INVESTIGATING THE INFLUENCE OF COGNITIVE DEMANDS AND PERSONAL FACTORS ON WORK-BODY POSTURES

by

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DEDICATION

I would love to dedicate this dissertation to my son, Sebastian. You are the most beautiful and amazing gift God could give me. You are my greatest blessing. Te amo demasiado, Hijo.

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ABSTRACT

Mental workload is a broad concept used by human factors and ergonomics professionals. It has become a topic of increasing importance since the introduction of technology in modern working environments. Mental workload assessment is an important component in the design of occupational tasks since inappropriate levels can cause errors, incidents, and be responsible for occupational diseases and musculoskeletal disorders. Until now, research studies have explored the effects of physical activity on mental workload. No study has analyzed the effects of mental workload on body postures even though studies have stated that in response to new information from the workplace environment, the human body orients in the direction of a stimulus, and this orientation reaction could affect the ongoing activity. This dissertation looked to 1) determine if psychosocial work factors affect perceived mental workload, 2) determine if changes in perceived mental workload generated changes in the body postures undertaken to perform an activity, and 3) explore if individual factors such as age, sex, personality traits, and anxiety mediate or exacerbate the influence of psychosocial work factors. Thirty-two participants performed two physical activities under four levels of mental workload. The results indicate, for the first time, that an increase in the perception of mental workload is associated with worse body postures that consequently could lead to work-related musculoskeletal disorders (WMSDs). Regarding the potential influence of individual factors, differences were not observed between mental workload conditions. However, individual characteristics such as anxiety, personality traits, and sex exhibited higher contributions to changes in perceived mental workload and body postures. This study is novel and contributes to overcoming an important shortcoming in the field of mental workload by considering the influence of psychosocial factors, keeping the physical load constant, on the perception of mental workload and its influence on body postures. This interaction between perceived mental workload and its effects on physical risk should be considered in occupational settings since often, employees are exposed to concurrent physical and mental demands that increase the likelihood of developing WMSDs.

CHAPTER ONE

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are one of the most significant occupational disorders. They have been a major reason for disability, decreased quality of life, and loss of productivity at workplaces, making them one of the most expensive health problems in industry (Bongers, de Winter, Kompier, & Hildebrandt, 1993; Eatough, Way, & Chang, 2012; Gómez, 2020). WMSDs in the United States (US) account for more than 30% of all nonfatal occupational injury and illness cases that resulted in absence from work in 2018 accounting for one-third of all workers' compensation costs (U.S. Bureau of Labor Statistics, U.S. Department of Labor, November 2019). According to the Center for Disease Control (CDC), musculoskeletal disorders account for 70 million physician office visits in the US annually. The direct cost of WMSDs is $20 billion a year while the total costs are between $45 and $54 billion annually (National Research & Institute of, 2001).

WMSDs have been recognized to be complex in nature, by having a composite and multifactorial origin that involves physical and biomechanical variables as well as psychosocial, organizational, and individual factors (WHO, 1985). It is believed that the probability of developing WMSDs is greater when several of these factors are present at the same time than when they occur alone (Svebak, 1988). However, the evidence of specific associations has yielded conflicting results (Bongers, Kremer, & Laak, 2002).

A substantial body of research has focused on evaluating the contribution of physical demands on WMSDs (Aasa, Barnekow-Bergkvist, Ängquist, & Brulin, 2005; Burnett & Campbell-Kyureghyan, 2008; Carneiro, Villarroya, Colim, Torres, & Arezes, 2019; Fredric Gerr et al., 2014; Oakman, Macdonald, & Wells, 2014; Zhou & Wiggermann, 2017). It is generally agreed that work-related physical demands can only partially explain the high prevalence of WMSDs (Asghari et al., 2019; Bao et al., 2016; Bongers et al., 1993; Bongers et al., 2002; Bru, Mykletun, & Svebak, 1996; Carayon, Smith, & Haims, 1999; Eatough et al., 2012; Kompier & van der Beek, 2008; Mehta, Nussbaum, & Agnew, 2012; Neupane & Nygård, 2017; Walsh, Varnes, Osmond, Styles, & Coggon, 1989; Westgaard, 1999). Lately, the potential etiologic relevance of psychosocial factors (e.g. job demands, job satisfaction, job stress, social support), job organizational factors (e.g. individual's work station, structure, climate, culture, and practices of the organization), and individual characteristics (age, sex, personality, coping, perception) in the development of WMSDs have gained attention (Asghari et al., 2019; Bao et al., 2016; Bongers et al., 2002; Carayon et al., 1999; Eatough et al., 2012; Gómez, 2020; Márquez Gómez & Márquez Robledo, 2015; Marras, Davis, Heaney, Maronitis, & Allread, 2000; Neupane & Nygård, 2017; Shahidi, Haight, & Maluf, 2013). The analysis of each of these factors' role and contributions in the development of WMSDs has helped to understand and reduce these disorders.

Marras and Hancock (2014) stated that humans' physical and cognitive respond depend on how they interpret the conditions under which they must perform their jobs. They argue that numerous factors influence the perception of the task at hand, such as physical environment, physical demands, cognitive demands, and psychosocial environment. Other studies have demonstrated that changes in postural or physical behavior can be a result of tasks that are perceived as mentally stressful; a condition that can be exacerbated by psychosocial factors such as time pressure, intensity, and duration of the task demands (Davis, Marras, Heaney, Waters, &

Gupta, 2002; Splittstoesser, Marras, & Best, 2012; Yang, Marras, & Best, 2011). This association between mental workload and physical behavior also appears to depend on other individual characteristics such as gender and personality (Davis et al., 2002; Marras et al., 2000). Mental workload is defined as a construct that represents the amount of cognitive effort required to perform a task. It encompasses many factors such as the interaction between task requirements, environment circumstances, and skills, behaviors, and perceptions of the operator (Hancock & Meshkati, 1988).

Numerous experimental studies have reported on the effects of physical demands, mental demands, the interaction between them, and the effects of concurrent mental and physical demands (dual-task environments) on musculoskeletal pain and disorders, some negative relationships have been reported (Basahel, Young, & Ajovalasit, 2010; da Silva, Tortorella, & Amaral, 2016; DiDomenico & Nussbaum, 2011; Mehta & Agnew, 2011, 2015; Mehta et al., 2012; Neupane & Nygård, 2017; Zhang, Liu, Feng, Gao, & Zhang, 2017). However, the relationships have been studied in terms of the influence of physical demands over mental demands and its effect on the development of WMSD but not the other way around, which is the influence of perceived mental workload over physical postures or physical behavior.

A growing body of research has shown a complex relationship between postural control or postural stability and cognitive demands that depend on factors of age, expertise, type of cognitive task, and cognitive processing required (Maylor, Allison, & Wing, 2001; Riley, Baker, & Schmit, 2003; Roerdink, Hlavackova, & Vuillerme, 2011; Siu & Woollacott, 2007; Stins, Michielsen, Roerdink, & Beek, 2009). Body behavior, especially body postures, can be used as an additional factor to consider in workload assessments in addition to factors such as mental and physical demands, performance, distractions, frustration, and others. Nevertheless, this relationship between workload and body postures has not been studied extensively in mental workload studies or concurrent mental and physical environments (Qiu & Helbig, 2012) despite evidence that shows every human action is guided by mind and body interactions (Mehta, 2016). This is true in any industry, particularly in healthcare, where most tasks are executed by humans (Tullar et al., 2010).

Healthcare is a complex industry categorized as a high-risk work environment for developing WMSDs (Tullar et al., 2010). Tasks on healthcare services are extremely diverse, requesting physical, cognitive, social, and emotional abilities (Hignett, Carayon, Buckle, & Catchpole, 2013). Consequently, task demands in healthcare environments usually exceed human capabilities, resulting in failures to perform procedures safely and increasing the risk of the work environment (Miller, Bagian, & Williams, 2014). These organizational and psychosocial factors influence healthcare workers' behavior, which in turn affects their health (for instance, neck-shoulder and low-back disorders on ambulance personnel; low-back, knees, ankles/feet pain in operating room nurses, burnout on nurses and physicians and the intention of leaving the profession, stress, fatigue, sleep deprivation) and patients' safety (drug dispensing errors, procedures or treatments not completed, wrong diagnostics) (Holden et al., 2011; Jatobá et al., 2016; Miller et al., 2014; Oakman et al., 2014; Young, Brookhuis, Wickens, & Hancock, 2015).

Most of the attention to mitigate these risks has been absorbed by the largest group in the healthcare sector: nurses (Oakman et al., 2014). Little attention has been given to non-clinical workers such as administrators, maintenance staff, food services staff, or sterile processing department staff (SPD). SPD workers are exposed to a variety of hazardous activities that include *repetitive and prolonged motions, potential infectious pathogens* such as blood, body fluids, and chemical substances, *psychosocial factors* such as auditory and visual alarms, high room temperatures, scarcity of time, cognitive work, high concentration, monotonous work, few opportunities to take breaks, and *biomechanical strain* generated from physically stressful tasks, standing almost the entire working day, and manual handling of heavy objects.

In the article "Human Factoring Healthcare: Making human factors more accessible," Miller et al. (2014) stated:

> It is time for organizations to use cognitive ergonomics and human factors analysis to make healthcare services safer for patients. …HFE (Human factors and ergonomics) take a system approach as it seeks to identify and promote the best fit between the people and the world within which they live and work. … HFE assesses factors of the environment, task, person, and organization, and the interactions among them all in order to support the human in the system. By uncovering knowledge and strategies, constraints, and affordances, it is possible to design safer, more effective, and more productive work systems.

The research conducted for this dissertation focuses on determining if increases in perceived mental workload create higher levels of physical risk due to changes in body postures to lay the foundation for future exploration into the influence of perceived mental workload over physical demands. By characterizing differences in body postures arising from the introduction of changes in the environment and working conditions (distractions, interruptions, noise, time available) in which the subject must perform the tasks, that could help to have a more informed picture and better understand how people negotiate between mental and physical demands when performing occupational activities.

The central hypothesis guiding this work was that an increase in perceived mental workload is associated with worse body postures. This interaction between perceived mental workload and its influence on physical risk should be considered in occupational settings because employees are often exposed to concurrent physical and mental demands that increase the likelihood of developing WMSDs.

Psychosocial work factors such as time to complete the task, distractions, and interruptions were used to create different mental workload conditions while keeping the same amount of physical demands and the same workstation design to evaluate mental workload influence over physical risks. The perception of mental workload (MWL) was measured with the NASA-TLX. Physical behavior or body postures were evaluated by ergonomic assessment tools such as REBA and RULA depending on the type of physical task performed in each work condition.

Other individual factors such as age, sex, personality type, and anxiety were included in the study to explore if they mediate or exacerbate the influence of the psychosocial work factors on body postures and mental workload.

Thesis outline

Figure 1.1 displays an overview of the research and its three primary contributions. Contribution 1 focused on demonstrating that perception and interpretation of the task on hand can be altered by increasing mental demands alone. It incorporated the measurement and comparisons of the SURG-TLX and the NASA-TLX. Contribution 2 focused on evaluating changes in body postures due to increments in mental demands. Contribution 3 consists of exploratory studies on the influences of individual characteristics on the perception of the task at hand, measured as perceived mental workload, and on body postures responses.

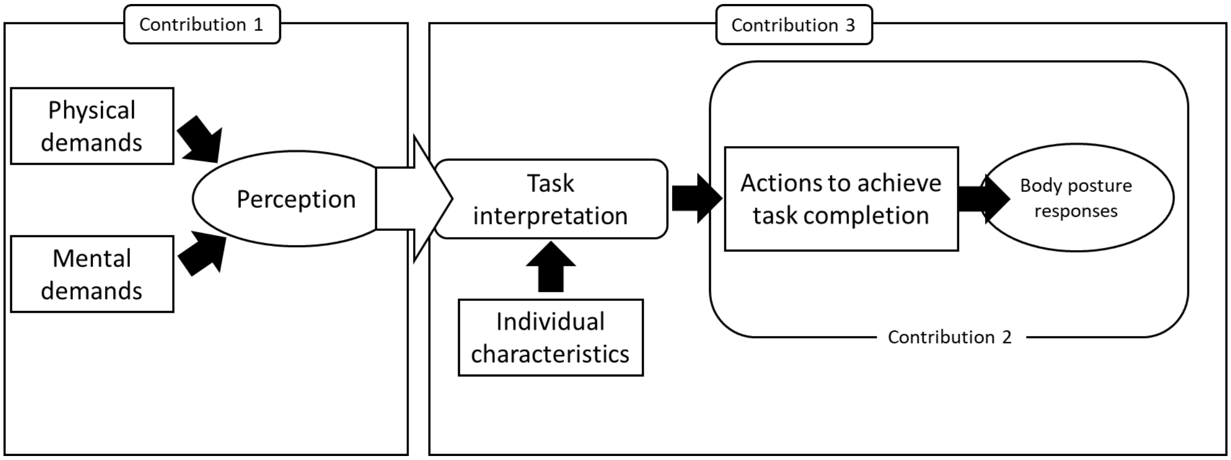

Figure 1.1 Research overview

CHAPTER TWO

LITERATURE REVIEW

The present research was motivated by a growing understanding that ergonomics and human factor professionals should be concerned about the whole context in which a person operates when performing a task. Modern efforts are starting to consider interactions between mental and physical demands as well as the many interactions between the elements of the environment that can have a profound influence on performance and overall system output. The main contributor to this dissertation research was identifying a gap in the body of research about the effect of the perception of mental workload over body postures. The following literature review begins with a discussion about mental workload and the evolution of research on metrics and assessment techniques, associations with physical activity, and effects on human performance. With this foundation, the review focuses on psychosocial factors that have impacts on performance and human behavior. Physical ergonomics and the effects of physical work on the human body will follow. The literature review concludes with a discussion on the identified gaps in knowledge in the existing research.

Mental Workload

Mental workload is a broad concept used by human factors and ergonomics professionals and has become a topic of increasing importance since the introduction of technology in modern working environments (Flemisch & Onken, 2002; Hancock & Meshkati, 1988; Klonowicz, 1995; Tsang & Vidulich, 2006; Wickens & Tsang, 2015; Young & Stanton, 2001; Young et al., 2015). The evolution of mental workload research has moved from finding ways to measure it

(Bainbridge, 1974; Damos, 1984; Hart & Staveland, 1988; Reid & Nygren, 1988; Zijlstra, 1993), to defining it (Hancock & Warm, 2003; Smith & Hancock, 1995; Welford, 1978), to apply it in real-world situations (Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2009; Lee, 2017; Makishita & Matsunaga, 2008; Pickup, Wilson, & Lowe, 2010).

Mental workload is a concept that remains surprisingly difficult to define. Numerous definitions have been offered with commonalities among the various interpretations however, there is no universal agreement between the definitions. According to the Dictionary for Human Factors/Ergonomics, mental workload is understood as “any measure of the amount of mental effort required to perform a task” (Stramler, 2018, p. 202). One way to think about mental workload is by objectively looking at the task itself, in which case it is often referred to as task-load. However, another way to think about mental workload is in terms of demand/resource balance which often refers to attentional resources theories where mental workload becomes a measure of the resources available to meet task demands (Welford, 1978; Wickens & Tsang, 2015; Wickens, 2002). In this scenario, mental workload is based on the assumption that each person has a fixed cognitive capacity defined by the difference between cognitive demands of a task and the person’s attention resources (Rubio, Díaz, Martín, & Puente, 2004). Mental workload can also be defined as an intervening variable that modulates the tunning between the demands of the environment and the organism’s capacity (Kantowitz, 2000). Thus, mental workload can be subjectively felt by the individual who perceives a cost while performing a task (Hart & Staveland, 1988)

Mental workload in ergonomics is a multidimensional construct involving the characteristics of the task, operator, and the environment where the task is performed. It incorporates psychosocial and organizational factors into the equation and individual differences that still are an unsolved puzzle regarding their impact on mental workload assessment (Bru et al., 1996; Carayon et al., 1999; Young et al., 2015). Mental workload assessment is an important component in the design of occupational tasks because inappropriate levels can cause errors and incidents, delayed information processing, affect performance, and be responsible for occupational diseases and musculoskeletal disorders (Carayon et al., 1999; Eatough et al., 2012; Kompier & van der Beek, 2008; Oakman et al., 2014; Sarsangi et al., 2017). Understanding how mental workload dynamically affects performance, modulates human-machine interaction, influences overall system output, and its role on workers' health implications are increasingly crucial in designing efficient and safe systems and workplaces (Marras & Hancock, 2014; Young et al., 2015).

The assortment of metrics and assessment techniques available reflects the multidimensional nature of mental workload. Young and Stanton (2001) distinguished four main categories of mental workload measures: measurement of performance in primary tasks, secondary tasks, physiological measures, and subjective self-reports. Measures of performance are techniques based on direct registration of the operator's capability to perform tasks at an acceptable level (low error likelihood and high level of efficiency) (DiDomenico & Nussbaum, 2008; Mehta et al., 2012). Physiological measures refer to the evaluation of heart rate, heart rate variability, respiration rate, blood pressure, eye movements, pupillary responses, facial muscle activation, electrodermal responses, and brain activity. However, the presence of cofounding factors and extraneous variables that affect these physiological indicators have impacted their validity on measuring mental workload (Basahel et al., 2010; Mehta & Parasuraman, 2014;

Shahidi et al., 2013; Tiwari et al., 2019; Westgaard, 1999; Zhang et al., 2017). Subjective mental workload reports can be categorized as uni- and multidimensional measures. The Cooper-Harper scale (Cooper & Harper, 1969) and the Rating Scale Mental Effort (RSME) (Zijlstra, 1993) are examples of uni-dimensional indices, while the well-known NASA Task Load Index (NASA-TLX) (Hart & Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT) (Reid & Nygren, 1988), are examples of multi-dimensional subjective measures. These multidimensional subjective measures derive an overall mental workload score based on different subscales including mental demand, time load, physical demand, temporal demand, psychological stress load, performance, effort, among others.

The challenge nowadays is to find ways of measuring workload with the operators at the center of their dynamic operating environments. Efforts are needed to integrate cognitive/mental and physical human subsystems and the entire context or group of conditions in which a human must operate (Marras & Hancock, 2014; Mehta, 2016). In other words, when measuring workload an overall system approach should be used to guarantee the consideration of the person in the context of the entire environmental system, its components, interactions, and the potential influence on the human cognitive and physical behavior.

This new holistic framework allows for understanding variations across different types of tasks and/or task demands. It also enables recognizing mental and physical human subsystems interactions with individual characteristics such as personality, age, sex, previous experience, skill level, depression, anxiety, sensory limitations, and perceptions. Furthermore, it helps researchers understand mental and physical interactions with psychosocial work factors such as job control, job rotation, breaks, overtime work, workstation design, work pressure, multitasking, interruptions, and distractions. It also helps understand interactions of mental and physical demands with the physical environment such as visual conditions, auditory environment, thermal conditions, olfactory stimulation, tactile information, haptic information, and even the effect of culture and its influence on human behavior and workload. The goal is to understand, in a comprehensive manner, how humans interact with their environments, recognizing the mind-body interactions, the interactions of the human with the entire context, and their influences on human capabilities, performance, overall system output, and associated workload (Marras & Hancock, 2014).

