) is represented by a coordinate system expressed with respect to a global frame. The motion between two consecutive segments can be calculated by attaching a sensor on each body segment of interest. However, the initial pose between the sensor and body is unknown. Thus the motion measurement cannot be converted into interpretable data such as upper limb joint angles unless appropriate calibration is performed. Therefore, a calibration was performed to establish the relation between each sensor coordinate system orientation and the corresponding body segment on which it was attached (i.e., anatomical segment coordinate system). In this way, the sensor orientations could drive the body segment orientations. In order to calculate clinically meaningful joint angles, anatomically derived joint rotation axes and joint coordinate systems are required.

The protocol for assessing upper arm and wrist kinematics consisted of the following steps: 1) positioning of the sensors on participants´ thorax, humerus, forearm and hand; 2) defining anatomical coordinate systems for the thorax and humerus and expressing the anatomical coordinate system orientation in the sensor coordinate system of the corresponding segment; 3) defining the anatomical coordinate system for the forearm and hand, and expressing the anatomical coordinate system orientation in the sensor coordinate system of the corresponding segment; and 4) computing joint angles and angular velocities (see Figure 8). This protocol is described more detailed below.

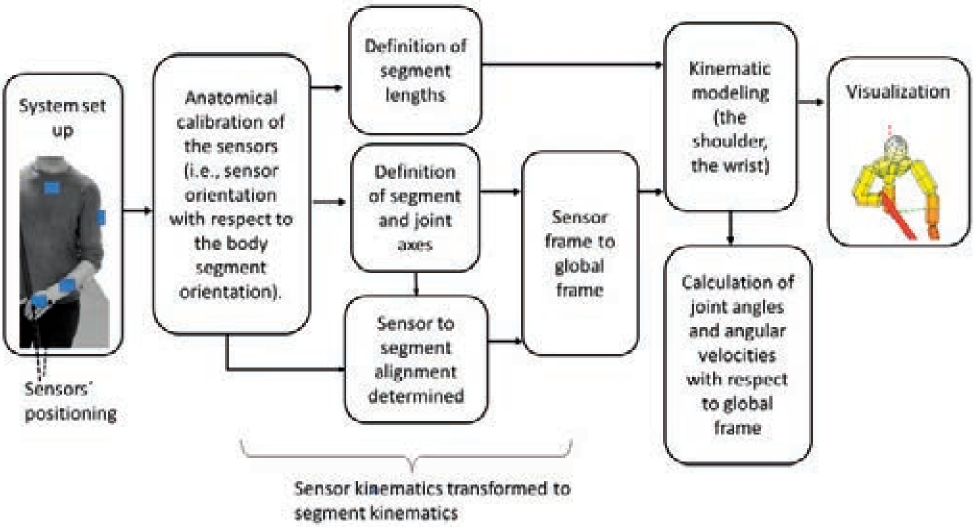


Figure 8. Process for assessing joint kinematics

Sensor positioning and calibration

At first, a total of twelve wireless sensors were placed on each participant´s body segments. (See Table 5 describing sensor placement and attachment). In Study III, seven of these sensors (units a-g) were used in order to record the upper arm elevation as well as wrist flexion/extension and ulnar/radial deviations. Remark: The remaining five sensors that were attached to participant´s head, scapulas and back (units h-k), as well as the mop (unit l) were utilized only for 3D visualization purposes.

Table 5. Sensor placement and attachment on a participant.

Units	Sensor placement and attachment
a	Thorax: on the centre of the sternum[a] in the pocket of a tight-fitting but elastic vest worn by the participant
b, e	Brachium (humerus): over the central third of the humerus in a slightly posterior position[b,c] using straps
c, f	Forearm: over the distal, flat surface of the ulna and radius[a,b]
d, g	Hand: located on the dorsal hand surface in the pocket of the half glove
h*	Head: with a band
I*, j*	Scapulas: in the pocket of elastic vest
k*	Lower back: in the pocket of elastic vest

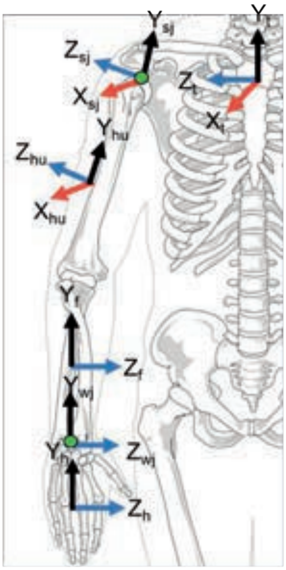
[a]van den Noort et al., (2014); [b]Cutti et al., (2008); [c]Parel et al., (2012); *for visualization purposes only

Then, calibration measurements were performed. Static calibration measurement was primarily conducted with the participant standing for a few seconds in a static upright posture, the upper arm along the trunk for neutral humerus external/internal rotation (0° elevation), the elbow in 90° of flexion (van den Noort et al., 2014), and the wrist in an anatomically neutral position with the 3rd metacarpal aligned with the long axis of the forearm and neutral forearm posture (supination/pronation). The validity of calibration was visually confirmed using measurements of the participant performing a T-pose (abduction 90°) and an N-pose (arms neutral beside the body). Using these calibration measurements, misalignments between the sensors and the underlying bones were determined (Morton, Baillie, & Ramirez-Iniguez, 2013).

Anatomical and joint coordinate systems

Shoulder and wrist kinematic models with 3D motions were reconstructed. The length of the segments was determined utilizing the body dimensions measured and subsequently fed into the software to construct a model. These relative distances between joints were determined only for visualization purpose.

Segment orientations were obtained by applying the sensor-to-segment alignment, and segment axes were generated using a static pose performed by each participant during calibration. Anatomically derived joint rotation axes and joint coordinate systems were then defined. Anatomical coordinate systems were based on International Society of Biomechanics (ISB) recommendations (Wu et al., 2005). Motions were described by anteriorly, superiorly and laterally directed axes, each perpendicular to one another. The shoulder was modelled as a joint with three degrees of freedom (DoF). The anatomical (i.e., segment) coordinate systems of the thorax and the humerus were based on assumption of vertical direction during the static upright calibration posture (i.e., y-axis pointing superiorly). For the thorax, these axes were aligned with the frontal, sagittal, and transverse planes (Figure 9). The humeral elevation through adduction-abduction is a rotation about the X axis; the extension-flexion is a rotation about the Z axis and the internal-external rotation is a rotation about the Y-axis (Figure 9). In study III, the humerus orientation relative to the thorax was described in terms of upper arm elevation. The elevation angle of the upper arm was recorded independent of direction (i.e., not separated into flexion/extension, abduction/adduction).



Thorax (t) coordinate system:
Y_t axis is directed superiorly
Z_t axis is directed laterally
X_t axis is directed anteriorly

Humerus (hu) coordinate system:
Y_{hu} axis is directed superiorly
Z_{hu} axis is directed laterally
X_{hu} axis is directed anteriorly

Forearm (f) coordinate system:
Y_f axis is directed proximally
Z_f axis is directed radially
X_f axis is directed volarly

Hand (h) coordinate system:
Y_h axis is directed proximally
Z_h axis is directed radially
X_h axis is directed volarly

Dorsal view of the right hand and forearm

Figure 9. Anatomical (i.e., body segment) coordinate systems as well as shoulder joint (sj) and wrist joint (wj) coordinate systems. Image modified from Pixabay.

For the wrist, forearm, and hand coordinate systems, the Y axis is directed proximally (see anatomical coordinate systems in Figure 9). In this study, the wrist was modelled as a single joint (merged radio-ulnar and radio-carpal joints, i.e., ulna and radius as a single segment). Wrist flexion (+)/extension (-) is a rotation about the Z axis and ulnar (+)/radial (-) deviation is a rotation about the X axis. The forearm pronation-supination is a rotation about the Y axis (not analysed in this study).

Once the anatomical coordinate systems were defined, the orientation of each body segment with respect to global frame was calculated. Since the coordinate transformation had been performed, a kinematic model for calculating the joint kinematics was put to use.

Computing joint kinematics

A joint rotation was defined as the orientation of a distal segment with respect to a proximal segment orientation (Roetenberg, Luinge, & Slycke, 2013). Therefore, calculation of joint angles and angular velocities (i.e., angular change per unit time) was conducted as follows: the orientation of the hand (unit d) was computed with respect to the forearm (unit c). Further, the humerus orientation (unit b) was expressed relative to the thorax (unit a). These joint rotations that describe joint angles were represented using Euler angles.

The kinematic parameters are presented in Table 2. The percentiles of angular and angular velocity distributions were calculated for characterising positions and movements of the upper arm and wrist (Hansson et al., 2010; Nordander et al., 2016;

Rislund et al., 2013; Wahlström et al., 2010). For the wrists, the 10th and 90th percentiles of angular distributions were used to describe the wrists′ extreme positions while mopping. The 10th percentile represents the angle that is exceeded in the extension or radial deviation direction for 10% of the time: i.e., as a measure of the peak extension or peak radial deviation of the wrist. Accordingly, the 90th percentile corresponds to the peak flexion or peak ulnar deviation.

In addition, the proportion of the mopping cycle time spent in predefined angular zones was calculated. Limits for the angular zones of the upper arm and wrist were set by modifying the European Standard EN1005-4 (2005) and the European Standard EN 1005-5 (2007). The mopping cycle time was calculated in order to define movement repetitiveness in general. These measured parameters covered the main dimensions of physical load: the aspects of frequency, time and level.

4.3.3 CR-10 scale

The level of perceived exertion for the shoulder area during floor mopping was assessed by Borg's Category-Ratio Scale (CR-10 scale) ranging from 0 to 10 (Borg, 1990). According to Borg (1982), the overall rate of perceived exertion is an integrated configuration of various signals, perceptions and experiences of the body overcoming physical strain. These self-reported measures of exertion have previously been used in evaluation of the effect of physical workload on the musculoskeletal system while mopping (Hopsu et al., 2000; Öhrling et al., 2012).

Previous research has shown the relationship between perceived exertion and physiological variables (e.g., blood lactate concentration and heart rate; Gamberale, 1972; Borg, 1990). The CR-10 scale has been shown to be an acceptable approach for quantifying muscle force (Troiano et al., 2008) and fatigue (Hummel et al., 2005). Subjective perception of exertion in the neck region is shown to correspond with physiological muscle fatigue of the upper trapezius during repeated shoulder elevation endurance tasks (Hummel et al., 2005). Similarly, positive correlation (r=0.99) has been indicated between ratings on a CR-10 scale and objective measure of exerted force (RMS values) (Troiano et al., 2008).

4.3.4 Questionnaire and anthropometric characteristics

Background information on participants' basic demographic data (e.g., age, gender), hand dominance and work experience characteristics was obtained by means of a self-administered questionnaire. Participants were also asked to assess their perceived musculoskeletal pain, and to assess the intensity of perceived pain in their shoulder and upper extremities over the last month by means of a Numeral Rating Scale (NRS-11) ranging from 0 (=no pain), to 10 (=worst imaginable pain). This scale is frequently used for pain assessment in various study populations (Hjermstad et al., 2011). It has been shown that NRS-11 has approximately equal sensitivity to changes in pain intensity compared to the Visual Analogue Scale (VAS) (Breivik, Björnsson, & Skovlund, 2000).

Anthropometric measurements consisted of body weight, height and Body Mass Index (kg/m^2). Further, anthropometric dimensions of the upper limbs were measured according to Pheasant (1996) as follows: shoulder height, shoulder breadth (biacromial), shoulder-elbow length, elbow-fingertip length and hand length. In addition, forearm length and distance between the elbow and hand grip were measured. Upper limb dimensions were measured to the nearest 0.1 cm. Body height was recorded to the nearest 0.5 cm and body weight to the nearest 0.1 kg.

4.3.5 Measurement protocol

An aluminium telescopic mop handle and a 60 cm wide mop frame with unlocked swivel mechanism were used in the experiment (Study II and III; see Figure 10). The shaft of the mop handle was 2.6 cm in diameter. The handle grip was composed of ribbed plastic, 13.5 cm in length and 3.2 cm in diameter. The mop weighed 850 g. A microfiber mop cloth (approximately 120 g) was used and a standard moisture content was achieved by dampening the mop with 60 ml of water.

Handle length extends from 100 to 170cm.

Figure 10. Mop device used in the experiment.

The pilot test was conducted prior to the actual experiment (in October 2014) in order to evaluate the feasibility of measurement protocol. Before the actual experiment, all participants had given their informed consent after being given a detailed description of the study both verbally and in text form. Fifteen minutes before the experiment, microfiber mop cloths were dampened and then put in plastic bag. Before the experiment, the mop cloths were weighed on a scale (Precisa model XT 6200C).

The experiment included three phases. First, the participants filled out a questionnaire, including questions about individual characteristics (e.g., age, dominant hand), experience in cleaning work and subjectively perceived symptoms and pain. The intensity of perceived pain for the shoulders and upper extremities over the previous month was assessed by means of a Numeral Rating Scale (NRS-11) (Hjermstad et al., 2011). After filling out the questionnaire, the anthropometric measurements (body weight, height and dimensions of upper limbs) were conducted and Body Mass Index (kg/m²) was calculated. Then, participants were instructed in the use of Borg's CR-10 scale (Borg, 1990). Before placing the electrodes, the skin was carefully prepared and skin impedance was measured. Electrode cables were fixed with elastic tape to minimize motion artefacts.

In the second phase of the experiment, subjects practiced each MVC test. Next, actual MCV test recordings were conducted. Inertial sensors were placed on the participant and mop, and calibration measurements were conducted. The anthropometric measurements, electrode placements, calibration postures and MVC tests were conducted by the same researcher (MAW). There was a rest period of 5 min before beginning the mopping trials.

