UNIVERSIDAD POLITÉCNICA DE MADRID
Facultad de Ciencias de la Actividad Física y del Deporte

Epidemiological and Experimental Studies of Musculoskeletal Disorders in Professional Cleaners

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Hao Man
Master of Physical Education

Madrid, 2024

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Doctoral Degree in Physical Activity and Sport Sciences

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Under the supervision of:
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Title: Epidemiological and Experimental Studies of Musculoskeletal Disorders in Professional Cleaners

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If I am allowed, I want to thank my younger self for taking on the challenge of starting this Ph.D. in Madrid. It meant struggling in a new language and culture, far from my friends and family, in a place that was mostly unfamiliar. I remember my freezer stocked with 'medio kilo' of this and 'medio kilo' of that every time I visited the *carnicería* or the *pescadería*. While this thesis represents my growth as a scientist, I also want to acknowledge my personal journey—from being a stranger in a strange land to finding a second home here in Spain.

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Abstract

This doctoral thesis provides an in-depth analysis of the relationship between occupational factors and musculoskeletal pain among professional cleaners, based on two studies.

The first study is a cross-sectional investigation spanning 2012-2018, which examines the associations between lifestyle, physical, and psychosocial factors and the prevalence of low-back pain (LBP) and neck/shoulder pain (NSP) in a sample of 1042 participants. The results show significant associations between lifestyle, physical, and psychosocial factors and the prevalence of LBP and NSP. Specifically, cleaners with obesity (BMI>30) experienced greater pain intensity in both LBP (3.75, 95% CI 3.21-4.28) and NSP (3.54, 95% CI 3.04-4.05) compared to those with a normal weight (2.87, 95% CI 2.49-3.24, P=.001 and 2.89, 95% CI 2.53-3.25, p=.01 respectively). Cleaners experiencing high physical exertion during work showed higher LBP and NSP compared with those experiencing low and moderate physical exertion (P<.0001). Low recognition from management was also associated with higher LBP and NSP (P<.05). While other factors such as smoking, leisure physical activity, influence at work, and support from colleagues did not reach statistical significance, their inclusion contributes to a better understanding of the complex interplay of factors impacting musculoskeletal health.

The second study examines forearm muscle activity during 9 common cleaning tasks in a real working environment. Seven healthy cleaners participated in this study (age: 35.17 ± 9.62 yr; height: 168.17 ± 8.06 cm; weight: 77.14 ± 13.78 kg; experience: 5.60 ± 3.29 yr). Surface wireless electromyography (EMG) was recorded from 2 muscles on both sides of the upper limb, flexor carpi ulnaris (FCU), and extensor carpi radialis (ECR), and normalized to maximal voluntary isometric contractions (MVIC). Top-3 demanding high-force tasks (90th percentile EMG) were the rough floor, dirty rough floor, and office floor mopping for the FCU, and mopping high walls, ceiling mopping, and baize cleaning for the ECR. Top-3 static work tasks (10th percentile EMG) were mopping low walls, ceiling mopping, and dirty rough floors mopping for the FCU and mopping of high walls, low walls, and ceiling for the ECR. The study identified the forearm muscles' most physically demanding work tasks during cleaning tasks. The development of better working tools is recommended to avoid high-force overload as well as prolonged static overload of these muscles in cleaners.

By identifying both broad occupational risks and specific task-related muscle strains, these studies encourage the development of interventions such as ergonomic tool development and workplace policies that address the multifactorial demands of the cleaning profession and promote cleaner well-being.

Resumen

Esta tesis doctoral proporciona un análisis exhaustivo de la relación entre factores ocupacionales y el dolor musculoesquelético entre los trabajadores de limpieza profesional, basado en dos estudios fundamentales.

El primer estudio es una investigación transversal realizada entre 2012 y 2018, que examina las asociaciones entre factores de estilo de vida, físicos y psicosociales y la prevalencia de dolor lumbar (LBP) y dolor de cuello/hombros (NSP) en una muestra de 1042 participantes. Los resultados muestran asociaciones significativas entre dichos factores y la prevalencia de LBP y NSP. Específicamente, los limpiadores con obesidad (IMC>30) experimentaron una mayor intensidad de dolor tanto en LBP (3,75, IC 95% 3,21-4,28) como en NSP (3,54, IC 95% 3,04-4,05) en comparación con aquellos con un peso normal (2,87, IC 95% 2,49-3,24, P=.001 y 2,89, IC 95% 2,53-3,25, p=.01 respectivamente). Los limpiadores que experimentan una alta exigencia física durante el trabajo mostraron un mayor LBP y NSP en comparación con aquellos que experimentan una exigencia física baja o moderada (P<.0001). El bajo reconocimiento por parte de la gerencia también se asoció con un mayor LBP y NSP (P<.05). Aunque otros factores como el tabaquismo, la actividad física en el tiempo libre, la influencia en el trabajo y el apoyo entre compañeros de trabajo no alcanzaron significancia estadística, su inclusión contribuye a una mejor comprensión de la compleja interacción de factores que impactan en la salud musculoesquelética.

El segundo estudio examina la actividad muscular del antebrazo durante 9 tareas de limpieza comunes en un entorno de trabajo real. Siete limpiadores saludables participaron en este estudio (edad: 35,17 ± 9,62 años; altura: 168,17 ± 8,06 cm; peso: 77,14 ± 13,78 kg; experiencia: 5,60 ± 3,29 años). La electromiografía de superficie inalámbrica (EMG) se registró en 2 músculos en ambos lados del miembro superior, el flexor carpi ulnaris (FCU) y el extensor carpi radialis (ECR), y se normalizó con relación a las contracciones isométricas máximas voluntarias (MVIC). Las tres tareas de alta fuerza más exigentes (percentil 90 de EMG) fueron el fregado de piso rugoso, fregado de piso sucio rugoso y fregado de piso de oficina para el FCU, y el fregado de paredes altas, fregado de techo y limpieza de paños para el ECR. Las tres tareas de trabajo estático superior (percentil 10 de EMG) fueron el fregado de paredes bajas, el fregado de techos y el fregado de pisos sucios y rugosos para el FCU y el fregado de paredes altas, paredes bajas y techos para el ECR. El estudio identificó las tareas de trabajo más exigentes físicamente para los músculos del antebrazo durante las tareas de limpieza. Se recomienda el desarrollo de mejores herramientas de trabajo para evitar la sobrecarga de alta fuerza, así como la sobrecarga estática prolongada de estos músculos en los limpiadores.

En conjunto, esta tesis enfatiza la necesidad de un enfoque holístico para abordar los trastornos musculoesqueléticos entre los trabajadores de limpieza. Al identificar tanto los riesgos ocupacionales amplios como las tensiones musculares específicas relacionadas con las tareas, estos estudios contribuyen a la base para intervenciones tales como el desarrollo de herramientas ergonómicas y políticas laborales que aborden las demandas únicas de la profesión de limpieza y promuevan el bienestar de los trabajadores de limpieza.

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Abbreviations and Acronyms

BMI	Body Mass Index
CI	Confidence Intervals
COPSOQ	Copenhagen Psychosocial Questionnaire
CTS	Carpal Tunnel Syndrome
ECR	Extensor Carpi Radialis
EMG	Electromyography
FCU	Flexor Carpi Ulnaris
LBP	Low-back Pain
LS	Least Square
LTPA	Leisure Time Physical Activity
MSD	Musculoskeletal Disorders
MVIC	Maximal voluntary isometric Contractions
NSP	Neck/shoulder Pain
RMS	Root Mean Square
SD	Standard Deviation
UNE	Ulnar Neuropathy at the Elbow
WEHD	Work Environment and Health in Denmark Study
WMSDs	Work-related Musculoskeletal Disorders

1. Introduction

1.1. The origin of the doctoral thesis

The origin of my doctoral thesis started from my curiosity and eagerness to learn.

The Biomechanical Analysis Research Group at UPM has collaborated with GESEME since 2017 to conduct workplace analyses focusing on musculoskeletal disorders (MSD) using electromyography (EMG). To date, we have analyzed 200 workers in various roles, with mant different tasks of each profession. Of these, we developed a protocol for cleaning tasks and utilized part of this project for my thesis, involving real workers in their actual job settings. Given these considerations, I achieved a high external validity due to the involvement ofn employees in their work environments.

What's more, the collaboration with Professor Lars Louis Andersen began in 2018, marking an important moment in the direction of this research. Professor Andersen introduced the concept of applying sports science principles to ergonomics to improve workers' well-being and aging. This encounter motivated my exploration into using ergonomic interventions to enhance working conditions and facilitated ongoing communication and collaboration.

During my exchange at the National Research Center for the Working Environment (NFA) in Denmark, with Professor Andersen's invitation, I conducted an epidemiological study as part of my doctoral thesis, which is difficult to carry out in Spain. While some of the data originates from prior years, these early studies laid essential groundwork and provided a comprehensive context for this doctoral work, highlighting the relevance of addressing musculoskeletal health in occupational settings. This collaboration has facilitated a focused approach to addressing the critical and evolving challenges of musculoskeletal health within the cleaning profession, aligning directly with the objectives of this doctoral research.

1.2. Background and Significance of the Cleaning Profession

Cleaners provide an essential service to industries, communities, and public environments, both indoors and outdoors. They are defined as people whose main job task is cleaning (e.g., housekeeper, building maintenance, and cleaning assistance). This profession is essential for maintaining hygiene and safety in various settings, including healthcare facilities, schools, office buildings, and hospitality venues. The COVID-19 pandemic highlighted the need to support and value the cleaning works, which has gained more attention from scientists and research in recent years.

Cleaners represent a large proportion of the workforce. This occupation engages approximately 4 million dedicated individuals only in Europe (Safety, Work, & Brun, 2010),

and 2 thousand individuals are registered as cleaners in 2019 in Spain. It is crucial to ensure that cleaners remain healthy and perform their physically demanding tasks.

However, cleaners tend to have limited access to formal education, leading to a confluence of factors such as low income, compromised health, and restricted socioeconomic resources (Donald E Eggerth, Bermang Ortiz, Brenna M Keller, & Michael A Flynn, 2019). Additionally, there are indicators that lowly educated occupational groups, typically characterized by strenuous physical labor, elevated rates of sick leave, and premature retirement, appear to have limited access to workplace health initiatives when contrasted with their more educated peers (Grosch, Alterman, Petersen, & Murphy, 1998; Heisig, Gesthuizen, & Solga, 2019; Sponselee, Kroeze, Robroek, Renders, & Steenhuis, 2022), which raises critical questions about the occupational health and well-being of cleaners, particularly concerning musculoskeletal disorders, a topic of central focus in this thesis.

1.3. Musculoskeletal Disorders of Cleaners

Musculoskeletal disorders (MSD) encompass a range of discomforts and injuries that impact the muscles, bones, nerves, tendons, ligaments, joints, cartilage, and spinal discs, that were documented in 1.7 billion people worldwide (World Health Organization, 2021). These disorders encompass a variety of issues such as sprains, strains, tears, soreness, pain, carpal tunnel syndrome, hernias, and connective tissues injuries leading to temporary or lifelong limitations in functioning and participation (B. R. da Costa & E. R. Vieira, 2010; Weigall, Simpson, Bell, & Kemp, 2005). Moreover, MSD frequently result in reduced productivity, disability (Fejer & Hartvigsen, 2008; "Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016," 2017), disease (B. I. Martin et al., 2008), short- and long-term sickness absence (Bergström, Bodin, Bertilsson, & Jensen, 2007; Côté et al., 2009; Nyman, Grooten, Wiktorin, Liwing, & Norrman, 2007), impaired work ability (Colombini & Occhipinti, 2006), and early retirement (Feleus et al., 2017; Martimo et al., 2009). Thus, the consequences are not only limited to the individuals' physical and psychological well-being (Saarni et al., 2006), but also have an impact on society as a whole, leading to higher healthcare expenditures (Mäntyselkä, Kumpusalo, Ahonen, & Takala, 2002).