Numerous studies have examined and reported on the interactions of physical and mental demands on human performance and health. Some studies have evaluated and quantified the effects of concurrent physical and mental demands on muscle responses and multi-site musculoskeletal pain (Mehta & Agnew, 2011; Mehta et al., 2012; Neupane & Nygård, 2017; Westgaard, 1999). Others have performed experiments to understand the effects of physical and mental activity on individuals' perception of workload and the sensitivity of such interaction on subjective mental workload assessment tools (Astin & Nussbaum, 2002; Cullen & Agnew, 2016; DiDomenico & Nussbaum, 2008; Mehta & Agnew, 2015). Concurrent physical and mental demands have also been associated with occupational accidents, decrements in performance, and burnout (Alarcón, Castillo-Díaz, Madinabeitia, Castillo-Rodríguez, & Cárdenas, 2018; Basahel et al., 2010; DiDomenico & Nussbaum, 2011; Hämmig, 2018; Sarsangi et al., 2017). Researchers have used subjective methods combined with objective techniques, such as electromyography (EMG) and eye-tracking signals, to evaluate the relationships between mental and physical workload (Zhang et al., 2017). More recently, electroencephalography

(EEG) has become a prime modality for mental workload assessment even during different physical activity levels in ambulant conditions (Albuquerque et al., 2018; Mehta & Parasuraman, 2014; Tiwari et al., 2019).

Although these studies have helped understand the relationship between physical and mental workload, they exhibit some limitations and shortcomings. For instance, all the studies have explored the effects of physical activity over mental workload perception; none have included the analysis of body postures as a possible indication of mental workload. In addition, just a few of them investigated the influence of sex or age. Still, just one has considered the potential influence of personality type or other individual characteristics such as skills, experience, or health status on mental or physical demands. Furthermore, only one study evaluated the effect of anxiety on performance (Alarcón et al., 2018). However, the experiments were focused on one specific type of task and on static activities where the participants could not move while performing the tasks. Most studies used arithmetic tasks as mental demands, which may not represent actual industry demands or practical tasks. Moreover, mental demands were manipulated to evaluate potential interactions with just one attentional resource pool or modality. Most of the studies limited the assessment tools used to subjective workload measures, and the experiments mostly manipulated physical demands holding the mental task constant. Table 2.1 shows a summary of these studies describing the research objective and their main limitations.

Table 2.1 Physical and mental demands interactions studies

Study	Objective	Limitations
Westgaard (1999)	Effects of concurrent physical and mental demands on muscle responses and multi-site musculoskeletal pain	No considered individual characteristics **Did not consider body postures**
Mehta and Agnew (2011)		Static tasks **Did not consider body postures** Not addressed sex, age, personality, anxiety Used just subjective tools

Table 2.1 Physical and mental demands interactions studies (Cont.)

Study	Objective	Limitations
Mehta et al. (2012)		No considered age, personality type, anxiety The mental task was an arithmetic task **Did not consider body postures**
Neupane and Nygård (2017)	Effects of concurrent physical and mental demands on muscle responses and multi-site musculoskeletal pain	Not performed in a controlled environment No objective measurements were carried out **Did not consider body postures**
Astin and Nussbaum (2002)	Effects of physical and mental activity on individuals' perception of workload and subjective mental workload assessment tools	Only subjective assessment tools. **Did not consider body postures.** Did not address age, personality, anxiety.
DiDomenico and Nussbaum (2008)		Only one type of mental stressor. **Did not consider body postures.** Did not evaluate individual differences.
Mehta and Agnew (2015)		**Did not consider body postures.** Static tasks. No considered personality type, anxiety. Just self-reports.
Cullen and Agnew (2016)		**Physical task was a balance task.** Static tasks. **Did not consider body postures.** Did not consider individual characteristics.
Basahel et al. (2010)	Physical and mental demands effects on occupational accidents, decrements in performance, and burnout	Not realistic tasks. **Did not consider body postures.** Single-channel perspective.
DiDomenico and Nussbaum (2011)		Did not evaluate individual differences. Mental tasks were kept constant. **Did not consider body postures.**
Sarsangi et al. (2017)		Used just self-report questionnaires. No manipulation of mental or physical demands. **Did not consider body postures.**
Hämmig (2018)		Self-report questionnaire tools. **Did not consider body postures.**
Alarcón et al. (2018)		**Did not consider body postures.** No considered individual characteristics. Only used self-reporting tools.
Mehta and Parasuraman (2014)	Subjective methods combined with objective techniques to evaluate relationships between mental and physical workload	Arithmetic task. Static task. Did not consider age, sex, personality, anxiety. **Did not consider body postures.**
Zhang et al. (2017)		Did not include sex, age, personality, anxiety. No manipulation of the mental task. **Did not consider body postures.**

Table 2.1 Physical and mental demands interactions studies (Cont.)

Study	Objective	Limitations
Albuquerque et al. (2018)	Subjective methods combined with objective techniques to evaluate relationships between mental and physical workload	Explored only the effects of physical activity on mental workload assessment. **Did not consider body postures.**
Tiwari et al. (2019)		Did not address individual differences' effects. No realistic tasks. **Did not consider body postures.**

To the best of my knowledge, this dissertation research is the first to evaluate the effects of perceived mental workload on body postures using postural risks assessment methods such as Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000; McAtamney & Hignett, 1995) and Rapid Upper Limb Assessment (RULA) (McAtamney & Nigel Corlett, 1993). Another unique characteristic of this research is studying the effects of mental workload over body posture while holding the physical demands constant. This dissertation research considered multiple individual characteristics such as age, sex, personality type, and anxiety into the analysis to explore if they mediate or exacerbate the effects of different working conditions on the perception of mental workload and body postures.

Psychosocial Factors

In the field of occupational health, the term psychosocial is frequently used to define a number of factors that are part of three domains: 1) factors related to the job and work environment, 2) factors associated with the outside work environment, and 3) individual characteristics of the employee. It is believed that interactions between factors in each domain, known as a stress process, impact performance and health status (Bongers et al., 1993; Eatough et al., 2012).

Numerous conditions referred to as work organization factors are included in the job and work environment domain. Organizational work factors are defined as the subjective perceived aspects of the work organization that have an emotional connotation for workers and managers and can result in stress and strain (Kompier & van der Beek, 2008; Putz-Anderson et al., 1997).

Work organizational factors include aspects related to job content (e.g., workload, mental demands, job control, multitasking, decision-making, mental processing, clarity of the job, monotonous work), organizational characteristics (e.g., communication, structures of the organization, career considerations, job security), interpersonal relationships at work (e.g., social support from colleagues and/or superiors, getting along with co-workers), temporal aspects of the work and task (e.g., shiftwork, overtime, time pressure, work-pace), physical environment (e.g., noise, lighting, temperature, furniture and equipment, physical constraints, physical layout, vibration, motion, air quality), financial and economic aspects (e.g., benefits, pay, equity), and community aspects (e.g., status, prestige) (Bongers et al., 1993; Carayon et al., 1999; Eatough et al., 2012; Kompier & van der Beek, 2008; Payne, 1988).

These organizational work factors are often referred to as risk factors that may have an impact on employees' health. For instance, H. Yang et al. (2016) demonstrated significant associations between neck pain and workplace factors such as hostile work environment, job insecurity, long work hours, and work-family imbalance. Other studies have demonstrated significant associations between various psychosocial factors (safety, work environment, job satisfaction, job demands,) and musculoskeletal disorders and pain (Baek, Yang, Lee, & Chung, 2018; Chen, Yu, & Wong, 2005; Ng, Voo, & Maakip, 2019; Putz-Anderson et al., 1997; Zamri, Moy, & Hoe, 2017).

Psychosocial factors associated with extra-work environment include those that could impact demands due to roles outside of work such as family responsibilities, work-home overflow, balance between job and work at home. Finally, individual factors are those related to the individual characteristics of the worker such as sex, age, social class, culture, education status, personality traits, attitudes towards life, job satisfaction, depression, anxiety, among others (Keita & Sauter, 1992; Payne, 1988; Sauter & Swanson, 1996).

There is increasing evidence that work-related psychosocial factors can have a substantial effect on the development of WMSDs. There is also a general recognition that factors other than those linked with physical demands play a role in the development and preservation of WMSDs (Aasa et al., 2005; Bongers et al., 2002; Bru et al., 1996; Davis et al., 2002; Eatough et al., 2012; Kompier & van der Beek, 2008; Marras et al., 2000; Marras & Hancock, 2014; Oakman et al., 2014; Shahidi et al., 2013).

For instance, Bongers et al. (2002) conducted a review of the literature and concluded that psychosocial workplace characteristics, such as monotonous work, time pressure, low control, and social support, may have a direct impact on velocity and acceleration of movements, applied force, and postures. Likewise, psychological characteristics of the workplace may generate several (sustained) stress responses that could cause physiological changes and different perceptions of the work situation that may lead to musculoskeletal problems. The studies considered in Bongers et al. (2002) reported an association between at least one work organizational factor and adverse upper extremity symptoms and disorders such as ache, pain discomfort in the elbow, wrist, shoulder, hand, arm, and neck, carpal tunnel, tendonitis, epicondylitis, nerve entrapment, impingement, among others.

Similarly, Eatough et al. (2012) discovered that musculoskeletal complaints and symptoms were caused by psychosocial work stressors and their resulting emotional strain. Their proposed model demonstrates that work psychosocial stressors can significantly impact employee health on psychological and physical levels. However, the cross-sectional nature of the study design did not allow for causal interpretations, and the findings were only speculative. Eatough et al. (2012) argue that future studies should assume a longitudinal design to better explain the causal relationships between stressors, strain, and WMSD symptoms.

Carayon et al. (1999) state that psychosocial work factors can initiate psychological stress that can affect hormonal, circulatory, and respiratory responses. Such responses could exacerbate the effects of the traditional ergonomics risk factors affecting employee behavior and attitude, leading to risky actions and consequently increasing physiological susceptibility to WMSDs. They presented a model in which work factors are categorized into five elements of the work system: *the task, the organizational context, the technology, the physical and social environment, and the individual*. This model highlights the need to incorporate all the elements of the system and their interactions when assessing and (re)designing work systems.

Davis et al. (2002) suggest a potential mechanism by which psychosocial stress may increase lumbar spine load and may help to explain the potential biomechanical mechanisms behind the occupational injury risk. They point out the necessity to think not only on the design of the workstation, but also on the demands of the job, workload, and environmental conditions which could affect the workers' biomechanical mechanisms. Likewise, Marras et al. (2000) evaluated the effects of psychosocial stress on muscle activity and spinal loading and demonstrated that there is a potential biomechanics pathway associated with psychosocial stress.

They considered individual factors such as sex and personality traits to explain the functioning of the biomechanical system.

Bao et al. (2016) evaluated the relationships between job organizational factors and biomechanical and psychosocial exposures, concluding that the relationships between the factors are highly complicated. Overall, work organization factors had strong associations with biomechanical variables and psychosocial aspects. Because the study followed a cross-sectional design, longitudinal data are still needed to confirm the effects are not merely associative but rather may potentially be causal. Shahidi et al. (2013) studied the effects of psychosocial factors such as mental concentration and positive and negative feedback about performance on cervical muscle activity. The authors concluded that mentally challenging tasks increase anxiety and forward head posture. Their findings suggest a need for future research on psychomotor responses to stress as a potential risk factor for the development of musculoskeletal pain.

Aasa et al. (2005) found associations between psychosocial demands, lack of social support, worry about work conditions, and neck-shoulder complaints, and low-back complaints in female and male ambulance personnel. The study incorporated individual characteristics such as sex, age, smoking habits, and physical activity. The authors noted that although worry is not a sign of pathology, it might have an effect (cross-sectional study) on muscle activation and thereby contribute to the development of WMSDs as has been previously stated by Johansson, Sjölander, Djupsjöbacka, Bergenheim, and Pedersen (1999). Bru et al. (1996) agree with the theory that musculoskeletal pain has a multifactorial origin. They concluded that psychosocial and organizational work factors are more strongly linked with neck and shoulder pain than with low-back pain among female hospital staff. However, the study was performed using only self-reported questionnaires and causal relationships could not be established.

Heard and Adams (2019) studied ways to estimate workload and the factors contributing to human workload accurately. They state that the overall workload should be decomposed into its components including cognitive, speech, auditory, visual, and physical workload. Likewise, Oakman et al. (2014) addressed organizational, technical, and individual factors focused on non-nursing healthcare occupational groups in an attempt to identify the key predictors of WMSD risk. Age, sex, psychosocial hazards, work-life balance, job satisfaction, and physical demands contribute significantly to the level of discomfort, explaining approximately one-quarter of the variance in the model. They highlight the importance of incorporating physical and psychosocial factors to allow for a more comprehensive and holistic multi-dimensional approach when researching WMSD risk prediction or assessment.

All the above-mentioned authors incorporated psychosocial work factors into their studies and demonstrated the importance of considering those types of hazards in predicting WMSDs. They also argued for the need for a holistic and multi-dimensional approach for risk management and assessment. However, most of these studies did not evaluate the interaction between psychosocial load and physical workload, movement, postures, and/or exerted forces, and none studied changes in whole-body postures. The studies had cross-sectional designs and were not conducted under control conditions, limiting the results to potential pathways and merely associations, therefore causal inferences could not be made. Besides, most of the studies did not consider dual-task or concurrent conditions and did not incorporate interruptions and/or distractions as psychosocial work factors.

This dissertation research conducted experiments under controlled conditions to allow for the establishment of causal relationships using realistic tasks that emulate activities performed in a Sterile Processing Department (SPD). The research study incorporated distractions and/or interruptions as psychosocial work factors to evaluate their influences on physical mental workload by assessing body postures using objective tools instead of self-reports. Also, the research implemented a dual-task environment design for the execution of the tasks and explored the influence of individual characteristics on the assessment.

Postural Analysis

Physical ergonomics (also known as traditional ergonomics) study the effects of physical work on the human body (Marras & Hancock, 2014). It deals with anthropometric, human anatomy and physiology, individual physical abilities, and has helped to form the basis in biomechanics as it relates to physical work systems. It has also contributed to implementing working conditions that prevent the development of WMSDs and improve the reliability, productivity, and quality of industrial operations (Coelho, Oliveira, Maia, Maia, & Dias-Teixeira, 2016; Marras & Hancock, 2014; Mehta, 2016).

A wide range of ergonomics methods can be used to measure exposure to physical risk factors. David (2005) classified them under three categories (1) self-reports, (2) observational methods, and (3) direct measurements. The classification is based on the precision of information gathered and the level of intrusiveness to the worker. In the category of self-reports, there are ordinal scales, visual analog scales, categorical data, operator self-evaluation from video films of the work sequence, Nordic Questionnaire, and web-based recording methods. The observational techniques include REBA (McAtamney & Hignett, 1995), RULA (McAtamney & Corlett, 1993), NIOSH Lifting Equation (Waters, Putz-Anderson, Garg, & Fine, 1993), OCRA (Occhipinti, 1998), LUBA (Kee & Karwowski, 2001), OWAS (Karhu, Härkönen, Sorvali, & Vepsäläinen, 1981), The Strain Index (Steven Moore & Garg, 1995) and more advanced observational methods like ROTA (Ridd, Nicholson, & Montan, 1989), HARBO (Wiktorin, Mortimer, Ekenvall, Kilbom, & Hjelm, 1995), PATH (Buchholz, Paquet, Punnett, Lee, & Moir, 1996), SIMI Motion (Frenken, Lohmann, Frenken, Steen, & Hein, 2014), biomechanical models, among others. The direct assessment methods category includes methods that rely on sensors attached to the subject such as optical motion capture by using lumbar motion monitors, electromyography (EMG), force measurement, electronic goniometers, inclinometers, and others.

The accurate measurement of workers' exposure to physical risk factors has been of vital importance in research studies and musculoskeletal disorders risk prevention programs and treatments for ergonomists, epidemiologists, occupational health physicians, and employees (Coelho et al., 2016; David, 2005; Jatobá et al., 2016). Several researchers have conducted postural analyses in an ample range of occupations and industries including healthcare services, manufacturing companies, production lines, aviation, and office environments. They have applied a variety of assessment methods focusing on identifying the contributions of physical risk factors to the incidence of musculoskeletal disorders (Burnett & Campbell-Kyureghyan, 2008; Carneiro et al., 2019; Coelho et al., 2016; Fredric Gerr et al., 2014; Gómez, 2020; Lapointe, Dionne, Brisson, & Montreuil, 2009; Park et al., 2009; Tantuco, Mirasol, Oleta, & Custodio, 2016). Others have studied the influence of physical risk factors on human performance (de Mattos, Neto, Merino, & Forcellini, 2019; Jatobá et al., 2016; Zhou &

Wiggermann, 2017). However, only physical risk factors have been evaluated in all these studies without considering mental demands or psychosocial work factors, and just two of the studies (Burnett & Campbell-Kyureghyan, 2008; Zhou & Wiggermann, 2017) were performed under controlled conditions.

More recent studies have focused on evaluating the effects of physical work demands on postural risk considering psychosocial work factors and mental demands. Some of the studies have used observational and self-report ergonomic assessment methods (Asghari et al., 2019; Gómez, 2020; Lapointe et al., 2009; Márquez Gómez & Márquez Robledo, 2015; Yu et al., 2015) while others used more advanced observational ergonomic methods (Bao et al., 2016; de Negreiros, da Silva, Arezes, Dangelino, & Padula, 2019). Although these studies included postural analyses as part of the research variables, the studies were not performed under controlled conditions where mental or physical demands were manipulated or analyzed considering different levels of mental workload.

The use of dual-task paradigms is common in this new and expanding research as well as the consideration of cognitive demands of the task (Maylor et al., 2001; Qu, 2010; Riley et al., 2003; Roerdink et al., 2011; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Siu & Woollacott, 2007; Stins et al., 2009; Vuillerme & Vincent, 2006; Woollacott & Shumway-Cook, 2002). Findings from these studies have revealed important insights into the role of cognitive demands in the control of posture under dual-task environments. The results suggest that postural stability or balance could be negatively affected by cognitive demands showing variations depending on the complexity of the cognitive task. The complexity of the cognitive task includes the type of task and required cognitive processing, the type of secondary task being performed, type of postural or physical task performed, individual characteristics such as age, participant expertise or skills, participant goals, and the instructions offered to participants.

The main limitations of the studies that used a dual-task paradigm are based on the fact that they were focused on evaluating the effect of the cognitive demands on balance or gait and not on occupational tasks neither on changes in body postures or posture behaviors. In addition, the secondary tasks were referred to just postural control tasks, for instance, standing, sitting, maintaining balance, or walking. Only one of the studies included executing a physical task (Qu, 2010) using the balance data collected as one of the outcome variables. Finally, none of the studies used any ergonomics methods listed before, for instance, RULA and REBA, to evaluate postures or physical risks exposure.

This dissertation research differs from the previous work by incorporating the analysis of body postures using ergonomic methods (REBA, RULA) and evaluating the perception of mental workload using NASA-TLX and SURG-TLX (Wilson et al., 2011). It also included individual characteristics such as age, sex, anxiety, and personality trait and considered psychosocial work factors such as distractions and interruptions. Furthermore, it incorporated the execution of realistic tasks that emulate the tasks performed in a hospital at the Sterile Processing Department (SPD), using a control experimental design that allowed establishing causal relationships of the effect of mental workload on body postures.

The objective is to move towards an approach that studies the entire human system and its interactions as a whole rather than evaluating the individual subsystems separately. The goal is to develop a comprehensive understanding and model the behavior of these interactive components and their effects on human perception of the work situation, associated workload, and the relationship between action and perception.

The long-term goal is to provide an integrated framework that will help set priorities in the prevention of WMSDs and job re(design), help improve the design of ergonomic interventions, and identify factors that could lead to the measurement of human current workload state.

Identified Gaps in Knowledge

Key gaps in knowledge and related research questions (RQ) were identified through the review of the literature on mental workload, psychosocial risk factors, and postural analysis.

Gap 1: Mental workload is a multidimensional construct that incorporates characteristics of the task, environment, and the operator. Studies have explored the effects of different levels of physical demands and concurrent tasks on mental workload perception. Still, little effort has been dedicated to studying the effects of psychosocial work factors, specifically time, distractions, and interruptions in occupational tasks (realistic tasks) on the perception of mental workload while the physical demands of the tasks are kept constant.