In the third phase of the experiment, the participants mopped the floor surface of a 20 m long and 1.79 m wide corridor back and forth once. Participants walked forward while they moved the mop from side to side in a figure-eight pattern. The participants were encouraged to use their habitual style and normal working rhythm, and they were allowed to practice before the first trial. Each participant performed four trials of mopping. Each trial consisted of using a different mop handle height (Figure 11) in randomized order. The mop handle heights were selected according to prior studies (Goggins, 2007; Hopsu et al., 2004; Woods & Buckle, 2005) and easily recognisable anatomical landmarks were chosen for practical adjustments. The mop height was also measured after each mop height adjustment. Breaks of 5 min were given between the trials to prevent the cumulative effect of local muscle fatigue. At the end of each trial, the participants were asked to verbally rate their level of perceived exertion for the shoulder area using a CR-10 scale from 0 to 10: 0 for ´nothing at all´ to 10 for ´an extremely strong´ exertion (Borg, 1990).

Figure 11. Four different mop heights were compared in this experiment. The top of the mop handle was adjusted to four levels as follows: (A) shoulder level: slightly below the lateral border of clavicle; (B) chin level: in line with chin; (C) nose level: in line with the apex of the nose; and (D) eye level: in line with the corner of the eye. Image (E): When the mop heights were adjusted, the participant stood in a neutral position, gripped the upper mop handle with the preferred hand and placed the opposite foot on the top of mop frame. The partipant selected the lower position hand´s height so that it was comfortable to perform the figure-eight mopping.

After the mopping trials, the participants were asked two open-ended questions concerning their subjective preference of the the experimental mop heights: ′What height of the mop handle do you prefer?′ and ′Why do you prefer that particular height?′ Mop handle lengths were measured after each mopping trial, and mop cloths were weighed after the last trial.

4.4 STATISTICAL ANALYSES

In Study I, the heterogeneity of the studies reviewed impeded statistical pooling of results. Thus, a Best Evidence Synthesis was conducted in order to generate final conclusions.

In study II, descriptive statistics (median, mean, standard deviation, range, quartiles) were calculated. The APDF parameters were logarithmically transformed due to the skewness of the distribution. After logarithmic transformation, the normality was tested using the Kolmogorov-Smirnov -test. The linear mixed model was used for statistical analysis to examine the differences in the shoulder muscle activities among four different mop handle heights. The Sidak method was performed for multiple comparison. The dependent variables used were logarithmically transformed shoulder muscle activity parameters: 10th, 50th, and 90th percentile APDFs of the root mean square (RMS) EMG data. Each logarithmically transformed EMG parameter (denoted by APDF10, APDF50 and APDF90) was used as a dependent variable and analysed separately. The mop handle heights (i.e., shoulder, chin, nose and eye level) and muscles (i.e., UT, IP, MD, AD) were used as fixed factors in all analyses. Further, in Study II, the non-parametric Friedman's test was used to examine the differences in perceived exertion among four different mop handle heights. It was hypothesized that shoulder muscle activities and perception of exertion would differ among different heights of mop handle. In all tests, $p<0.05$ was considered as statistically significant.

In Study III, descriptive statistics (median, mean, standard deviation, range, standard error of the mean, percentiles or percentages of time) were calculated according to the muscle activity, position or movement parameters. The Shapiro-Wilk normality test revealed that the EMG and kinematic parameters did not display normal distribution. The non-parametric Friedman's test was used to examine the within-subject differences in kinematic and EMG parameters among four different mop handle heights. Each kinematic and EMG parameter was analysed separately. It was hypothesized that the upper arm elevation angles and angular velocities would differ among different mop handle heights. Probability values of $p<0.05$ were considered statistically significant. In the case of significant results, post hoc analyses using the Wilcoxon signed-rank test were conducted with a Bonferroni correction applied, resulting in a significance level set at $p<0.008$.

All values in the thesis for Study II and III are presented as group median unless otherwise indicated. In Studies II and III, data were analyzed using SPSS Statistics versions 22.0 and 23.0 (SPSS Inc., Chicago IL, USA).

4.5 ETHICAL CONSIDERATIONS

The study was conducted in conformity with the Declaration of Helsinki. All study procedures involving human subjects were approved by the Committee on Research Ethics of the North Savo Hospital District, Finland. Written informed consent was obtained from all participants after the study protocol was explained to them.

5 RESULTS

The results are presented here according to each of the studies of which this dissertation is composed and following the aims of the study (Studies I-III). The first sub-section describes the results from Study I concerning the effects of the performed technical measures in floor mopping work, and proposes ergonomic strategies for reducing musculoskeletal load. The second sub-section presents results from Study II concerning shoulder muscles activities and perceived exertion. The third section describes results from upper arm and wrist positions and movements as well as forearm muscles' activities. The final part of the chapter summarizes the findings of this study.

5.1 RESULTS FROM STUDY I

5.1.1 Literature search and screening

The search (covers the period from 1987 to February 2017) identified 2002 references once the results from the different databases were combined and duplicates removed. Overall, 1993 references and full text papers were excluded for not meeting the eligibility criteria. Thus, the database search identified nine studies. Five additional papers were identified through a manual search. A total of 14 studies met the inclusion criteria. However; three of the studies were excluded from this review as those studies measured the musculoskeletal load of the upper extremities associated with mopping but they did not examine any specific measure that can be isolated from the study. As a result, 11 papers were included in the review (see Figure 2 for study selection procedure in the Original Publication I).

5.1.2 Study characteristics and quality

Characteristics of the included 11 studies are presented in Original Publication I, in Table 3. Eight of the 11 studies included in the review were research articles and three were conference papers, the sample size for instrumented measurements varying across studies from 6 (Conner & Irwin, 2009) to 37 (Hopsu et al., 2000). Eight of the included studies were experiments with within-subject designs and the remaining three studies were observational studies. Most of the studies were carried out in Europe (n=10, 91%) and almost half the studies (5/11, 45%) were published between 2007 and 2017 (see Table 6). The majority of studies involved a majority of female participants (apart from one study with male participants and two studies not reporting gender).

Table 6. Relative frequency table for included studies examining floor mopping and musculoskeletal load and strain of upper extremities.

Years	Frequency (f)	Percentage frequency
1987-1996	2	18
1997-2006	4	36
2007-2017	5	45
Total	11	≈100%

The study quality rating scores on the JBI critical appraisal tool range from 3 to 6 for observational studies and 4 to 6 for experiments. None of the studies were classified as meeting the criteria for ′high′ quality. Ten out of 11 studies included in this review were classified as meeting the criteria for ′medium′ quality with one study classified as of ′low′ quality. Details of the results of critical appraisal for all the included studies are presented in Original Publication I, Appendix B.

Bias and strength of results

None of the studies included were longitudinal or randomized control studies. As to establishing cause-and-effect relations, there was no confusion in the experiments analyzed about which variable was measured as an independent variable (′cause′, e.g., type of tool) and as a dependent variable (′effect′, e.g., level of electrical activity of the muscle). In addition, in each study the outcomes were measured in the similar way in compared groups. These factors strengthen the internal validity of studies at the data collection stage.

In the absence of random assignment (i.e., a lack of random allocation of participants in groups), the included quasi-experimental studies are more prone to bias because not all possible confounders can be controlled. None of the studies included control groups in their experiments, which may weaken the validity of causal inferences. However, all the experiments employed within-subject design in which each participant served as their own control. In most experiments, the reliability of measurements performed was good but there was lack of reporting as to intra-rater or inter-rater reliability within the studies.

In some (2/3) observational studies, study samples as well as participants and settings were not clearly defined. The potential confounding factors (e.g., lack of control of the presence of other cleaning tasks) were identified in all studies. Nevertheless, the strategies for dealing with them were not always stated (or were not applicable).

Appropriate statistical analysis was used in the majority of studies (9/11), which increases the strength of the results obtained. However, the sample size for individual studies were small, and none of the studies reported sample size calculations and power analyses. In addition, it was decided that it would be inappropriate to synthesize the results quantitatively due to the methodological differences (e.g., methods, outcome measures, data reporting) across the included studies. Thus, a best-evidence synthesis approach was used.

5.1.3 Evidence synthesis

In the studies reviewed, the upper extremities' load and strain in mopping was evaluated by a variety of methods, outcomes and outcome measures. The most commonly used musculoskeletal outcome was muscle load (activity), which was noted in nine studies. Five studies assessed posture outcomes and three studies evaluated perceived exertion outcomes. Two of the studies examined force outcomes and a single study evaluated repetition outcomes (i.e., mopping cycle time). Details for outcome measures of original studies are presented in Original Publication I, Table 3.

The performed technical measures and the associated floor mopping conditions across the 11 studies were grouped into four main categories that represent ergonomic strategies for reducing musculoskeletal load of the upper extremities. These categories are named as follows: (a) mop design; (b) mopping method; (c) mopping technique; and (d) environment modification (Table 7). The category of mop design was further divided into the following subcategories: handle type and type of tool.

Technical measures

A synthesis of results of the effects of specific measures on physical risk factors (i.e., musculoskeletal outcomes of upper extremity) is presented in Table 7. Six medium-quality studies out of 11 studies found a positive effect on musculoskeletal outcomes. The following technical measures performed in the studies reviewed were found to reduce musculoskeletal strain of the upper extremities: different mop design considerations such as handle type (Wallius et al., 2016; Öhrling et al., 2012); a type of tool (Conner & Irwin, 2009); less amount of water used in a mop (Hopsu et al., 2000); utilizing a push mopping technique as opposed to the figure-eight technique (Hagner & Hagberg, 1989); and work environment improvements, that is: attaching electric cords above the floor in office buildings before cleaning (Kumar, Chaikumarn, & Lundberg, 2005b). Following the assessment of measures, evidence synthesis for each ergonomic strategy was determined.

Table 7. Synthesis of studies examining effects of different measures on physical risk factors in mopping work, organized by specific categories of strategies.

Author, year	Study design	Technical measure #	Posture		Force	Muscle Activity		Repetition	Perceived Exertion
			Arm	Wrist		Arm	Wrist*		
Mop design (handle type): individual adjustable tools									
Wallius et al. (2016)	Experimental	Mop adjustability: four different mop handle heights compared	n/a	n/a	n/a	+	n/a	n/a	+
Öhrling et al. (2012)	Experimental	Mop adjustability: easily adjustable handle and non-adjustable type of handle compared	n/a	n/a	n/a	+	+	n/a	+
Mop design (type of tool): use of alternative types of tools									
Conner & Irwin (2009)^{c}	Experimental	Comparison of four types of mopping systems: flat mop with a microfiber pad; mop and bucket; backpack system; and bent-handled applicator.	n/a	n/a	n/a	+	+	n/a	n/a
Søgaard et al. (1996)	Observational	Mopping with mini-mop compared to traditional scrub and cloth method.	-	n/a	n/a	-	n/a	-	n/a
Søgaard et al. (2001)	Experimental	Mopping with mini-mop (i.e., a round-headed mop with long threads) compared to scrubbing (both with ordinary handle and a handle equipped with force dynamometers).	-	n/a	-	-	n/a	n/a	n/a
Woods & Buckle (2005)	Observational	Two types of hand-held mop squeezing mechanisms compared: standard bucket and hand-lever bucket.	n/a	n/a	-	n/a	n/a	n/a	n/a
Mopping technique: use of the mopping technique resulting in less musculoskeletal strain									
Hagner & Hagberg (1989)	Experimental	Comparison of two mopping techniques: push mopping technique and figure-eight technique.	+	n/a	n/a	+	n/a	n/a	n/a
Mopping method: use of mop materials and associated methods either without water or minimal amount of water									
Cabeças (2007)	Observational	Comparison of two types of mopping method: cotton dust mop and cotton wet mop.	n/a	n/a	n/a	n/a	-	n/a	n/a
Hopsu et al. (2000)^{c}	Experimental	Seven different mopping methods compared: dry, damp, moist, wet, micro fibre-dry, micro fibre-damp and oil.	-	n/a	n/a	+	+	n/a	-
Environment modification: pre-actions for ensuring clear floor surface									
Kumar et al. (2005b)	Experimental	Comparison of office mopping task before and after the environment modification (i.e., electric cords on a floor surface and electric cords attached above the floor).	+	n/a	n/a	n/a	n/a	n/a	n/a
Kumar et al. (2008)^{c}	Experimental	Comparison of mopping between two types of floor surface: polished floor and non-polished floor.	n/a	n/a	n/a	-	-	n/a	n/a

Note. # Measures performed in original studies (e.g., effects of handle type on physical risk factors (i.e., musculoskeletal strain outcomes of upper extremity) examined); (+) = measure resulted in reduction in musculoskeletal strain (i.e., exposure level, duration or frequency); (-) = no effect; (n/a) = effect of measure on musculoskeletal strain not examined; * wrist or forearm; ^{c} conference paper

Strategies and measures for reducing musculoskeletal load

Mop design. Six of the studies reviewed examined measures regarding mop design (see Table 8): three medium-quality studies found a reduction in musculoskeletal outcomes, whereas two medium-quality studies and one low-quality study found no effect. Thus, application of evidence synthesis guidelines showed that there was a moderate level of evidence for changes in mop design in the reduction of musculoskeletal load. In examining the subcategory of this strategy (i.e., handle type), we see that the two medium-quality studies that evaluated an adjustable type of mop handle (Wallius et al., 2016; Öhrling et al., 2012) provided a moderate level of evidence that individual adjustable tools have an effect on musculoskeletal load. Wallius et al. (2016) found that shoulder muscle strain for the hand placed higher on the mop handle and level of perceived strain were decreased by adjusting the height of the upper mop handle. Similarly, Öhrling et al. (2012) demonstrated that the use of easily adjustable mop handles in staircase mopping decreased levels of perceived strain and muscle strain for the right-hand shoulder and for the left-hand wrist.

Table 8: Level of Evidence for Ergonomic Strategies and Accompanying Messages

Level of evidence* (direction of effect)	**Category of strategies**	**Original study, year**	**Quality rating**	**Message for practice**
Moderate (positive)	Mop design: handle type	Wallius et al. (2016) (+)	Medium	Practice consideration
		Öhrling et al. (2012) (+)	Medium	
Moderate (no effect)	Mop design: type of tool	Conner & Irwin (2009)(+)	Medium	
		Søgaard et al. (1996)	Medium	
		Søgaard et al. (2001)	Medium	
		Woods & Buckle (2005)	Low	
Mixed	Mopping method	Cabeças (2007)	Medium	Not enough scientific evidence to guide current practices
		Hopsu et al. (2000) (+)	Medium	
	Environment modification	Kumar et al. (2005b) (+)	Medium	
		Kumar et al. (2008)	Medium	
Insufficient	Mopping technique	Hagner & Hagberg (1989) (+)	Medium	

* None of the studies met the criteria for a strong or partial level of evidence. (+) positive effect study: i.e., reduction in musculoskeletal strain was found due to the technical measure performed in the study (e.g., change of method or tool).