Occupational injuries rank as the prevailing health concern faced by cleaners on a global scale, constituting a significant challenge within professions (Zock, 2005). A literature review published in ScienceDirect emphasizes the higher injury rates and musculoskeletal disorders experienced by workers performing cleaning duties, particularly in the form of MSD, which can affect the forearm and elbow region (Lin et al., 2022). The prevalence of MSD among cleaners varies significantly across regions, with rates ranging from 74% in the United Kingdom (Woods & Buckle, 2006) to as high as 90% in Taiwan (Chang, Wu, Liu, & Hsu, 2012). Moreover, the 12-month prevalence exceeded 70% in Sweden (Unge et al., 2007) and 52.3% in Ethiopia (Melese, Gebreyesus, Alamer, & Berhe, 2020), while the 4-week prevalence in workplace settings reached 84% in Las Vegas (Krause, Scherzer, & Rugulies, 2005). Interestingly, hospital cleaners in Norway exhibited a comparatively lower prevalence at 56% (Lasrado, Møllerløkken, Moen, & Van den Bergh, 2017).

Cleaners are often at risk of developing work-related musculoskeletal disorders (WMSDs) over time, particularly in the upper limbs: including the neck, shoulders, upper back, low-back, elbows, and wrists (Figure 1) (Bruno R da Costa & Edgar Ramos Vieira, 2010; Nordander et al., 2016; Nordander et al., 2013; Van Rijn, Huisstede, Koes, & Burdorf, 2009). Concretely, nearly 90% of cleaners reported WMSDs in at least one body part (Chang et al., 2012). Another study that surveyed 1216 cleaners found that 74% had muscular discomfort in the last year

and as a result, 23% experienced sickness absence (Woods & Buckle, 2006). Of these, highest prevalence (71.6%) was reported in the shoulder regions (Lim et al., 2022). Low-back pain (LBP) is also a main area of concern, affecting nearly 50% of cleaners (Woods & Buckle, 2006). Hand/wrist pain and discomfort is a common problem, with a prevalence of 42% followed by elbow pain with a prevalence of 33%(Chang et al., 2012).

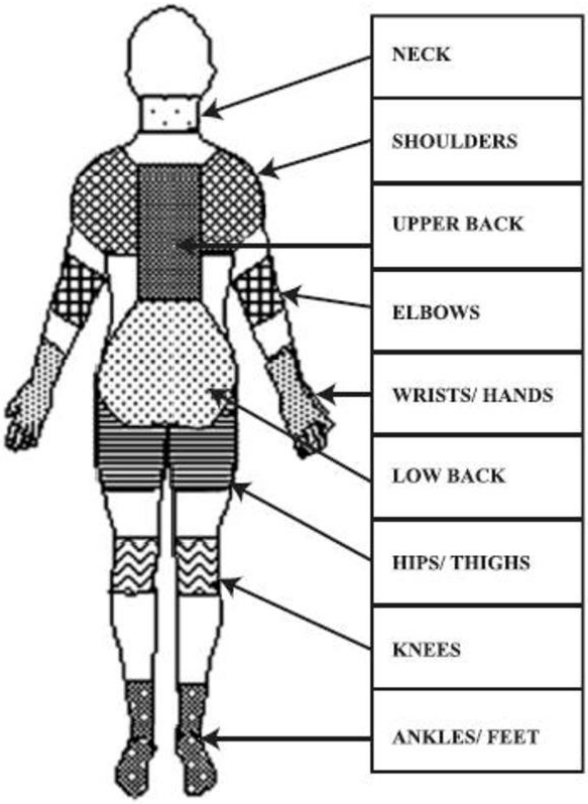


Figure 1. Nordic Body Map. Source: Iridiastadi dan Yassierli, 2015.

1.3.1. Risk Factors of MSD among Cleaners

Often, cleaning tasks generally consist of awkward postures in both static and dynamic muscular activities, repetitive movements and lifting heavy objects such as sweeping, mopping, scrubbing, swabbing, vacuuming, buffing, and handling cleaning machines, trash and furniture (Kumar & Kumar, 2008). Also, it is widely acknowledged that employees in physically demanding occupations, such as cleaners, face an elevated risk of developing Musculoskeletal Disorders (MSD) (J. H. Andersen, Haahr, & Frost, 2007; A. Holtermann et al., 2010). The repetitive and strenuous nature of cleaning tasks, which often involve lifting, bending, and sustained periods of standing or kneeling, places a substantial biomechanical load on the musculoskeletal system. This sustained mechanical stress can lead to microtrauma, inflammation, and, over time, the development of chronic MSD.

In addition to the occupational demands, individual factors play a crucial role in the occurrence of MSD among cleaners. Advancing age is identified as a significant predictor, as it often coincides with a decline in musculoskeletal resilience and regenerative capacity. Female gender, too, presents unique considerations, as differences in anatomy and hormonal fluctuations may influence susceptibility to certain types of MSD. Moreover, lifestyle-related factors like smoking, higher body mass index (BMI), and low levels of physical activity are consistently linked to a higher incidence of MSD (Feveile, Jensen, & Burr, 2002; Haukka, Ojajärvi, Takala, Viikari-Juntura, & Leino-Arjas, 2012; L. Viester et al., 2013). For example, leisure time physical activity (LTPA), generally beneficial (Andreas Holtermann, Schnohr, Nordestgaard, & Marott, 2021), has nuanced effects for those in physically demanding roles, potentially impacting the prevalence of lower back pain (LBP) and neck/shoulder pain (NSP) differently. These factors not only affect overall health but can also exacerbate the impact of occupational demands on the musculoskeletal system.

Beyond the physical aspects, the role of psychosocial factors in the development of MSD among cleaners is an area of increasing interest. While the physical demands of the job are substantial, the psychosocial work environment can significantly modulate the risk. A comprehensive literature review consistently highlights that cleaning is notably associated with high physical and psychosocial workloads, further substantiating the link to musculoskeletal issues (Kumar & Kumar, 2008). Factors such as job dissatisfaction, high job strain, low social support, and inadequate control over work pace and tasks have been associated with a heightened risk of MSD (Sterud, Johannessen, & Tynes, 2014; van den Heuvel, van der Beek, Blatter, Hoogendoorn, & Bongers, 2005). This underscores the complex interplay between physical and psychosocial elements in shaping the musculoskeletal health of cleaners.

Nevertheless, the aetiology of MSD is to a large extent unknown but is frequently attributed to a multifaceted interplay between individual, physical, and psychosocial risk factors (Visser & van Dieën, 2006; Zock, 2005). The biopsychosocial model of pain also accorded that these factors influence the sensation of pain (Engel, 1977). This model suggests that pain is influenced by a complex interplay of various factors, including individual characteristics (e.g., age, sex, BMI), psychological stressors (e.g., job strain, mental health), and social determinants (e.g., socioeconomic status, social support).

While there is existing research discussing individual risk factors that affect MSD among cleaners, there is a notable gap in the literature when it comes to comprehensive investigations that simultaneously consider all these factors. Therefore, further research on this topic is warranted. Understanding these multifaceted risk factors is imperative for

developing targeted interventions and ergonomic modifications to mitigate the occurrence and impact of MSD in the cleaning profession.

1.3.2. Neck/shoulder Pain

Neck and shoulder pain often co-occur, as illustrated in Figure 2, which depicts the muscles in this region. This combination of pain poses unique difficulties due to potential reductions in motion, impacting various routine activities. In Europe, 25% of workers have reported work-related neck/shoulder pain (NSP) (de Kraker & Blatter, 2005).

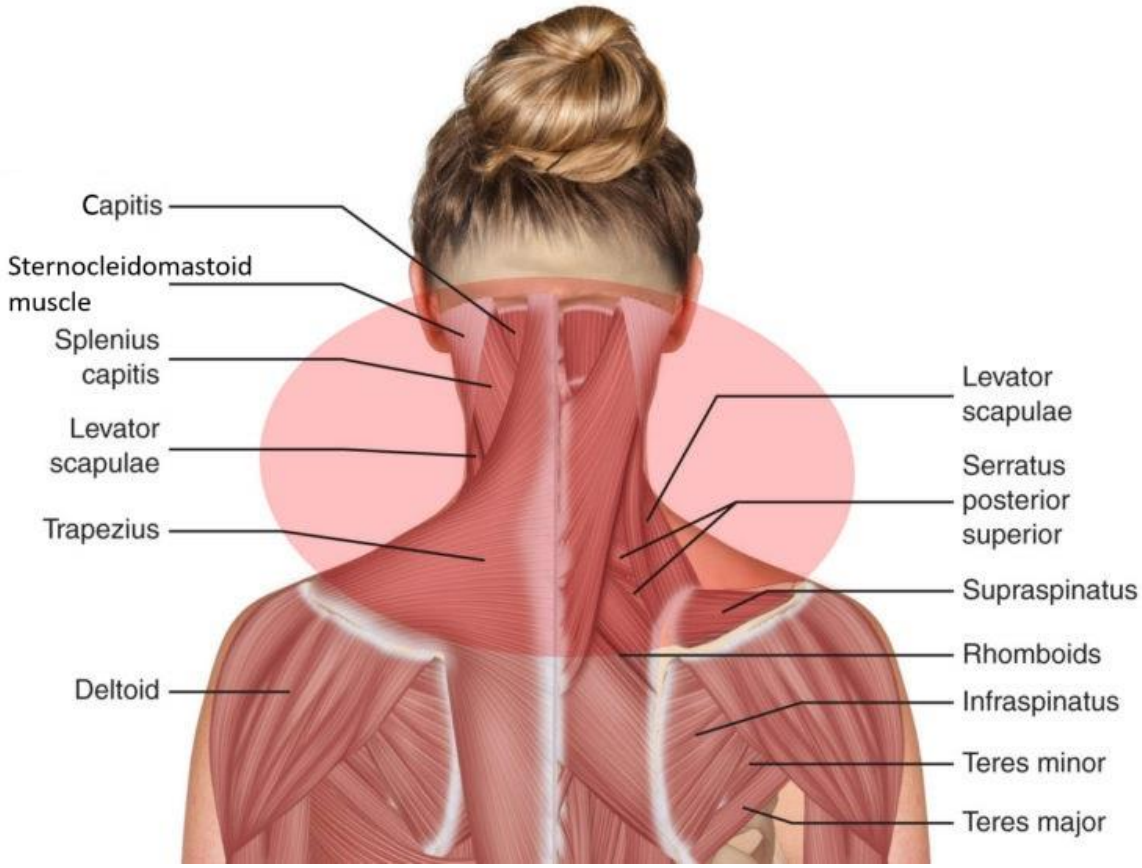


Figure 2. Muscles of neck and shoulder part. Source: https://fusionteachertraining.com/neck-shoulders/.

Figure 2 provides a visual insight into the complex musculature contributing to neck and shoulder pain. Understanding these anatomical structures is pivotal in our broader objective of investigating musculoskeletal disorders among cleaners. This pain is gaining increased attention, surpassing even the traditionally emphasized issue of low-back pain (LBP) (Östergren et al., 2005). While LBP has historically been the primary concern, the rising

occurrence of neck and shoulder pain underscores the need for a comprehensive examination of these specific issues in the cleaning profession.

1.3.3. Low-back Pain

Low-back pain, defined as pain and discomfort localized below the lower rib margins and above the inferior gluteal folds (see Figure 3), is a prevalent symptom experienced by individuals worldwide (Vrbanić, 2011). The duration of LBP varies, categorized as acute (lasting under 6 weeks), sub-acute (6-12 weeks), or chronic (over 12 weeks). Additionally, LBP may be classified as specific or non-specific, with the latter indicating that the experience of pain cannot be confidently attributed to another underlying condition (World Health Organization, 2023).