RQ1: Is perceived mental workload affected by psychosocial factors while keeping the physical demands of the task the same?

Gap 2: Research shows relationships between postural control and cognitive demands; however, the relationship between perceived mental workload and body postures has not been considered in mental workload studies on concurrent mental and physical environments of occupational tasks.

RQ2: Does perceived mental workload affect the body postures assumed to perform a task?

RQ3: Is there an association between changes in body postures and perceived mental workload?

Gap 3: Studies have shown that humans respond according to how they interpret the conditions in which they have to perform their jobs. This interpretation can depend on individual factors; however, little is known about the potential influence of individual characteristics on the perception of mental workload and body postures.

RQ4: Can individual characteristics such as age, sex, personality trait, or anxiety level help to explain the changes in the perception of mental workload?

RQ5: Can age, sex, personality trait, and anxiety level help to explain changes in body postures?

The research questions stated above are addressed in the next four chapters with a general discussion of the findings and conclusions following afterward. Addressing the identified gaps about the interaction between postural risk and mental workload and the potential influence of individual characteristics is expected to lead to several practical implications in work and tasks design, workload planning, and process selection that will positively impact workers' health.

CHAPTER THREE

EVALUATING PHYSICAL AND MENTAL WORKLOAD INTERACTIONS IN A STERILE PROCESSING DEPARTMENT

Contribution of Authors and Co-Authors

Manuscript in Chapter 3

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Contributions: conception of the work, data collection, data analysis, and interpretation, drafting the article

Co-Author: Frank Marchak

Contributions: critical revision of the article and final approval of the version to be published

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Abstract

This study originated during the execution of a kaizen event in the Sterile Processing Department (SPD) at a local hospital (Claudio, Cosgriff, Nino, & Valladares, 2021). The Sterile Processing Department (SPD) is responsible for decontaminating, inspecting, preparing, sterilizing, storing, and dispatching sterile medical and surgical supplies, instruments, and equipment throughout the hospital to ensure infection prevention and control within the healthcare organization. SPD provides special attention to Operating Rooms (ORs). The study results indicated that increases in REBA scores and NASA-TLX indices were associated with days with higher workloads. SPD staff assumed more awkward body postures when they were in rush conditions or when more surgeries were scheduled in the ORs.

Introduction

Work in healthcare facilities has been categorized as a high-risk job for developing WMSDs (Tullar et al., 2010). Most of the attention to mitigate the risks associated with WMSDs has been focused on nursing (Oakman et al., 2014) as it represents the largest group in the healthcare sector. Little to no attention has been given to other non-clinical workers. For instance, Sterile Processing Department (SPD) workers are exposed to various hazardous conditions that include mentally and physically demanding tasks, which may impose an elevated risk in developing WMSDs. SPD staff and other occupational groups play a key role in the delivery of high-quality healthcare services since all processes within a hospital are interrelated. Hence, any attempt to reduce WMSDs in those non-clinical occupational groups should be considered as a step in the path to improve patient care (Miller et al., 2014; Oakman et al., 2014).

An SPD is generally divided into two major areas: decontamination and sterilization (Figure 3.1). The decontamination process aims to protect workers in the assembly area from contracting diseases caused by microorganisms that may be present in the equipment or other surgical supplies. Personnel working in the decontamination area wear protective clothing such as scrub uniforms, rubber gloves, shoe and hair covers, safety goggles, and face masks. In the decontamination area, equipment, instruments, and other surgical supplies are cleaned by manual and mechanical cleaning processes and chemical disinfection processes. Decontamination workers are in charge of sorting, disassembling, and manually soaking every item received from the ORs. Some items are then placed in a washer used to clean heat-tolerant items. The washers have many cycles that are programmed according to the type of equipment or instruments contained in the load. Once the items have been decontaminated, they are received in the sterilization area.

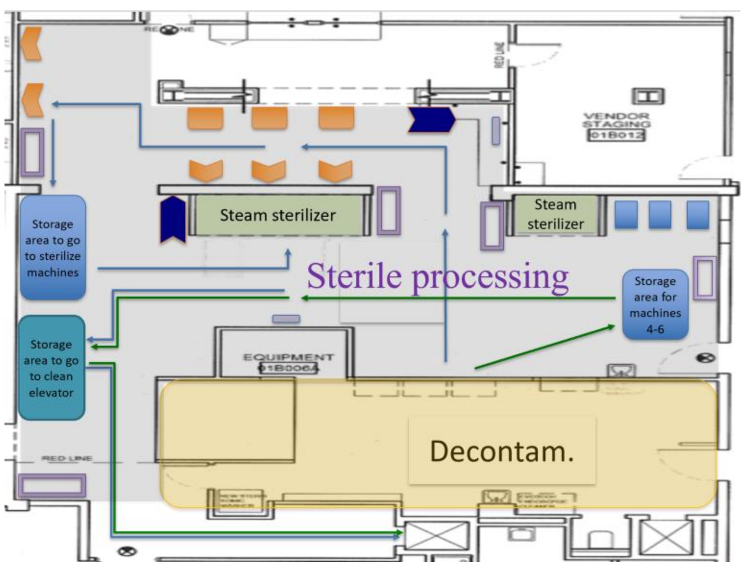

Figure 3.1 Sterile Processing Department at the local hospital

Workers in the sterilization area wear surgical attire, shoe covers, and hair covers. In this area, instruments are inspected and assembled into sets or trays following a recipe card with instructions for assembling each tray. Subsequently, each tray is placed in a rigid container and wrapped using special textile sheets to go to the sterilization machine. After sterilization, items are stored in the sterile area, until they are dispatched to the OR. SPD workers are exposed to awkward positions, repetitive or prolonged motions, forceful manual exertions, potentially infectious pathogens such as blood, body fluids, and chemical substances used in the process.

In addition, SPD workers are exposed to biomechanical strain generated from physically stressful tasks, standing almost the entire working day, and manual handling of heavy objects such as trays (Figure 3.2). According to ergonomics principles, all these factors may impose an elevated risk in developing WMSDs or result in a possible issue.

Figure 3.2 Postures assumed by SPD staff

WMSDs have been recognized to be more complex than previously thought, incorporating risks influenced by several combinations of a diverse range of psychosocial and work organizational hazards in addition to the more widely known hazards associated with physically demanding work (Bru et al., 1996; Carayon et al., 1999; Kompier & van der Beek, 2008; Strater, 2005). However, little has been reported on quantifying the relationship between perception of mental workload and physical demands and its influence on the development of WMSDs. It is important to understand the interaction between postural risk and perception of mental workload as it could serve to identify if concerns about mental workload are due to physical issues or vice versa. Consequently, this study aimed to determine how SPD work design is related to WMSDs and to determine if there was any relationship between awkward body postures and the perception of mental workload.

The Rapid Entire Body Assessment (REBA) method is a postural analysis tool that provides a quick and easy measure to assess a variety of working postures for risk of WMSDs (Hignett & McAtamney, 2000; McAtamney & Hignett, 1995). REBA appears to be the only method sensitive enough to capture the unpredictable working postures observed in healthcare and other service industries (Chiasson, Imbeau, Aubry, & Delisle, 2012; Hignett & McAtamney, 2000). REBA has also proved to be suitable for whole-body evaluation and best for both static and dynamic works. Likewise, REBA assessment has the advantages of being inexpensive and requires only minor equipment (David, 2005; Kong, Lee, Lee, & Kim, 2018; Shanahan et al., 2013). REBA helps to avoid inconsistency on the data because the use of self-report tools has shown that participants identify the absence of postural risk factors appropriately but cannot identify their presence correctly (Lapointe et al., 2009). Therefore, it was decided to evaluate the risk of developing WMSDs using an objective tool such as REBA.

Regarding the perception of mental workload, several tools exist for its evaluation and prediction (Rubio et al., 2004). Subjective measures have been used extensively due to their practical advantages such as easy implementation and non-intrusiveness. These tools can be administrated after the task is completed without disturbing the operator. No special equipment or data collection procedures are required and are quick and inexpensive to administer and analyze (Hill et al., 1992; Mehta & Agnew, 2015; Rubio et al., 2004). The most popular self-reporting rating scales which currently dominate the literature are the National Aeronautical and Space Administration Task Load Index (NASA-TLX) (Sandra G. Hart & Staveland, 1988; Huggins & Claudio, 2018) and Subjective Workload Assessment Technique (SWAT) (Huggins & Claudio, 2018; Reid & Nygren, 1988). Both tools have been applied successfully in different environments showing high reliability (Huggins & Claudio, 2018; Nygren, 1991; Rubio et al., 2004). NASA-TLX has shown some advantages over SWAT, such as high sensitivity to determine physical and mental demands and workload for tasks that involve different muscle groups (Mehta & Agnew, 2015; Nygren, 1991). NASA-TLX includes the influence of physical demands associated with job tasks while SWAT does not (Hill et al., 1992; Huggins & Claudio, 2018; Mehta & Agnew, 2015; Nygren, 1991). NASA-TLX is widely considered the most robust tool available for reporting not only perceptions of mental workload but perceptions of overall workload (DiDomenico & Nussbaum, 2008; G. Young, Zavelina, & Hooper, 2008). Therefore, the NASA-TLX was chosen to obtain the participants' perception of workload.

The combination of a subjective self-reporting tool (NASA-TLX), an objective tool (REBA), and the engagement of an actual workforce carrying out realistic occupational tasks were unique aspects of this research. Until now, nobody has conducted studies that involved non-subjective tools or self-report questionnaires in a real workplace to evaluate the interaction between physical and mental workload. This study was a first attempt to learn if perceived mental workload (measured with NASA-TLX) creates higher levels of physical risk (measured with REBA) by using a subjective self-reporting tool (NASA-TLX) and an objective tool (REBA).

Methods

Each participant was given verbal and written descriptions of the experiments and was required to complete an informed consent form approved by the Institutional Review Board (IRB) for research involving human subjects at Montana State University.

Participants

Twelve SPD employees (seven males and five females) took part in phases 1, 2, and 3 of the study. Their mean age (sd) was 31.61 (± 11.27) years old, time working at SPD was 4 (± 5.79) years, and the number of working hours per week was 35.61 (± 11.54) hours/week. Eleven participants were right-handed and one was left-handed. Normally, SPD workers take two breaks of 15 min/each in addition to the 30 min lunch break.

Location

The three phases of the study were conducted in the Sterile Processing Department (SPD) of a mid-size local hospital. The hospital is an Acute Care facility with a medium volume, 86 bed facility, with over 2,000 employees where 200 are physicians. The health professionals cover over 35 specialties and compose more than 20 clinics.

Methods

Tasks for the sterile process included in the study were those performed at the decontamination area and the sterilization area. Processes commonly performed in these areas include chemical disinfection, sorting, disassembly, soaking, placing objects in the washers, inspection, trays assembly, wrapping, placing trays in sterilization machines, and delivery to the ORs or other internal or external facilities. The study was divided into three phases.

In Phase 1, a Customized Nordic Questionnaire was used to determine the prevalence of musculoskeletal disorders and the existence of perceived risk factors for injury in the SPD. It was designed based on the Standardized Nordic Questionnaire proposed by Kuorinka et al. (1987). This questionnaire provided information related to personal and demographic details, the job or activities performed by each participant, general musculoskeletal disorders in the entire body, and details about musculoskeletal pain in the neck, shoulders, elbows, hands, wrists, upper back, and lower back.

Phase 2 consisted of the ergonomic assessment in the SPD. It was conducted using REBA. The tasks were performed in the facility to capture the natural work environment as much as possible and ensure the participants performed their duties as they normally do. Each of the activities performed in SPD was videotaped and the ergonomic assessment was done through the analysis of the videotapes. After obtaining several snapshots and estimating REBA scores for several awkward postures, the most awkward postures were identified as the ones with the highest REBA scores. The highest REBA score was then established for each activity and each participant per day.

Phase 3 consisted of participants' perception of mental workload in the SPD. It was evaluated using the NASA-TLX. The total task load score was obtained assuming equal weights for the dimensions. This way to obtain the NASA-TLX task load score is known as raw NASA-TLX (RTLX; (Byers, 1989; Sandra G Hart, 2006). It was decided to use the raw NASA-TLX score because it has been proven that traditional TLX scores and raw scores are almost perfectly correlated. In some cases, RTLX has shown even better (less variable) predictions of workload. Therefore, the dimensional weighting procedure may be ignored without compromising the measures (Byers, 1989; Nygren, 1991). Participants were asked to provide their perception of mental workload by filling out the NASA-TLX questionnaire immediately after they finished a task from which they had been videotaped.

Data were collected for seven days to ensure information from all shifts, different workloads, and all the participants, resulting in 181 data points. Statistical analyses were performed using Multivariate Analysis of Variance (MANOVA) to identify the effects of the independent variables over the dependent variables. These statistical analyses were performed using JMP 13.0 and Minitab 18.0. The independent variables were: type of day, established as a normal day (<= 25 surgeries in total) and busy day (more than 25 surgeries in total), participant number (12 in total), and type of task. Tasks were classified as: assembly, wrapping, decontamination, loading-unloading sterilizer machines, loading-unloading elevators, moving trays to carts, racks, or work stations, loading-unloading the tray rack, loading-unloading washers, and packing. The dependent variables were REBA and NASA-TLX scores.

Results

Phase 1: Nordic Questionnaire

Results from the Nordic Questionnaire were useful to obtain a description of the population who took part in the study noticing the prevalence of musculoskeletal disorders and the existence of perceived risk factors among the participants. The lower back was the most common body area where SPD staff experienced discomfort (75%) in the last 12 months and the last seven days, but it did not prevent them from doing their normal duties. Knees and ankles/feet

(66.67%) were the second body part in which SPD staff experienced discomfort in the last 12 months. Twenty-five percent (25%) of the participants experienced discomfort in their knees in the last seven days (Table 3.1), and 12.50% of those who experienced discomfort in their ankles/feet were prevented from performing their normal duties.

Table 3.1 Nordic questionnaire: Percentage of participants who experienced discomfort in the last seven days

Body Part	**No. of Participants**	**%**
Lower back	4	33
Ankles/feet	4	33
Knees	3	25
Shoulders	3	25
Neck	3	25
Wrists/hands	3	25
Upper back	3	25
Hips/thighs	2	17
Elbows	1	8

Hips/thighs were not one of the most affected body parts (16.67%), but they had a high percentage (75%) of preventing normal duties when pain or discomfort was present. One or more employees had experienced discomfort in one or more parts of their body in the last seven days. These results were expected due to the nature of the job at the SPD, where employees remain standing for more than half of their shift, adopted unnatural postures for the neck, back, and shoulders, handling heavy loads repeatedly, and bending many times through the day.

Phase 2: Ergonomic Assessment (REBA scores)

A total of 181 REBA scores were obtained (7 days of data) after the videotapes were analyzed and the most awkward posture per task was chosen. The minimum and maximum scores were selected for each of the tasks performed at SPD. The objective was to obtain the range of risk of each activity since the same activity is performed by different employees many times a day. Table 3.2 shows the minimum and maximum REBA scores for each activity.

Any task with a REBA score between 4 – 7 represents medium Musculoskeletal Disorder (MSD) risk. A score of 8 – 10 represents a high MSD risk and anything above 10 represents a very high risk (Hignett & McAtamney, 2000; McAtamney & Hignett, 1995). REBA scores indicated that the tasks decontamination and moving of trays were the activities with very high risk, therefore, changes are required immediately (REBA = 11).

Table 3.2 REBA scores per task

Task	**REBA**	
	Min	Max
Decontamination	8	11
Movements of trays to carts, racks, work stations	5	11
Load-unload tray racks	9	10
Load-unload elevators	8	10
Wrapping	5	10
Assembly	5	10
Load-unload sterilizer machines	6	9
Load-unload washers	5	9
Packing	5	6

Assembly, wrapping, load-unload elevators, load-unload tray racks are activities with high risk (REBA = 10) in which investigations and implementation of changes are needed. Packing is the activity with the least risk; however, its REBA score indicates that further investigation and changes are required soon. In all the activities performed at SPD, a task redesign is required (minimum REBA score was 5). These REBA scores are indicative of a medium to very high risk (scores higher than 4) of the development of musculoskeletal disorders.

On average, REBA scores were lower on normal days and higher on busy days, confirming what had been empirically observed during the execution of different projects at SPD regarding the adoption of more awkward postures by SPD workers on busy days.

Figure 3.3 shows the behavior of REBA scores by day, participant, and task. The highest REBA score was observed in participant # 8 who oversees the loading and unloading of trays on a rack in which it is necessary to adopt postures that are out of the range of natural postures. Likewise, REBA scores changed by the task. The activities decontamination, load-unload elevators, and loading-unloading tray rack have the highest scores.

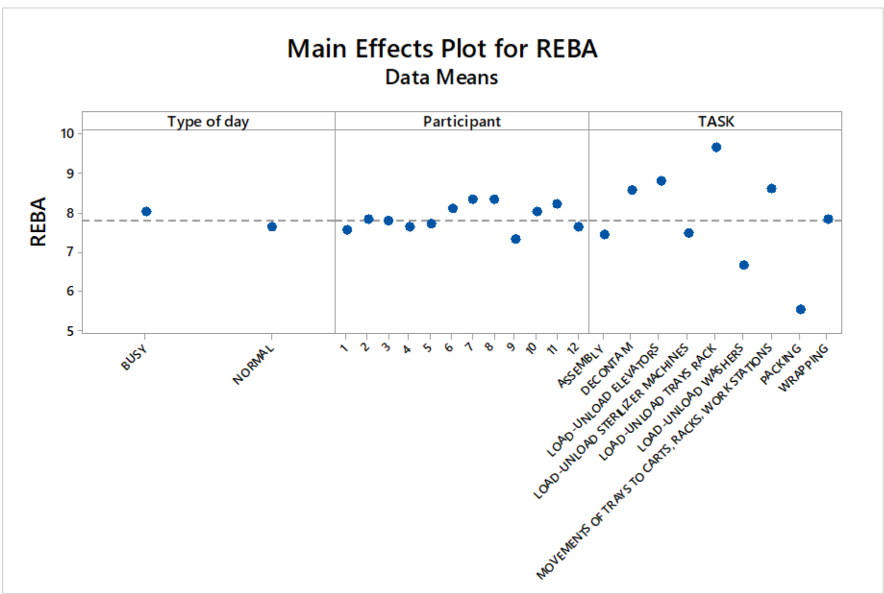

Figure 3.3 Average REBA scores by day, participant, and task.

Phase 3: Workload Assessment (NASA-TLX scores)

Figure 3.4 shows the NASA-TLX average scores by type of day, participant, and task. On average, scores are higher on busy days than on normal days. The highest score (participant 12) can be explained by the fact she/he is an on-call employee which means every time he/she gets a call to show up at work is because typical operations are overwhelmed. Participant 10 has the next highest index which might be related to the participant being in charge when the supervisor is out of the office. The task with the highest NASA-TLX scores was loading-unloading elevators which can be explained by the fact that every time the dirty elevators must be unloaded it translates to more instruments arriving at SPD to be processed. NASA-TLX scores showed similar behavior to REBA scores with higher indices on busy days than on normal days. Regarding NASA-TLX indices by participants, differences could be highly related to levels of responsibility.