Type of tool. Four studies, three of medium-quality (Conner & Irwin, 2009; Søgaard et al., 1996; Søgaard et al., 2001) and one of low-quality (Woods and Buckle, 2005), examined alternative types of tools. One of them (Conner & Irwin, 2009) found a reduction in musculoskeletal outcomes while the other three studies found no effect. The study by Conner and Irwin (2009) compared four different floor-finishing and clean-up applicators and found significantly lower muscle strain for the upper arms and forearms while using a bent-handled applicator versus the flat mop or traditional mop-and-bucket system. A bent-handled applicator was reported to be equal to the backpack system. The other two studies (Søgaard et al., 1996; Søgaard et al., 2001) evaluated the change from a traditional scrubbing method to mopping with mini-mop and detected no significant differences in the shoulder muscle strain. Further, differences in the arm angles, the moments of force in the shoulders and work cycle times were minor between mopping and scrubbing. Thus, the authors concluded that changing the floor cleaning tool was not a sufficient preventive strategy for reducing the load on the shoulder (Søgaard et al., 2001). One study (Woods & Buckle, 2005) reported no differences in levels of hand force between the two types of manual mop-squeezing mechanisms used. Thus, these four studies provided moderate evidence for concluding that changing the type of tool (as implemented in the studies reviewed) has no effect on musculoskeletal load.

Mopping technique. One medium-quality study (Hagner & Hagberg, 1989) evaluated two different techniques for performing mopping and showed positive effect on musculoskeletal outcomes for the push mopping technique as opposed to the figure-eight technique. This study reported significantly less shoulder muscle strain and perceived strain, as well as more convenient upper arm postures, while utilizing the push mopping technique as opposed to the figure-eight technique. This single study provided insufficient evidence for concluding that use of a particular mopping technique reduces musculoskeletal load.

Mopping method. Two medium-quality studies evaluated mopping methods in which the mop head material and the associated moisture level of the mop heads were contributing factors. The study by Hopsu et al. (2000) compared seven different mopping methods in which mop head moisture level ranged from dry to wet. The stydy demonstrated that the forearm and shoulder muscular strain of microfiber dry or dry mopping methods were significantly lighter than methods utilizing water (i.e., wet and moist mopping methods). The mopping method had no effect on perceived strain or postures of the arms (Hopsu et al., 2000). Another study (Cabeças, 2007) compared the use of a cotton dust mop and wet mopping with a string mop and showed no significant differences in muscle strain for the wrists between mopping with these two methods. Thus, using evidence synthesis guidelines, mixed evidence was found that mopping floors with methods without water or a minimum amount of water reduces musculoskeletal load.

Mopping environment modifications. Two medium-quality studies assessed the effects of pre-actions for ensuring a clear floor surface for mopping: one found no effect (Kumar et al., 2008) whereas one found a positive effect on physical exposure outcomes (Kumar et al., 2005b). The study by Kumar et al. (2008) compared mopping on two types of floor surfaces (polished versus non-polished floor) and detected no significant differences between these two types of floor surfaces in muscle strain for the wrist and shoulder while mopping. Another study (Kumar et al., 2005b) showed that pre-actions in the work environment, such as fixing electrical cords above the floor, reduced the time spent in harmful arm postures above the shoulder level. Thus, application of evidence synthesis guidelines indicated that these studies provide mixed evidence that pre-actions for ensuring a clear floor surface reduces musculoskeletal load.

Recommendations/suggestions

Application of the evidence synthesis guidelines indicated that none of the ergonomic strategies for reducing musculoskeletal load met the criteria for a strong level of evidence. Therefore, this precludes recommending any specific strategy or measure for inclusion in practice. However, the strategy concerning individually adjustable tools showed a moderate level of evidence. Therefore, use of adustable mop handles can be considered as practice to consider.

5.2 STUDY PARTICIPANTS (STUDIES II AND III)

A total of 13 volunteer professional cleaners (12 females and 1 male) participated in this study. The mean age of the participants was 41 years (range 21-58). The mean weight and height of participants were 70 (range 52-83) and 163 (range 149-180), respectively. The participants' work experience in cleaning work was 11 years (range 1-29). All except one of the participants were dominant right-handed. Twelve out of 13 participants used their right hand higher on the mop handle (i.e., upper position hand) during the floor mopping experiment.

Demographic and anthropometric data for the participants and the experimental heights of the upper mop handle (i.e., mop height measured with respect to anatomical landmarks) are shown in Table 9. In the month prior to the experiment, symptoms in the shoulder region had been experienced by 10 participants and the mean intensity of the pain was 4.6 (range 1-8) using the NRS-11 scale. One participant had experienced soreness in his/her forearms in the month prior to the experiment.

Table 9. Means and standard deviations (SD) of participants' demographic and anthropometric characteristics as well as experimental height of the upper mop handle in Study II and III (n=13)

Characteristic	**Mean (SD)**
Age (years)	41 (14.6)
Experience in cleaning work (years)	11 (11.4)
Height (cm)	163 (8.1)
Weight (kg)	70 (9.6)
Body Mass Index (kg/m²)	26.5 (4.0)
Shoulder height (cm)	135.5 (7.0)
Shoulder-elbow length (cm)	33.8 (2.3)
Elbow-fingertip length (cm)	43.5 (1.9)
Hand length (cm)	17.3 (0.8)
Shoulder breadth (biacromial) (cm)	35.7 (3.1)
Forearm length (cm)	24.7 (2.6)
Distance between elbow and hand grip (cm)	31.6 (3.0)
Height of the mop handle	**Mean (SD)**
Height of mop at shoulder level (cm)	136 (6.8)
Height of mop at chin level (cm)	143 (8.1)
Height of mop at nose level (cm)	151 (7.9)
Height of mop at eye level (cm)	155 (7.6)

5.3 SHOULDER MUSCLE ACTIVITIES AND PERCEIVED EXERTION (STUDY II)

5.3.1 Muscle activities

Descriptive data for the APDF10, APDF50 and APDF90 parameters are shown in Table 10. Both the mean and median values are presented to describe the shape of the distribution (Table 10). At static activity level, APDF10 values ranged from 0.2% MVC to 13.7% MVC. The respective values for the median activity level (APDF50) ranged from 0.6% to 21.9% MVC. At peak activity level, APDF90 values ranged from 1.1% to 31.9% MVC.

The linear mixed model analysis revealed that the height of the upper mop handle had a statistically significant effect on log(APDF10) (*p*<0.001), log(APDF50) (*p*=0.003) and log(APDF90) (*p*=0.026) parameters.

Table 10. Median, mean and standard deviation (SD) values of APDF10, APDF50 and APDF90 EMG parameters during floor mopping with four different mop heights.

Muscle	**Shoulder level Median (mean±SD)**[a]	**Chin level Median (mean±SD)**[a]	**Nose level Median (mean±SD)**[a]	**Eye level Median (mean±SD)**[a]
Upper trapezius				
APDF10	1.28 (1.60 ± 1.26)	1.29 (1.78 ± 1.61)	1.87 (2.32 ± 1.53)	1.87 (3.23 ± 3.52)
APDF50	3.24 (3.94 ± 2.49)	3.40 (4.45 ± 2.93)	5.45 (5.76 ± 2.63)	5.87 (7.45 ± 4.93)
APDF90	6.43 (7.72 ± 4.61)	7.83 (9.38 ± 5.58)	10.30 (11.12 ± 4.59)	12.70 (13.58 ± 6.60)
Infraspinatus				
APDF10	2.59 (3.07 ± 1.70)	2.55 (3.20 ± 1.85)	2.77 (3.53 ± 2.09)	3.50 (4.06 ± 2.32)
APDF50	4.44 (4.96 ± 2.37)	4.27 (5.13 ± 2.38)	4.54 (5.76 ± 2.66)	5.82 (6.86 ± 3.21)
APDF90	8.30 (8.83 ± 3.59)	7.98 (8.61 ± 3.11)	8.36 (9.28 ± 3.58)	9.25 (10.76 ± 4.41)
Anterior deltoid				
APDF10	1.30 (1.50 ± 0.97)	1.15 (1.53 ± 1.15)	1.25 (1.86 ± 1.66)	2.28 (2.44 ± 1.93)
APDF50	3.05 (3.32 ± 2.07)	3.47 (3.69 ± 2.85)	3.49 (4.57 ± 3.92)	4.97 (5.45 ± 4.01)
APDF90	6.68 (6.40 ± 3.69)	5.73 (6.65 ± 5.12)	7.75 (8.68 ± 6.97)	9.83 (10.85 ± 7.60)
Middle deltoid				
APDF10	0.60 (1.23 ± 1.52)	0.65 (1.11 ± 1.13)	0.74 (1.35 ± 1.21)	0.90 (1.27 ± 0.90)
APDF50	2.05 (3.59 ± 2.59)	1.90 (3.12 ± 2.10)	2.36 (3.13 ± 2.18)	2.90 (3.14 ± 1.81)
APDF90	4.84 (7.44 ± 4.36)	4.88 (6.22 ± 3.38)	4.45 (5.56 ± 3.37)	5.40 (5.67 ± 3.09)

[a] with non-log transformed data. 10th, 50th and 90th percentiles of Amplitude Probability Distribution Function (APDF) of EMG from the upper trapezius, infraspinatus, anterior and middle deltoid muscles. Units are in terms of percentage of maximum voluntary contraction (MVC).

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In pairwise comparisons, log(APDF10) and log(APDF50) values were statistically significantly higher when the mop handle height was adjusted to eye level as compared to shoulder level (*p*<0.001 and *p*=0.006, respectively; see Table 11). Similarly, log(APDF10) and log(APDF50) values were statistically significantly higher at eye level compared to chin level (*p*=0.001 and *p*=0.012, respectively; see Table 11). Log(APDF90) values were also statistically significantly higher at eye level compared to chin level (*p*=0.044, see Table 11). There were no statistically significant differences detected when the nose level was compared to other mop handle heights (see Table 11). Likewise, no statistically significant differences were found in any of the EMG parameters between shoulder level and chin level.

Table 11. Multiple comparisons of logarithmically transformed EMG parameter values among four different heights of mop during floor mopping

Height of the mop handle[a]	log(APDF10)[b]		log(APDF50)[b]		log(APDF90)[b]	
	Mean difference[c] (95% CI)	**p[d]**	**Mean difference[c] (95% CI)**	**p[d]**	**Mean difference[c] (95% CI)**	**p[d]**
A vs B	-0.006 (-0.115, 0.102)	1.000	-0.009 (-0.121, 0.104)	1.000	0.003 (-0.107, 0.113)	1.000
A vs C	-0.096 (-0.204, 0.013)	0.113	-0.068 (-0.181, 0.045)	0.502	-0.032 (-0.142, 0.078)	0.969
A vs D	-0.166 (-0.274, -0.57)	**<0.001**	-0.142 (-0.254, -0.029)	**0.006**	-0.109 (-0.219, 0.001)	0.054
B vs C	-0.090 (-0.198, 0.019)	0.163	-0.059 (-0.172, 0.053)	0.657	-0.035 (-0.145, 0.075)	0.953
B vs D	-0.160 (-0.268, -0.051)	**0.001**	-0.133 (-0.245, -0.020)	**0.012**	-0.112 (-0.222, -0.002)	**0.044**
C vs D	-0.070 (-0.178, 0.039)	0.429	-0.073 (-0.186, 0.039)	0.410	-0.077 (-0.187, 0.033)	0.332

[a] Mop height adjustment: A= shoulder level, B= chin level, C= nose level, D= eye level.
[b] 10th, 50th and 90th percentiles of Amplitude Probability Distribution Function (APDF) of shoulder muscle (upper trapezius, anterior and middle deltoid, infraspinatus) activity parameters. [c] Mean difference in logarithmically transformed %MVC (percentage of maximal voluntary contraction) values. [d] Linear Mixed Model.
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The muscles also had statistically significant effect on log(APDF10), log(APDF50) and log(APDF90) parameters (*p*<0.001 for each parameter). In pairwise comparisons, log(APDF10) values were statistically significantly higher for the IP muscle than for the UT, AD and MD muscles (*p*<0.001 for each muscle). At log(APDF50) and log(APDF90), muscle activity levels were also statistically significantly higher for the IP muscle than for the AD and MD muscles (*p*<0.001); however, there was no statistically significant difference between the IP and UT muscles. At log(APDF50) and log(APDF90), levels of muscle activity were significantly higher for the UT muscle than for MD and AD muscles (*p*<0.001 for each muscle).

5.3.2 Perceived exertion

The perceived exertion (CR-10) ratings for floor mopping using different mop handle heights are presented in Figure 12. The ratings of perceived exertion ranged from 0.5 (′extremely weak′) to 5 (′heavy′). Participants rated floor mopping exertion as ′very weak′ (median 1) for the shoulder area when the mop height was adjusted to chin level. Mopping was considered ´weak´ (median 2) at shoulder level and ´moderate´ (median 3) both at nose level and eye level mop heights (see Figure 12).

Statistically significant differences were detected between chin level and nose level (*p*=0.011), as well as between chin and eye level mop handle heights (*p*=0.005). Less perceived strain was found when the mop was adjusted to chin level compared to nose level. Similarly, less strain was found for the chin level mop height than for the eye level mop height.

Responses to the open-ended question concerning subjective preference for mop height showed that the chin level was most preferred by 10 out of 13 participants. Common reasons given for their preferencies were comfort and less perceived strain on the upper arm.