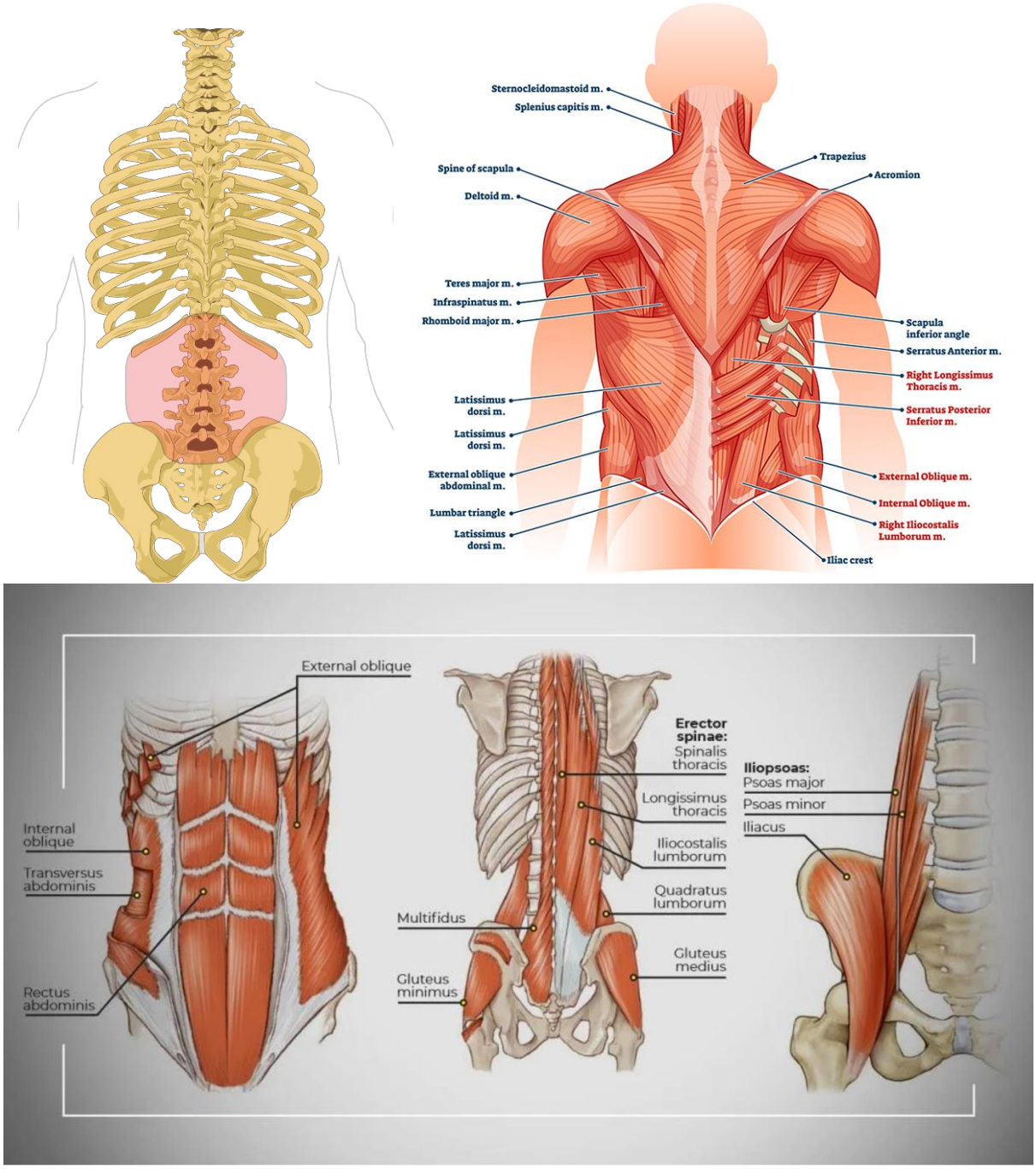


Figure 3. Location and low-back muscles. Source: https://en.wikipedia.org/wiki/Lumbar (left), Hina Firdous, 2023 (right) and https://samarpanphysioclinic.com/deep-muscles-of-the-core/ (below).

Figure 3 visually represents the anatomical boundaries of LBP, aiding in a better understanding of its localization. Understanding these distinctions is crucial for our investigation into musculoskeletal disorders among cleaners. LBP stands as the most prevalent symptom globally, affecting diverse populations. Its ubiquity underscores the significance of exploring this issue within the cleaning profession, where physical demands are substantial. As we delve into the prevalence and characteristics of LBP, our research aims

to contribute valuable insights into the specific issues faced by cleaners and potential avenues for intervention and support.

1.3.4. Forearm and Wrist: Key Muscles and Risk Factors for WMSDs

Cleaners often engage in a forceful grip, numerous repetitions, and continuous movement of the wrist, making the forearm particularly vulnerable to work-related musculoskeletal disorders (WMSDs). Chronic WMSDs in this region can lead to functional impairment, (Richards, 1996). Reports from Taiwan indicated a high prevalence of discomfort in the hand/wrist (41.7%) and elbow (33.3%) among cleaners (Jer-Hao Chang et al., 2012).

Carpal tunnel syndrome (CTS) is a prevalent upper extremity neuropathy caused by compression of the median nerve in the carpal tunnel, which can also lead to ulnar neuropathy at the elbow (UNE) (Baker, Moehling, Desai, & Gustafson, 2013). Studies have shown that 48% of 179 floor cleaners were diagnosed with CTS, and 7% with UNE (Mondelli et al., 2006). Factors contributing to CTS include high levels of hand-arm vibration, prolonged wrist flexion/extension, radial/ulnar deviation, and forceful or repetitive hand movements (Ibrahim, Khan, Goddard, & Smitham, 2012; S. Martin, 1991; Pelmear & Taylor, 1994). Another study suggests that high-repetition wrist flexion/extension and strong grip requirements are risk factors (Palmer, Harris, & Coggon, 2007).

Repetitive tasks involving wrist rotation (supination/pronation) can also contribute to injuries like humeral epicondylitis and pronator teres syndrome(Hartz, Linscheid, Gramse, & Daube, 1981; Price, 1982; Steinbach, Fritz, Tirman, & Uffman, 1997). It was indicated that repeated supination and pronation, especially with the wrist extended, could add to the prevalence of epicondylitis (Viikari-Juntura et al., 1991). Almost all cleaning tasks require a forceful grip and high repetitions with all the directions of wrist movements, this might be the reason why the cleaning category has a high risk of hand/wrist WMSDs.

Other conditions commonly affecting cleaners include tendonitis, marked by tendon inflammation due to repeated movement (Safety & Work, 2008), and epicondylitis, also known as tennis or golfer’s elbow, where tendons around the elbow become inflamed due to repetitive gripping and twisting motions (CDC, 2010).

1.4. Electromyography (EMG): A Biomechanical Tool for Understanding Muscle Activity

Electromyography (EMG) is a diagnostic technique that measures muscle response or electrical activity in response to a nerve's stimulation of the muscle (Lúzar, Zorrilla, & García, 2005; Massó et al., 2010). Specifically, it is based on recording variations in the electrical potential generated by a muscle when it activates due to a sequence of electrical impulses originating from the central nervous system control centers and transmitted through the efferent pathways of motoneurons to the terminal motor endplates of motor units (Enoka, 1994). Thus, the electromyograph detects the electric potential generated by muscle cells when activated. The signals can be analyzed to detect abnormalities, activation level, or recruitment order, or to analyze the biomechanics of human or animal movement (Raez, Hussain, & Mohd-Yasin, 2006). Moreover, most of our understanding of the role of individual muscles in movement is founded on an integrated analysis of EMG, anatomical and kinematic information (Gatesy, 1997; Goslow, Seeherman, Taylor, McCutchin, & Heglund, 1981; Jayne & Lauder, 1993; Stern & Larson, 2001).

1.4.1. Key Objectives of EMG Measurements

The primary purpose of EMG measurements is to understand the activity of one or more muscles during specific actions and EMG is arguably the most commonly used tool for investigating muscle function during locomotion (Roberts & Gabaldón, 2008). This includes:

1. Determining Muscle Activity: EMG helps identify whether a muscle is active or at rest at any given moment.
2. Quantifying Muscle Activity: It provides insights into the degree of muscle activation during active periods, reflecting the level of muscular effort. It's important to note that this measure is distinct from muscle strength, as the recorded electrical signal depends on the ionic concentration within the muscle.
3. Exploring Muscle Relationships: EMG also aids in understanding how a muscle interacts and coordinates with other muscles involved in the action under study. This encompasses examining intermuscular and intramuscular coordination and the phenomenon of coactivation, where both agonist and antagonist muscles exhibit activity simultaneously (Donaldson, Donaldson, & Snelling, 2003).
4. Analizing fatigue: EMG serves as a valuable tool for analyzing muscle fatigue during prolonged or repetitive activities (Luttmann, Jäger, & Laurig, 2000). By monitoring

changes in muscle activity patterns over time, EMG can identify signs of fatigue, such as a decline in muscle activation or altered coordination (Rampichini, Vieira, Castiglioni, & Merati, 2020). This information is crucial for assessing the physiological impact of tasks on muscles and can inform strategies for preventing fatigue-related injuries or optimizing work processes to minimize the risk of musculoskeletal disorders.

1.4.2. Applications of EMG

There are two types of EMG. Needle EMG is an electrodiagnostic medicine technique commonly used by neurologist (Daube & Rubin, 2009; Rubin, 2019). Surface EMG is a non-medical procedure used to assess muscle activation by several professionals, including physiotherapists, kinesiologists, and biomedical engineers (Stegeman, Blok, Hermens, & Roeleveld, 2000). EMG is used clinically for the diagnosis of neurological and neuromuscular problems (Campanini, Disselhorst-Klug, Rymer, & Merletti, 2020), and it is also used in many types of research laboratories, including those involved in biomechanics, motor control, neuromuscular physiology, movement disorders, postural control, and physical therapy.

In the domain of sports medicine, EMG serves as a critical tool in examining muscle activation patterns to develop data-driven training and rehabilitation programs, aiding athletes in enhancing their performance and preventing injuries (Khaiyat & Norris, 2018).

1.4.3. Importance of EMG in Work Environment

While EMG is widely recognized for its applications in sports medicine (Raez et al., 2006), its utility extends beyond the realm of athletics. It serves several crucial functions that contribute to the well-being of workers and the overall efficiency of occupational tasks. EMG's role in the work environment can be summarized as follows:

1. Assessment of Muscle Activity: EMG allows for the precise measurement and analysis of muscle activity in real-time (Hellig, Rick, Mertens, Nitsch, & Brandl, 2019). In physically demanding occupations, understanding the level of muscle activation is vital for optimizing work tasks, reducing fatigue, and preventing overexertion. This data can inform adjustments to job design and work processes to minimize the risk of MSD.
2. Ergonomic Design: By quantifying muscle activity and fatigue, EMG aids in the development of ergonomic work environments (Motamedzade, Afshari, & Soltanian, 2014). Employers can use this information not only to design workstations but also to

test the efficiency of tools and equipment. EMG provides valuable insights into how different tools affect muscle activation and fatigue levels, helping employers identify and implement tools that are not only ergonomically designed but also more efficient, reducing worker fatigue and enhancing overall productivity.

3. Injury Prevention: EMG data helps identify patterns of muscle activity that may lead to overuse injuries or MSD (Faucett, Garry, Nadler, & Ettare, 2002). With this insight, employers can implement targeted injury prevention programs that include stretching routines, rest breaks, or job rotation strategies. These initiatives are instrumental in reducing workplace injuries and absenteeism.
4. Rehabilitation and Recovery: In cases where workers have experienced injuries, EMG can play a vital role in rehabilitation (Pilkar et al., 2020; Stawiarska & Stawiarski, 2023). It provides a means to monitor and assess muscle function during recovery, ensuring that employees can safely return to work with reduced risk of re-injury.
5. Individualized Training: EMG can be used to develop individualized training programs for workers. By understanding the unique muscle activity profiles of employees, training can be tailored to address their specific needs, improving performance and reducing the risk of workplace injuries.

In summary, EMG is an invaluable tool in the work environment, enhancing both the health and productivity of employees. It empowers organizations to create safer, more ergonomic workplaces, minimize the risk of musculoskeletal injuries, and optimize the efficiency of job tasks. By leveraging EMG technology, employers can foster a work environment that prioritizes the well-being of their workforce while maintaining high levels of performance and productivity.

1.4.4. State of the Art in EMG Studies on Occupational Health

To better contextualize the role of EMG in assessing occupational health, Table 1 provides a summary of notable studies that have employed EMG for evaluating muscle activity in physically demanding professions. These studies span multiple countries and varied sample sizes, highlighting the diversity in methodological approaches. By detailing these studies, we establish a clear foundation for the need for focused EMG research on cleaners, as there remains a gap in understanding muscle activity in this specific occupation.