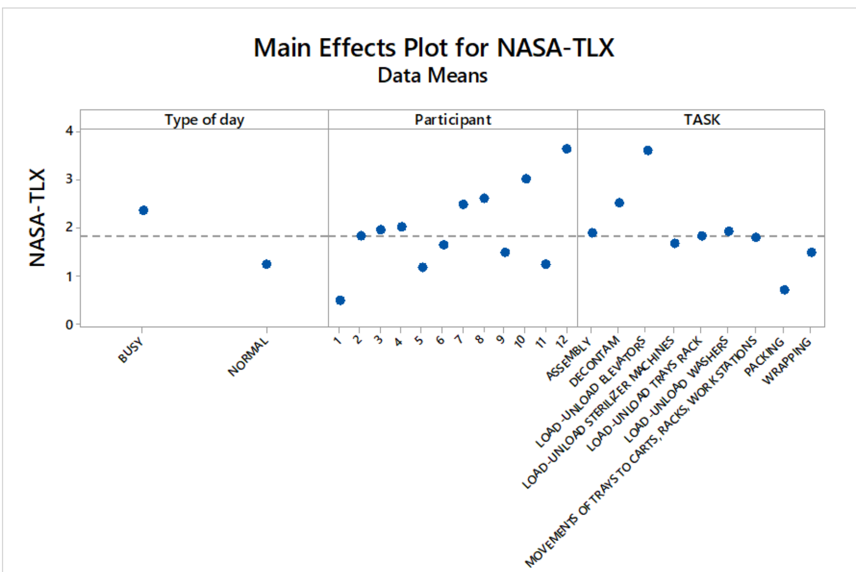

Figure 3.4 Average NASA-TLX scores by day, participant, and task.

ANOVA and MANOVA Analysis

After verifying the normality assumptions for the response variables REBA and NASA-TLX, further analysis was performed to explore the effect of the independent variables on each of the response variables. ANOVA analysis was conducted to determine the factors that significantly affect each of the response variables. The results of the ANOVA on REBA scores versus the type of day, participants, and tasks indicated that the type of task performed is the only factor that has a significant effect on REBA scores ($p < 0.001$). The results of the ANOVA on NASA-TLX scores versus the type of day, participants, and tasks indicated that all factors have a significant effect on NASA-TLX scores ($p < 0.007$). The same results were obtained considering participants as a random factor and when including order two interactions of the variables in the ANOVA.

Additionally, a MANOVA analysis was conducted to determine if the type of day, task, or participant affects REBA scores and NASA-TLX scores together. The findings indicated that all variables (the type of day, participant, and task) had significant effects on NASA-TLX and REBA scores ($p< 0.001$).

Additional analysis was performed using the type of day (busy or normal) as the main factor since it represents a balance condition, and thus, it was the variable that could be fixed across all participants. REBA and NASA-TLX scores showed similar behaviors with higher values on busy days and lower values on normal days (Figure 3.5).

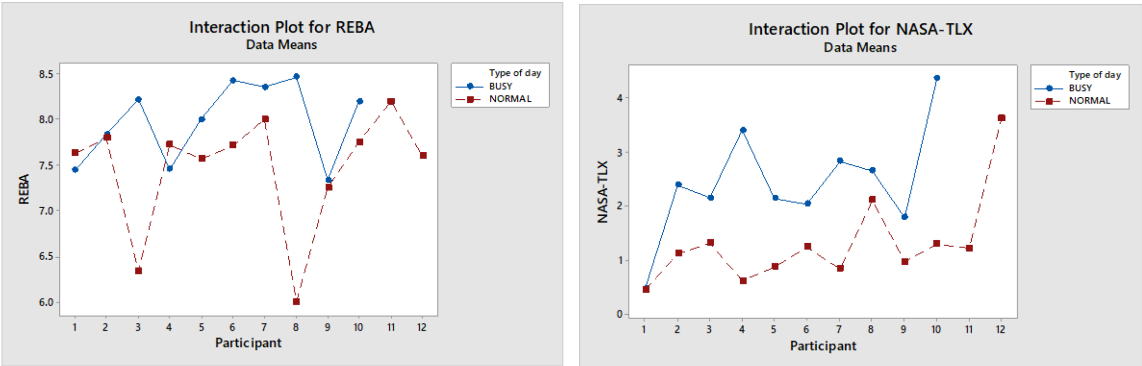

Figure 3.5 REBA indices, total NASA-TLX scores by participants, and type of day

These results led to the conclusion that there might be a relationship between REBA scores (risky postures) and NASA-TLX scores. NASA-TLX scores were significantly different between busy and normal days (p = 0.000), while REBA scores were not (p= 0.129). Therefore, a correlation analysis was performed. The analysis yielded a Pearson correlation coefficient for REBA and NASA-TLX of 0.208 (p=0.005).

Discussion

The results indicated that all variables (type of day, participant, and task) have significant effects on NASA-TLX and REBA scores. Participant (as an independent variable) has the biggest effect which can be attributable to individual factors. According to the literature, some of these factors include age, personality, coping, perception, health status, body mass index (BMI), experience, and others (Bongers et al., 2002; Carayon et al., 1999).

Higher scores of REBA and NASA-TLX were observed in activities performed at the decontamination area, where employees are exposed to stressors such as higher temperatures, infectious pathogens, chemical substances, or higher levels of responsibility. These findings support the statement presented by Carayon et al. (1999) who pointed out the importance of examining both ergonomic and psychosocial work factors (perception of workload) in studies that seek to solve WMSDs since ergonomic risk factors such as repetitive motions and the duration of exposure are directly tied to the workload requirements and individual characteristics.

Increases in REBA and NASA-TLX scores were associated with days with higher workloads. Similar results have been reported in previous studies that used only self-report surveys, in which increases in physical workload levels were associated with greater perceptions of mental demand, temporal demand, higher effort, frustration, and perceptions of failure (Mehta & Agnew, 2015). However, it was not possible to determine if the REBA scores increased due to the mental workload or the other way around. Causal inferences could not be established given the study design; it was an observational cross-sectional design, and thus, it did not apply any mechanism to control or minimize confounding influences or control on the levels of mental workload.

A Pearson correlation coefficient of 0.208 (p = 0.005) indicated the possible association between REBA and NASA-TLX scores. Although this was a weak to moderate positive correlation, it seems that the perception of workload generates changes in the manner people perform tasks that lead to the adoption of more uncomfortable postures contributing to WMSDs (Landy, 1989). This result relates with the statement presented by Bongers et al. (2002) that states that psychosocial workplace characteristics such as time pressure, work pace, concentration, social support, job responsibilities, job rotation, among others may have a direct impact on postures that may lead to musculoskeletal disorders.

In practice, the study warned of the need to carry out actions, in some cases as a matter of urgency, to reduce the levels of risk to acceptable values of REBA scores and consequently reduce the risk of musculoskeletal disorders. The recommendations regarding the postural risk factor should be oriented mainly in the redesign of the workplace through the layout organization, machinery, equipment, transportation device, and tools used, among others. Recommendations related to the risk of the repetitiveness of movements should be directed mainly to consider recovery times by including pauses at work. Regarding the mental workload, some actions should be considered, such as intervention at the level of employee turnover, implementation of stretching programs, training, and awareness, which would significantly reduce the development of WMSDs.

Conclusion

The results found in the study confirm that the SPD presents biomechanical risk factors that make it vulnerable to the risk of musculoskeletal disorders. High-risk levels could be due to postural issues, repetitiveness, and manipulation of loads, all associated with a higher prevalence of musculoskeletal disorders, together with unfavorable levels of mental workload also related to these types of occupational diseases. Work Design at SPD, based on REBA scores obtained, leads to a medium-very high risk (REBA > 4) of the development of WMSDs therefore future studies on discomfort are needed to determine the most suitable process and work design that will minimize WMSD risks.

The type of day (busy or normal), type of task, and the participants significantly affected REBA and NASA-TLX scores. In general, REBA and NASA-TLX scores tend to be higher on busy days than on normal days. The findings raise awareness and warn employees about the need to evaluate themselves and pause to analyze how they perform their duties under high levels of workload to reduce WMSD risk in healthcare settings.

A potential association between the perception of mental workload (NASA-TLX scores) and body postures (REBA scores) was identified. Future research should investigate the role of specific task demands, physical and mental demands, and psychosocial factors such as time pressure, job support, job satisfaction, work environmental conditions, and their effect on the perception of mental workload and the association with the body postures adopt to perform the task.

The results of this study led to the design and analysis of a new study performed as an experiment under controlled conditions. The new study investigated if increases in NASA-TLX scores were due to increases in physical or mental demands and evaluated if the adoption of more awkward body postures were due to changes in mental workload (Chapter 4).

CHAPTER FOUR

ASSOCIATION BETWEEN PERCEIVED WORKLOAD AND ADVERSE BODY POSTURES

Contribution of Authors and Co-Authors

Manuscript in Chapter 4

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Contributions: critical revision of the article and final approval of the version to be published

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Manuscript Information

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Abstract

A previous study conducted at a Sterile Processing Department (SPD) in a local hospital identified a potential association between perceived mental workload and adverse body postures. However, causal inferences were not possible to establish given the study design. Consequently, the objective of this study was to determine if the perception of mental workload causes workers to use more risky body postures. Objective and subjective assessment tools (REBA and NASA-TLX scores) were used to measure body postures and mental workload perception. The findings indicated a positive relationship between the perception of mental workload (NASA-TLX scores) and adverse body postures (REBA scores) suggesting that people tend to adopt more awkward postures when they feel they are in a rush condition, or they have more things to do.

Introduction

Work-related musculoskeletal disorders (WMSDs) are adverse health outcomes that result from hazard exposure that negatively impact employees' health over a wide variety of industries and occupations. WMSDs continue to be one of the most serious health problems that the working population has to deal with, especially since they involve personal suffering and have a substantial negative economic impact (Eatough et al., 2012).

In the field of WMSDs, a substantial body of research has been appropriately focused on the physical demands that employees must perform at work. For instance, studies have been done to determine the association between physical exposure variables and musculoskeletal outcomes in manufacturing workers (Fredric Gerr et al., 2014), evaluate the association of physical and mental strain with the beginning and persistence of multi-site musculoskeletal pain (Neupane &

Nygård, 2017), reduce the high push forces and awkward postures while patients are transporting in hospital beds (Zhou & Wiggermann, 2017), and identify key factors that can be useful to predict WMSDs risk in non-nursing healthcare workers (Oakman et al., 2014). Similarly, workplace interventions have been conducted to reduce WMSDs risk-focused primarily to controlling physical hazards derived from the execution of certain manual handling tasks (Burnett & Campbell-Kyureghyan, 2008; Márquez Gómez & Márquez Robledo, 2015; Park et al., 2009; Tullar et al., 2010).

WMSDs have been recognized to be complex, incorporating risks influenced by a diverse range of psychosocial hazards, in addition to the more widely known hazards associated with physically demanding work. Aasa et al. (2005) conducted a cross-sectional study and examined the role of physical and psychosocial factors in paramedics founding evidence that suggests links between the level of psychological demands and neck-shoulder complaints. Numerous studies have identified the relationship between job demands and job stress with the possibility of developing WMSDs (Carayon et al., 1999; Eatough et al., 2012; Kompier & van der Beek, 2008; Neupane & Nygård, 2017; Oakman et al., 2014).

A previous study, conducted in the Sterile Processing Department (SPD) at a local hospital showed that physical ergonomic risk associated with performing a task might be influenced by work posture which can be modified adversely in response to increased workload. This is despite the fact that there were no changes to the workstation. The study conducted at the SPD discovered a potential association between perceived job demands and adverse body postures. However, causal inferences were not possible given the study design. That previous study was an observational cross-sectional design, so it was no mechanism to control or minimize confounding influences or third variables could be applied neither control on the levels of mental workload, also the sample size was small (12 participants).

This new research study aimed to determine if increases in perceived mental workload affect body postures creating higher levels of physical risk. This interaction between perceived mental workload and body postures should be considered in occupational settings since employees are simultaneously exposed to physical and mental demands that increase the likelihood of developing WMSDs. Consequently, this new study was designed to be performed as an experiment under controlled conditions. The objective was to control the mental workload levels and evaluate their effect on body postures.

Methods

Approval from the local Institutional Review Board was obtained before the study. Informed consent was obtained from all participants.

Participants

Eighteen volunteers took part in this new controlled experimental study (44% females). Participants were between young adults to adults. Their mean age (s.d.) was 28.55 (9.57) years. All participants were in good health and just one reported a history of musculoskeletal disorders within the previous twelve months.

Tasks

The experiment was performed in the Ergonomic and Human Factors Lab at Montana State University. Participants were asked to emulate duties performed at a Sterile Processing Department (SPD). The study focused primarily on evaluating the activity related to loading and unloading racks which are usually performed at the assembly area of the SPD. The activity consisted of sorting objects, a variety of boxes, and light metal sticks, in a rack following certain conditions. The conditions restricted the use of certain levels in the rack for certain types of objects and the position and direction in which the objects could be placed in the rack. The activities were designed to control the workload and study its effect on body postures (response variable).

The experiment was divided into two conditions; each condition was comprised of the physical task at different levels of mental and physical loading. In condition 1, with no load (UL) or normal condition, the participants were asked to sort a fixed number of objects following the restrictions. In condition 2, with load (L) or busy condition, a stimulus was presented by an audible alarm and an announcement with the phrase "Turn over OR #, Turn over OR #" (OR # = operating room number) repeated at fixed intervals of time. Along with the alarm, the same number of objects used in condition 1 were placed on the table to be sorted in the rack by the participant. The alarm was turned off two times during condition 2.

Condition 1 lasted for about 1 minute, while condition 2 lasted for 2 ½ minutes. At the end of each condition, a rest period of at least 2 minutes was provided to minimize cumulative mental and physical fatigue. Participants were asked to provide their perception of mental workload during this rest period by filling out the subjective workload assessment tool.

Participants were not instructed to use any specific lifting technique or adopt any ergonomic postures to complete the tasks, no time limit was imposed to complete any of the two conditions. Conditions were randomly presented to the participants to avoid any order effects.

Assessment Tools

Participants were asked to provide their perception of workload by filling out the NASA-TLX questionnaire. Various tools exist for the evaluation and prediction of mental workload (Rubio et al., 2004). Subjective measures have been used extensively to evaluate mental workload due to their practical advantages; easy implementation, non-intrusiveness, and quick and inexpensive to administer and analyze (Hill et al., 1992; Mehta & Agnew, 2015; Rubio et al., 2004).

The NASA-TLX is a multidimensional questionnaire designed to obtain a subjective measure of mental workload on six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration (Sandra G. Hart & Staveland, 1988). The NASA-TLX questionnaire was administrated after each treatment condition. The total task load score was obtained assuming equal weights for the dimensions. This way to obtain the NASA-TLX score is known as raw NASA-TLX (RTLX) (Byers, 1989; Sandra G Hart, 2006).

The objective measure of the study is the ergonomic assessment. It was conducted using the Rapid Entire Body Assessment (REBA) method (Hignett & McAtamney, 2000). REBA is a postural analysis tool that provides a quick and easy measure to assess a variety of working postures for the risk of WMSDs. REBA has the advantages of being inexpensive, not requiring former ergonomic skills, and requiring only minor equipment (Chiasson et al., 2012; David, 2005). Participants were videotaped while performing the tasks. The ergonomic assessment was done through the analysis of the videotapes. The most awkward posture was extracted from the videos and used to determine a REBA score for each condition and participant.

Data Analysis

Statistical analyses were performed using the Student's two-sample t-test and Analysis of Variance (ANOVA) to evaluate whether there was a statistically significant difference between the two conditions on workload perceptions and body postures. Pearson correlation coefficients were calculated to determine the relation between REBA and NASA-TLX scores of each dimension and total score. The statistical analyses were performed using Minitab 18.0. The independent variables were the different conditions created for the experiment, established as normal or unload (UL) and busy or load (L). Dependent measures were REBA scores, mental demand (MD), physical demand (PD), temporal demand (TD), performance (P), effort (E), frustration (F), and Task Load Index (NASA-TLX) scores. All statistical analyses were evaluated at a significance level of $\alpha = 0.05$.

Results

The perception of workload, as reflected in the NASA-TLX score and its dimensions, was significantly affected by changes in mental and physical difficulty levels of the task, Load, and Unload conditions of the experiment ($p=0.001$). Figure 4.1 depicts the interval plots for REBA, the total NASA-TLX scores, and each NASA-TLX dimension score for each condition of the experiment.

Increases in the load of the task significantly increased REBA scores ($p = 0.001$) as well as all NASA-TLX dimension ratings: Physical demand (PD) ($p = 0.011$), Temporal demand (TD) ($p = 0.001$), Performance (P) ($p = 0.004$), Effort (E) ($p = 0.007$), Frustration (F) ($p = 0.010$), except Mental demand (MD) in which the increment was not significantly different ($p = 0.104$).

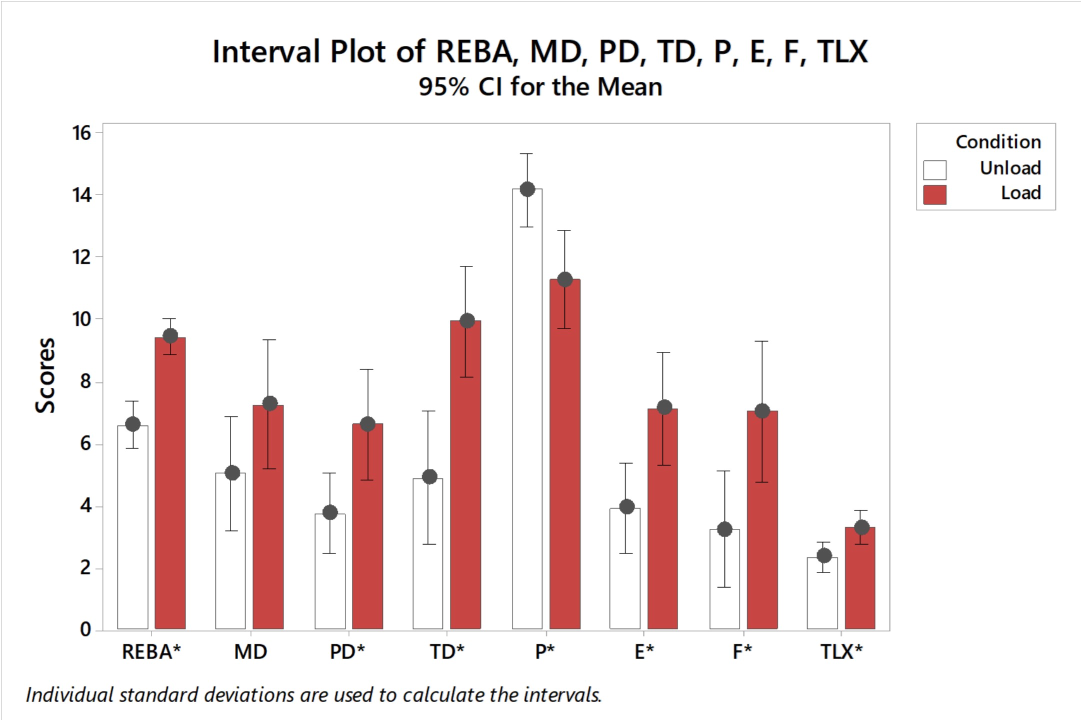


Figure 4.1 Interval plots of REBA, total TLX scores, and NASA-TLX dimensions scores by workload condition (Significant differences indicated by an asterisk)

The t-test of the REBA scores showed that they were significantly affected by the perception of workload (condition of the experiment: p = 0.001). Higher REBA scores were associated with a higher level of workload (Figure 4.2). The t-test for the total NASA-TLX scores (TLX) showed a significant difference in each condition (p = 0.010), indicating higher NASA-TLX scores for the load condition (Figure 4.3).