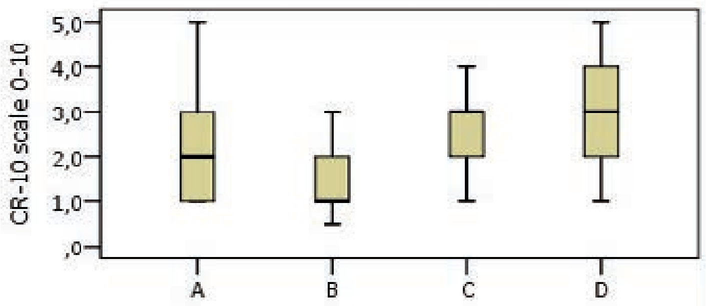

Figure 12. Minimum, maximum, median and quartiles of perceived exertion during floor mopping with four different heights of the mop. Mop handle height adjustments: A= shoulder level, B= chin level, C= nose level, D= eye level.
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5.4 POSITIONS, MOVEMENTS AND FOREARM MUSCLES' ACTIVITIES (STUDY III)

The mean mopping cycle time was 1.76 s (SD 0.39) for all participants and all floor mopping trials. For both the UP- and LP-arm, Friedman's test revealed that there were significant differences in arm elevation angles (50th and 99th percentiles), and the percentage of cycle time in the ´neutral´ position (<20°) and ´moderate´ (20-60°) levels of arm elevation, depending on the mop handle height (*p*<0.026 for each parameter; Table 12 and 13). For the UP-arm, there were also statistically significant differences in arm angular velocity and time at rest parameters, depending on the mop handle height (*p*<0.0001 for each parameter). Conversely, for the LP-arm, no significant differences were found in angular velocity or time at rest among different handle heights (*p*>0.098 for both parameters). The statistical significance was not computed for the ´severe´ (>60°) upper arm elevation zone because only two participants exceeded this limit (see Table 12 and 13).

Figure 13 illustrates wrist flexion/extension and ulnar/radial deviation angles during mopping using different mop handle heights. For the UP hand, there were no statistically significant differences in any of the wrist kinematic parameters (*p*>0.117 for each parameter), nor in any of the EMG parameters (*p*>0.226 for each parameter). Neither were there significant differences found in the FCU muscle activity levels for the lower hand (*p*>0.102). However, for the LP-hand, there were significant differences in wrist flexion/extension angles (10th, 50th and 90th percentiles) depending on mop handle height (*p*≤0.020 each parameter, Figure 14b). In addition, the height of the mop handle had a statistically significant effect on ECR muscle activity levels in the LP-hand (Figure 15b). The results for post hoc pairwise comparisons are presented below.

5.4.1 Arm elevation

The upper-position hand

For both the 50th and 99th percentiles of arm elevation, differences were statistically significant between the shoulder-level versus the eye- and nose-level mop adjustments (*p*<0.005 for each parameter), as well as between the chin-level versus the eye-level and nose-level (*p*<0.005 for each parameter). The difference between the nose-level and eye-level mop adjustments was also found as statistically significant (*p*<0.004 for both parameters). The median values for both the 50th and 99th percentiles of arm elevation showed that the eye-level mop height resulted in higher elevation angles than all other mop handle heights (see Table 12). Similarly, the nose-level mop height implied higher elevation angles than shoulder- and chin-level mop heights (see Table 12).

Table 12. Upper arm position and angular velocity for the upper-position hand in cleaners (n=12-13) during floor mopping using four different mop handle heights.

Parameter	Mop height Shoulder level Median (range)	Chin level Median (range)	Nose level Median (range)	Eye level Median (range)	*p*-value
Arm elevation[a]					
50th (°)	15 (11-29)[B,C]	16 (11-34)[D,E]	19 (10-43)[B,D,F]	24 (12-46)[C,E,F]	<0.0001*
99th (°)	21 (15-46)[B,C]	24 (15-50)[D,E]	27 (16-57)[B,D,F]	35 (18-60)[C,E,F]	<0.0001*
<20° (% time)	86 (0-100)[B,C]	81 (0-100)[D,E]	58 (0-99)[B,D]	30 (0-98)[C,E]	<0.0001*
20-60° (% time)	14 (0-100)[B,C]	19 (0-100)[D,E]	42 (1-100)[B,D]	70 (2-100)[C,E]	<0.0001*
>60° (% time)	0 (0)	0 (0)	0 (0-3)	0 (0-11)	-
Rest[a] (% time)					
<20°+ <5°/s[#]	15 (0-26)[C]	15 (0-26)[E]	10 (0-28)	5 (0-19)[C,E]	<0.0001*
Angular velocity					
50th (°/s)	16 (10-23)[C]	15 (11-25)[E]	16 (8-32)[F]	24 (12-36)[C,E,F]	<0.0001*

* Friedman's test, statistically significant p<0.05. In pairwise comparisons Bonferroni corrected p-value <0.008 (Wilcoxon signed-rank test): [A]=shoulder level vs. chin level, [B]=shoulder level vs. nose level, [C]= shoulder level vs. eye level, [D]=chin level vs. nose level, [E]= chin level vs. eye level, [F]= nose level vs. eye level

[a] Data missing for one participant (n=12). [#] Upper arm elevation <20° and velocity <5°/s.

For both the ′neutral′ position (<20°) and for ′moderate′ (20-60°) levels of arm elevation, statistically significant differences were detected between the shoulder-level versus the eye-level and nose-level (*p*=0.003 for each parameter), as well as between the chin-level versus the eye-level and nose-level (*p*=0.003 for each parameter). Participants spent more time in positions below 20 degrees of arm elevation while floor mopping with shoulder-level or chin-level mop adjustment as compared to nose-level or eye-level (Table 12). Participants also maintained ′moderate′ levels of elevation for shorter periods of time when the mop was adjusted to shoulder-level or chin-level as compared to eye-level or nose-level (Table 12).

The lower-position hand

There were statistically significant differences between the chin-level and eye-level mop adjustments for the 50th and 99th percentiles of arm elevation, for the percentage of cycle time in a ′neutral′ position, and for the percentage of cycle time at ′moderate′ levels of arm elevation (*p*<0.005 for each parameter). Arm elevation angles (50th and 99th percentiles) and time in ′moderate′ levels of elevation were lower for the chin-level mop adjustment than for the eye-level mop adjustment (see Table 13). Less time was spent in the ′neutral′ position (<20° of arm elevation) when mop height was adjusted to eye-level as compared to chin-level (see Table 13).

Table 13. Upper arm position and angular velocity for the lower-position hand in cleaners (n=12-13) during floor mopping using four different mop handle heights.

	Mop height				
Parameter	**Shoulder level Median (range)**	**Chin level Median (range)**	**Nose level Median (range)**	**Eye level Median (range)**	***p*-value**
Arm elevation[a]					
50th (°)	21 (12-29)	20 (13-29)[E]	20 (13-30)	22 (15-32)[E]	0.026*
99th (°)	25 (15-33)	24 (16-35)[E]	24 (15-33)	27 (17-36)[E]	0.016*
<20° (% time)	44 (2-100)	50 (1-100)[E]	49 (1-100)	28 (0-100)[E]	0.019*
20-60° (% time)	56 (0-99)	50 (0-98)[E]	51 (0-99)	72 (0-100)[E]	0.019*
>60° (% time)	0 (0)	0 (0)	0 (0)	0 (0)	-
Rest[a] (% time)					
<20°+ <5°/s[#]	6 (0-29)	10 (0-29)	8 (0-31)	3 (0-30)	0.098
Angular velocity					
50th (°/s)	11 (7-21)	12 (6-20)	10 (8-17)	12 (7-20)	0.720

* Friedman's test, statistically significant p<0.05. In pairwise comparisons Bonferroni corrected p-value <0.008 (Wilcoxon signed-rank test): [A]=shoulder level vs. chin level, [B]=shoulder level vs. nose level, [C]= shoulder level vs. eye level, [D]=chin level vs. nose level, [E]= chin level vs. eye level, [F]= nose level vs. eye level.

[a] Data missing for one participant (n=12). [#] Upper arm elevation <20° and velocity <5°/s.

5.4.2 Wrist angles and extreme positions

The upper-position hand

Results showed that floor mopping was performed with upper wrist in extended and ulnar deviated position (Figure 13a, c). For the 50th percentile, extended wrist positions were similar for all four mop heights, between –12° and –10° (*p*=0.117, Figure 14a). The corresponding values for the 50th percentile of deviation was between 11° and 15° (*p*=0.552, Figure 14c).

During mopping, the peak (10th percentile) wrist extension was between –41° and –28° (*p*=0.593, Figure 14a) and the peak flexion (90th percentile) was between 17° and 23° for all mop heights (*p*=0.212, Figure 14a). The corresponding values for peak radial deviation (10th percentile) were between –6° and 1° (*p*=0.348, Figure 14c) and for peak ulnar deviation (90th percentile) between 20° and 25° (*p*=0.921, Figure 14c). The amount of time spent in the 'extreme' wrist position was high: 56%, 43%, 49% and 56% of the mopping cycle time for shoulder, chin, nose and eye mop handle heights, respectively (*p*=0.220).

The lower-position hand

The height of the upper mop handle affected the position of the LP-wrist. Statistically significant differences were revealed between the shoulder and eye levels for the 10th, 50th and 90th percentiles of flexion/extension (*p*<0.007 for each parameter, Figure 14b), as well as between the chin and eye levels for the 50th percentile (*p*=0.007). The mopping task was performed with an extended wrist position (Figure 13b). For the 10th percentile, the shoulder-level mop adjustment resulted in more extended wrist positions (–30°) than the eye-level adjustment (–23°) (Figure 14b). The corresponding values for the 50th percentile were –25° for shoulder level and –19° for eye level (Figure 14b). Even the 90th percentiles implied extended positions (Figure 14b). Average deviation angles were around neutral position for all mop heights (*p*>0.100 for each parameter) (see Figure 13d and Figure 14d). The amount of time spent in 'extreme' wrist positions was between 1 and 3% (*p*=0.837).

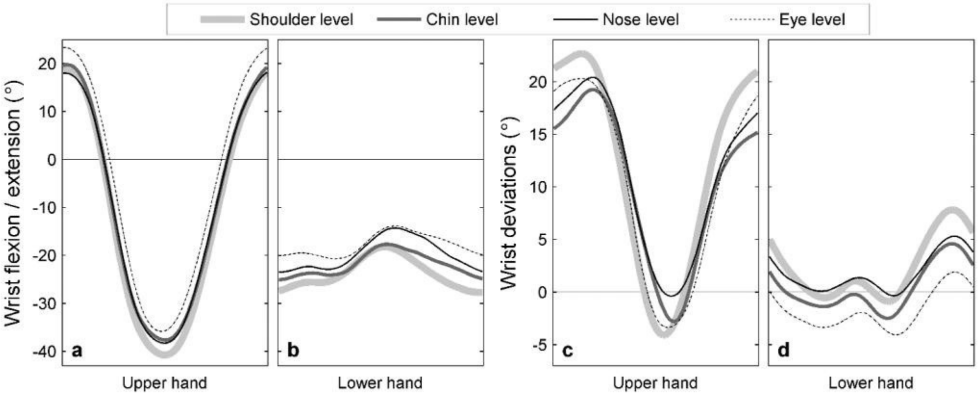

Figure 13. Mean angles for wrist flexion/extension and ulnar/radial deviation during floor mopping using four different mop handle heights. The X-axis denotes the time interval of one mopping cycle. All cycles are interpolated to the same length and averaged. Wrist flexion/extension: positive denote flexion, negative denote extension. Wrist deviations: positive denote ulnar deviation, negative denote radial deviation. (a, c): upper hand (n=12), (b, d): lower hand (n=13).
Wallius, M-A., Bragge, T., Karjalainen, P. A., Järvelin-Pasanen, S., Rissanen, S. M., Vartiainen, P., & Räsänen, K. (2018). Effects of Mop Handle Height on Forearm Muscle Activity, Wrist and Upper Arm Posture and Movement During Floor Mopping. IISE Transactions on Occupational Ergonomics and Human Factors, 6(2), 84-97, reprinted by permission of the Institute of Industrial and System Engineers, https://www.iise.org/Home/ and by permission of the publisher (Taylor & Francis Ltd, http://www.tandfonline.com).

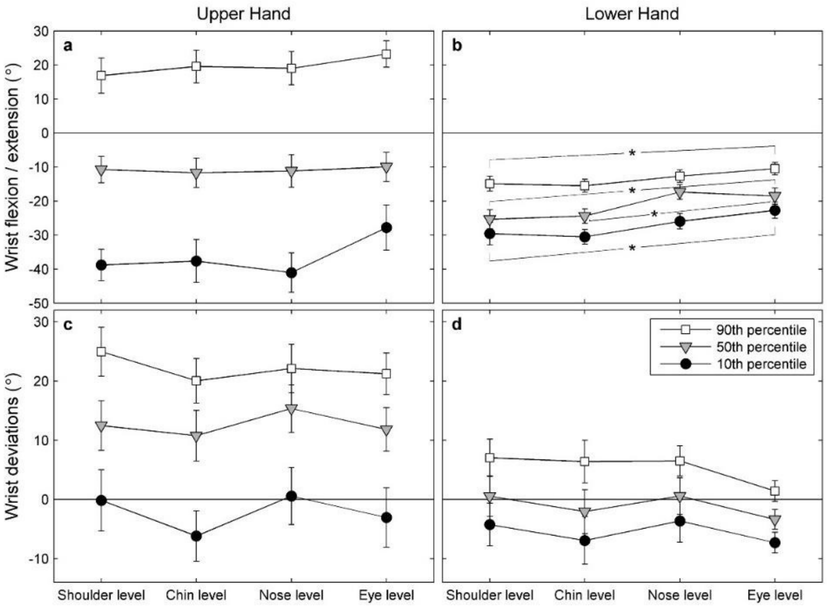

Figure 14. 10th, 50th, 90th percentiles for wrist flexion(+)/extension(-) and ulnar(+)/radial(-) deviation postures while floor mopping using four different mop handle heights. Data are presented as medians and standard errors. (a,c): upper hand (n=12). (b,d): lower hand (n=13). Asterisk indicates statistically significant differences in pairwise comparisons with Wilcoxon signed-rank test (p < 0.008 after Bonferroni correction).
Wallius, M-A., Bragge, T., Karjalainen, P. A., Järvelin-Pasanen, S., Rissanen, S. M., Vartiainen, P., & Räsänen, K. (2018). Effects of Mop Handle Height on Forearm Muscle Activity, Wrist and Upper Arm Posture and Movement During Floor Mopping. IISE Transactions on Occupational Ergonomics and Human Factors, 6(2), 84-97, reprinted by permission of the Institute of Industrial and System Engineers, https://www.iise.org/Home/ and by permission of the publisher (Taylor & Francis Ltd, http://www.tandfonline.com).