Table 1: Overview of Key EMG Studies on Muscle Activity in Physically Demanding Work Environments.

Authors& Year	**Profession**	**Participants (N)**	**Type of EMG**	**Muscles Studied**	**Key Findings**
Januario, Franca, Moreira, and Oliveira (2018)	Computer-based tasks	45	Surface electromyography (sEMG)	Upper trapezius (UT) and wrist extensors (WE)	Only WE showed differences between dominant and non-dominant arm.
Young, Trudeau, Odell, Marinelli, and Dennerlein (2013)	Touch-screen tablet use	15	surface electromyography	Upper trapezius, anterior deltoid, flexor carpi radialis, flexor carp ulnaris, and extensor radialis	Muscle activity for the wrist significantly varied across configurations and between hands.
Åkesson, Hansson, Balogh, Moritz, and Skerfving (1997)	Dentists	12	Surface electromyography	Upper trapezius muscle bilaterally, flexor and extensor muscles of the right forearm	Dentists are exposed to high load on the trapezius muscles bilaterally, and steep, prolonged forward bending of the head.
Skals, Bláfoss, Andersen, de Zee, and Andersen (2021)	Supermarket workers	17	Surface electromyography	Trapezius descendens and erector spinae longissimus	Cucumbers and bread required highest muscular efforts for the shoulder/neck; Bananas, milk, cucumbers and bread required highest efforts for the lower back.

Afsharipour, Petracca, Gasparini, and Merletti (2016)	Violin and cello players	27	Surface EMG (sEMG)	Right trapezius and right and left erector spinae muscles	Back muscles of violin and cello players were activated asymmetrically, specifically in fast movements.

1.4.5. EMG Findings in Upper Limb Musculoskeletal Health

Unlike the general musculoskeletal disorders of NSP and LBP, upper limb disorders in cleaners—specifically the wrists and forearms—present unique risks related to repetitive movements and prolonged gripping. The upper limb's network of muscles, spanning from the forearm to the hands, is central to the daily tasks of professional cleaners, as shown in Figure 4. Cleaners face increased risk for conditions like carpal tunnel syndrome (CTS) and tendinitis due to frequent wrist flexion/extension, ulnar/radial deviation, and high repetition. Understanding the detailed of these muscles is essential for comprehending the potential challenges they face.

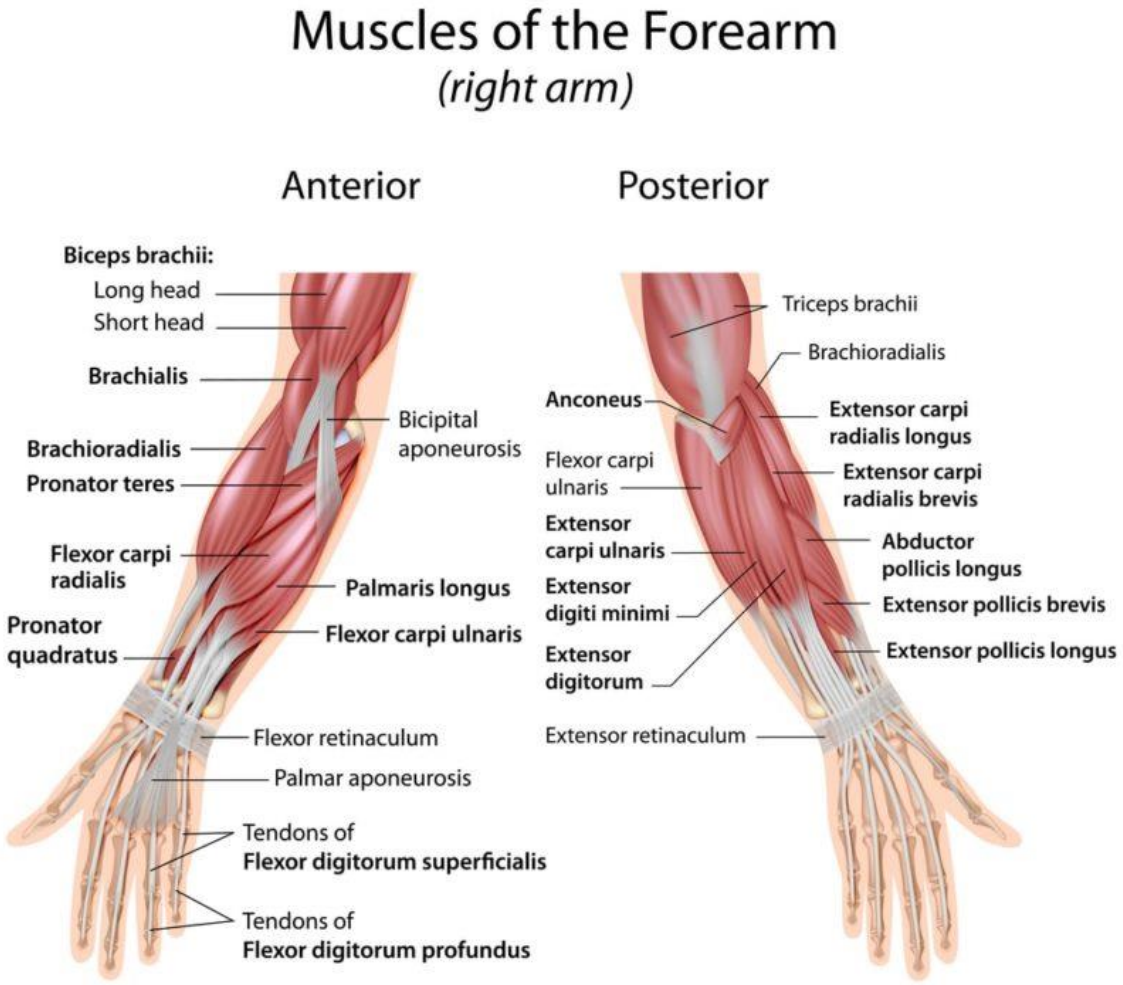


Figure 4. Muscles of Forearm and hand (right arm). Source: www.alilamedicalimages.com.

Using EMG to pinpoint cleaning tasks that exert the greatest strain on forearm muscles is crucial for targeted prevention and intervention. EMG's ability to measure precise muscle activity provides an in-depth view of how tasks contribute to fatigue and risk of WMSDs. For

example, repetitive gripping or twisting motions increase forearm muscle activity, identifying high-risk tasks.

Since most WMSDs of the forearm are chronic conditions that lead to functional impairment, it is important to treat muscle activity as an overuse mechanism and understand forearm muscle recruitment in complex hand/wrist and elbow actions to prevent injuries. In the past research which has examined forearm muscle activity, it has been reported that the co-activation as well as individual activation of wrist flexors and extensors are playing an important role in maintaining wrist stability (Matsushita, Handa, Ichie, & Hoshimiya, 1995). Specifically, wrist flexors are playing a predominant role in producing grip strength and wrist flexion forces (Duque, Masset, & Malchaire, 1995; Imrhan, 1991; Kattel, Fredericks, Fernandez, & Lee, 1996; Mogk & Keir, 2003); while the wrist extensors concomitantly stabilize during grip movements and inhibit the forces produced by wrist flexors (Bober, Kornecki, Lehr Jr, & Zawadzki, 1982; G. M. Hägg, Öster, & Byström, 1997; Johansson, Björing, & Hägg, 2004). It has also been reported that increased muscle activity of wrist extensors have been linked to the WMSDs of the upper extremity (O'sullivan & Gallwey, 2002), and decreasing the ulnar deviation of the wrist and the muscle activity accordingly may reduce the symptoms associated with WMSDs (H.-M. Chen, Lee, & Cheng, 2012). However, it has not been clarified if isolated muscle activities of the forearm produce comparable demands of actions that encompass the use of multiple muscles.

Our exploration of this area aims to uncover the specific risk factors associated with forearm related WMSDs among cleaners, offering valuable insights for preventive measures and interventions in this physically demanding profession.

2. Research Problems and Objectives

2.1. Objectives in English

The previous section has made clear the interest and adequation of analizing the underlying factors in musculoskeletal pain in cleaners. Techniques such as EMG have been used in other working fields, but nothing has yet been done in the cleaning industry. This doctoral thesis, therefore, seeks to address the following objective:

General Objective: To comprehensively investigate the occupational factors contributing to musculoskeletal disorders (MSD) among professional cleaners, with an emphasis on identifying risk factors, anatomical patterns of pain, and specific muscle activity in order to inform targeted ergonomic interventions and improve workplace conditions.

From this general objective derive two more specific objectives:

Specific Objective 1: To analyze the prevalence and risk factors of MSD among professional cleaners. This objective is achieved through a cross-sectional epidemiological study, examining various lifestyle-related, organizational, physical, and psychosocial factors and their associations with MSD.

Specific Objective 2: To investigate muscle activity patterns during common cleaning tasks by employing surface electromyography (EMG) to assess muscle activation. This objective is addressed through an experimental study that evaluates the physical demands placed on relevant muscles, providing insights into task-specific muscle loads within a real working environment.

2.2. Objetivos en Español

La sección anterior ha dejado claro el interés y la adecuación de analizar los factores subyacentes al dolor musculoesquelético en limpiadores. Técnicas como la EMG se han utilizado en otros campos laborales, pero aún no se ha hecho nada en la industria de la limpieza. Esta tesis doctoral, por lo tanto, busca abordar el siguiente objetivo:

Objetivo General: Investigar de manera exhaustiva los factores ocupacionales que contribuyen a los trastornos musculoesqueléticos (TME) en limpiadores profesionales, con énfasis en identificar factores de riesgo, patrones anatómicos de dolor y actividad muscular específica, con el fin de informar intervenciones ergonómicas específicas y mejorar las condiciones laborales.

De este objetivo general se derivan dos objetivos más específicos:

Objetivo Específico 1: Analizar la prevalencia y los factores de riesgo de los TME en limpiadores profesionales. Este objetivo se aborda a través de un estudio epidemiológico transversal, examinando diversos factores relacionados con el estilo de vida, organizativos, físicos y psicosociales, y sus asociaciones con los TME.

Objetivo Específico 2: Investigar los patrones de actividad muscular durante tareas comunes de limpieza utilizando la electromiografía de superficie (EMG) para evaluar la activación muscular. Este objetivo se aborda mediante un estudio experimental que evalúa las demandas físicas impuestas en los músculos relevantes, proporcionando información sobre las cargas musculares específicas de las tareas en un entorno laboral real.

3. Methods and Results - Epidemiological Study of Professional Cleaners

3.1. Research Rationale and Overview

This study investigates the prevalence of neck/shoulder and low back pain (NSP and LBP) through a cross-sectional analysis, highlighting the associations between pain, lifestyle, physical, and psychosocial factors. These areas are commonly reported pain sites among cleaners, providing a basis for identifying broad, systemic factors contributing to musculoskeletal health.

3.2. Methods

3.2.1. Study design and population

This cross-sectional study consisted of professional cleaners, who participated in four questionnaire rounds (2012, 2014, 2016, 2018) of the Work Environment and Health in Denmark Study (WEHD) (L. L. Andersen, Thorsen, Flyvholm, & Holtermann, 2018; L. L. Andersen et al., 2021; Johnsen et al., 2019). In short, the source population was professional cleaners living in Denmark, aged 18-64 years, working ≥35 hours/month and income ≥3000 DKK (approximately 400 €) per month during the previous 3 months. Through four rounds, 1042 responses were received from the included sample. Reporting follows the STROBE guidelines for cross-sectional studies (Vandenbroucke et al., 2014).