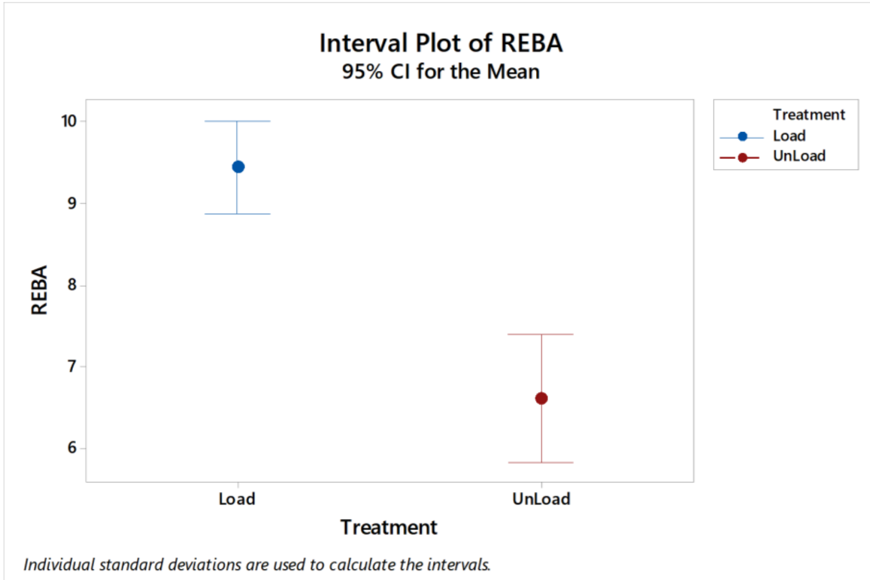


Figure 4.2 Interval plot of REBA scores vs treatment conditions

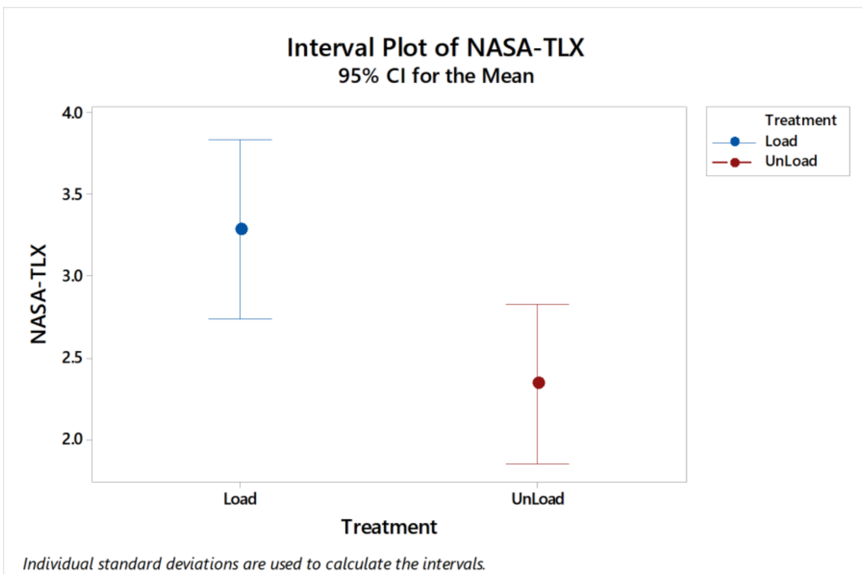


Figure 4.3 Interval plot of NASA-TLX indices vs treatment conditions

Table 4.1 shows the Pearson Correlation coefficients between REBA and NASA-TLX values. REBA scores exhibit a weak correlation with total NASA-TLX scores (TLX), however, REBA scores had a moderate correlation with temporal demand, performance, effort, and frustration dimensions using a level of significance of 0.15 (r = 0.290, -0.336, 0.247, and 0.282).

Table 4.1 Pearson Correlation Coefficients

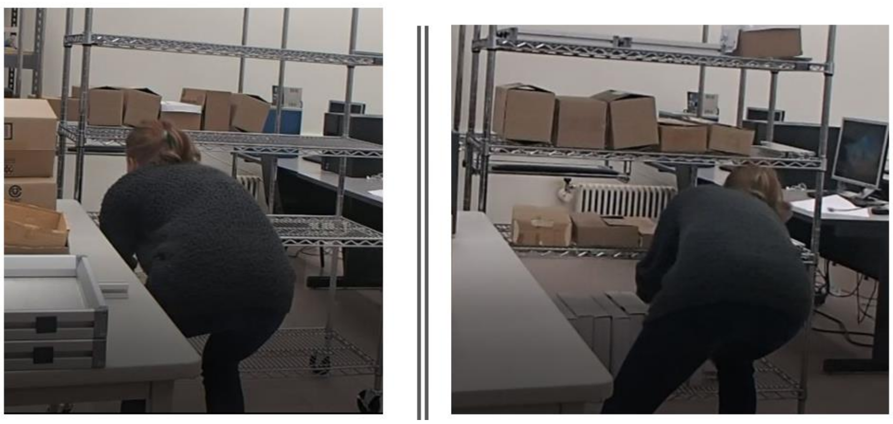
	REBA	TLX	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort
TLX	0.194						
	0.256						
Mental Demand	0.102	0.935					
	0.554	0.000					
Physical Demand	0.111	0.825	0.762				
	0.521	0.000	0.000				
Temporal Demand	**0.290**	0.891	0.795	0.652			
	0.086	0.000	0.000	0.000			
Performance	**-0.336**	-0.344	-0.284	-0.445	-0.491		
	0.045	0.040	0.093	0.007	0.002		
Effort	**0.247**	0.873	0.758	0.718	0.744	-0.403	
	0.146	0.000	0.000	0.000	0.000	0.015	
Frustration	**0.282**	0.881	0.778	0.688	0.822	-0.548	0.737
	0.096	0.000	0.000	0.000	0.000	0.001	0.000

Cell Contents
Pearson correlation
P-Value

Differences were observed in the body postures adopted by the participants to perform the tasks of the experiment under both treatment conditions. In Figures 4.4 and 4.5, it can be observed how a person performing the same task in the same workstation can adopt different postures due to increments in workload. Note that the posture in the load condition (Figures 4.4b and 4.5b) is ergonomically worse than in the unloaded condition (Figures 4.4a and 4.5a). This behavior was observed in all the participants. Overall, these results suggest causal effects between manipulated levels of mental and physical demands and changes in physical posture.

a. Unload condition b. Load condition

Figure 4.4 Placing boxes on lowest rack level participant a



a. Unload condition b. Load condition

Figure 4.5 Placing boxes on lowest rack level participant b

Additional ANOVA tests were conducted, this time considering each of the response variables (NASA-TLX dimensions, total NASA-TLX scores, and REBA scores) as one of the independent variables. The goal was to investigate if NASA-TLX dimensions scores and total NASA-TLX scores had any significant effect on REBA scores and vice versa.

The ANOVA for REBA scores considering the total NASA-TLX score and each of its dimension's scores as independent variables showed that along with the condition (load or unload), no other variable had a significant effect on REBA scores (p-values 0.168 - 0.820).

Regarding the ANOVA for NASA-TLX and each of its dimensions taking REBA scores as the independent variable, the results also showed that REBA scores did not have a significant effect on NASA-TLX scores (p-values 0.131 - 0.874).

Discussion

Participants' workload perceptions (total NASA- TLX scores) were higher in the load condition than in the unloaded condition, which showed that the design of the experiment allowed the manipulation of the level of mental workload and therefore, the effect expected to be created by the design of the experiment was achieved. Similar results have been reported in previous studies that used only self-report surveys, in which increases in physical workload levels were associated with greater perceptions of mental demand, temporal demand, higher effort, frustration, and perceptions of failure (Mehta & Agnew, 2015).

It was then found that increases in mental workload perception (NASA-TLX scores), associated with the load condition in the experiment, had a significant adverse effect on REBA scores. REBA scores were significantly different between Load and Unload conditions in the experiment ($p = 0.001$), meaning that increments in mental workload perception caused participants to use more risky and awkward work postures. Workload items considered cognitive (mental demands, temporal demands, and frustration) have been reported to positively correlate with physical discomfort in the past (Arellano, Martinez, Perez, & Alcaraz, 2015). Similarly, a positive correlation between REBA scores and temporal demand, performance, effort, and frustration scores was found (level of significance of 0.15).

In general, the results help recognize that factors other than those related to physical workload play a role in the development of WMSDs since the perception of mental workload has a significant effect on postures that lead to physical ergonomic risk factors and therefore to WMSDs. The results of this study help raise awareness that physical risk associated with performing a task can be influenced by work posture that could be modified adversely in response to the increased mental workload, even though no changes were made to the workstation design.

Nevertheless, it was not possible to draw specific conclusions about the reasons underlying the observed relationship between perception of mental workload and awkward body postures. Several factors may contribute to this relationship, such as physical and behavioral mechanisms, individual characteristics and psychological capacity, and health indicators. Likewise, even though the design of the experiments allowed for the manipulation of mental workload, it was not possible to determine if the increments in the perception of mental workload were due to the increments on the physical demands of the task or to the incorporation of psychosocial work factors such as alarms.

Conclusion

People tend to adopt more awkward postures (Higher REBA scores) when they feel they are in a rush condition or have more things to do. This study established a causal relation between higher perceived mental workload and adverse body postures. While the study was able to establish the link between mental workload and adverse physical postures, future research should investigate the role of specific psychosocial factors, for instance, time to perform the task, job level, job support, distractions, interruptions, noise, alarms, and/or other individual factors such as age, sex, anxiety level, personality type, and the effect they might have on the experience of adverse mental workload and their association with body postures and the onset of musculoskeletal disorders.

Increments in mental workload are related to worsening postures at work. This interaction between postural risk and mental workload in a certain job leads to several practical implications in task design, scheduling staff, process selection, work design, and training plans. It should be considered in occupational settings since employees are simultaneously exposed to these types of risk factors that increase the likelihood of developing WMSDs. Considering the prevalence of musculoskeletal symptoms among employees, adjustments or changes to reduce the effects of these risk factors, even on a small scale, likely create a significant positive impact on workers’ health and therefore on public health.

CHAPTER FIVE

EVALUATING THE EFFECT OF PERCEIVED MENTAL WORKLOAD AND BODY POSTURES

Abstract

Mental workload is a multidimensional construct that involves the characteristics of the task, individual factors, and the environment where the task is performed. Responses to tasks that are perceived as mentally demanding can exacerbate ergonomics risk factors affecting employee behavior and attitude, leading to risky actions such as awkward body postures and consequently increasing physiological susceptibility to work-related musculoskeletal disorders. The present study looked to establish if the perception of mental workload can be affected by psychosocial work factors that generate changes in the environment in which humans must perform the tasks. The study also looked to determine if changes in the perceived mental workload generated changes in the body postures undertaken to perform an activity to lay the foundation for future exploration into the influence of perceived mental workload over physical demands. The results of this study indicate, for the first time, that an increase in the perception of mental workload is associated with worse body postures.

Introduction

Mental workload is a concept that remains surprisingly difficult to define. According to the Dictionary for Human Factors/Ergonomics, mental workload is understood as “any measure of the amount of mental effort required to perform a task” (Stramler, 2018, p. 202). It can also be defined in terms of demand/resource balance which often refers to attentional resources theories where mental workload becomes a measure of the resources available to meet task demands (Rubio et al., 2004; Welford, 1978; Wickens & Tsang, 2015; Wickens, 2002).

Mental workload is a multidimensional construct involving the characteristics of the task, operator, and the environment where the task is performed. It incorporates psychosocial and organizational factors as well as individual differences into the equation (Bru et al., 1996; Carayon et al., 1999; Young et al., 2015) such that it can be defined as an intervening variable that modulates the balance between the demands of the environment and the capacity of the person (Kantowitz, 2000). Thus, mental workload can be subjectively felt by the individual who perceives a cost while performing a task (Hart & Staveland, 1988).

The proper assessment of mental workload is important in the design of occupational tasks because inappropriate levels are associated with occupational diseases and musculoskeletal disorders, accidents, and negative effects on overall work performance (Carayon et al., 1999; Eatough et al., 2012; Kompier & van der Beek, 2008; Oakman et al., 2014; Sarsangi et al., 2017). Therefore, researchers need to integrate cognitive demands, physical demands, and psychosocial factors that describe the total context or group of conditions in which the human must operate when measuring mental workload (Marras & Hancock, 2014; Mehta, 2016). Consequently, when measuring mental workload an overall system approach should be used to consider the person in the context of the entire environmental system, its components, interactions, and the potential influence on the human cognitive and physical behavior.

Changes in postural behavior, musculoskeletal disorders, and pain can be a result of tasks that are perceived as mentally demanding; a condition that can be exacerbated by psychosocial factors such as time pressure, intensity, and duration of the task demands (Baek et al., 2018; Bongers et al., 2002; Carayon et al., 1999; Chen et al., 2005; Davis et al., 2002; Ng et al., 2019; Shahidi et al., 2013; Splittstoesser et al., 2012; Yang et al., 2011; Zamri et al., 2017). Such responses could exacerbate the effects of ergonomics risk factors affecting employee behavior and attitude, leading to risky actions such as awkward body postures and consequently increasing physiological susceptibility to work-related musculoskeletal disorders (WMSDs). However, the relationship between the perception of mental workload and body postures has not been investigated extensively in mental workload studies or concurrent mental and physical environments (Qiu & Helbig, 2012) despite evidence that shows every human action is guided by mind and body interactions (Mehta, 2016).

Previous studies have demonstrated an association between mental workload and adverse changes in body postures (L. Nino et al., 2020; V. Nino et al., 2019). However, in these studies, the manipulation of mental workload was done by increasing the physical demands of the tasks and incorporating an alarm as a psychosocial factor. Therefore, it was not possible to evaluate if the perception of mental workload can be altered only by psychosocial factors such as time to complete the task, auditory stimuli as alarms, and interruptions while keeping the same amount of physical demands and the same workstation design.

The present study looked to determine if the perception of mental workload can be affected by psychosocial work factors that generate changes in the environment in which the subject must perform the tasks while the physical demands are held constant. The study also sought to determine if changes in the perceived mental workload generated changes in the body postures undertaken to perform an activity to lay the foundation for future exploration into the influence of perceived mental workload over physical demands. Characterizing differences in body postures arising from changes in the work environment (distractions, interruptions, time available) could help develop a more informed picture of how people negotiate between mental and physical demands when performing occupational activities. The central hypothesis guiding this work was that an increase in the manipulated perception of mental workload would be associated with worse body postures.

Methods

Participants

Study participants consisted of healthy young adults, with a distribution of 17 females and 15 males. They were all free of lower and upper extremity surgeries, had no lower and upper extremity injuries within three months of study participation, and had not had diagnosed concussions within a year of study participation. Study participation involved one lab visit lasting between 1.5 to 2 hours.

Experimental Overview

Approval from the University's Institutional Review Board was obtained before recruitment and experimentation. A repeated measure experimental design was used by asking participants to perform two physical tasks that emulated activities performed in a local hospital's sterile processing department (SPD) (L. Nino et al., 2020) under four levels of mental workload. The two physical demands conditions consisted of an upper extremity task and a whole-body physical task.

The manipulation of mental workload included: baseline condition, auditory condition (presence of an alarm); time restriction condition (time pressure imposed to complete the task); and interruption condition (presence of an interruption), for a total of 8 combinations of treatments. The order of the different conditions was randomly assigned to each participant based on an R command "sample" distribution with no replacements (e.g., sample (1:3, 3, replace=FALSE)) (Team, 2021). Because mental workload manipulation was expected to influence participants' perception and performance of the tasks, the baseline conditions were completed first; the remaining conditions were assigned randomly using 1=time pressure condition, 2=auditory stimuli condition, 3=interruption condition for the R command. Table 5.1 displays the eight treatment conditions for the study.

Table 5.1 Treatment Combinations

	Mental Workload or Mental stressor			
	None	Time pressure	Auditory Stimuli	Interruption
Type of task	Baseline	Time restriction	Alarm	New task
Upper-extremity	0	1	2	3
Whole-body	0	1	2	3

Experimental Procedure

The study was conducted in the Human Factors Laboratory at Montana State University during the summer and fall of 2021. The experimental tasks emulated activities performed in the sterile processing department (SPD) of a hospital. Specifically, the whole-body task emulated demands of the decontamination area while the upper extremity/seating condition emulated a task performed at the sterilization area.

The upper extremity task consisted of assembling a container following instructions that indicated the objects that needed to be placed inside the container, the position in which those objects should be placed, and the order in which the different parts within the box had to be assembled. After the container was assembled, the participants had to complete a series of stacking activities with the rest of the containers on the table. The stackings were based on the size and shape of the containers. This task emulated the assembly of trays (containers with surgical instruments on) performed at the sterilization area in the SPD. The number of “trays” (containers) to assemble was held constant throughout all conditions. Figure 5.1 shows one of the participants performing the upper-extremity task.

Figure 5.1. Participant performing the upper-extremity task

The whole-body task consisted of sorting a variety of plastic containers in a rack following certain conditions. The conditions restricted the use of the levels in the rack for certain types of objects (parts of the plastic containers) and the position and direction in which the containers should be placed in the rack. This activity emulated loading a rack with trays to wash them, performed at the decontamination area in the SPD. The number of objects to place in the rack was held constant in all mental workload conditions. Figure 5.2 shows one of the participants performing the whole-body task.

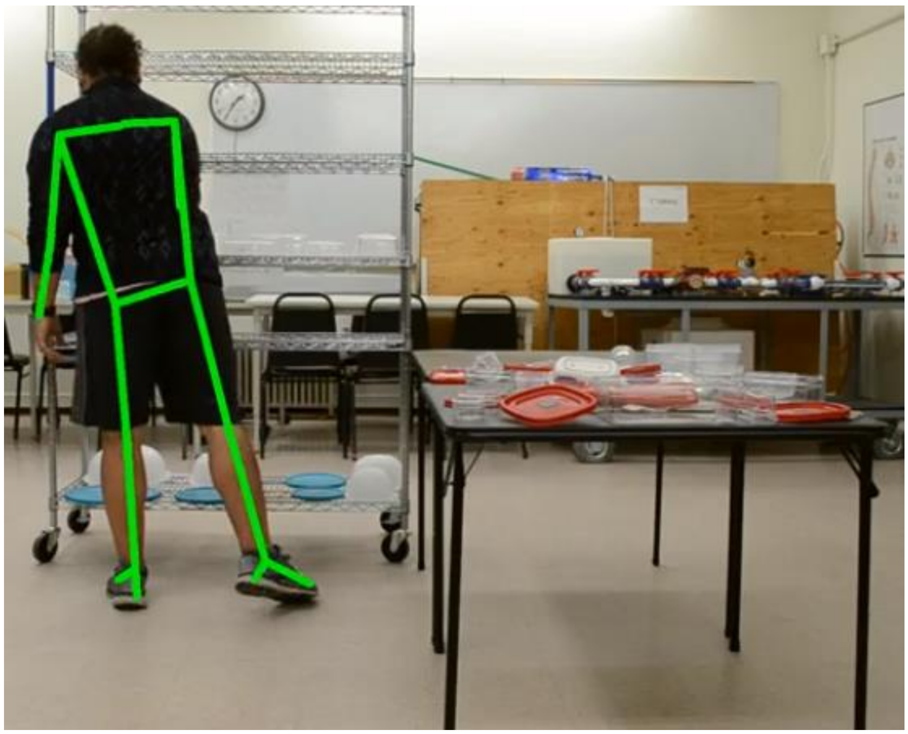


Figure 5.2. Participant performing the whole-body task

The various conditions were designed to manipulate the perception of mental workload. Each condition compromised one of the two physical tasks at different levels of mental workload. Mental workload was manipulated by including a time constraint to complete the activity, auditory stimuli (an alarm), and interruptions. The baseline condition consisted of the participant performing the physical tasks in the absence of any mental workload stressors. The baseline task took an average of two minutes.

For the time constraint condition, participants were informed they now had only two minutes to complete the whole task. For instance, two minutes to put all containers and lids on the rack or two minutes to complete the assembly of the tray and the other stacks of containers. The enunciation of two minutes to complete the task was done to create an impression on the participants that they had less time to do the tasks than in the baseline condition, even though the time was the same. The time constraint condition took an average of two minutes.