5.4.3 Angular velocities and time at ´rest´

For the UP arm, statistically significant differences in the 50th percentile of arm angular velocity were found between the eye level versus the shoulder level and chin level, as well as between the eye level and nose level (*p*<0.007 for each parameter). Arm angular velocity was higher for the eye-level mop adjustment than for other heights of the mop (see Table 12).

For the UP arm, statistically significant differences in the percentage of cycle time at ´rest´ (<20° and <5°/s) were found between the shoulder-level and eye-level mop adjustments, as well as between the chin level and eye level (*p*=0.003 for both parameters). The time at ´rest´ tended to be lower when the mop handle height was adjusted to eye level as compared to shoulder level or chin level (see Table 12).

For both UP- and LP-wrists, no statistically significant differences were detected in rest time or angular velocity among different mop handle heights. For the lower hand, the time spent at ´rest´ was between 1 and 8% for all mop heights (p=0.198). The corresponding median values for the upper hand were close to zero for all mop handle heights (*p*=0.413). For the upper hand, the flexion/extension velocities (50th percentile) were 62°, 60°, 61° and 67°/s for the shoulder, chin, nose and eye level mop heights, respectively (*p*=0.270). The wrist angular velocity for the LP hand was between 18° and 20°/s for all mop heights (*p*=0.280).

5.4.4 Forearm muscles' activities

Figure 15 presents data for the forearm EMG parameters. For APDF10 of the LP hand, there were statistically significant differences in ECR muscle activity levels between the shoulder level versus the chin level or nose level ($p \leq 0.007$ for each parameter, Figure 15b). For APDF50 of the LP hand, statistically significant differences in ECR muscle activity levels were detected between the shoulder level versus the nose level or eye level ($p \leq 0.007$ for each parameter). In APDF10, the median ECR muscle activity was higher at shoulder level as compared to chin level or nose level (see Figure 15b). Similarly, in APDF50, the median ECR muscle activity was higher at shoulder level as compared to nose level or eye level (see Figure 15b).

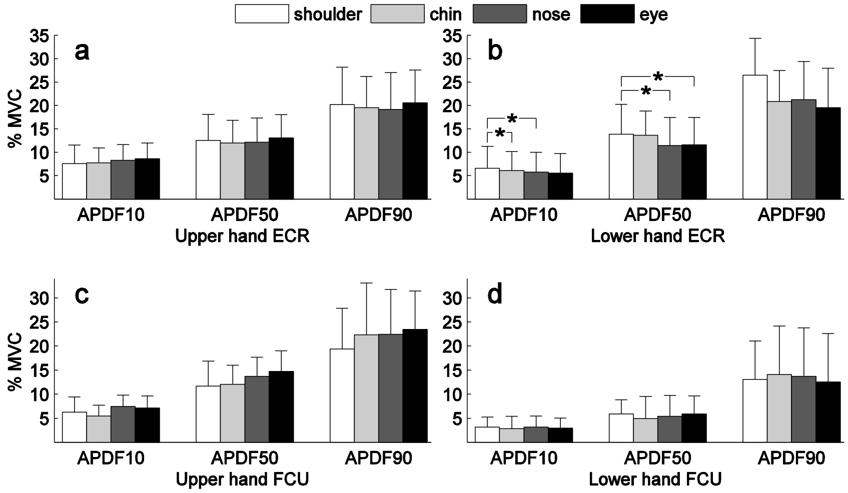

Figure 15. Median and standard deviation (SD) for the 10th, 50th and 90th percentiles of Amplitude Probability Distribution Function (APDF) of EMG from the flexor carpi ulnaris (FCU) and extensor carpi radialis longus and brevis (ECR) muscles while mopping using four different mop handle heights. Units are in terms of percentage of maximum voluntary contraction (MVC). (a,c): upper hand, (b,d): lower hand. *Statistically significant differences in pairwise comparisons with Wilcoxon signed-rank test ($p < 0.008$ after Bonferroni correction). N=13, except for upper hand FCU muscle (n=12).
Wallius, M-A., Bragge, T., Karjalainen, P. A., Järvelin-Pasanen, S., Rissanen, S. M., Vartiainen, P., & Räsänen, K. (2018). Effects of Mop Handle Height on Forearm Muscle Activity, Wrist and Upper Arm Posture and Movement During Floor Mopping. IISE Transactions on Occupational Ergonomics and Human Factors, 6(2), 84-97, reprinted by permission of the Institute of Industrial and System Engineers, https://www.iise.org/Home/ and by permission of the publisher (Taylor & Francis Ltd, http://www.tandfonline.com).

5.5 RESULTS SUMMARY (STUDY I-III)

Based on the findings of the systematic review (Study I), the levels of evidence for ergonomic strategies associated with positive effects on musculoskeletal load were as follows: moderate evidence for use of individually adjustable tools, mixed evidence for pre-actions ensuring a clear floor surface and mopping of floors without water or minimum amount of water, and insufficient evidence for use of a particular mopping technique resulting in less musculoskeletal strain. Therefore, the use of adjustable mop handles can be considered to be a good practice for reducing musculoskeletal load. However, none of the strategies and measures yielded a strong level of evidence for reducing musculoskeletal load, a finding which precludes the recommendation of any strategy or measure for use in practice.

The results from Studies II-III indicated that the mop height adjustments at the shoulder and chin level were associated with a more neutral upper-arm posture, significantly lower velocity, more time at rest (elevation <20° and <5°/s) and lower shoulder muscle activity for the UP arm. Significantly less perceived strain was also assessed with chin-level mop height than nose-level and eye-level mop heights. For the LP arm, elevation angles were significantly reduced and more time was spent in the neutral arm position when the mop was adjusted to chin level as compared to eye level (see Figure 16). Although the use of the mop at shoulder height increased wrist extension and ECR muscle activity in the LP hand, the time spent in extreme wrist positions or rest did not differ significantly across the range of mop handle heights. Moreover, the height of the upper mop handle did not have any significant impact on the position or movement of the UP wrist or bilateral FCU muscle activity.

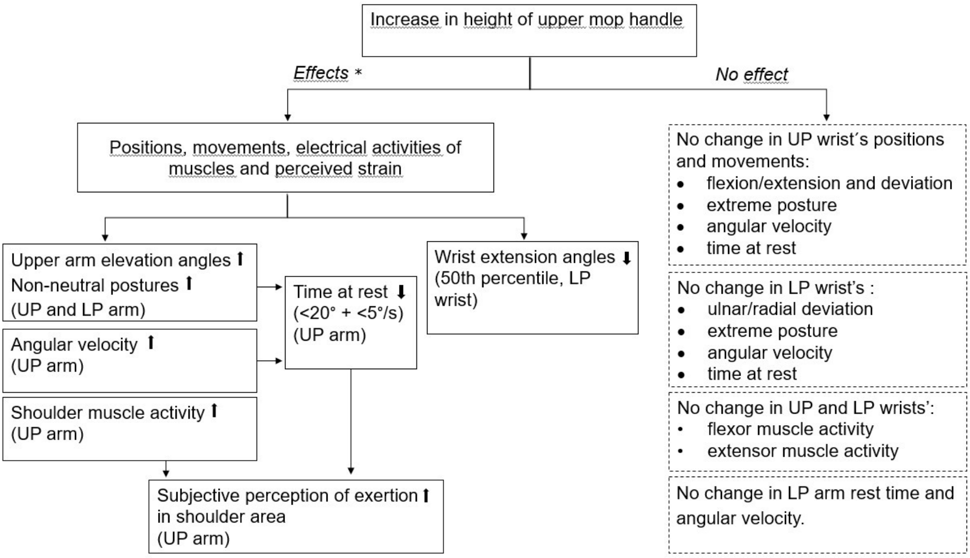

Figure 16. Trends observed in musculoskeletal load and strain when the height of the upper mop handle was increased from chin level to eye level (n=13, Study II and III). * Statistically significant differences detected between the mop handle heights (*p*<0.008 in pairwise comparisons). LP= lower-position hand; UP= upper-position hand

6 DISCUSSION

This chapter presents general discussion of the key findings from the study, after which factors related to the study's trustworthiness are discussed. The validity and reliability of the systematic review and experimental study is examined separately. The chapter is rounded off with a presentation of conclusions, implications for practise and suggestions for future research.

6.1 DISCUSSION OF RESULTS

6.1.1 Mop adjustability in musculoskeletal load reduction

With regard to the present study, the adjustability of the mop is one technical advance that can reduce musculoskeletal load and strain of the upper extremities associated with mopping provided that it is used correctly (Studies I-III). Based on the systematic review findings, the evidence for using individually adjustable tools in reducing musculoskeletal load is moderate (Study I). The results of the experimental study (Studies II-III) indicated that the use of mop height adjustment has a positive impact on the electrical activities of the shoulder muscles and on the positions and movements of the upper arm, and that these findings were corroborated by acute subjective strain response to the workload. Working at lower heights of the mop might decrease a cleaner's susceptibility to shoulder MSDs a decrease resulting from a more frequent neutral upper arm position, lower shoulder muscle activity levels and more time at rest (elevation <20° and <5°/s), particularly for the UP arm.

The findings of the study showed that upper-arm positions, movements or strain of shoulder muscle were similar when shoulder-level and chin-level mop heights were used. As the height of the mop handle was lowered from eye level to shoulder or chin level, a trend of decreasing shoulder muscle activities was observed. This can be explained by the fact that at the lowered mop heights the arm elevation angles and angular velocities were decreased, whereas the time at rest was increased. This trend of decreasing muscle strain associated with lowered mop heights (chin level in particular) was supported by reduced perceptions of strain. One can postulate that a decrease in shoulder flexion movement at lower mop handle heights may explain the reduction of shoulder muscle activity levels and arm elevation, because it has been shown that IP, UT and AD muscles' activities steadily rise as forward flexion increases (Heuberer, Kranzl, Laky, Anderl, & Wurnig, 2015). Further, higher UT muscle activity at greater mop heights might to some extent be due to shoulder shrug movement. The UT muscle elevates and retracts the clavicle (Camargo & Neumann, 2019) and exerts a significant influence on kinematics across the shoulder girdle (Phadke, Camargo & Ludewic, 2009). In a cleaning task that requires a large amount of stabilization of the shoulder during continuous upper limb motions (Søgaard et al., 1996), maintaining the position of the arm and scapula with greater arm elevation angles may also explain the increase in shoulder muscle activity. The stabilizing role of the rotator cuff muscles (including IP muscle) at the shoulder joint is also essential (Day, Taylor, & Green, 2012). However, the EMG activity of a muscle during a movement does not clarify if the muscle is active, for instance, in a stabilizer rather than mover role without further consideration of the biomechanics of the shoulder joint complex.

Although there is no consensus in the literature regarding a safe limit for arm elevation, exposure to work postures involving elevated arms is recognized as a risk factor for shoulder pain (Coenen et al., 2016; Mayer et al., 2012; van Rijn et al., 2010) and tasks requiring repeated or sustained flexion or abduction have been strongly associated with shoulder disorders (Bernard, 1997). An arm elevation of greater than 60° during occupational tasks has been considered to be of concern in many studies (Bernand, 1997; Hanvold et al., 2015; Ohlsson et al., 1995; Zhu et al., 2017). In the present study, cleaners rarely mopped with their arms above this level. However, eye-level mop adjustment led to elevation angles as high as 60° (range from 18° to 60° for 99th percentile) and cleaners maintained their both upper arms in the 20°–60° elevation zone for about 70% of the mopping time. According to the European standard EN 1005-4 (2005) this arm elevation zone is unacceptable if movement frequency is at 10 or above per minute. In the present study, the mopping cycle time (mean 1.76s) was short which is also in line with previously reported mopping cycle times showing (about 1.5s) (Søgaard et al., 2001). On the contrary, the amount of time spent in this elevation zone was significantly reduced while using lower mop heights. Similarly, for the UP arm, the majority of the mopping time (>80% of time) was spent at arm angles of less than 20° of elevation and more time was spent at rest (<20° and <5°/s) while working with shoulder- or chin-level mop heights.

In order to decrease the duration of elevated UP-arm positions and to increase the proportion of time spent on rest (elevation <20° and <5°/s), the use of lower mop heights (i.e., shoulder- and chin-level) can be regarded as a means of reducing shoulder load and strain associated with mopping. In addition, mean static levels for the IP, AD and UT muscles associated with eye-level mop adjustment were high and can also be decreased by lowering the mop height. A high static load of the trapezius muscle is associated with neck-shouder disorders (Aarås, 1994); therefore, reducing the activity of the UT muscle is crucial. Although opposite findings also exist which show only weak correlation between low-level UT muscle activity and pain in neck-shoulder region for the office workers (Jensen, Nilsen, Hansen, & Westgaard, 1993), more recent studies have shown that reduced muscle rest or sustained trapezius muscle activity are predictors of neck and shoulder pain (Hanvold et al., 2013; Østensvik, Veiersted, & Nielsen, 2009). The most recent study by Balogh et al. (2019) showed that the prevalence of tension neck syndrome increases with increasing trapezius muscle activity. Therefore, use of a lower adjustment of the mop that can help the progress of muscular recovery (e.g., to increase the number of short interruptions of activity in the UT muscle during mopping or the proportion of mopping time when muscle is at rest), is justifiable. A discrimination level of 0.5% MVC has been reported for muscular rest levels (Veiersted, Forsman, Hansson, & Mathiassen, 2013).