3.2.2. Predictors

Age (continuous variable, which was categorized into 18-49 years and 50-64 years) and sex for each individual were drawn from the Central Person Register of Denmark. Lifestyle factors included body mass index (continuous variable, BMI, kg/m^2 which was categorized into normal weight, overweight and obesity), smoking status (categorical variable: current smoker, non-smoker), leisure-time physical activity (continuous variable, total weekly hours of leisure physical activity, which was categorized into 2 hours or less, 3 to 5 and 6 hours or more a week). To assess perceived physical exertion, the following question was used asking, "How physically demanding do you normally consider your present work?" using an 11-point numeric rating scale (G. A. Borg, 1982) from 0 ('not demanding') to 10 ('extremely demanding'). For the subsequent statistical analysis, we converted it into 3 categories: 0-4 as 'low physical exertion', 5-7 as 'moderate physical exertion' and 8-10 as 'high physical exertion'. This is a general measure of overall physical work demands and reflects the balance between the physical work demands and the physical capacity to perform the work (L. L. Andersen, Clausen, Persson, & Holtermann, 2012).

Based on the Copenhagen Psychosocial Questionnaire (COPSOQ) (Pejtersen, Kristensen, Borg, & Bjorner, 2010), three psychosocial factors were included: 'recognition from management' (1 item), 'influence at work' (2 items), and 'collaboration and support from colleagues' (2 items). The response categories were "Always", "Often", "Sometimes", "Rarely", and "Never/almost never" for all questions. For further analyses, the response categories of the psychosocial variables were linearly normalized on a scale of 0–100 (i.e., poor, 0–50; moderate, 50–75; and good, 75–100).

3.2.3. Outcome Variable: Intensity of Musculoskeletal Pain

Participants rated pain intensity in the low-back and neck/shoulder respectively, on a horizontal scale of 0-10 as the worst pain during the previous three months, where 0 is no pain and 10 is the worst imaginable pain (Pincus et al., 2008).

3.2.4. Statistical Analyses

General linear models (SAS, version 9.4) were used to estimate pain intensities in relation to the aforementioned predictors (mutually adjusted). Results are reported as least square means and 95% confidence intervals. P-values less than 0.05 were accepted as statistically significant.

3.3. Results

Table 1 shows the demographics, lifestyle, and work-related characteristics of the included professional cleaners (564, 184, 145 and 149 in 2012, 2014, 2016 and 2018 respectively) in terms of age, sex, BMI, lifestyle, influence at work, and musculoskeletal pain. Pain intensity was 3.53 (SD 3.11) and 3.33 (SD 3.22) in the neck/shoulder and low-back, respectively.

Table 2: Descriptive statistics for the main study variables. Values are the percentage of participants or mean and standard deviations (SD).

	N	%	Mean	SD
Questionnaire round				
2012	564	54.13		
2014	184	17.66		
2016	145	13.92		
2018	149	14.30		
Age (years)				
< 50 years	481	46.16		
≥50 years	561	53.84		
Sex				
Men	238	22.84		
Women	804	77.16		
Body Mass Index ($kg \cdot m^{-2}$)				
Normal weight	514	49.33		
Overweight	348	33.40		
Obesity	180	17.27		
Smoking				
Current smoker	261	25.05		
Non-smoker	781	74.95		
Leisure time physical activity				
2 hours or less a week	366	35.12		
3-5 hours a week	295	28.31		
6 hours or more a week	381	36.56		
Perceived physical exertion				

Low 0-4	221	21.21		
Moderate 5-7	480	46.07		
High 8-10	341	32.73		
Recognition from management				
Low 0-50	533	51.15		
Moderate 50-75	274	26.30		
High 75-100	235	22.55		
Influence at work				
Low 0-50	191	18.33		
Moderate 50-75	363	34.84		
High 75-100	488	46.83		
Collaboration and support from colleagues				
Low 0-50	183	17.56		
Moderate 50-75	398	38.20		
High 75-100	461	44.24		
Pain intensity (0-10)				
Neck-shoulder			3.53	3.11
Low-back			3.33	3.23

Table 2 shows the adjusted pain intensities of neck/shoulder and low-back in relation to the predictors. Female participants (3.70, 95% CI 3.39 - 4.01) experienced significantly higher odds of neck/shoulder pain (P<.0001) than male participants (2.60, 95% CI 2.15 - 3.06). Those who with less than 50 years (3.04, 95% CI 2.63 - 3.44) experienced significantly lower odds of low-back pain (P<.001) than those with 50 years or older (3.56, 95% CI 3.18 - 3.93).

BMI, physical exertion and recognition from management were significantly associated with both NSP and LBP. Individuals with obesity (BMI>30) experienced significantly higher NSP (difference 0.65, 95% CI 0.15 - 1.16, P=.0114) and LBP (difference 0.88, 95% CI 0.35 - 1.41, P=.0011) than those with normal weight. The results showed that participants with high physical exertion experienced significantly higher odds of pain intensity than those with low physical exertion of both neck/shoulder and low-back (P<.0001). Those with low recognition from management showed significantly higher NSP and LBP than those with moderate (P=.0007 and P=.0298, respectively) and high recognition (P=.0053 and P=.0027, respectively).

Other predictors which involved in this study like smoke, physical activity, influence at work and support from colleagues were not significantly associated with NSP or LBP (P>.05).

Table 3: Association between predictors and pain intensity of neck/shoulder and low-back (least square means and 95% confidence intervals).

	Neck/shoulder pain		Low-back pain	
	LS means (95% CI)	**Difference (95% CI)**	**LS means (95% CI)**	**Difference (95% CI)**
Sex				
Men	2.60 (2.15 - 3.06)	1	3.11 (2.63 - 3.59)	1
Women	3.70 (3.39 - 4.01)	1.10 (0.67 - 1.53) ***	3.48 (3.15 - 3.81)	0.37 (-0.08 - 0.82)
Age				
Less than 50 years	3.02 (2.63 - 3.40)	1	3.04 (2.63 - 3.44)	1
50 years or older	3.28 (2.92 - 3.64)	0.27 (-0.10 - 0.63)	3.56 (3.18 - 3.93)	0.52 (0.14 - 0.90) **
BMI				
Normal weight	2.89 (2.53 - 3.25)	1	2.87 (2.49 - 3.24)	1
Overweight	3.02 (2.61 - 3.42)	0.12 (-0.28 - 0.53)	3.27 (2.85 - 3.70)	0.41 (-0.01 - 0.83)
Obesity	3.54 (3.04 - 4.05)	0.65 (0.15 - 1.16) *	3.75 (3.21 - 4.28)	0.88 (0.35 - 1.41) *
Smoking				
Current smoker	3.23 (2.78 - 3.68)	0.17 (-0.25 - 0.59)	3.46 (2.99 - 3.93)	0.33 (-0.11 - 0.77)
Non-smoker	3.07 (2.76 - 3.38)	1	3.13 (2.80 - 3.46)	1
Physical exertion				
Low 0-4	2.44 (1.97-2.92)	1	2.63 (2.13 - 3.14)	1
Moderate 5-7	2.75 (2.38-3.12)	0.31 (-0.17 – 0.79)	2.87 (2.49 - 3.26)	0.24 (-0.26 – 0.74)
High 8-10	4.26 (3.83-4.68)	1.81 (1.28 - 2.34) ***	4.38 (3.93 - 4.83)	1.74 (1.19 - 2.30) ***
Leisure physical activity				

2 hours or less a week	3.24 (2.85 -3.63)	1	3.23 (2.82 - 3.64)	1
3-5 hours a week	3.16 (2.72 - 3.59)	-0.08 (-0.54 - 0.37)	3.37 (2.91 - 3.82)	0.14 (-0.34 - 0.62)
6 hours or more a week	3.05 (2.64 - 3.46)	-0.19 (-0.62 - 0.24)	3.29 (2.86 - 3.73)	0.07 (-0.38 - 0.52)
Recognition from management				
Low 0-50	3.65 (3.30-3.99)	1	3.74 (3.38 - 4.10)	1
Moderate 50-75	2.89 (2.45-3.33)	-0.76 (-1.20 to -0.32) **	3.23 (2.77 - 3.69)	-0.51 (-0.97 to -0.05) *
High 75-100	2.92 (2.42-3.42)	-0.73 (-1.24 to -0.22) *	2.92 (2.39 - 3.45)	-0.82 (-1.36 to -0.29) *
Influence at work				
Low 0-50	3.09 (2.59 - 3.60)	1	3.33 (2.80 - 3.86)	1
Moderate 50-75	3.08 (2.66 - 3.49)	-0.02 (-0.55 - 0.51)	3.39 (2.95 - 3.83)	0.06 (-0.50 - 0.61)
High 75-100	3.28 (2.91 - 3.65)	0.19 (-0.34 - 0.72)	3.17 (2.78 - 3.56)	-0.16 (-0.72 - 0.40)
Collaboration and support				
Low 0-50	3.20 (2.68 - 3.73)	1	3.32 (2.77 - 3.87)	1
Moderate 50-75	3.14 (2.74 - 3.55)	-0.06 (-0.60 - 0.48)	3.16 (2.74 - 3.59)	-0.16 (-0.72 - 0.40)
High 75-100	3.11 (2.73 - 3.48)	-0.10 (-0.66 - 0.47)	3.41 (3.01 - 3.80)	0.08 (-0.51 - 0.68)

*P<.05

**P<.001

***P<.0001

4. Methods and Results - Experimental Study (Using EMG)

4.1. Research Rationale and Overview

This study focuses specifically on muscle strain in the forearm muscles, using surface electromyography (EMG) during common cleaning tasks. This targeted approach reflects the specific demands of the cleaning tasks, which predominantly involve hand and wrist movements for gripping and manipulating tools, with the trunk primarily stabilizing the body rather than engaging dynamically. As a result, assessing the forearm muscles, particularly the flexor carpi ulnaris (FCU) and extensor carpi radialis (ECR), was deemed most relevant for evaluating task-related physical strain in real-world cleaning environments.

4.2. Methods

4.2.1. Study Design and Justification for Muscle Selection

This study was born out of a collaboration between GESEME and the Sports Biomechanics Laboratory of UPM. This gave us the opportunity to analyze cleaning workers at a cosmetics factory in Valencia, Spain. The project consisted in measuring a range of upper limb muscles for comprehensive insight into muscle activity during cleaning tasks. As a result, a report was produced identifying the physically demanding tasks for the different muscles. However, in order to publish a scientific study, a limitation was found. We focused exclusively on maximum voluntary isometric contraction (MVIC) in the forearms -specifically the flexor carpi ulnaris (FCU) and extensor carpi radialis (ECR), as assessing other muscles posed risks that the company did not permit. As this test are the scientific standard reference for EMG analysis, only these two muscles appear in the final article.

4.2.2. Subjects

Eight participants, employed in a cosmetic factory in Valencia, Spain, initially enrolled in the study. However, one participant did not complete the full testing protocol, resulting in a final cohort of seven cleaners (age: 35,17±9,62 years; height: 168,17±8,06 cm; weight: 77,14±13,78 kg; range of experience: 2-10 years), all of whom were right-handed. The inclusion criteria were 1) working full time, 2) no history of injury within the previous 6 months, and 3) habitual performance of the tasks analyzed in the study. After being informed of the risks of the study, subjects provided written informed consent. This study was approved by the Ethics Committee of the Universidad Politécnica de Madrid. All measurements were performed at the factory during a normal workday with regular cleaning tasks, ensuring that the factory operated under its standard conditions. We measured all the cleaning workers on the 19th of April 2018 (Thursday afternoon), and the 20th (Friday morning).

4.2.3. Equipment

The electromyographic activity of four muscles was recorded using the wireless Trigno Delsys® system set at 1111 Hz. This system allowed workers to perform their daily real tasks with complete freedom of movement and was composed of a receiver device, a data registering software, and a series of surface wireless electrodes placed on each of

the muscles. The signal gain of the electrodes was 909V/V±5%. The EMGWorks Acquisition software (Delsys, Inc. Massachusetts, U.S.A) was used to visualize and record the data.

4.2.4. Procedure

After all recording sites were shaved and sanitized with an isopropyl alcohol swab, the sensors were placed on the skin on the flexor carpi ulnaris (FCU) and the extensor carpi radialis (ECR) of both arms using double-sided tape, following the SENIAM protocol for electrode placement (Perotto, 2011) (figure 5). Next, participants engaged in two rounds of maximal voluntary isometric contractions (MVIC) for each muscle group. A 60-second rest was observed between series, while a 3-minute interval was enforced between assessments of different muscles. During the MVIC, participants sustained maximal effort for 5 seconds, guided by verbal encouragement. The test was performed in a seated position with the palms of the subject resting against a table for the FCU and the back of the hands against the table for the ECR.