The auditory condition consisted of researchers turning on an audible alarm that indicated the time available to complete the activity was running out; therefore, participants had to perform the task faster. The alarm was turned on after 30 seconds of initiating the task and in 15-second intervals until the activity's time ended for all participants. Hence, the alarm intended to create the impression that the time to perform the activity was shorter than in the baseline condition. As with previous conditions, the alarm condition took an average of two minutes (they were the same).

The interruption condition consisted of a member of the research team moving into the experimental area with an assembled tray (box with containers on it) and asking for help from the participant. The person asked the participant to check the tray and verify that it had been appropriately assembled. Participants were instructed to stop what they were doing at the moment to check the tray and answer the question asked. After the interruption, participants returned to the primary task and attempted to and finish it on time. The interruption condition took an average of two and a half minutes.

Participants were not instructed to use any specific lifting technique or adopt specific postures to complete the tasks. With the exception of the baseline condition being completed first, conditions were randomly presented to the participants to avoid any order effects. At the end of each condition, a rest period of 2-3 minutes was provided to minimize cumulative mental and physical fatigue (Marras et al., 2000). During the rest period, participants filled out the subjective mental workload assessment tools.

Experimental Variables

Dependent measures consisted of body postures and perception of mental workload. Rapid Entire Body Assessment (REBA) (Hignett & McAtamney, 2000; McAtamney & Hignett, 1995) and Rapid Upper Limb Assessment (RULA) (McAtamney & Nigel Corlett, 1993) methods were used to evaluate body postures. The NASA Task Load Index (NASA-TLX) (Sandra G. Hart & Staveland, 1988) and the Surgery Task Load Index (SURG-TLX) (Wilson et al., 2011) were applied to measure the perception of mental workload.

RULA is a valid and reliable tool used to evaluate the risk of musculoskeletal disorders associated with specific tasks within a job and to determine exposure to possible risk factors such as posture, repetitive motion, and force. It is used to evaluate task demand on the trunk, neck, and upper extremities (McAtamney & Nigel Corlett, 1993). REBA is a postural analysis tool that provides a quick and easy measure to assess a variety of working postures for risk of WMSDs (Hignett & McAtamney, 2000; McAtamney & Hignett, 1995) and has been proven to be suitable for whole-body evaluations. RULA and REBA were designed for easy use and have the advantages of being inexpensive and requiring only minor equipment (David, 2005; Kong et al., 2018; Micheletti et al., 2019; Shanahan et al., 2013). They help avoid inconsistency in the data present with self-report (Lapointe et al., 2009).

RULA and REBA yield quantitative indices that represent the risk at which a worker is exposed during the performance of a task and allowing to derive the urgency level of intervention and the actions needed (Hignett & McAtamney, 2000; McAtamney & Nigel Corlett, 1993; Micheletti et al., 2019). REBA and RULA scores were estimated using Tumeke Ergonomics software (TuMeke), a computer vision joint tracking tool for ergonomic assessments which provides fast, accurate, and comprehensive ergonomic postural risk assessment analysis. It extracts joint position using computer vision techniques to perform industry standards risk assessments such as REBA and RULA and summarizes injury risk (McAtamney & Hignett, 2004; McAtamney & Nigel Corlett, 2004). Dr. Alan Hedge, Director of Human Factor and Ergonomics Laboratory at Cornell University, is the advising chief scientist at Tumeke Ergonomics and has validated the results and reports offered by the platform (Noland, 2021).

NASA-TLX is considered the most robust tool available for reporting mental workload perceptions and overall workload perceptions (DiDomenico & Nussbaum, 2008; G. Young et al., 2008). It is a multidimensional questionnaire designed to obtain a subjective measure of mental workload on six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration (Sandra G. Hart & Staveland, 1988; Hill et al., 1992; Huggins & Claudio, 2018). The total task load score was obtained assuming equal dimension weights of 0.167, which have been proven to make as good or even better predictions of mental workload scores than those obtained using the TLX paired comparison technique (Huggins & Claudio, 2018; Nygren, 1991). This way to obtain NASA-TLX scores is known as raw TLX scores (RTLX) (Byers, 1989; Sandra G Hart, 2006).

Participant perception of mental workload was also measured using the Surgical Task Load Index (SURG-TLX). SURG-TLX was derived from the NASA-TLX and has been validated across various workloads in surgery and healthcare occupations (Berg et al., 2015; Forsyth et al., 2018; Hallbeck, Lowndes, & Bingener, 2013; Wilson et al., 2011). It measures responses across six dimensions of mental workload: mental demands, physical demands, temporal demands, task complexity, situational stress, and distractions. As with NASA-TLX, a two-part evaluation is required when applying SURG-TLX. The first part consists of calculating the weights of the six dimensions following a set of 15 paired comparisons. Weights scores range from 0 to 5, with 5 being the most important contributing factor. The second part involves rating the dimensions using a 20-point Likert where zero is "very low" and 20 is "very high". The workload score for each dimension is estimated by multiplying the rating assigned to the dimension by its corresponding weight. The total score is calculated by aggregating the scores of the six dimensions (Forsyth et al., 2018; Wilson et al., 2011).

Statistical Analyses

A priori power analysis was performed using repeated measures within factors ANOVA F tests, with an effect size $f = 0.3$ (considered medium by Cohen standards (Lakens, 2013)), error probability $\alpha = 0.05$, default correlation among repeated measures of 0.5, four number of groups, and total sample size of 30 participants, resulting in a statistical power higher than 88% for the variables of the study. A linear mixed model with condition (levels: baseline, time constraint, auditory, and interruption) as the main effect and participant as a random effect was used to identify group differences in NASA-TLX scores. This was done to validate that the experimental conditions were associated with the intentional manipulations in mental workload. Where a main effect of condition was present, pairwise comparisons were investigated using Tukey's HSD tests.

Linear mixed models were also used to test the main effects of condition on REBA and RULA scores. Normality of model residuals was checked by reviewing q-q plots, histograms, and residual vs. fit plots to verify those model assumptions were met. In addition to the condition main effect, "participant" was introduced in the models as a random effect. NASA-TLX scores were considered a covariate with and without interacting with the condition's main effects. Model selection was informed by comparing AICc and BIC values for alternate models for the same dependent variable, with the optimal model selected being the one that minimized those two model fit criteria (Brewer, Butler, & Cooksley, 2016). Models with significant condition effects were analyzed further through post-hoc analyses using Tukey multiple pairwise comparisons. Magnitudes of differences between conditions were quantified using Cohen's effect size (d) (Lakens, 2013). Significance for all tests was set at $\alpha = 0.05$.

Results

Mental Workload

Thirty-two participants, 53% females and 47% males between the ages of 20 and 55, provided their written informed consent to participate in the study. Data for all participants in each condition were collected and used in the study. Participants took the same amount of time to complete the tasks in each condition so that the differences observed were not to actual time constraints or changes in the physical demands of the tasks but rather perceived changes in demands.

A main effect of the condition was observed for NASA-TLX scores on the whole-body task ($F = 55.17$, $p < 0.001$) and on the upper extremity task ($F = 17.96$, $p < 0.001$).

In the *whole-body task* the baseline condition was associated with lower NASA-TLX scores than the time constrained (**Table 5.2**; d: 1.409, $p < 0.001$), auditory (d: 1.938, $p < 0.001$), and interruption (d: 1.886, $p < 0.001$) conditions. The time constraint condition was associated with lower NASA-TLX scores than the auditory (d: 0.409, $p < 0.001$) and interruption (d: 0.369, $p < 0.001$) conditions. No significant changes were observed between auditory and interruption conditions (d: 0.039, $p > 0.10$) for NASA-TLX scores (Figure 5.3).

Table 5.2 Cohen's d effect sizes for all Mental Workload (NASA-TLX) pairwise comparisons.

	NASA-TLX Scores Whole-Body Task		
	Baseline	Time Constraint	Auditory
Time Constraint	1.409 *		
Auditory	1.938 *	0.409 *	
Interruption	1.886 *	0.369 *	0.039
	NASA-TLX Scores Upper Extremity Task		
	Baseline	Time Constraint	Auditory
Time Constraint	0.643 *		
Auditory	0.909 *	0.252	
Interruption	0.948 *	0.289	0.039

*indicates $p < 0.050$

For the *upper extremity task*, the baseline condition was associated with smaller NASA-TLX scores than the time constraint (**Table 5.2**; d: 0.643, $p < 0.001$), auditory (d: 0.909, $p < 0.001$), and interruption (d: 0.948, $p < 0.001$) conditions. Small effects were observed between time constraint condition compared to auditory (d: 0.252, $p > 0.25$) and interruption (d: 0.289, $p > 0.150$) conditions, yet these comparisons did not reach statistical significance. No significant changes were observed between the auditory and interruption (d: 0.039, $p > 0.100$) conditions (Figure 5.4).

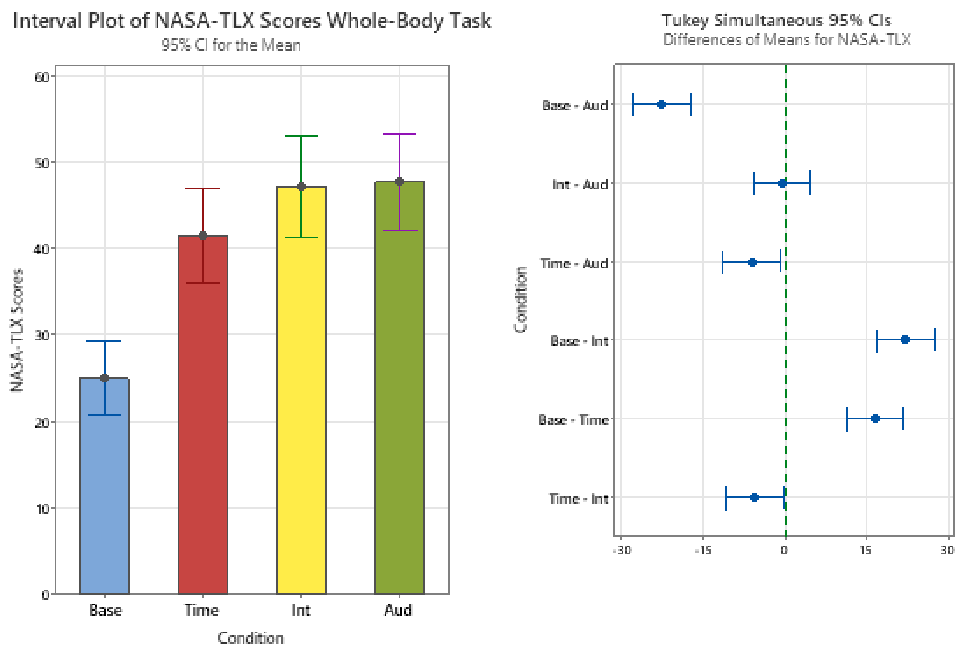


Figure 5.3 Interval plot for NASA-TLX scores Whole-Body task and Tukey comparisons between conditions (higher NASA-TLX scores higher perceived mental workload)

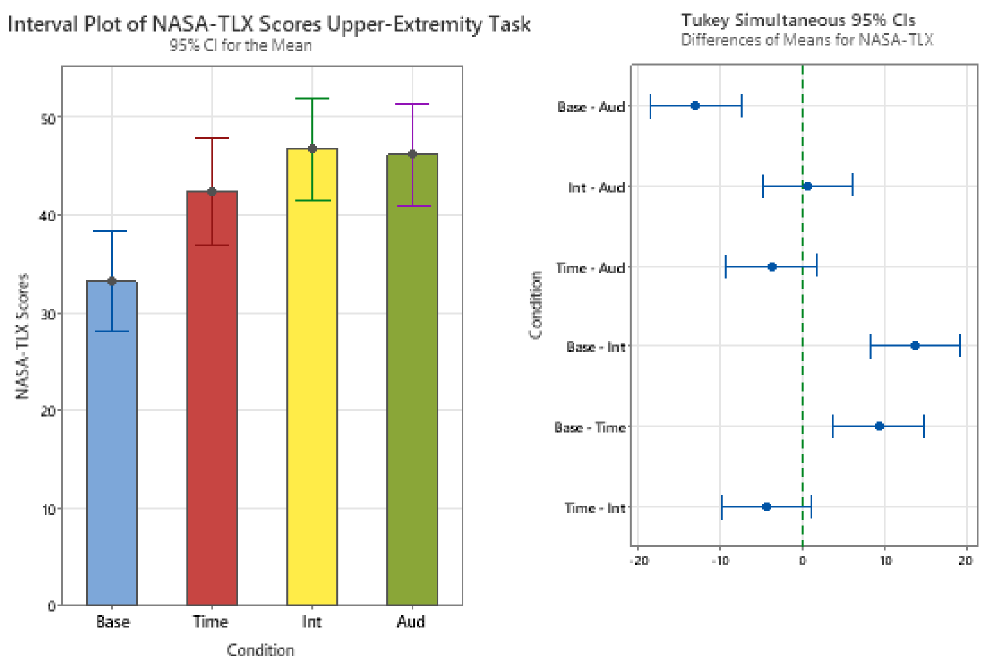


Figure 5.4 Interval plot for NASA-TLX scores Upper-Extremity task and Tukey comparisons between conditions (higher NASA-TLX scores higher perceived mental workload)

Likewise, condition was a main effect for the SURG-TLX scores for the whole-body ($F = 72.22$, $p < 0.001$) and upper extremity tasks ($F = 37.96$, $p < 0.001$). Similar to the NASA-TLX scores, SURG-TLX scores for the *whole-body task* were lower in the baseline condition than the time constraint (**Table 5.3**; d: 1.602, $p < 0.001$), auditory (d: 2.214, $p < 0.001$), and interruption (d: 2.195, $p < 0.001$) conditions. Small effects on the SURG-TLX scores were observed between time constraint and auditory (d: 0.485, $p < 0.005$) and interruption (d: 0.47, $p < 0.010$) conditions. Changes were not observed on the SURG-TLX scores between the auditory and interruption conditions (d: 0.015, $p > 0.05$).

In the *upper extremity task*, SURG-TLX scores were lower in the baseline condition than the time constrain, auditory, and interruption conditions (all $d > 0.9$, all $p < 0.001$). The time constraint condition was associated with lower SURG-TLX scores than the auditory condition (d: 0.362, $p < 0.015$) and the interruption condition (d: 0.255, $p = 0.136$), though it reached statistical significance only with the auditory condition. No effect was observed between the auditory and interruption conditions (d: 0.106, $p = 0.800$).

Table 5.3 Cohen's d effect sizes for all Mental Workload (SURG-TLX) pairwise comparisons.

	SURG-TLX Scores Whole-body Task		
	Baseline	Time Constrain	Auditory
Time Constraint	1.602 *		
Auditory	2.214 *	0.485 *	
Interruption	2.195 *	0.47	0.015
	SURG-TLX Scores Upper Extremity Task		
	Baseline	Time Constrain	Auditory
Time Constraint	0.989 *		
Auditory	1.455 *	0.362 *	
Interruption	1.318 *	0.255	0.106

*indicates $p < 0.050$

Body Postures

The mixed-effects model that best explained REBA scores (R-sq adj = 67.75%, AICc = 404.00, BIC = 409.52) contained NASA-TLX scores as a covariate in addition to condition as a fixed factor and participant as a random factor (Table 5.4).

For RULA scores a mixed-effect model that exhibits good properties (R-sq adj = 51.99%, AICc = 278.94, BIC = 284.46) also contains NASA-TLX scores as a significant covariate, condition as a fixed factor, and participant as a random factor as significant variables (Table 5.4). However, the model that better explains RULA scores behavior contains only condition and participant as significant variables (R-sq adj = 50.59%, AICc = 274.47, BIC = 280.01). The following results are presented based on the models considered as the best model based on the lowest AICc and BIC values.

Table 5.4 Statistical Summary F-values (P Values) of Significant Analyses of Variance for REBA and RULA

	Mixed Effects Model for REBA			
Effect	Participant, Condition	**NASA-TLX, Participant, Condition**	NASA-TLX, Participant, Condition	NASA-TLX, Participant
Condition	28.30 (< 0.001)	**6.34 (0.001)**	3.96 (0.274)	------
NASA-TLX	------	**11.78 (0.001)**	13.13 (< 0.001)	68.12 (< 0.001)
Condition*NASA-TLX	------	**------**	3.96 (0.010)	------
R-sq (Adj)	67.18 %	**67.75 %**	68.37 %	62.45 %
AICc	407.68	**404.00**	422.46	416.38
BIC	413.22	**409.52**	427.93	421.95
	Mixed Effects Model for RULA			
Effect	**Participant, Condition**	NASA-TLX, Participant, Condition	NASA-TLX, Participant, Condition	NASA-TLX, Participant
Condition	**19.31 (< 0.001)**	12.03 (< 0.001)	1.26 (0.291)	------
NASA-TLX	**------**	4.22 (0.043)	4.12 (0.046)	19.89 (< 0.001)
Condition*NASA-TLX	**------**	------	0.16 (0.921)	------
R-sq (Adj)	**50.59 %**	51.99 %	51.04 %	36.51 %
AICc	**274.47**	278.94	303.60	302.31
BIC	**280.01**	284.46	309.08	307.88

Bold models indicate primary model based on lowest AICc and BIC values

Differences were observed in the body postures used for the activities under the different experimental conditions. A main effect of condition was observed for REBA scores (F = 28.30, p < 0.001). The baseline was associated with lower REBA scores compared to the time constraint, auditory, and interruption conditions (**Table 5.5**; p < 0.001). No other pairwise comparisons reached significance (p > 0.400) (Figure 5.5). NASA-TLX scores were a significant covariate in the model even after including factors for condition and participant, with higher NASA-TLX scores associated with higher REBA scores (F = 11.78, p = 0.001; **Table 5.4**).

A main effect of condition was observed for RULA scores (F = 19.31, p < 0.001). The baseline condition exhibited lower RULA scores than the time constraint, auditory, and interruption conditions (**Table 5.5;** p < 0.001). No other pairwise comparisons reached statistical significance (all p > 0.004) (Figure 5.6). As with REBA scores, NASA-TLX scores were a significant covariate in the model, with higher scores associated with worst RULA scores (F = 4.22, p = 0.043; **Table 5.4**).

Table 5.5 Cohen’s d effect sizes for all REBA and RULA scores pairwise comparisons.