Regarding the wrists, the height of the upper mop handle did not have a significant impact on strain on the FCU muscle or any of the upper hand´s wrist position or movement parameters. This indicates that adjustment of the mop does not affect the upper wrist´s loading. For the lower hand, however, the use of the mop height at shoulder level resulted in somewhat higher static and median activity levels for the ECR muscle than did use of the mop at nose and eye level (<1% MVC for static activity level and <2.3% MVC for median activity level). Further, the lower hand´s wrist was more extended (6°) while using a shoulder-level or chin-level mop height compared to eye-level. The practical importance of this statistically significant finding among mop heights is probably minor, because the median (50th percentile) wrist positions were near to neutral wrist position and the use of the mop at shoulder level did not increase extreme wrist positions or decrease the time at ´rest´ (i.e., inside an ellipse with major flexion axis -20 to 20° and minor deviation axis -10 to 10° and velocity <5°/s). However, it can be concluded that the chin-level mop adjustment can be regarded as the optimal height for a mop.

Even though mop tools have undergone improvements in handle adjustability, it appears that high muscle loading, repetitiveness and improper working positions of the wrists (the UP wrist in particular) are still commonly associated with mopping. This experimental study indicates that, despite the specific mop height, static activity levels for the extensor and flexor muscles bilaterally were high. One can postulate that high static activity levels for the forearm muscle may also be due to low muscular rest. Specifically, the earlier study by Nordander et al. (2013) showed a strong negative correlation between forearm muscle activity measure (10th percentile value of percentage of maximal voluntary electrical activity) and muscular rest measure ($r_s = -0.90$ for Spearman rank-correlation coefficients). As to positions and movements for the upper hand, approximately half of the mopping time was spent in extreme wrist positions, and the wrist flexion-extension velocities were high (between 60°/s to 67°/s for all mop heights). These findings also explain why the time spent in ´rest´ was negligible. The measured wrist velocities exceeded the threshold limit value for wrist velocity of 20 °/s suggested for over the course of an eight-hour working day. Increasing wrist velocities and forearm extensor muscle activities are associated with increasing prevalence of tension neck syndrome (Balogh et al., 2019.)

Therefore, the role of adjustable handles in providing solutions for reducing the musculoskeletal strain on the wrists is therefore found to be nonexistent. The aforementioned workplace risk factors such as exertions involving flexed, extended or deviated wrist or repetitive hand exertions and wrist acceleration, are associated with the increased risk of upper extremity disorders (Keyserling, 2000). The angular velocity of wrist is the most consistent risk factor for elbow/hand disorders (Nordander et al., 2013) as well as for shoulder disorders (Nordander et al., 2016). Therefore, controlling the wrist working speed in mopping is crucial. Although the cumulative risk of combined physical exposures is not entirely known, mopping involves several risk factors exposing cleaners to the risk of MSDs. Therefore, reduction of any risk factor is justifiable.

6.1.2 Strategies and measures for reducing musculoskeletal load

Based on systematic review of findings published over nearly the past 30 years, the effects on musculoskeletal load and strain of the upper extremities of the performed technical measures involved in mopping work have been assessed in the 11 studies included in the evidence synthesis. Six medium-quality studies out of 11 studies showed that the following technical measures involved in mopping work indicated a positive effect on musculoskeletal strain of the upper extremities: mop design considerations such as type of tool (Conner & Irwin, 2009) and mop adjustability (Wallius et al., 2016; Öhrling et al., 2012), mopping floors without water or a minimal amount of water (Hopsu et al., 2000), utilization of the push mopping technique rather than the figure-eight technique (Hagner & Hagberg, 1989) and adjustment of the work environment, that is, attaching the electric cords above the floor surface before mopping (Kumar et al., 2005b). All the included studies were cross-sectional; with such study design, exposure and outcomes were measured simultaneously. Thus, no conclusions can be drawn regarding the effects of measures on development of musculoskeletal load over time.

These above-mentioned measures of mopping work consider worker- and context-specific factors: the manner in which the mopping was conducted (worker) and the requirements of the work setting, such as tools and equipment, furniture and other physical objects (context). Together, these measures reflect the basic idea of ergonomics: to design the work systems so that they fit to worker using them (Stubbs, 2000). This idea is realized through reduction of physical load in designing or modifying the job, tools and working methods.

Evidence for four main category of strategies and two subcategories of strategies was derived from 10 medium-quality studies and one low-quality study. These categories of strategies, designated as: as mop design (handle type and type of tool), mopping technique, mopping method and environment modifications, showed insufficient, mixed or moderate levels of evidence for reducing musculoskeletal load of the upper extremities. The small number of studies and their methodological limitations, as well as inconsistency of findings, precludes the recommendation of any specific ergonomic strategy or measure for immediate incorporation into cleaning practice. Mop design considerations, in particular individually adjustable tools, is an ergonomic strategy indicating a moderate evidence for reducing musculoskeletal load. Thus, use of adjustable mops can be suggested as a practice worth considering.

Established ergonomic strategies (i.e., individually adjustable tools, utilization of mop materials and methods utilizing the minimum possible amount of water, utilization of working techniques resulting in less musculoskeletal strain, as well as pre-actions for ensuring a clear floor surface) indicate the need for a more comprehensive approach when designing or modifying cleaning tools and methods from the viewpoint of musculoskeletal load reduction. In tool design and evaluation, the control of physical stress factors depends not only on the tool (design features such as handle form and dimension) but also the context (task and workplace factors) of the job being performed (Radwin, 2006). Therefore, no one of the strategy or measure can be assured of successful integration into cleaning practice. The links among the worker, the work task and the environment should be optimized. Such optimization requires understanding of the work system; such understanding is an essential phase in the user-centered design (UCD) approach in which users are involved throughout the design process (Leonard, Moloney, & Jacko, 2006).

This review found moderate evidence of the use of alternative type of tools having no effect. On the one hand, the inconsistency in results may reflect a heterogeneity in mopping systems (tools and equipment) used within this particular sub-category of strategy in which a wide variety of mopping tools was compared. On the other hand, it was surprising that, in most studies reviewed, the focus of comparisons of mop tools used was on the quantification and analysis of existing risk factors and musculoskeletal strain associated with the use of different tools, rather than on design ergonomics (i.e., ergonomic goals in the design of initiatives). This focus on factors other than design ergonomics might also explain why no effect on musculoskeletal load was found. Nevertheless, the review findings do not indicate that the search for alternative types of tools is not worth continuining. However, the findings may indicate that a need exists for different approaches for developing tools if the primary goal is decreasing the musculoskeletal load associated with mopping. In examining all the included studies, it seems that ergonomic processes appear to be initiated out of development a solution or implementation of a solution and then following the evaluation of the results. Only two studies (Kumar et al., 2005b; Woods and Buckle, 2005) reported how the ergonomic problems were worked out and solved. In order to achieve a good result, in addition to the solution development and implementation stages, the problem identification phase and analysis phase are also essential in many ergonomic processes (Kilbom & Petersson, 2006). Similarly, the stages from problem analysis to proposal of solutions and solution assessment are also important in design processes (Albayrak, Wauben, & Goossens, 2009). Therefore, future studies may require engaging ergonomics in the process of cleaning tool design.

Considering that each part of the work system (equipment, task, environment, organization and personnel) may have an effect on another part (Stubbs, 2000), it is not surprising that the formulated ergonomic strategies are also interrelated. For instance, in the evaluation of musculoskeletal strain in the development of mopping methods, there are underlying factors influencing musculoskeletal load and strain to be taken into account, such as task-related factors (design features of tools, mopping environment considerations). In addition, underlying user-related factors also have an impact on musculoskeletal strain. These include not only user elements, such as anthropometrics, but also the manner in which the mop is used (i.e., mopping technique). Given that the interaction of the worker, the work setting (e.g., furniture, other physical objects) and the environment determines the manner by which cleaning task is performed (Kumar, 2006; Weigall et al., 2006), integration of ergonomic strategies into practice is not straightforward. On the one hand, environmental factors influence the ability to use the tool ergonomically (Jensen et al., 2011); on the other hand, individual ability (e.g., awareness of ergonomic guidelines) affects how the techniques are integrated in practice (Jensen et al., 2011; Samani et al., 2012). Thus, it can be concluded that when the main focus is development of cleaning tools and methods from the standpoint of reduction of musculoskeletal load, consideration of task- and user-related factors is essential in order to ensure the success of the implementation of the strategies.

The reviewed studies of various types of mops and methods used in diverse mopping conditions also highlights the need for contextualizing different mopping systems to the task and user (see Figure 17). However, there was minimal research providing evidence that the main ergonomic principles, task- and user elements were taken into account in the tool design process. Although earlier studies have indicated that new tools and methods need to be contextualized for different cleaning tasks and environments (Kumar & Kumar, 2008; Weigall et al., 2006), there was a paucity of studies reporting how environmental factors, such as interior design characteristics and furnishing, influenced the workload experienced while mopping. This review found that there is mixed evidence for the positive impact of pre-actions for ensuring the accessible floor surface on reduction of musculoskeletal load. The study by Kumar et al. (2005b) indicated that environmental factors are important for work performance: modifications of the physical surroundings in office environment positively affected the upper-limb working postures while mopping. This finding also indicates that it is not the mopping tool per se, but rather challenges concerning interior design, that can also make tools difficult to use ergonomically. This study (Kumar et al., 2005b) utilized a participatory ergonomics approach and showed that the involvement of cleaning workers in identifying problems and formulating solutions to these problems was important. It is well-recognized that active worker involvement facilitates identification of real needs for improvements (Albayrak et al., 2009; Fernandes, Hurtado & Batiz, 2015) and allows for the possibility that the solutions proposed will be practical and accepted by workers (Burgess-Limerick, 2018). When designing tools for professional users, the ´participatory design´ (PD) methodology can be used to involve users in the design process and to improve human-product interaction: that is, use of tools appropriate for the context in which it is utilized (Albayrak et al., 2009). However, given that cleaners work in a wide variety of workplaces, utilization of appropriate tools does not rule out the requiring that cleaning workers' needs should also be considered in the process of interior and furniture design.

This thesis proposes a preliminary framework for increasing the understanding of the need for a more comprehensive approach in development of cleaning tools and methods from an ergonomics point of view (see Figure 17). This framework presents four ergonomic strategies as key factors that should be considered in order to enhance the chances of the success of development of cleaning systems so that musculoskeletal load can be reduced. These strategies highlight the significance of task- and user-related elements as intervening factors that should be taken into account in development of cleaning work from the viewpoint of musculoskeletal load reduction, and also as factors contributing to integration of strategies into practice. Therefore, understanding the underlying factors and the links among the four ergonomic strategies calls out for the integration of ergonomics in the tool design process. Given that mopping situations are diverse by nature, concentration on the main ergonomic principles (e.g., handle dimension) in the tool design may prove to be an insufficient strategy for reducing musculoskeletal load. In addition to design features of tools and user elements (e.g., anthropometric considerations), environmental factors such as workstation design characteristics should also be considered in order to contextualize different mopping tools to the task and user. This approach emphasizes the necessity of interaction between researchers, designers, health care practitioners and cleaning professionals in order to ensure successful implemention of health working practices in cleaners' work. Designing of new products (Albayrak et al., 2009, dos Santos, Farias, Monteiro, Falcão, & Marcelino, 2011) or designing an ergonomic research project demands a multidisciplinary approach: have design teams made up of people who have expertise in problem analysis and problem-solving (Kilbom & Petersson, 2006). A multidisciplinary approach is necessary in order to take into consideration both human and productivity aspects (Kilbom & Petersson, 2006). Further, this framework points toward the future by revealing the gap warranting further exploration. Understanding the organizational ergonomics dimensions of reduction of musculoskeletal load is necessary for supporting ergonomics development of cleaning tools and methods.

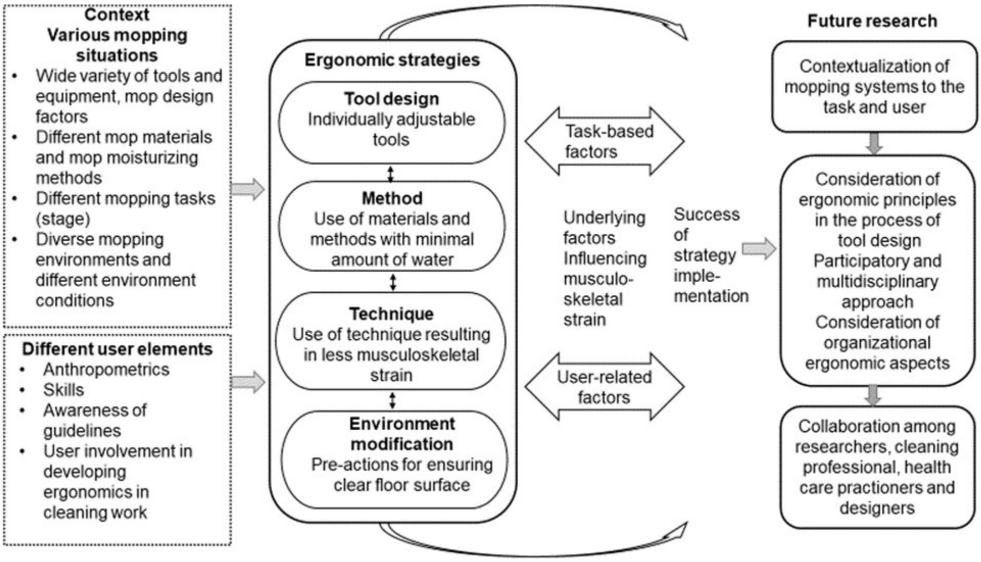

Figure 17. A preliminary framework for guiding future development of cleaning tools and methods from the viewpoint of musculoskeletal load reduction.

As to the risk factors for WMSDs associated with mopping work, this review found that none of the studies identified any technical measure that reduced repetitive movements of the upper extremities while mopping. Similar findings have been reported in a questionnaire by Pekkarinen (2009) which showed that modern tools have not managed to decrease the amount of monotonous repetitive cleaning work. Similarly, in the early 2000s, a comparison of different types of floor cleaning equipment showed that a change of equipment had not managed to facilitate reduction of the shoulder load (Blangsted et al., 2000). The findings of the Blangsted study regarding shoulder loading were similar to those in the study by Søgaard et al. (2006) which compared different floor cleaning tools.