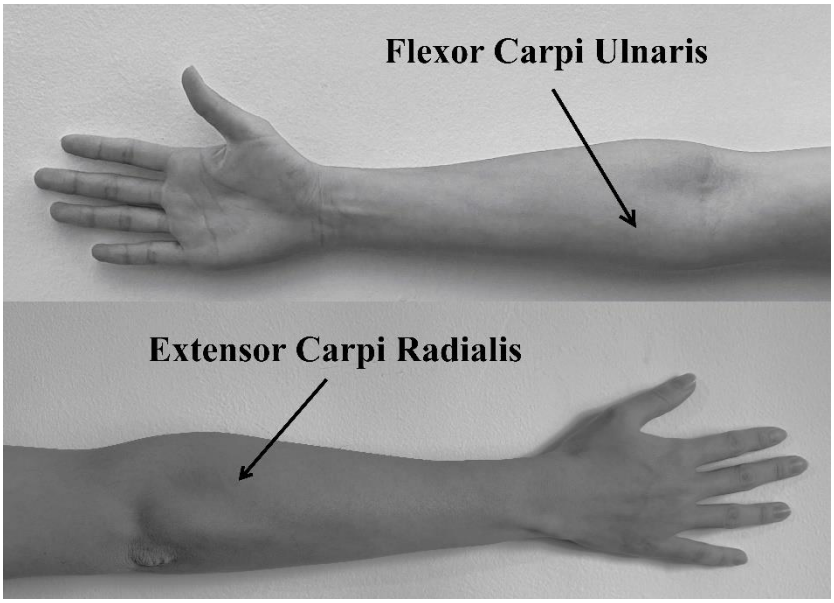


Figure 5. Muscles were measured in the present study.

Following the MVIC, one minute of each task was recorded. Participants were instructed to perform the tasks as they usually do (some of them are shown in figure 6-8), including the adjustment of the mops according to their individual preferences. The specific details and order of these tasks are explicitly delineated in Table 3, mirroring the

participants' customary work routine. A standardized rest period of five minutes was conscientiously implemented between tasks.

Figure 6. Task 6 Floor Scrubbing.

Figure 7. Task 7 Scrubbing in Corners.

Figure 8. Task 9 Baize Cleaning.

Table 4: Task name, description, and physical load of nine measured tasks.

	Task Name	Description	Physical Load
1	Mopping of high walls	Clean the wall above the worker's head using a mop with an adjustable length to fit their height.	Manual, overhead
2	Mopping of low walls	Clean lower part of wall till 2 meters high using a mop with adjustable length.	Manual
3	Ceiling Mopping	Clean a ceiling approximately 3.5 meters high using a mop with adjustable length.	Manual, overhead
4	Rough Floor Mopping	Clean a stain on a rough anti-slip floor using a mop with adjustable length and moving through the room.	Manual
5	Dirty Rough Floor Mopping	Clean a rough anti-slip floor using a mop with adjustable length without moving through the room.	Manual, with extra strength
6	Floor Scrubbing	Clean a rough anti-slip floor with a cleaning machine and moving through the room.	Machine
7	Scrubbing in Corners	Clean a rough anti-slip floor with a cleaning machine but now more complicated areas of the room (corners and areas close to heavy machines).	Machine, with extra strength
8	Office Floor Mopping	Clean an office floor using a mop with adjustable length and moving through the room.	Manual
9	Baize Cleaning	Use baize to clean the heavy machines on the production line.	Manual

4.2.5. Data Processing

The EMG data were processed using the EMGWORKS-Analysis® from Delsys®. First, signal filtering was performed using a bandpass Butterworth filter with a cut-off frequency of between 20–300 Hz. The signal was smoothened and rectified by calculating the root mean square (RMS) of the filtered signal with a window amplitude of 0.05 seconds and a window overlap of 0.025 seconds. These RMS signals were normalized to the maximum amplitude obtained during MVIC tests of the FCU and the ECR muscles. For MVIC values we used the average activity during 500 milliseconds in which the muscle activity was higher and did the mean of the two rounds. The 10th, 50th, and 90th percentiles of the amplitude probability distribution function (APDF) (Jonsson, 1982), expressed as a percentage of MVIC (%MVC) for the two muscles (FCU, ECR) were calculated for each subject, both hands and each cleaning task.

The amplitude of muscle activity from a prolonged EMG recording was ranked into three levels of activity defined as static, median, and peak (Hansson et al., 2000; Jonsson, 1982; Nordander et al., 2000). Static muscle activity (the 10^{th} APDF percentile, P10) was considered an indicator of the level of sustained, low-amplitude muscle activity required for biomechanical functions such as maintaining postural control. Median and peak muscle activity (the 50^{th} APDF percentile, P50, and the 90^{th} APDF percentile, P90) represented median- and high-amplitude muscle activity respectively, which are required more for dynamic tasks, especially the P90 was considered as less frequent workload (Hansson et al., 2000; Jonsson, 1982; Marker et al., 2016).

4.2.6. Statistical Analysis

All statistical analysis was performed using the SPSS® v.24 software. Normal distribution was tested by two methods: the Saphiro-Wilk test, which showed a nonsignificant result, and graphical examination using Q-Q plots to visually evaluate the data's normality. Consequently, we determined differences between each task and between muscles using a repeated measure 3-way ANOVA for each of the percentiles was performed: Task (9) * Muscle (2) * Arm (2). Within-factor differences were analyzed using Bonferroni's correction. The significance level was set at $p<0.05$. Partial eta squared was used to inform of effect size following Cohen's interpretation of .01 for a small effect, .06 for a medium effect, and .14 for a large effect. (Cohen, 1992). We were also informed of the

statistical values and degrees of freedom for each test. Data are reported as mean ± standard deviation (SD).

4.3. Results

Significant differences were found between tasks in the three percentiles (P10: $F_{8.48}$=17.39, p<.001, η2=.74; P50: $F_{8.48}$=9.64, p<.001, η2=.62; P90: $F_{8.48}$=8.61, p<.001, η2=.59). No differences were found between the dominant and non-dominant arms, or between the two muscles measured (p>.05).

On one hand, the interaction between task and arm was significant only at P90 ($F_{8.48}$=2.16, p=.048, η2=.26). The post hoc analysis showed that in P90 there were differences between both arms in task 6 (p=.006), which was the activation of the dominant and non-dominant arms 9.1% and 7.1% of MVIC respectively. Also, differences between arms were found in P10 in task 8 (p=.030), with activation of 3.3% in the dominant arm and 2.8% in the non-dominant pair (table 4).

Table 5: Mean (SD) of the FCU and ECR muscle activation levels in 10th, 50th and 90th percentiles during nine different cleaning tasks.

	Mean ± SD / Task Name	P10		P50		P90	
		Dominant	Non-dominant	Dominant	Non-dominant	Dominant	Non-dominant
1	Mopping of high walls	4.7 ± 1.9%	4.5 ± 2.3%	8.8 ± 2.4%	8.7 ± 4.1%	17.0 ± 4.6%	17.5 ± 7.1%
2	Mopping of low walls	4.8 ± 1.8%	4.5 ± 1.8%	8.7 ± 2.5%	8.5 ± 2.0%	17.0 ± 5.6%	15.5 ± 2.8%
3	Ceiling Mopping	4.1 ± 1.7%	4.2 ± 1.9%	9.4 ± 5.2%	8.0 ± 3.4%	23.7 ± 12.9%	16.7 ± 8.8%
4	Rough Floor Mopping	3.8 ± 1.8%	3.3 ± 1.6%	8.8 ± 4.7%	7.7 ± 3.7%	18.8 ± 10.3%	21.2 ± 10.1%
5	Dirty Rough Floor Mopping	4.5 ± 2.4%	3.8 ± 1.8%	9.9 ± 5.7%	9.1 ± 4.1%	21.6 ± 12.5%	22.7 ± 9.0%
6	Floor Scrubbing	2.4 ± 1.8%	1.9 ± 1.0%	4.0 ± 2.3%	3.6 ± 2.2%	9.1 ± 5.0%*	7.2 ± 4.4%
7	Scrubbing in Corners	2.8 ± 1.7%	2.9 ± 1.4%	5.2 ± 2.4%	5.8 ± 4.1%	11.8 ± 4.0%	11.7 ± 6.2%
8	Office Floor Mopping	3.3 ± 1.5%*	2.8 ± 1.2%	7.6 ± 3.9%	8.3 ± 3.0%	17.0 ± 9.0%	21.2 ± 8.9%
9	Baize Cleaning	2.3 ± 1.1%	1.7 ± 1.1%	5.8 ± 3.6%	3.9 ± 2.5%	20.9 ± 13.2%	14.6 ± 6.8%

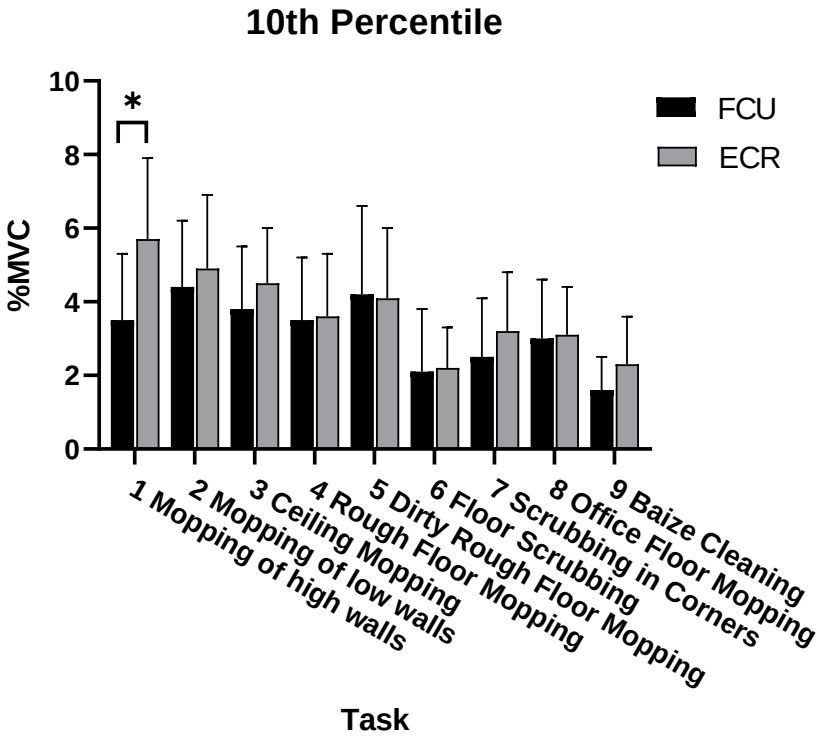
* $p<0.05$ between dominant and non-dominant arms