	REBA Scores		
	Baseline	Time Constrain	Auditory
Time Constraint	1.127 *		
Auditory	1.492 *	0.285	
Interruption	1.465 *	0.261	0.025
	RULA Scores		
	Baseline	Time Constrain	Auditory
Time Constraint	1.050 *		
Auditory	1.494 *	0.308	
Interruption	1.373 *	0.178	0.154

*indicates p < 0.050

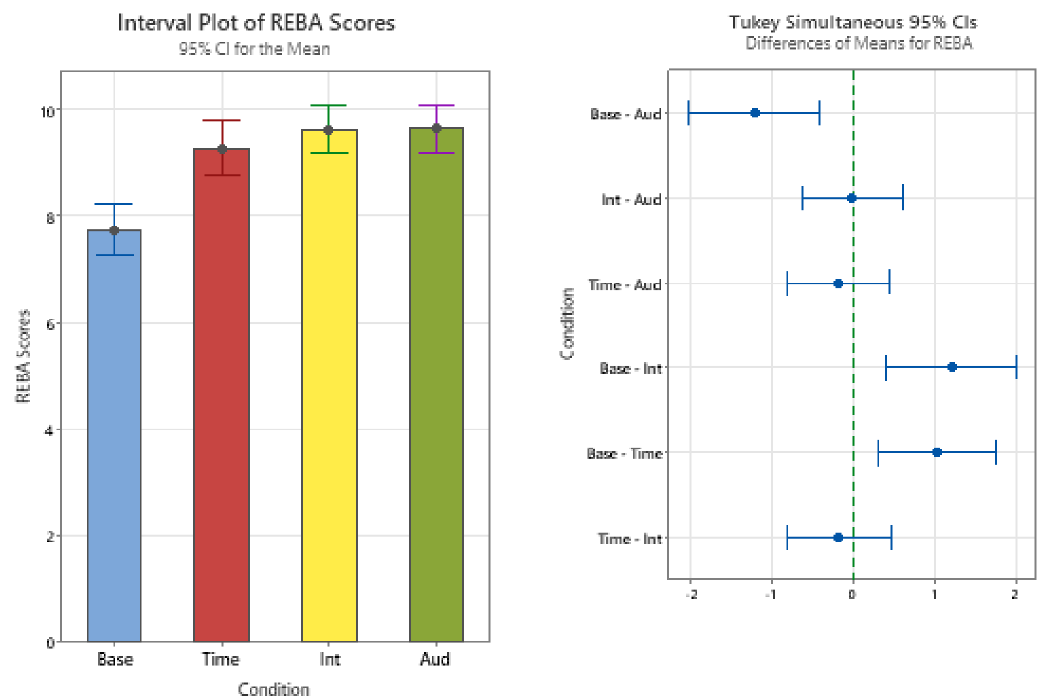


Figure 5.5 Interval plot REBA scores and Tukey comparisons between the conditions

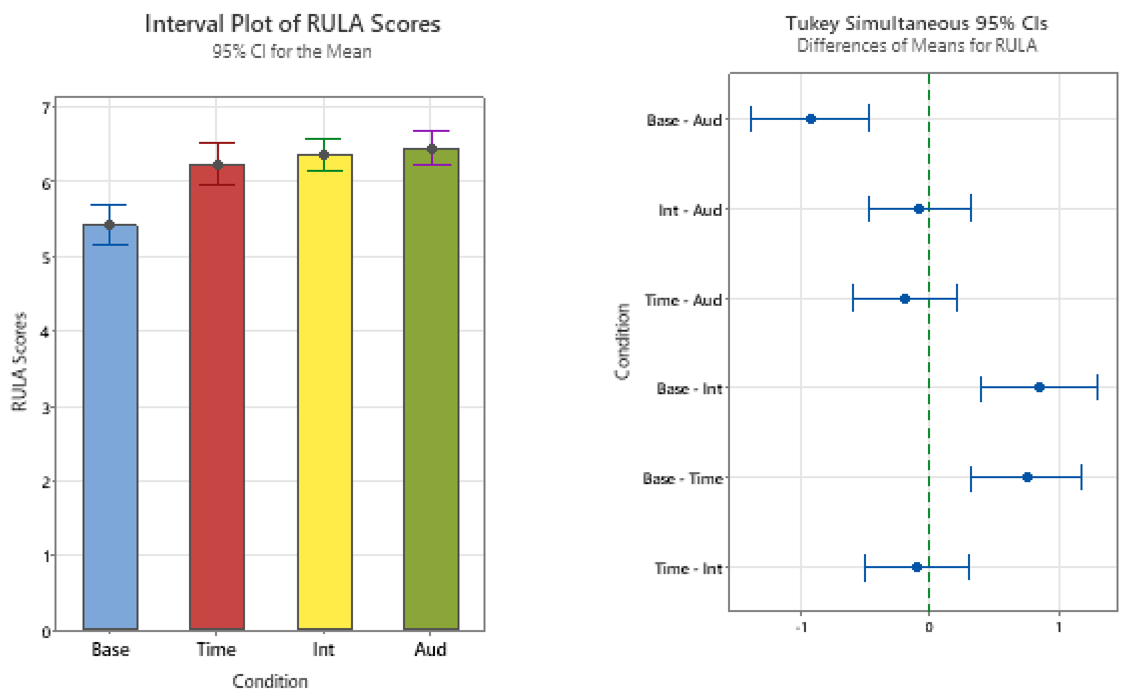


Figure 5.6 Interval plot RULA scores and Tukey comparisons between the conditions

Discussion

The results of the effect of psychosocial work factors on the perception of mental workload lay the foundation for exploring the influence of perceived mental workload over body postures. The results of this study largely support our hypothesis and indicate, for the first time, that an increase in the perception of mental workload is associated with worse body postures.

One of the objectives of this study was to determine the effects of psychosocial work factors on perceived mental workload when the physical demands of the task are held constant. It was hypothesized that changes in psychosocial work factors such as the perception of the total time available to complete the task, auditory stimuli (alarm) as distractions, and interruptions would have effects on the perception of mental workload measurable by NASA-TLX scores. Support for this hypothesis would provide new insights to understand how humans interact with the entire environment in which they perform activities, which included not only physical demands of the task but also psychosocial factors such as distractions, interruptions, alarms, and others, and the associated level of mental workload.

The current study results suggest that even when the physical demands of a task are kept the same, some other factors, such as alarms, interruptions, and time constraints affect the perception of mental workload. Previous studies have found that such changes in the perception of mental workload were due to different levels of physical demands in concurrent physical and mental demands environments (Astin & Nussbaum, 2002; Cullen & Agnew, 2016; DiDomenico & Nussbaum, 2008; DiDomenico & Nussbaum, 2011; Mehta & Agnew, 2011, 2015). However, the current results suggest that by changing only psychosocial work factors, the perception of mental workload can be affected even though the physical demands of the task stay the same in the different conditions in which the tasks were performed.

Time constraint, auditory, and interruption conditions were designed to raise the perception of mental workload. Statistically significant differences in NASA-TLX scores for the standing and the sitting conditions, RULA scores, and REBA scores responses were observed between the baseline condition and the other three mental workload conditions (time constraint, auditory, and interruption). NASA-TLX scores for the standing task increased for the mental workload conditions by 66.0%, 88.4%, and 90.8% for the time constraint, interruption, and auditory conditions compared with the baseline. The same was observed for the NASA-TLX scores on the sitting condition, with increments of 27.7% for time constraint, 39.1 % for auditory, and 40.8% for the interruption conditions against the baseline.

The mean NASA-TLX scores in the baseline condition for the whole-body task were 25 (+/- 11.71), which is above the 25% percentile of the potential range of scores on the NASA-TLX questionnaire. Considering the frequency distribution of scores reported by (Grier, 2015), in which 1000 global NASA-TLX scores from more than 200 publications were analyzed, the mean value for the baseline condition, 25, is lower than 90% of the scores, even the higher end of the confidence interval, 36.71 is below 75% of the scores. When considering only scores from similar types of tasks such as Classification, or Process Control tasks, 36.71 is slightly above 25% of all scores. Therefore, it is safe to say that a low mental workload was observed in the baseline condition for the whole-body activity. Following the same type of comparison and analysis, it can be said that a high mental workload was observed in the time constraint (41.50 ± 15.13), interruption (47.09 ± 16.27), and auditory (47.69 ± 15.24) conditions. For the upper-extremity task, medium levels of mental workload were observed in the baseline condition (33.22 ± 14.30) and high mental workload for time constraint (42.41 ± 15.10), interruption (46.78 ± 14.55), and auditory (46.22 ± 14.49) conditions.

For the whole-body task, REBA exhibited increased scores for the mental workload conditions (time constraint, interruption, and auditory) compared with the baseline by 12.5%, 14.7%, and 14.8% respectively. The results indicated that REBA scores were worse in the auditory condition, followed by interruption and time constraint conditions than in the baseline condition. The lowest REBA scores were observed on the Baseline condition and exhibited the lowest NASA-TLX scores (Figure 5.5). The results aligned with previous studies that reported associations between workplace psychosocial work factors such as hostile work environment, work pace, work schedule, insufficient recovery time, lack of job control, and reported neck, shoulder, and upper body pain (Aasa et al., 2005; Burgel, White, Gillen, & Krause, 2010; Chen et al., 2005; Faucett & Rempel, 1994; Kääriä, Laaksonen, Rahkonen, Lahelma, & Leino-Arjas, 2012; Lang, Ochsmann, Kraus, & Lang, 2012; Lu, Nakata, Park, & Swanson, 2014; Shan, Bin Adon, Rahman, Hassan, & Ismail, 2011; H. Yang et al., 2016). Likewise, epidemiologic studies in psychosocial factors and WMSDs have listed high perceived job stress as a factor with a 50% attributable fraction associated with these types of disorders (Council, 2001).

In the REBA mixed effect model, the independent role of condition after accounting for variance explained by mental workload as captured by the NASA-TLX covariate for REBA scores suggests that some factor(s) associated with the differences in conditions may be affecting the postures. If NASA-TLX scores are assumed to be a good measure of mental workload, and it, therefore, explains variance that can be attributed to mental workload when included in the model, something else is then being explained by the condition factor that is not captured by the NASA-TLX. It looks like something that is not purely mental could be responsible for creating those changes in body postures. This could be explained by a cascading effect that could be originated on the participants due to the conditions of the experiment and their possible level of commitment to complete the task assigned. Nevertheless, such an effect was out of the scope of the present study and should be incorporated in future studies.

In-depth analysis, t-test comparisons between baseline and auditory conditions (auditory condition exhibited the worst REBA scores) of the scores obtained for the different body parts (trunk, upper arm, lower arm, neck, and legs) included in REBA and the percentage of time on medium and high risk observed for each body part, showed that a possible mechanism by which REBA scores increased is through alterations in the neck and upper arm postures (significantly different compared to the baseline condition with p-values < 0.05). Interestingly, the risk percentage in the legs decreased, suggesting that people exerted less pressure on their legs or stopped using them to the same extent to put more weight and pressure on their upper arms when they experienced higher levels of mental workload. It seems that increases in the perception of mental workload affect more the upper body than the lower body for the whole-body condition of the experiment. These results provide initial evidence that helps to support the workstyle model proposed by Feuerstein and colleagues (Michael Feuerstein, 1996; M. Feuerstein, Huang, Haufler, & Miller, 2000), which is based on the principle that the manner a person performs work tasks in response to changes in work demands and workplace psychosocial stressors is predictive of upper extremity symptoms. Furthermore, these mental workloads and body behavioral responses have been hypothesized by several researchers as factors underlying upper extremity disorders (Armstrong et al., 1993; Bergqvist, Wolgast, Nilsson, & Voss, 1995; Michael Feuerstein, Shaw, Nicholas, & Huang, 2004; F. Gerr et al., 2002; Keyserling, 2000; Pransky, Robertson, & Moon, 2002).

For the upper-extremity task, RULA scores increased when comparing the baseline condition with the time constraint, interruption, and auditory conditions by 13.1%, 14.5%, and 16.4% correspondingly. The lowest RULA scores were observed on the Baseline condition that also exhibited the lowest NASA-TLX scores (Figure 5.6). Once again, perception of mental workload negatively affects body postures, having the person assuming more awkward body postures under higher levels of mental workload for the upper-extremity activity as well.

In-depth analysis, t-test comparisons of the scores obtained for each of the body parts included in RULA (trunk, upper arm, lower arm, and neck) and the percentage of time on medium and high risk performed between the baseline and auditory conditions revealed that variations of the RULA scores were due to changes in trunk postures and an increase in the percentage of time that participants had a medium to high-risk posture while performing the activity for the lower and upper arm. These results could help explain the association between psychosocial work characteristics such as job stress, low decision authority, work pace, high conflicting demands, emotional exhaustion, and low-back pain that have been reported before in several studies (Davis & Heaney, 2000; Fernandes, Carvalho, Assunção, & Silvany Neto, 2009; Hemingway, Shipley, Stansfeld, & Marmot, 1997; Hoogendoorn et al., 2001; Jansen, Morgenstern, & Burdorf, 2004).

It is important to note that the study is not looking to evaluate the relationship of the magnitude of the RULA or REBA scores to the magnitude of pain, discomfort, or specific musculoskeletal disorders, and this remains a critical gap in the literature. A larger number of participants would have been required if this study was to test such a relationship. The current study aimed to establish if perceived mental workload has any effects on body postures in an attempt to demonstrate that if a comprehensive ergonomic assessment of a task or workplace has to be made, physical, mental, and psychosocial variables should be incorporated into the study.

Regarding the practical implications of the REBA and RULA scores observed between the different conditions, the lowest REBA scores were observed in the baseline condition (7.75 ± 1.3) compared with the time constraint (9.28 ± 1.4), interruption (9.63 ± 1.2), and auditory (9.66 ± 1.2) conditions. REBA scores on the higher mental workload conditions (time constraint, auditory, and interruption) associated with high-risk of developing musculoskeletal disorders and indicate that investigation and implementation of changes to improve work conditions and decrease REBA scores are needed. Meanwhile, REBA scores in the baseline condition were within the medium-risk range of musculoskeletal disorders, indicating that further investigation and changes are required soon. RULA scores exhibited the lowest values in the baseline condition (5.41 ± 0.8) compared with the time constraint (6.22 ± 0.8), interruption (6.34 ± 0.6), and auditory (6.44 ± 0.6) conditions. In this case, the RULA scores moved from the medium-high risk range in the baseline condition to the very-high risk range of musculoskeletal disorders. This indicates a pressing need to implement changes for the higher mental workload conditions. The baseline scenario requires further investigation and changes should occur soon. In the context of the experiment, the different mental workload conditions were designed based on the psychosocial factors that were present during observations at an SPD. From the results, it could be interpreted that there are opportunities for improvements in the work design at SPD. For instance, changes could focus on eliminating or avoiding alarms, interruptions, and time pressure imposed to complete the activities to avoid increments on perceived mental workload that can lead to the adoption of more awkward postures and will help on reducing the risk of WMSDs. Regarding the changes needed in the baseline condition (absence of mental workload stressors), the changes could be interpreted as the need to improve the workstation design or how the activities are performed. These could be addressed by offering ergonomic training to employees or conducting ergonomics interventions, so SPD staff become more aware of the postures they may avoid or which are the most appropriate postures to assume when performing the activities to decrease the risk of developing WMSDs.

A post-hoc correlation analysis between the six dimensions of the NASA-TLX and the total NASA-TLX score showed that dimensions are correlated to the perception of mental workload in the following decreasing order: performance, physical demand, frustration, mental demand, temporal demands, and effort ($r = 0.399$, 0.747, 0.755; 0.788; 0.860; 0.861 correspondingly). The correlation analysis of SURG-TLX scores showed the same results as the NASA-TLX score analysis but in a more notable way. Dimensions of the SURG-TLX such as task complexity and physical demands with Pearson correlation coefficients of $r = 0.033$ and $r = 0.267$ respectively, demonstrate that the difficulty and physical demands of the tasks were poorly related to changes in the perception of mental workload. SURG-TLX was instead more associated with distractions, mental demands, temporal demands, and situational stress dimensions ($r = 0.468$; 0.539; 0.68; 0.719 respectively). In linear regression models for the dimensions of the NASA-TLX and the SURG-TLX, the physical demand, performance, and task complexity dimensions are not affected (do not reach statistically significant difference, p-values

> 0.05) by the condition of the experiment. **These results provide a piece of early evidence that factors other than physical and mental demands can influence the perception of the task at hand as has been previously suggested in other studies (Marras & Hancock, 2014; Mehta, 2016). Hence, it is important to consider psychosocial work factors when designing workstations or staff scheduling or when conducting ergonomics evaluations.**

A few limitations of the study should be noted. The design of the study might not be optimal because the baseline condition was performed first for both tasks and the standing condition was done before the sitting condition. Because the psychosocial factors (time constraint, alarm, interruption) were expected to influence participants' perception of mental workload, the baseline condition was completed before the other conditions. Likewise, because the sitting task required a higher level of concentration (assembly tasks) it was performed after the standing condition. In ideal circumstances, participants would forget previous experimental sessions and there would be no carry-over effects. However, a strong carry-over effect would be expected to happen if the conditions with higher mental workload were performed first. The impact of psychosocial factors in this study might be underrepresented because the results are based on short-term responses. The impact of long-term exposure may be different and probably result in different interpretations of the tasks at hand generating different mental workload and body behaviors responses. To have conducted the conditions over a longer period of time would have resulted in higher scores, however, it is known that people adjust their working posture to alleviate loading on areas where they feel discomfort (McAtamney & Nigel Corlett, 1993). Another limitation is related to the fact that information about right or left-handed was not collected from the participants neither the potential influence of this factor on the posture assumed to perform the activities was evaluated. Despite these limitations, this study provides a first look into the effects of different psychosocial factors on the perception of mental workload and the influence on body postures, suggesting that higher perceived mental workload is associated with worst body postures that could help explain musculoskeletal pain or disorders.

Conclusion

This study aimed to evaluate the effects of changes in perceived mental workload on the postures assumed to perform an activity. Perceived mental workload was influenced by incorporating psychosocial factors such as time available, alarms, and interruptions into the experimental conditions. The results showed that we successfully increased NASA-TLX and SURG-TLX scores between the baseline condition and the time constraint, alarm, and interruption conditions for both the sitting and standing up tasks. Results also showed that there were no statistical differences between time constraint, alarm, and interruption conditions.

The study results demonstrate that **body postures assumed to perform an activity are negatively affected by mental workload perception without alterations or changes on the design of the workstation or the physical demands of the task.** Previous studies have suggested that effects of psychosocial work factors on postural behavior might exist (Asghari et al., 2019; Kermit G Davis et al., 2002; Gómez, 2020; Splittstoesser et al., 2012; G. Yang et al., 2011), the changes on REBA and RULA scores from the present study confirm these statements.

These results could also help explain associations between psychosocial work factors and musculoskeletal disorders and pain (Baek et al., 2018; Chen et al., 2005; Ng et al., 2019; Putz-Anderson et al., 1997; H. Yang et al., 2016; Zamri et al., 2017) since those musculoskeletal ailments may be due to the body postures assumed when performing the tasks.

This association between the perception of mental workload and higher risk of WMSDs due to the adoption of more awkward body postures (higher REBA and RULA scores) suggests opportunities for intervention more focused on the design of healthy organizations and efforts in the balance between physical demands of the task and psychosocial work factors.

The results also suggest a potential mechanism for the increase of upper body musculoskeletal complaints and disorders resulting from psychosocial work factors caused by modern work demands that now demand higher levels of mental concentration, a more rapid work pace, and the incorporation of alarms in industry and service sectors.

The results found in the current study recognized the need to expand on the evidence of the level of risk to develop musculoskeletal disorders associated with REBA and RULA scores. Studies are needed to identify specific associations of REBA/RULA scores (body postures) with musculoskeletal disorders that could be done by conducting correlation analysis using biomechanical responses. These studies could also help evaluate whether REBA/RULA scores appropriately reflect musculoskeletal risk and what type of musculoskeletal pain or disorders might be expected to occur due to the postures assumed when performing activities. Studies of this nature might help determine the applicability of these ergonomic assessments methods.

Regarding the relationship between perceived mental workload and body postures, questions arise about the influence of different individual factors such as age, sex, anxiety, and personality traits. Studies are needed to evaluate if such individual characteristics mediate or exacerbate the influence of psychosocial factors on the perception of mental workload and body postures. These questions will be explored in the following chapter of this dissertation.

CHAPTER SIX

EFFECTS OF INDIVIDUAL FACTORS IN THE PERCEPTION OF MENTAL WORKLOAD AND BODY POSTURES: AN EXPLORATORY STUDY.

Abstract

Studies have revealed that physical and mental demands, psychosocial factors, and individual factors can contribute to the development of work-related musculoskeletal disorders (WMSDs). However, much is still unknown regarding the effects of individual characteristics on WMSDs susceptibility. Previous studies discovered that people assumed more awkward body postures to perform an activity when the perception of mental workload is higher. However, little is known about the potential influence of individual characteristics on the perception of mental workload and body postures. This research study explored if individual characteristics such as age, sex, personality trait, and anxiety trait rating help explain those changes or differences in the perception of mental workload and body postures. The results suggest that individual characteristics such as age, sex, anxiety level, and personality have a modifying role on perceived mental workload and body postures.