Further, this systematic review revealed that no new types of equipment or method of floor mopping have managed to show a positive effect on wrist position or use of force. These findings suggest that the high force required in handling the mop, movement repetitiveness, and poor postures of the wrists are the main risk factors that should be addressed in future studies of mop design. These risk factors should be alleviated in order to lessen the probability of disorder (e.g., CTS), since it is the combination of risk factors that increases the risk (Palmer et al., 2007). The information obtained in the present experimental study showed that reducing the wrists′ load (e.g., extreme positions and angular velocities) is of the greatest importance. Although changing the wrist posture to a neutral position will also reduce the force components, considering only one or two risk factors may be an ineffective approach to managing and preventing the risk of cleaners' developing MSDs. These results indicate that a more comprehensive approach to reducing musculoskeleletal load and strain is needed. Further, a seach for totally new ideas and novel applications of new technology for improving cleaning work may be necessary. Based on the findings of this study, the role of new technology in offering solutions for reducing the risk factors of WMSDs of the upper extremities related to mopping seems to be minor. As for technological innovations, robotic cleaning equipment is becoming increasingly available for consumer use. Although it has been shown that robotic mops can help improve the efficiency of floor cleaning compared to hand mopping in residential floors (Smestad, Wollmer, Tschida, & Carlson, 2016), none of the reviewed studies investigated any technical innovation that may impact on load, such as repetitiveness during manual mopping. It could be promising to investigate whether or not robot-assisted cleaning provides an opportunity for eliminating repetitive floor cleaning work.

6.2 STRENGTHS AND LIMITATIONS OF THE STUDY

6.2.1 Systematic review

A strength of the results includes the fact that this review was the first systematic review to explore floor mopping and musculoskeletal load and strain of the upper extremities from the broad perspective of physical risk factors over an extended time frame.

The validity of the systematic review was confirmed by the quality of the review process. This systematic review used an ′apriori′ design: research questions and eligibility criteria were established prior to the conduct of the review (Shea et al., 2007). Further, this study utilized explicit and rigorous methods for identifying, critically appraising and synthesizing pertinent literature in order to answer the predefined research questions (Aveyard, 2014; Harris, Quatman, Manring, Siston, & Flanigan, 2014). The literature search was planned carefully, focusing on the relevant databases corresponding to the topic of review and research questions, and the search process was carefully documented. Before performing the final data searches, preliminary searches were carried out in order to create a reliable understanding of prior studies of the topic and to determine appropriate search terms. The assistance of an information specialist was significant for the trustworthiness of the exhaustive search process. The PRISMA checklist with 27 items was utilized in order to ensure that the contents of the review and analysis were appropriate (Moher et al., 2009). Furthermore, in order to improve the trustworthiness of this review, two members independently reviewed and evaluated the articles until consensus was reached (Harris et al., 2014; Saini & Shlonsky, 2012; Shea et al., 2007).

In addition, the methodological quality of the included studies was also independently appraised and carefully reported, and the results of the quality assessment were utilized in formulating conclusions (Shea et al., 2007). As to the trustworthiness of the evidence synthesis, data from the included studies were synthesized in a transparent and systematic manner (Saini & Shlonsky, 2012; Snilstveit et al., 2012).

In considering the limitations of the literature search, a potential bias arises from the years of publication chosen, and the lack of effort to identify articles written in languages other than English, which is a potential source of publication bias (Aveyard, 2014; Harris et al., 2014). Even if a carefully formulated electronic search strategy was performed, there remains the possibility that not all relevant literature was identified. Cognizant of the fact that no single search strategy ensures that all information relevant to a research question will be retrieved (Aveyard, 2014; Bramer, Rethlefsen, Kleijnen, & Franco, 2017; Mattioli et al., 2012), in this thesis the electronic database search was supplemented by other searches in order to improve the coverage of the relevant studies. These supplemental searches included the use of hand-searches such as scrutinizing of reference lists (Harris et al., 2014) and manual search of Google Scholar (Bramer et al., 2017). However, some studies had to be excluded because they investigated different cleaning tasks but did not separately document data on floor mopping.

A lack of effort to systematically identify unpublished peer-reviewed studies may have introduced bias into the systematic review (Aveyard, 2014). Evidence suggests that contact with investigators can help in identifying grey literature, unpublished research and those studies that can also be found from poorly-indexed bibliographic databases (Brueton, Tierney, Stenning & Rait, 2017). However, grey literature was not systematically scanned and experts and researchers working in this field was not contacted. However, the inclusion of conference proceedings in this review may reduce publication bias.

Extractor bias is a possible limitation, because at least two independent data extractors should be used (Shea et al., 2007). However, one author of the present study was the primary extractor of studies identified in the literature search, while the other researcher checked the data extraction accuracy.

As to critical appraisal, the use of a design-specific critical appraisal tool was used in the present review, although this approach might preclude direct comparison of the quality of the studies utilizing a different design (Crowe & Sheppard, 2011; Katrak et al., 2004). However, there is no single generic appraisal instrument which will be valid for the wide range of study designs that exist, nor does there exist one appraisal tool which is universally recognized as the standard by which all others are judged (Crowe & Sheppard, 2011; Katrak et al., 2004). Thus, in the present systematic review, the type of literature guided the selection of the tools. The use of these critical appraisal tools assisted in the development of a systematic approach in this review process, and ensured that all studies were assessed with equal rigor (Aveyard, 2014). The quality of the selected studies varied, and the lack of high-quality studies may lower the validity of the results. Considering that the findings regarding the methodological rigor and scientific quality of studies should be taken into account in the analysis and the conclusions of the review (Shea et al., 2007), the findings of the quality assessment were explicitly stated in formulating recommendations or suggestions. However, the fact that authors′ own study was included in the systematic review is also a potential source of bias. The involvement of a third researcher serving as an external reviewer (independent of the study) during the review process would have helped to avoid bias.

One major limitation of this systematic review is its lack of ability to draw direct comparisons between the studies and to combine them mathematically due to the heterogeneity of the exposure assessment methods and the outcome measures used. One can postulate that this limitation may partly be due to a general uncertainty in the methodology concerning exposure-response relationships and a lack of standardized approaches to the assessment of workplace factors (that is, selection of study parameters and methods). This issue is discussed more detail in the final section of this dissertation.

A threat to the external validity of the review is that most of the included studies had small sample sizes, as well as that some of the studies had deficiencies in describing the study sample and participants. Thus, the samples may have been non-representative of the general population of cleaners, which may limit the generalizability of results. In addition, the studies may have been underpowered for detecting differences in the outcome measures; there is as well an increased risk for Type II error. However, all the experiments used within-subject design, which is a more powerful design for detecting differences in outcome measures than is the case with between-subject design.

All in all, keeping in mind its limitations and strengths, interpretation of the results of this systematic review should be treated with caution. This caution is warranted because many ergonomic strategies have been investigated by only two studies. In addition, only a limited number of studies were published in the past ten years.

6.2.2 Experimental study

The reliability of the experiment was confirmed in several ways. The pilot study was conducted to ensure a reliable and repeatable procedure for taken measurements. In the actual experiment, the experimental conditions were carefully controlled so as to minimize possible errors from uncontrolled variations. For example, special attention was paid to the level of cleanliness of the floor as well as to elimination of external disturbances. In order to minimize the effect of experimental conditions on mopping performance, before the actual experiment took place cleaners were allowed to mop until they felt comfortable mopping. Additionally, a period of sufficient recovery time was kept before the experiment and between the trials in order to eliminate possible muscle fatigue effects.

In order to avoid systematic bias in results, the preparation of the mop (i.e., moistening of the mop) was standardized. Although mop dampness was controlled, the same mop cloth was used in all four mopping trials. This fact might mean that the level of moisture in the mop cloth was somewhat different between trials. However, it is worth noting that the weighing of mops showed an average of 9.5 grams weight loss over the course of the four trials. Thus, the effect of weight loss on muscle demand is likely to be minimal, and randomization of the mop heights also reduced the risk of systematic bias.

When considering the limitations of the EMG method, the phenomenon of crosstalk in myographic signals affects the reliability of EMG measurements (Talib et al., 2019). Therefore, in the present study, the reliability of EMG measurements was improved by taken into consideration the following factors: careful skin preparation (measurement of skin impedance level), proper placement of the electrodes, electrode size (Cram et al., 2011) and inter-electrode distance (Farina et al., 2002). Additionally, the electrode leads were carefully taped and high-pass filtering (20 Hz) of the EMG signals was used to reduce motion artefacts. In order to reduce the measurement error with regard to electrode placement, the same researcher (MAW) attached the EMG electrodes.

Being cognizant of the limitations regarding the normalization methods using maximal voluntary contractions (Burden et al., 2010), the present study used preliminary training of MVC tests with participants before the experiment and standardized verbal encouragement during MVC tests. These were done to ensure that the contractions were as close to maximal as possible MVC for the shoulder normalization in order to improve the validity of the method used. As to the documentation of the normalized EMG values, such reporting varies in the literature. This study reported EMG values as %MVC (not %MVE), although normalization refers to the electrical activities obtained during MVC; amplitudes were not converted into force or torque. This practice of documentation can be regarded as a limitation of this study. This is so because this practice of documentation may affect intepretation of the results because the values are expressed as %MVC. The study by Bao et al. (1995) has shown that ramp prodecure (i.e., a normalization method in which EMG amplitude is coverted into force or torque) resulted in significantly higher values than the MVE procedure (i.e., referring to the electrical activity obtained during MVC) at the static and medial occupational load levels. Therefore, one can postulate that in the present study, the derived numerical values of the muscle activities (%MVC) during the mopping task may be somewhat underestimated at static and median activity levels. However, this practice of documentation does not affect the reliability of the study results (differences between mop handle heights). Rather, this practice should be taken into account when %MVC values are compared to Jonsson's (1982) threshold limit values or are compared to other studies.

As for motion analysis, this study utilized inertial sensors that, to the author's knowledge have rarely been utilized in upper-limb ergonomics research to date. This method can be considered as applicable for physical ergonomics problem solving, because it allows for field recordings and measurements of multi-dimensional and multi-joint upper limb movements simultaneously in the course of a dynamic work task. Another advantage of this method was that it was capable of detecting the time, level and frequency aspects of musculoskeletal load. Inertial sensors are regarded as an accurate and reliable method for examining human movements (Cuesta-Vargas et al., 2010). For example, sensors are capable of accurately estimating wrist positions (Zhou & Hu, 2010) and upper upper arm/shoulder kinematics (Cutti et al., 2008; El-Gohary & McNames, 2012). However, the degree of their accuracy and reliability depends on the site and task (Cuesta-Vargas et al., 2010). With regard to calibration, the overall accuracy of inertial sensor-based (including the sensor type used in present study) joint angle data depends on the level of rigor of the experimental procedure (Bouvier et al., 2015). Acquisition of reliable data depends upon minimal soft tissue artefact (Bouvier et al., 2015; Cutti et al., 2008; Schall et al., 2016). Therefore, careful attention was given to sensor placement and secure skin attachment. The use of straps to minimize sensor movement appeared to work well. Further, a measurement drift is a common source of error in the utilization of IMUs and greatly affects position accuracy (De Baets, van der Straaten, Matheve, & Timmermans, 2017; Filippeschi et al., 2017; Zhou & Hu, 2010). In this study, heading drift was corrected manually by off-line methods utilizing visual inspection. Further, due to the fact that magnetometer signals are easily distorted by the presence of electromagnetic (Schall et al., 2016) and/or ferromagnetic materials (Filippeschi et al., 2017; Schall et al., 2016), objects and devices capable of producing electromagnetic or ferromagnetic interference were manually removed from the vicinity of the sensor. All recordings were performed at the same place, with a homogeneous magnetic environment maintained during the experiment. Thus the possible effect of such artefacts is probably minor and presumably insignificant for the interpretation.

In this study, neutral arm posture (i.e., reference position) was defined with the upper arm hanging alongside the body with elbow flexed, which may somewhat differ from a ´zero elevation reference position´ recording in which participants were leaning to the side with the arm hanging while holding a dumbbell in the hand (Wahlström et al., 2016) or without any weight in the hand (Dahlqvist, Nordander, Forsman, & Enquist, 2018). Despite the fact that in the present study reference posture (0° of elevation) was visually confirmed so as to avoid arm abduction, it is possible that the middle obesity of participants might affect the reference posture. Thus, change of elevation angle (°) may be underestimated. However, the present study utilized measurement protocol of van den Noort et al. (2014) and Cutti et al. (2008); in this study sample, the effect of the reference posture is probably minor and insignificant for the interpretation of results.

The present study describes the effects of the adjustment of the mop handle with respect to working posture, movement and muscular loading as well as cleaners' subjective strain responses to the workload**.** The productivity or quality of cleaning was not measured in this experiment which can be regarded as one limitation of this study. It is unknown whether or not the mopping performed in the experiment resulted in equivalent levels of floor cleaning efficacy at the experiment.

The primary limitation of the data relates to it small sample size (Studies II-III). As a result, given that considerable variation exists in physiological responses between individuals (Balogh, Hansson, Ohlsson, Strömberg, & Skervfing, 1999), the study may have been underpowered for detecting differences in the outcome measures. However, the experiment was conducted in accordance with within-subject design specifications so fewer participants may be required in order to attain the same level of statistical strength as a that attained with a parallel design. Further, despite the small sample size, statistically significant differencies in the outcome measures were found (e.g., in electrical activities of the shoulder muscles, arm elevation angles and acute subjective strain responses). Thus, the number of participants can be considered to be sufficient for the present experimental field study utilizing the within-subject design and controlling for intervening variables.

Another issue regarding the study sample is the fact that all but one of the participants were female. It is well-known that there are differences in anthropometric body characteristics between genders (Pheasant & Haslegrave, 2005). However, the population of cleaners is predominantly females. Thus, the sample corresponds to the population of users for whom this information is intended. Further, the mean BMI of this sample was 26.5 kg/m^2 which categorizes the average person in this study as overweight. This finding corresponds to the sample (n=48) of Finnish cleaners reported on the study by Hopsu et al. (2004). Further, it cannot be concluded that these differences between genders limit the generalizability of the findings to male cleaners. This is due to the fact that mop height is adjusted for the participant´s own anatomical landmarks; the greater length in one antropometric dimension (e.g., upper arm length), is also associated with greater length in another dimension (e.g., elbow-fingertip length). That is, the relative anthropometric dimensions possibly remain the same.