FCU: flexor carpi ulnaris

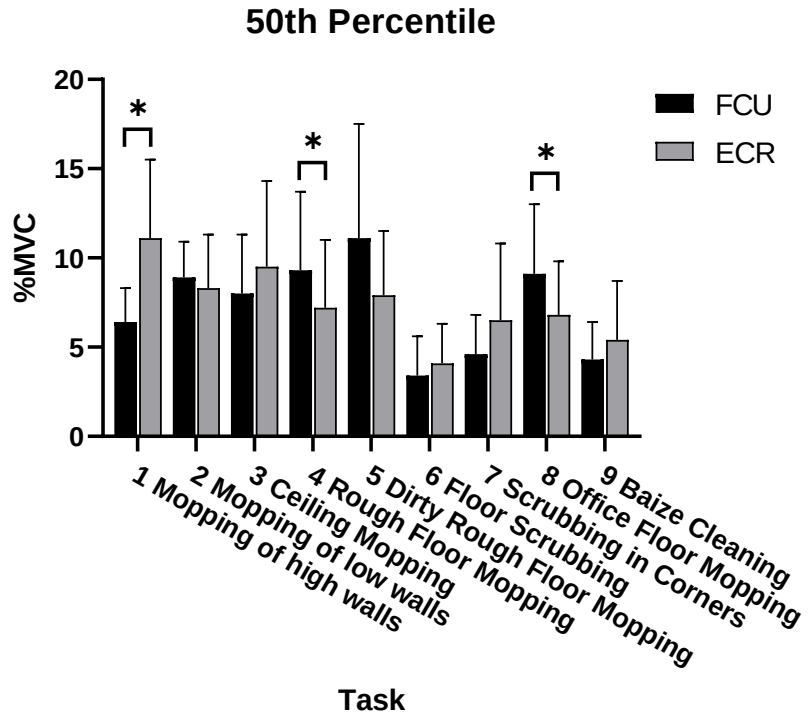
ECR: extensor carpi radialis

On the other hand, a significant interaction was found between the task and muscle in the three percentiles (P10: $F_{8.48}$=3.21, p=.005, η2=.35; P50: $F_{8.48}$=7.36, p<.001, η2=.55; P90: $F_{8.48}$=11.70, p<.001, η2=.66). As what is showed in figure 9a, in P10 the FCU showed a significant lower muscle activity than the ECR muscle during task 1 (FCU=3.5%, ECR=5.7%, p=.048). In the P50 variable also, the FCU showed a significant lower muscle activity than the ECR muscle during task 1 (FCU=6.4%, ECR=11.1%, p=.018), while during task 4 and 8 the FCU showed a significant higher muscle activation than the ECR (Task 4: FCU=9.3%, ECR=7.2%, p=.012; Task 8: FCU=9.1%, ECR=6.8%, p=.033, figure 9b). Finally, in P90, during tasks 1 and 3 the FCU showed a smaller muscle activation than the ECR (Task 1: FCU=14.6%, ECR=19.9%, p=.037; Task 3: FCU=16.2%, ECR=24.2%, p=.031), while during tasks 4, 5 and 8 the FCU showed a significant greater activation than the ECR (Task 4: FCU=24.4%, ECR=15.6%, p=.005; Task 5: FCU=27.9%, ECR=16.5%, p=.014; Task 8: FCU=22.9%, ECR=15.3%, p=.019, figure 9c).

9a



9b



9c

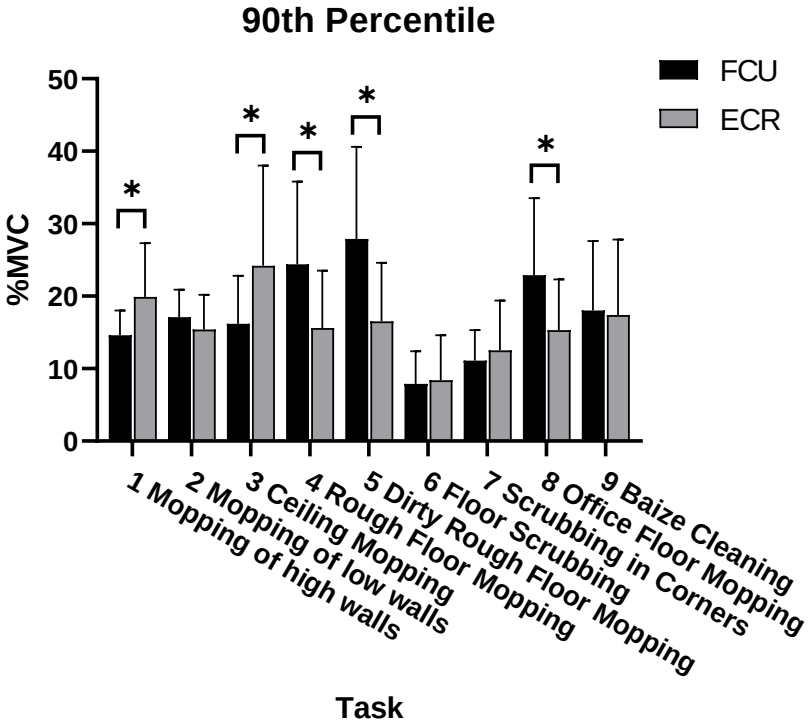


Figure 9a, 9b and 9c. Median and standard deviation (SD) for the 10th, 50th and 90th percentiles of Amplitude Probability Distribution Function (APDF) of EMG from the flexor carpi ulnaris (FCU) and extensor carpi radialis (ECR) muscles while performing 9 different cleaning tasks. Units are percentage of maximum voluntary contraction (%MVC). * $p<0.05$.

5. Discussion

5.1. Discussion - Epidemiological Study of Professional Cleaners

The main findings of this study were that BMI, physical exertion and recognition from management were independently associated with both neck/shoulder pain and low-back pain among professional cleaners, while smoking, physical activity levels, influence at work, and support from colleagues failed to reach significant associations.

Our results indicate that individuals with obesity (BMI>30) experienced greater pain intensity compared to those with a normal weight. Likewise, overweight individuals also showed a tendency towards increased low-back pain intensity. A study conducted on the working population of the Netherlands demonstrated an association between BMI and musculoskeletal symptoms. Specifically, it found that obesity was associated with neck/shoulder and back issues (L. Viester et al., 2013). Similar results were reported for low-back pain in computer workers (Sethi, Sandhu, & Imbanathan, 2011) and another study showed a positive association between BMI and musculoskeletal pain in the low-back and neck/shoulder areas in university students (Tantawy, Abdul Rahman, & Abdul Ameer, 2017).

These findings are consistent with the hypothesis that obesity may lead to increased mechanical loading on the spine, which can contribute to systemic chronic inflammation and potentially explain the observed low-back pain (Shiri, Karppinen, Leino-Arjas, Solovieva, & Viikari-Juntura, 2010). However, the relationship with neck/shoulder pain is multifaceted and may involve a combination of mechanical and non-mechanical factors, such as posture, muscle strain, inflammation, and metabolic effects, as suggested by previous research (Laura Viester et al., 2013). The results indicate that cleaners with high scores of perceived physical exertion experience a significant risk of both LBP and NSP, compared with cleaners reporting low- and moderate physical exertion. Perceived physical exertion, which reflects the balance between physical work demand and the physical capacity of the worker (Lars L Andersen et al., 2010; G. Borg & Linderholm, 1967), plays a pivotal role in understanding the impact of strenuous work on musculoskeletal health. In our prospective cohort study on healthcare workers, we discovered that strenuous perceived physical exertion was positively associated with low-back pain, while there was no significant association with neck/shoulder pain (L. L. Andersen, Clausen, Persson, & Holtermann, 2013). One possible explanation is that NSP has mainly been related to repetitive work performed for prolonged periods without rest (Larsson, Søgaard, & Rosendal, 2007), which is predominantly found in cleaning work (Lim et al., 2022; Melese et al., 2020). Additionally, another study of personal care workers in an old age home showed that perceived physical demands of cleaning tasks are associated with LBP (Yeung & Yuan, 2011). Thus, reducing the perceived physical exertion like promoting rest periods and inventing better cleaning tools can contribute to reducing the risk of musculoskeletal pain.

Another interesting finding was that leisure time physical activity (LTPA) was not associated with either NSP or LBP, while it is widely acknowledged that a lack of LTPA contributes to MSD (Blangsted, Søgaard, Hansen, Hannerz, & Sjøgaard, 2008; Bull et al., 2020; Shiri & Falah-Hassani, 2017). A cross-sectional study in Sweden reported that people who performed aerobic activity for more than one hour per week were less likely to experience neck and shoulder pain (Peterson & Pihlström, 2021). Moreover, lack of physical activity was considered one of the strongest risk factors for low-back pain in healthcare personnel (Rezaei, Mousavi, Heshmati, & Asadi, 2021). However, it remains controversial that some studies have found an increased risk of low back pain in physically active subjects (Auvinen, Tammelin, Taimela, Zitting, & Karppinen, 2008; Mattila, Saarni, Parkkari, Koivusilta, & Rimpelä, 2008). A systematic review suggested that LTPA is beneficial for all workers, but workers in low occupational physical activity jobs experience a greater reduction in health risks compared to those in high occupational physical activity jobs (Prince et al., 2021).

Understanding the implications of the diverse findings and the absence of clear associations is crucial. While existing literature suggests that a lack of LTPA is linked to musculoskeletal disorders, it's important to recognize that our study focused on a specific occupational group—cleaners—whose work-related physical demands may overshadow the potential effects of LTPA. The interplay between occupational activity and LTPA, as well as how they contribute to musculoskeletal symptoms, requires further examination. Moreover, the nuances of the 'dose-response' relationship between LTPA and musculoskeletal symptoms should be considered. It's possible that certain thresholds of LTPA are required to produce observable effects, and these thresholds may vary for different musculoskeletal conditions.

While the literature consistently reports associations between psychosocial factors and LBP (Fernandes Rde, Carvalho, Assunção, & Silvany Neto, 2009; Hoogendoorn et al., 2001), as well as NSP (Sterud et al., 2014), our study reveals a more nuanced picture, that only recognition from management was found to be significantly associated with NSP and LBP. It's important to note that when examining diverse psychosocial factors in the context of different occupations, the existing body of literature often lacks a unified consensus. For instance, a cross-sectional study showed that job control was associated with NSP, but not social support, among workers with monotonous, repetitive work (J. H. Andersen et al., 2002). Interestingly, the influence of work organization is significantly associated with musculoskeletal pain among nurses (Freimann, Pääsuke, & Merisalu, 2016). On the other hand, social support did not predict MSD in any body part among offshore oil installation workers (W. Q. Chen, Yu, & Wong, 2005).

One potential explanation for the absence of associations between influence at work, collaboration and support of colleagues, and the pain intensity of LBP or NSP in the context of cleaning tasks may be attributed to the nature of the work itself. Cleaning tasks are typically well-defined, requiring little individual autonomy, and often performed independently. However, the notable impact of recognition from management on LBP and NSP among cleaners suggests that it plays a distinct role in workload distribution, task assignment, or feedback, warranting further research to fully grasp the complex interplay of these factors in the cleaning profession. Furthermore, variations in study outcomes and the multifaceted nature of psychosocial influences make it challenging to pinpoint clear, overarching trends or associations across different workplace settings.

5.1.1. Practical Relevance

The findings underscore the need for practical interventions to address modifiable risk factors. Implementing health and wellness programs to manage BMI, reducing physical exertion through ergonomic improvements, and enhancing organizational support by increasing recognition from management are effective strategies to reduce musculoskeletal pain among cleaners. Ergonomic training and regular assessments are essential to ensure safe work practices. By adopting a holistic approach that includes individual, physical, and organizational factors, it is possible to mitigate the risks of musculoskeletal disorders in this workforce.

5.1.2. Strengths and Limitations

The cross-sectional nature of the study did not allow a clear causal relation between individual, physical, and psychosocial factors, and the pain intensity of low-back and neck/shoulder to be established. Also, the questionnaires were not collected in the same year, and labour market status could have changed over these years. This temporal separation is significant because these changes in labour market status can impact the interpretation of the study results. Moreover, there are repeated samples, where some individuals responded to the questionnaires in more than one round. It's worth noting that the two-year period between data collection points helps to mitigate some of these concerns, providing a reasonable timeframe for understanding potential changes. Exposure and outcome measures were collected before the COVID-19 pandemic, and post-pandemic data are needed to verify the present findings.

This present study also has some strengths. It discussed the individual, physical and psychosocial factors independently associated with LBP and NSP. It might give valuable insights into the specific factors that contribute to LBP and NSP among cleaners. Additionally, by assessing these factors collectively through a questionnaire, the study offers insights into the multifaceted nature of musculoskeletal pain and provides a comprehensive understanding of their combined contributions to the multifaceted nature of musculoskeletal pain and their potential implications for intervention and prevention strategies for this occupation.

5.2. Discussion - Experimental Study (Using EMG)

This study has assessed the forearm muscle activity during a range of different cleaning tasks, in order to identify the work tasks most physically demanding. For this purpose, the muscle activity of the FCU and ECR from both dominant and non-dominant arms were investigated during nine cleaning tasks in a real working environment, including mopping of high walls, low walls, and ceiling mopping; rough floor and dirty rough floor mopping; floor scrubbing and scrubbing in corners; office floor mopping, and baize cleaning.

Overall, the results did not confirm the first hypothesis, as forearm muscle activity (flexors plus extensors) did not differ between dominant and non-dominant arms during the majority of the included work tasks. When each task was compared between arms, large effect significant differences were found in task 8 office floor mopping (10th percentile) and task 6 floor scupper (90th percentile). This is in accord with Naik and Khan (2020), who made a postural simulation and verified that the dominant hand is maintained at a higher level during repetitive flexion-extension as compared to the non-dominant hand.

When the activity of flexors and extensors were compared independently of arms, top-3 demanding high-force tasks (90th percentile) were rough floor, dirty rough floor and office floor mopping for the FCU, and mopping of high walls, ceiling mopping and baize cleaning for the ECR, confirming the second hypothesis. Top-3 static work tasks (10th percentile) were mopping of low walls, ceiling mopping and dirty rough floor mopping for the FCU and mopping of high walls, low walls, and ceiling mopping for the ECR.

Interestingly, among all the tasks evaluated, task 6 floor scrubbing showed the lowest median and peak muscle activity of both FCU and ECR muscles. However, when looking at the top-3 tasks with the highest median and peak FCU muscle activity, they were all related to floor mopping: rough floor, dirty rough floor and office floor mopping. During these tasks, the FCU showed significantly more activities than ECU with large effect sizes. This clearly illustrates that floor mopping tasks require wrist flexors strength to produce and maintain grip during moderately- and highly demanding tasks. In contrast to these findings, Wallius et al. (2018) found that ECR produced higher muscle activity than FCU in median and peak levels. One possible reason could be the difference in wrist posture, the study of Wallius et al. (2018) performed floor mopping tasks at four different heights in a specific manner, and the cleaners in our study, who were not given specific instructions on how to perform the tasks and did them in their usual manner.

Furthermore, about static muscle activity, ECR exhibited higher activity than FCU during all the cleaning tasks, although only task 1 mopping of low walls showed a significant difference

(6.3 % MVC). There was a suggestion that static muscle activity levels were exceeding the threshold value of 5% MVC for long-term work (Jonsson, 1982). Interestingly, task 2 mopping of high walls also demonstrated static muscle activity of ECR higher than 5% (5.5% on concrete). A possible explanation might be that holding the mop in the air would put a lot of pressure on the wrist, causing greater ulnar deviation, while other tasks like ceiling mopping and floor mopping need less strength for static gripping. Additionally, muscle fatigue from prolonged activity may increase muscle activity levels during these tasks, contributing to the observed results. Another study which did forearm EMG on mopping task had similar findings (Wallius et al., 2018). Forman, Forman, and Holmes (2021) also suggested that the wrist extensors likely demonstrate consistently higher muscle activity during most tasks of the hand and wrist, which is likely a leading mechanism behind why they develop chronic overuse injuries more frequently than the wrist flexors.

5.2.1. Perspectives

The intricate arrangement of forearm muscles is a function of an extensive range of motion at the distal upper limb, where several muscles participate during motor tasks (Bawa, Chalmers, Jones, Søgaard, & Walsh, 2000; Fleckenstein et al., 1994; Loren et al., 1996). This adds a level of difficulty to the research and challenges our understanding of the dynamic capacities of movements and the neuromuscular treatment for disorders of the forearm. Therefore, Grieg and Wells suggested the need for research to assess prehensile capabilities in multi-component, dual-task exertions that can be better transferred to working demands and daily living tasks (Greig & Wells, 2004; Wells & Greig, 2001).

Practical solutions to minimize ergonomic risks include developing advanced cleaning tools with features like softer, ergonomic grip handles and adjustable-length handles, which can reduce force, enhance comfort, and promote better posture. Lightweight materials can further lessen the physical load. In task management, task rotation is crucial, particularly by varying the frequency of high-force and static work tasks to prevent muscle overuse and imbalance. Additionally, training cleaners to use both arms for certain tasks, like floor mopping, can distribute muscle load evenly, reducing the risk of WMSDs.

5.2.2. Strengths and limitations

This study has some limitations that should be taken into consideration. First, although the number of subjects was sufficient to reveal statistically significant differences with large effect sizes, these results might not be representative of the general population of cleaners. Second, the duration of each task was limited, but likely still reflects the nature of the specific task. However, it is necessary to evaluate the effect of accumulated physical exposure during a full workday, to fully determine the detrimental effect of high-force cleaning tasks.

To our knowledge, this is the first study evaluating the electromyographic activity of the FCU and ECR during real cleaning tasks. We find that the level of activation of wrist flexors and extensors during cleaning tasks is comparable with the demands of the complex working task, allowing for the development of better working tools and improved organization of work tasks to prevent overload of the forearm muscles and thereby decrease the risk of WMSDs.

Future studies should aim to increase the sample size and extend research to various industries to enhance the generalizability of our results. Investigating the effects of longer measurement durations will allow a more nuanced understanding of the ergonomic challenges and solutions in this profession, providing a clearer picture of the long-term impacts of different tasks.

5.3. Overall Discussion

These findings offer a comprehensive perspective on MSD risks within the cleaning profession: the first study provides insights into broader, systemic pain patterns, while the second study hones in on specific task-related muscle loads. This dual approach contributes to a more thorough understanding of the occupational factors that contribute to MSD among cleaners, laying a foundation for ergonomic improvements tailored to mitigate both general and task-specific physical demands.

The epidemiological study highlights that individual factors such as BMI and perceived physical exertion, along with psychosocial factors like recognition from management, are significantly associated with neck/shoulder pain (NSP) and low-back pain (LBP). In contrast, lifestyle factors such as leisure time physical activity (LTPA) showed no clear associations, likely due to the high physical demands of cleaning tasks overshadowing potential benefits of LTPA. These results suggest the importance of considering both physical and psychosocial work conditions in intervention strategies.

The experimental study complements these findings by identifying specific cleaning tasks that impose significant physical demands on the forearm muscles. Tasks like mopping rough floors and ceilings were found to cause high muscle activation in the wrist flexors and extensors, potentially contributing to muscle fatigue and chronic overuse injuries. The absence of significant differences in muscle activity between dominant and non-dominant arms in most tasks highlights the uniformly high physical strain experienced during cleaning work, emphasizing the need for ergonomic solutions tailored to task-specific demands.

Taken together, these studies reveal a critical interplay between individual, physical, and organizational factors in the development of MSD among cleaners. Practical interventions such as promoting ergonomic tools, encouraging task rotation, and enhancing organizational recognition can mitigate these risks. Moreover, future research should address the long-term effects of cleaning work, explore broader occupational settings, and develop more nuanced approaches to balancing occupational and leisure physical activity. By integrating these findings, a holistic strategy can be devised to improve the musculoskeletal health and overall well-being of cleaners.

6. Conclusions

6.1. Conclusions - Epidemiological Study of Professional Cleaners

This cross-sectional study investigated the risk factors of low back pain (LBP) and neck and shoulder pain (NSP) among professional cleaners. The findings identified BMI, physical exertion, and recognition from management as key factors associated with both LBP and NSP.

By implementing health and wellness programs, ergonomic improvements, and enhancing organizational support, it is possible to mitigate the risks of musculoskeletal disorders. Focusing on ergonomic training and regular assessments will ensure safer work practices. Adopting a comprehensive approach that considers individual, physical, and organizational factors is crucial for improving the health and well-being of professional cleaners.

6.2. Conclusions - Experimental Study (Using EMG)

The study identified the forearm muscles' most physically demanding work tasks during a range of cleaning tasks. Three floor mopping tasks (rough floor, dirty rough floor, and office floor mopping) were identified as the top-3 physically demanding high-force tasks for the wrist flexors, while three tasks characterized by overhead movement (mopping of high walls, ceiling mopping, and baize cleaning) were identified for the wrist extensors. In addition to organizing how the daily tasks are structured and performed, the development of intelligent working tools for professional cleaners is recommended to avoid high-force overload.

6.3. General Conclusions

This doctoral thesis explores the occupational and task-specific factors contributing to musculoskeletal disorders (MSDs) among professional cleaners, with a focus on low back pain (LBP), neck/shoulder pain (NSP), and forearm strain.

The findings highlight obesity, high physical exertion, and limited management recognition as significant contributors to LBP and NSP, underscoring the importance of addressing both physical and psychosocial workplace factors. Additionally, task-specific muscle strain, particularly during activities like floor and ceiling cleaning, emphasizes the need for ergonomic interventions.

These results provide actionable insights for developing targeted strategies, such as ergonomic tool design, task rotation, and supportive workplace policies, to mitigate MSD risks and promote cleaner well-being. The research contributes to a deeper understanding of occupational health in physically demanding professions, paving the way for future improvements in ergonomics and workplace safety.

6.4. Practical Implications

The findings from this study offer significant insights into the design of interventions to mitigate musculoskeletal disorders (MSD) among professional cleaners. Several practical applications can be implemented based on the specific needs identified in the study:

1. Ergonomic Interventions:

Given the high prevalence of MSD associated with specific tasks, it is essential to design cleaning tools that reduce physical strain. For instance, ergonomic tools with lightweight, adjustable handles can help lessen the muscular demand on the forearm and wrist during overhead and floor mopping tasks. These tools should be tested for their impact on muscle activation to ensure they effectively reduce static and dynamic loads on the forearm muscles.

2. Workload Management:

To prevent overuse injuries, workload management strategies should be considered. This may include task rotation, where cleaners alternate between high- and low-intensity tasks. Task rotation can prevent prolonged muscle activation and provide recovery time, especially during tasks that require awkward postures, such as overhead or floor-level cleaning. Additionally, integrating rest breaks during prolonged task performance can help alleviate sustained muscle activation and reduce the risk of muscle fatigue.

3. Health and Wellness Programs:

Establishing health and wellness programs tailored to the specific needs of cleaners can have a positive impact on reducing MSD risks. These programs could include regular physical assessments to monitor musculoskeletal health, along with exercise routines that emphasize strengthening and stretching key muscle groups such as the forearms, shoulders, and back. Programs aimed at encouraging a healthy body weight and regular physical activity can further reduce the risks of MSD, as findings have shown a correlation between obesity and increased pain in cleaners.

4. Utilization of EMG Data for Training:

The EMG data collected in this study can serve as a valuable tool for developing training programs that highlight risk-prone movements. By using EMG insights, training sessions can emphasize the correct posture and techniques for tasks requiring repetitive motions, such as mopping or scrubbing, to minimize excessive muscle load. In particular, training on maintaining neutral wrist postures can help reduce strain on the wrist extensors (ECR) during overhead tasks.

5. Policy and Organizational Support:

Organizations employing cleaners can enhance workplace support systems that prioritize employee health and safety. Management recognition and support, which was shown to correlate with reduced MSD prevalence, should be further explored and integrated into workplace policies.

6.5. Future Research Directions

This study opens several avenues for future research that could deepen the understanding of MSD risk factors and improve occupational health for cleaners. A very straightforward idea would be to replicate the EMG study with other muscle groups to complement the information provided by the second study.

Given that psychosocial factors, such as management recognition and social support, can influence MSD prevalence, future studies should further explore the interaction between these factors and physical workload, as well as propose possible interventions focusing on diminishing the impact of these factors.

Future research could focus on intervention studies that test the effectiveness of ergonomic tools, task rotation strategies, and rest breaks on reducing muscle strain. Comparative studies could determine which intervention methods yield the most significant reductions in MSD symptoms.

Conducting longitudinal studies would allow researchers to track the development of MSD over time, providing insights into the chronic effects of physical demands associated with cleaning tasks. By following cleaners over several years, it might be possible to identify the long-term health impacts of specific tasks, such as sustained overhead mopping or floor scrubbing, and to determine if these tasks are predictive of future MSD. These studies could be or not coupled with intervention studies that test the effectiveness of ergonomic tools, task rotation strategies, and rest breaks on reducing muscle strain in short, mid or long term.

Future research may also include educational interventions involving resistance training to compensate for or correct the upper/lower crossed syndromes caused by work. These interventions could focus on strengthening muscles that are often underdeveloped due to the nature of cleaning tasks, potentially reducing the risk of developing MSDs over time.

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