This study considered four mop handle heights based on anatomical landmarks rather than on scaling to individual participant height. A strength of this study is the practical applicability of scientific knowledge. Adjustment of the mop is an example of a kind of technique not too demanding to employ. According to Jensen et al. (2011), those techniques that did not demand radical changes in previous work habits seemed to be regarded as the techniques most easy to integrate. Nevertheless, it should be noted that the results cannot be generalized to diverse mopping environments.

One strength of this study is that exposure data were collected using three methods, utilizing both objective and subjective measurements. The results given by the three methods matched well: for instance, eye-level mop height perceived as more strenuous included higher levels of shoulder-loading exposures such as muscular loading and arm elevation. Both types of information (i.e., objective and subjective) are essential and complementary in the process of formulating recommendations for practice.

Another strength of this study is its use of direct technical measures allowing for close examination of upper-limb angular velocities, combined time and posture categories (e.g., percentage of time below 20° of arm elevation) as well as of combined posture and movement categories such as ´percentage of time at rest´. The measurement methods used in this study also provided quantitative measures on continuous scales. Observational or self-report methods are not capable of providing such quantitative measures. Further, the large number of parameters involved in the study were carefully selected based on previous studies showing upper-limb risk factors associated with floor mopping, as well as on consideration of the well-known physical risk factors related to UEMSDs.

Regarding the selection of variables, the fact that all variables were not independent has to be taken into account. It is a well-known fact that there are significant relations between various exposure measures, such as between wrist and upper arm movement measures (e.g., 50th percentiles of velocities) (Hansson et al., 2010) and between forearm muscular activity measures (e.g., between 50th and 90th percentiles as well as between 50th and 10th percentiles) (Hansson et al., 2009). Similarly, arm elevation measures (10th and 50th percentiles), arm elevation (99th percentile) and movement measures (50th percentile velocity) are known to relate to one another (Hansson et al., 2010). In addition, relations between UT muscle activity measures (e.g., 10th and 90th percentiles) have also been reported (Hansson et al., 2010; Nordander et al., 2016). In general, relations between the movement and muscular load are not unexpected: an active movement of the wrist requires activity of the muscles (Hansson et al., 2009), and work that requires movements of the hands also involves movements of the upper arms (Hansson et al., 2010). So, the relations between variables seemed to be unavoidable in this study as well, since both the muscular activity and movement were relevant measures to be quantified. In addition, the present study (Study II) examined the three amplitude levels (10th, 50th and 90th percentiles of APDF) in order to to gain a better understanding of the extent of muscular efforts associated with mopping using the different mop heights examined. Additionally, in Study III, regardless of the obvious dependency between the variables (e.g., arm elevation zones <20°, 20-60° and >60°), it was decided to conduct statistical testing of the variables. This dependency does not exert an influence on statistical testing and analyses because these dependent variables were not tested simultaneously.

Regarding the selection of the number of specific arm angular sectors and their limits, this study documented a large selection of variables associated with upper arm postures because to date, threshold limit values for making increased risk for UEMSDs are not available and a variety of sector limits was applied in previous studies. One can question the selection of both the percentage of time in specific arm angular section variable and arm angular percentiles variable because these are both extracted from the same amplitude distribution. Nevertheless, the use of the percentage of time sectors requires knowledge of the shape of the amplitude distribution. Therefore, angular percentiles were also documented in order to provide quantitative information about the exposure in question: that is, measure of physical units (°) that can be obtained by continuous scales. The use of both variables in measuring arm elevation supported the interpretation of results.

This study examined the effect of mop height on the shoulders in a mopping task involving arm elevation. It must be acknowledged that proper arm elevation is the result of the interaction between the glenohumeral and scapulothoracic joints (Fayad et al., 2008). Although motion of the scapula is essential for normal function of the upper limb, in this study kinematics during mopping was limited to motions of the upper arm only. In addition to shoulder kinematics factors (Hughes, Green & Taylor, 2012), alterations in scapular kinematics play an important role in the development of shoulder disorders such as SIS (Chopp-Hurley & Dickersson, 2015; Michener, McClure & Karduna, 2003; Struyf, Nijs, Baeyens, Mottram, & Meeusen, 2011; Timmons et al., 2012). Potential mechanisms of these kinematic alterations that may contribute to the development of SIS by reducing the size of subacromial space during arm elevation have been extensively studied (Chopp-Hurley & Dickersson, 2015; Ludewic & Reynolds, 2009; Michener et al., 2003). Therefore, it could be essential to evaluate whether there exist abnormal scapular kinematic patterns (i.e., scapular rotations that are supposed to narrow the subacromial space) that could contribute to the development of SIS when cleaners routinely use their arms in highly elevated positions while mopping.

Although it is recognized that cleaners are at increased risk of injury due to the combination of physical, individual and work organizational risk factors (Weigall et al., 2005), this thesis focused on physical risk factors and microergonomics. However, it must be noted that both micro- and macroergonomics strategies are needed for promoting well-being and health of cleaners (Kumar & Kumar, 2008). Furthermore, assessment of the exposure-health-effect relationship fell outside the scope of this thesis. Given the multifactorial nature of neck and shoulder disorders (Larsson et al., 2007) and the multiple hazards that cleaners face on the job, a more holistic approach to risk reduction in prevention of MSDs must be considered that, along with postural aspects, takes account of environmental and organizational aspects of cleaning work (Kumar & Kumar, 2008; Weigall et al., 2005; Woods & Buckle, 2006). Measures addressing the organizational load factors of floor cleaning work should be explored in order to assist the recovery of musculoskeletal systems and to optimize the physical load on cleaning professionals. For instance, introducing variation into the work by means of job enlargement and frequent rest periods have been considered as important measures for improving cleaning work (Blangsted et al., 2000; Sogaard et al., 2006).

6.2.3 Challenges faced in ergonomics research

This study faces challenges worth discussing. It disclosed the need for establishment of standardized exposure measures for technical measurements and permissible exposure levels (i.e., the quantitative exposure limits) for the musculoskeletal load of upper limbs.

This experimental study utilized exposure measures that are suitable for quantitative evaluation of floor mopping and for identifying the height of the mop handle which causes the lowest level of exposures. However, it is not possible to predict the preventive impact of ergonomically optimal mop height. The change in musculoskeletal strain (e.g., reduction in arm elevation angles) due to change in mop handle height cannot be directly translated into change of risk for developing

UEMSDs. Similarly, the findings of the systematic review showed a reduction in musculoskeletal strain due to the change of mopping method. However; whether it could have a considered preventive effect is predicated upon the exposure-outcome relation of risk being known. At present, such information on quantitative exposure-response relations (i.e., the quantitative relationship between physical exposure factors and UEMSDs) are known only to a limited extent. Pooled data from cross-sectional epidemiological studies by Nordander et al. (2013; 2016) have reported exposure-response relations for a large number of physical exposures for the upper limbs. Such knowledge about the exposure-response relationship may be an important step forward towards finding the relevant quantitative exposure measures and definition of occupational exposure limits for musculoskeletal load.

Another issue regarding quantitative exposure measures is the fact that the effects of combined exposure are not fully known. This fact also complicates the conclusions that can be drawn from the findings of the present study. Specifically, mopping involves exposure to a combination of physical factors; thus, prioritizing the physical risk factors in order to counteract risk for UEMSDs is challenging.

These uncertainties concerning exposure-outcome associations of working postures and musculoskeletal symptoms might also be reflected in the studies of this systematic review in which a wide variety of musculoskeletal outcomes were used and data presentation varied considerably. For instance, it is acknowledged that no consensus exists in the scientific community on the selection of specific arm elevation variables (Weber et al., 2018). These aforementioned factors highlight the need for the establishment of standardized exposure measures in order to increase the comparability of study findings.

Because exposure-outcome associations are not yet fully determined, this may explain the fact that no generally accepted threshold limit values for the upper limbs′ workload and strain are yet available. For a given exposure-outcome relationship, many exposure cut-points associated with elevated risk of MSDs for the upper extremities are available in the literature (Punnett, 2014). In addition, the guidelines suggested in the ISO standards should be interpreted with care, due to the fact that these standards are consensus-based; specific exposure limits have not been set according to evidence-based scientific methods (Armstrong et al., 2018). Recently, some load action levels for upper arm postures and movements at work have been proposed (Arvidsson, Dahlqvist, Enquist, & Nordander, 2017; Weber et al., 2018). These kinds of load action levels are possibly needed, not only among researchers but also among practitioners such as occupational physiotherapists in Finland. Ongoing technical development has led to simplified application of equipment (Dahlqvist, Hansson, & Forsman, 2016; Yang, Grooten, & Forsman, 2017), as well as easy availability and diminished cost of equipment (Weber et al., 2018). Thus, the use of motion-capturing technology is becoming even more feasible for occupational health practitioners in measuring musculoskeletal strain of the upper limb in workplaces. Therefore, limit values for acceptable workload based on scientific evidence are necessary for risk assessment.

7 CONCLUSIONS

The present study justifies the following conclusions:

1. Levels of evidence for effective ergonomic strategies are as follows: A) Moderate, for the use of individually adjustable tools; B) Mixed, for the use of various mop materials associated with their methods, including without or minimal amount of water and pre-actions for ensuring clear floor surface; and C) Insufficient, for the adoption of mopping techniques resulting in less musculoskeletal strain.

2. Mop height adjustment impacts the electrical activities of the shoulder muscles of the upper arm steering the mop and perceived exertion. Use of adjustment also affects the upper arms´ and LP-wrist´s positions, the UP-arm´s movements as well as electrical activities of the forearm muscles.

3. Utilization of adjustable mop handles (height of the mop) can be considered a good practice for reducing musculoskeletal load and strain.

4. There is no evidence for any measure indicating positive effects on the most vulnerable risk factors of the wrists: position, force and repetition.

5. Correct use of adjustable mops in which the upper mop handle is situated at about at the chin level enables alleviation of strain of the shoulder muscles, according to their electrical activity and perceived strain. This adjustment also minimizes possible negative consequences for strain on the wrists and forearm muscles.

This thesis proposes a preliminary framework for guiding future ergonomic development of cleaning tools and methods. This framework indicates that a more comprehensive approach is required in order to improve the contextualization of tools and methods to the task and user, and therefore this framework calls for integration of ergonomic knowledge into the process of tool design and utilization of a participatory ergonomic approach.

8 IMPLICATIONS FOR PRACTICE AND FUTURE RESEARCH

Implications for practice

1. The information in this study on the significance of mop adjustability can be utilized by employers responsible for the purchase of cleaning tools and for maintaining a healthy working environment for cleaners.

2. The results regarding suggested mop height adjustment can standardize the instructions given to cleaners and could be used by cleaning supervisors and managers responsible for ergonomic guidance at workplace as well as in the professional education of cleaners. These results could also be utilized in primary prevention in occupational health care; for example, in a context of physical examination of cleaning professionals and provision of ergonomic guidance.

3. The detailed information provided in this study on positions and movements associated with mopping can be useful for occupational physiotherapists when searching for compensatory working techniques for mopping on account of musculoskeletal impairment. This information can also be utilized as a basis for programs aimed at improving technical skills through training in ergonomics and helping the progress of recovery.

4. This thesis strengthens the knowledge base on musculoskeletal strain of upper extremities in floor mopping work. The information in this study on shoulder loading related to professional cleaning work could be utilized in expanding the advice given to occupational health care professionals in Finland, because the guidelines concerning cleaners´ physical examination do not currently recognize the health hazard for shoulders. This thesis confirms that, due to the many physical risk factors involved in mopping, the shoulders are also at risk for developing MSDs in the course of cleaning work.

5. This study proposes a preliminary framework for better understanding the need for a more comprehensive approach in developing ergonomics in cleaning work. This framework can be utilized in future ergonomic development of cleaning tools and equipment, and can also be applied by occupational health practitioners in ergonomic assessments of cleaning work.

Suggestions for future research

1. Further research on different mop height adjustment mechanisms is needed to ensure the easy usability of such equipment.

2. Ergonomic measures should be directed at the alleviation of the wrists´ load and strain in the course of mopping. On the one hand, research on the impacts of redesign of mops (e.g., use of curved handles) on wrist posture is suggested. Such research requires incorporation of ergonomics into the process of tool design at an early stage, and a participatory ergonomics approach utilizing a multidisciplinary design team. On the other hand, discovery of new technological solutions (e.g., opportunities to utilize robot-assisted cleaning) is required for reducing the repetitiveness of the movement of the upper limbs.

3. The preliminary framework proposed in this study needs to be expanded to enhance the understanding of organizational ergonomics aspects in the reduction of physical load in floor cleaning work. Longitudinal intervention studies investigating long-term effects of technical and organizational measures on floor cleaning work in diverse environments, including both exposure and musculoskeletal health effect variables, is suggested.

4. Research regarding establishment of standardized, quantitative exposure measures of upper limb workload for technical measurements and permissible action levels is suggested. Such research may improve the comparability between studies and the prediction of preventive effect of ergonomic measures.

5. Previous descriptions of shoulder kinematics during floor mopping have been limited to motions of the upper arm or glenohumeral joint. Future study is suggested to measure three-dimensional scapulothoracic kinematics during mopping in order to examine whether there exist abnormal kinematic patterns (such as alteration in scapular position) that could contribute to the development of shoulder impingement if cleaners repeatedly use their arms in elevated positions while mopping.

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Floor mopping work is associated with high levels of risk for the upper extremities. The results of this doctoral thesis shows that utilization of adjustable mop handles can be considered to be a good practice for reducing musculoskeletal load and strain. This study determines the optimal height for the upper mop handle and the position of the upper arm. This study also proposes a preliminary framework for guiding future development of the ergonomics of cleaning tools and methods.

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