Introduction

Work-related musculoskeletal disorders (WMSDs) are complex by having a composite and multifactorial origin that involves physical and biomechanical variables as well as psychosocial, organizational, and individual factors (WHO, 1985). Previous studies have revealed that physical and mental demands, psychosocial factors, and individual factors can contribute to the development of WMSDs (da Costa & Vieira, 2010; Dianat, Bazazan, Souraki Azad, & Salimi, 2018; Nourollahi, Afshari, & Dianat, 2018; Widanarko, Legg, Devereux, & Stevenson, 2014). Given the multifactorial nature of WMSDs, further research considering physical and mental demands, psychosocial work factors, and individual variables seems valuable.

Oakman et al. (2014) addressed organizational, technical, and individual factors in an attempt to identify the key predictors of WMSDs risk. Age, sex, psychosocial hazards, and physical demands contribute significantly to the level of discomfort, explaining approximately one-quarter of the variance in the model. They highlight the importance of incorporating physical, psychosocial, and individual factors to have a more comprehensive and holistic multi-dimensional approach when researching WMSDs risk prediction or assessment.

A growing body of research has shown a complex relationship between postural control and mental workload that depends among other factors of age, expertise, type of cognitive task, and cognitive processing required (Maylor et al., 2001; Riley et al., 2003; Roerdink et al., 2011; Siu & Woollacott, 2007; Stins et al., 2009). This association between body behavior and mental workload also appears to depend on other individual characteristics such as sex and personality (Davis et al., 2002; Marras et al., 2000).

Mental workload is a multidimensional construct involving the characteristics of the task, the operator, and the environment where the task is performed. It incorporates psychosocial factors, organizational work factors, and individual differences that are still an unsolved puzzle regarding their impact on mental workload assessment (Bru et al., 1996; Carayon et al., 1999; Young et al., 2015). It is believed that interactions between those factors impact performance and health status (Bongers et al., 1993; Eatough et al., 2012). Individual factors are those related to the characteristics of the worker such as sex, age, social class, culture, education status, personality traits, attitudes towards life, job satisfaction, depression, anxiety, among others (Keita & Sauter, 1992; Payne, 1988; Sauter & Swanson, 1996).

In Chapter Five, it was discovered that changes in perceived mental workload due to psychosocial work factors have negative effects on body postures. People assumed worse body postures to perform an activity when the perception of mental workload was higher. Differences were noted between participants in their reactions to psychosocial factors. However, little is known about the potential influence of individual characteristics on the perception of mental workload and body postures. Figure 6.1 shows that the perception of mental workload for the whole-body activity varied markedly when different individuals were subjected to various conditions. Some participants demonstrated substantial increases in NASA-TLX scores, whereas others exhibited smaller differences. This behavior was also observed in NASA-TLX for the upper-extremity task, REBA, and RULA scores.

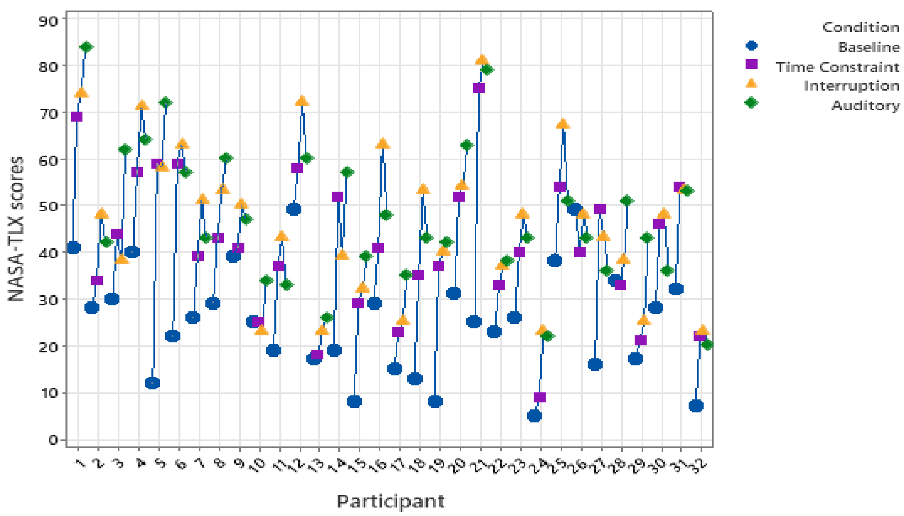


Figure 6.1 NASA-TLX scores whole-body task for each participant across conditions

Therefore, this research study explored if individual characteristics such as age, sex, personality trait, and anxiety trait rating can help to explain variability in response to changes in the perception of mental workload and body postures. It was hypothesized that there is a relationship between psychosocial factors, perceived mental workload, body postures, and individual parameters (sex, age, anxiety, and personality traits). The objective of the study was to investigate the impact of individual factors and psychosocial factors on perceived mental workload and body postures.

Methods

Participants

Thirty-two participants (53% females and 47% males) between the ages of 20 and 55 participated in the study. The participants were free of lower and upper extremity surgeries, had no lower and upper extremity injuries within three months of study participation, and had not had diagnosed concussions within a year of study participation. Study participation involved one lab visit lasting between 1.5-2 hours.

Experimental Design

Approval from the University's Institutional Review Board was obtained before recruitment and experimentation. Informed consent was obtained from all participants. Participants performed two physical tasks at four levels of mental workload (baseline, time constraint, alarm, and interruption). The physical activities were divided into a whole-body task performed standing (Figure 6.2) and an upper-extremity task performed seated (Figure 6.3).

A repeated measures within-subjects experimental design was used by having participants perform both physical tasks under the different mental workload conditions. Each subject went through all eight treatment conditions. With the exception of the baseline condition being completed first, conditions were randomly presented to the participants to avoid any order effects.

Figure 6.2 Participant performing the whole-body task

Figure 6.3 Participant performing the upper-extremity task

Independent variables consisted of individual characteristics including age, sex, anxiety STAI trait rating (Spielberger, Gorsuch, & Lushene, 1970), and personality traits. Personality traits were classified into Extraverts or Introverts, Sensors or Intuitors, Thinkers or Feelers, and Judgers or Perceivers (Myers, 1998). Dependent variables consisted of perception of mental workload and body postures. Mental workload was assessed by the NASA-TLX (Hart & Staveland, 1988), using equal weights for the total load score (raw NASA-TLX, or RTLX) (Byers, 1989; Hart, 2006; Huggins & Claudio, 2018). Body postures were measured using the Rapid Entire Body Assessment (REBA) method (Hignett & McAtamney, 2000) for the standing activity, and the Rapid Upper Limb Assessment (RULA) method (McAtamney & Nigel Corlett, 1993) for the sitting activity.

Experimental Procedure

The study was conducted in the Human Factor Laboratory at Montana State University during the summer and fall of 2021. Upon arrival, participants signed a consent form and filled out two questionnaires, the Myers-Briggs Type Indicator (MBTI) and the Spielberger State-Trait Anxiety Inventory (STAI-Trait). Other individual characteristics of the participants were collected such as age and sex assigned at birth. Participants were asked to emulate duties performed at a Sterile Processing Department (SPD). The experimental activities, conditions, and protocol are described in Chapter 5. Briefly, participants complete two physical activities, the whole-body task and the upper-extremity task that emulate activities perform at the sterile processing department (SPD) in a hospital, under four different conditions. Manipulations of psychosocial factors including a time constraint, an alarm, and interruptions were introduced to create different levels of mental workload. The effects of individual factors on perceived mental workload and body postures were explored.

Myers-Briggs Type Indicator (MBTI) was used to characterize participants' personality traits (Myers, 1998). MBTI is one of the most widely used instruments to assess personality, applied in more than 700 research studies (Carlson, 1985; Marras et al., 2000; Murray, 1990). It consists of four pairs of opposite preferences, called dichotomies: 1) Extraversion (E) or Introversion (I); 2) Sensing (S) or Intuition (N); 3) Thinking (T) or Feeling (F) and; 4) Judging (J) or Perceiving (P). The MBTI instrument combines the four preferences denoted by its letter producing 16 possible personality types (e.g., ENTJ, ISFP). Each of these personality types could influence people's responses to a certain work situation or task and, under certain circumstances, can energize or stress a person (Myers & Myers, 1980).

The MBTI has proven to be reliable for use in various work situations, various ethnic groups, age groups, international samples across six regions, including Africa, Asia, Australia, Europe, Latin America, and the Middle East. MBTI has shown superior internal consistency and test-retest reliability compared to other personality assessments (Carlyn, 1977; Murray, 1990; Schaubhut, Herk, & Thompson, 2009).

Spielberger's State-Trait Anxiety Inventory (STAI) was used to measure anxiety in the participants (Spielberger et al., 1970). The STAI is a self-report designed to measure and differentiate anxiety as a trait and as a state. It was decided to use only the trait anxiety part since it refers to feelings of tension, apprehension, and it seems like a stable personality trait. People with high trait anxiety tend to see more situations as dangerous than those with lower trait scores. (Spielberger et al., 1970).

The STAI-Trait consists of a 20-item questionnaire ranging from 20 to 80 points that describes how people generally feel. The STAI has been used in more than 816 published studies (Barnes, Harp, & Jung, 2002). Reliability, validity, and sensitivity of the STAI have been reported by (Barnes et al., 2002; Gaudry, Vagg, & Spielberger, 1975; Quek, Low, Razack, Loh, & Chua, 2004; Speilberger & Vagg, 1984).

Analyses

Repeated measures analysis of variance (ANOVA) was performed for all dependent variables. Analyses were done including each of the individual characteristics, one at a time, condition (baseline, time constraint, alarm, and interruption), and the interaction effect between the individual factor and condition. The goal was to evaluate individual characteristics' main and interaction effects on perceived mental workload and body postures.

After these analyses, a forward selection stepwise general linear model (Alpha to enter 0.25) was created for each of the response variables (NASA-TLX, REBA, and RULA scores), including condition as a main effect and also all the individual characteristics (age, sex, anxiety rating, and personality traits). This was done to directly compare the relative ability of these individual factors to explain variance in the response variables, following a multi-causal framework and laying out the contributions of the different factors as proposed by (Cole & Rivilis, 2004). Factors that reached statistical significance were analyzed further using post-hoc comparisons via Tukey multiple pairwise comparisons. All statistical analyses were evaluated at a significance level of $\alpha = 0.05$. Multiple comparison corrections were not used in this exploratory study.

<u>Results</u>

Thirty-two participants provided written informed consent for study participation. Table 6.1 summarizes participants' sex, age, anxiety trait rating, and personality type. It can be seen from Table 6.1 that the average age, anxiety trait, and MBTI dichotomies distribution was similar for males and females.

Table 6.1 Participants Individual Characteristics: Sex, age, anxiety rating, and personality traits

Participant	Sex	Age (yrs)	Anxiety Trait	MBTI Personality	Extraverts/ Introverts	Sensors/ Intuitors	Thinkers/ Feelers	Judgers/ Perceivers
1	F	23	53	ENFJ	E	N	F	J
2	F	27	41	ISTJ	I	S	T	J
3	M	27	36	INTJ	I	N	T	J
4	F	22	51	ESFP	E	S	F	P
5	M	31	39	INFJ	I	N	F	J
6	F	25	43	ISTJ	I	S	T	J
7	F	26	26	ENFJ	E	N	F	J
8	F	58	23	ENFJ	E	N	F	J
9	F	29	37	ENFJ	E	N	F	J
10	M	19	32	ESFJ	E	S	F	J
11	M	30	47	ENFP	E	N	F	P
12	F	21	39	ENFJ	E	N	F	J
13	M	24	54	ENTJ	E	N	T	J
14	F	20	38	INFJ	I	N	F	J
15	F	21	32	ISFJ	I	S	F	J
16	F	21	57	ISFJ	I	N	F	P
17	F	27	51	ISFJ	I	S	F	J
18	M	21	51	ENTJ	E	N	T	J
19	F	22	32	ESTJ	E	S	F	J
20	F	21	31	ENFJ	E	N	F	J
21	M	21	64	ENFP	E	N	F	P
22	F	21	63	ISTJ	I	S	T	J
23	M	20	45	ENFJ	E	N	F	J
24	M	18	28	ESTJ	E	S	T	J
25	M	19	37	ENFP	E	N	F	P
26	M	34	38	ENFJ	E	N	F	J
27	F	31	56	INFP	I	N	F	P
28	M	21	38	INTP	I	N	T	P
29	M	41	31	ESFJ	E	S	F	J
30	M	19	63	ESFJ	E	S	F	J
31	F	24	34	ENFJ	E	N	F	J
32	M	33	34	ENFP	E	N	F	P
Male	15	25.20	42.47		E = 12	S = 4	T = 5	J = 10
		(7.05)	(11.22)		I = 3	N = 11	F = 10	P = 5
Female	17	25.82	41.59		E = 9	S = 7	T = 3	J = 14
		(8.90)	(11.72)		I = 8	N = 10	F = 14	P = 3
All	32	25.53	42.00		E = 21	S = 11	T = 8	J = 24
		(7.96)	(11.31)		I = 11	I = 21	F = 24	P = 8

Average values with standard deviations in parentheses

MBTI = Myers-Briggs Type Indicator: introversion (I)/extroversion (E), sensing (S)/intuition (N), thinking (T)/feeling (F), judging (J)/perceiving (P).

Statistically significant NASA-TLX scores for the standing and the sitting conditions, RULA scores, and REBA scores responses were observed between the baseline condition and the other three mental workload conditions (time constraint, auditory, and interruption) as presented in Chapter Five. Those results demonstrated that people assumed more awkward body postures to perform an activity under higher levels of perceived mental workload.

Table 6.2 summarizes the ANOVA analyses performed including one of the individual factors at a time, condition, and the interaction effect between condition and the individual characteristics. Each row in the table shows the p-values for the individual characteristics in each of the models. The condition row presents the higher p-values obtained after all models were evaluated. No interaction effects were observed between condition and any of the individual characteristics (sex, age, anxiety trait rating, personality traits) for any of the response variables (NASA-TLX, RULA, REBA scores).

Table 6.2 Statistical Summary (P Values) of Significant Analysis of Variance for NASA-TLX, REBA, and RULA Scores.

	Standing Task		**Sitting Task**	
Effect	NASA-TLX	REBA	NASA-TLX	RULA
Condition	< 0.008 *	< 0.001 *	< 0.012 *	< 0.001 *
Sex	0.008 * F > M	0.527	0.994	0.439
Extroverts/Introverts	0.445	0.822	0.753	0.011 * I > E
Sensors/Intuitors	< 0.001 * N > S	0.290	< 0.001 * N > S	0.048 * N > S
Thinkers/Feelers	0.009 * F > T	0.306	0.241	0.345
Judgers/Perceivers	0.183	0.051	0.014 * P > J	0.829
Anxiety	0.038 *	0.803	0.208	0.389
Age	0.568	0.968	0.018 *	0.141

*indicates p < 0.050

Sex was a main effect for NASA-TLX scores in the whole-body activity (Table 6.2). When the NASA-TLX scores in the standing task were contrasted for males and females, a difference was observed for females (43 ± 16) compared with males (37 ± 17), 18.7% higher NASA-TLX scores for females. It seems that women had a higher perceived mental workload for the whole-body activity across the conditions (Figure 6.4). However, as seen in Table 6.2, sex was not significantly associated with NASA-TLX for the sitting task, REBA, and RULA scores (Table 6.2).

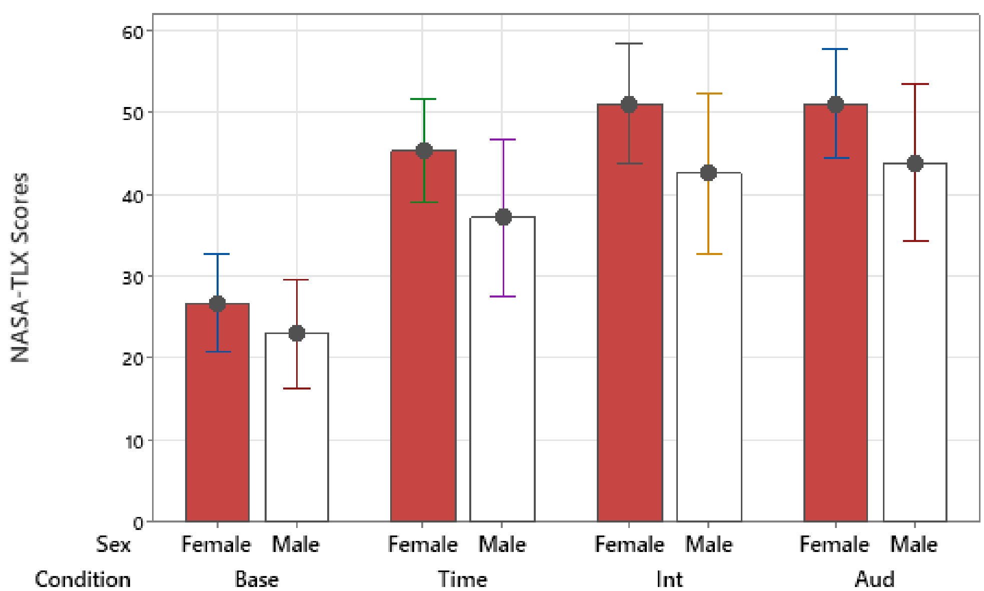


Figure 6.4 Interval plot NASA-TLX scores for men and women across conditions

A significant difference in RULA scores occurred between extroverts and introverts, with higher RULA scores for introverts (6.3 ± 0.7) than extroverts (5.9 ± 0.8) across conditions (Figure 6.5). No other significant differences were linked to extroverts and introverts (Table 6.2).

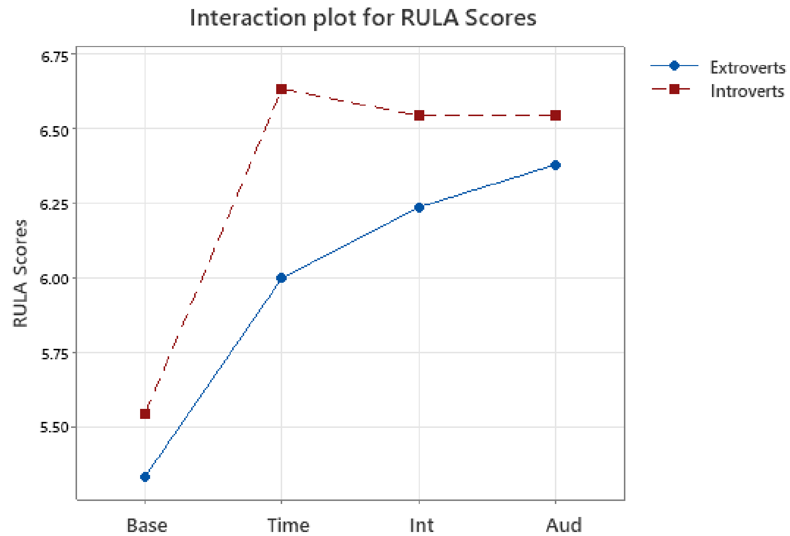


Figure 6.5 Interaction plot RULA scores for extroverts and introverts across conditions

A main effect for sensors and intuitors was observed for NASA-TLX scores in both activities (standing and sitting) and for RULA scores (Table 6.2). Intuitors had worse RULA scores (6.2 ± 0.8) than sensors (5.9 ± 0.8) and higher perceptions of mental workload across the conditions. NASA-TLX scores for the whole-body activity were higher for intuitors (43.83 ± 17.0) than for sensors (33.61 ± 15.6). Likewise, the perceived mental workload in the upper-extremity task was higher for intuitors (45.54 ± 15.3) than for sensors (35.70 ± 13.7) (Figure 6.6). No differences were observed between intuitors and sensors for REBA scores.

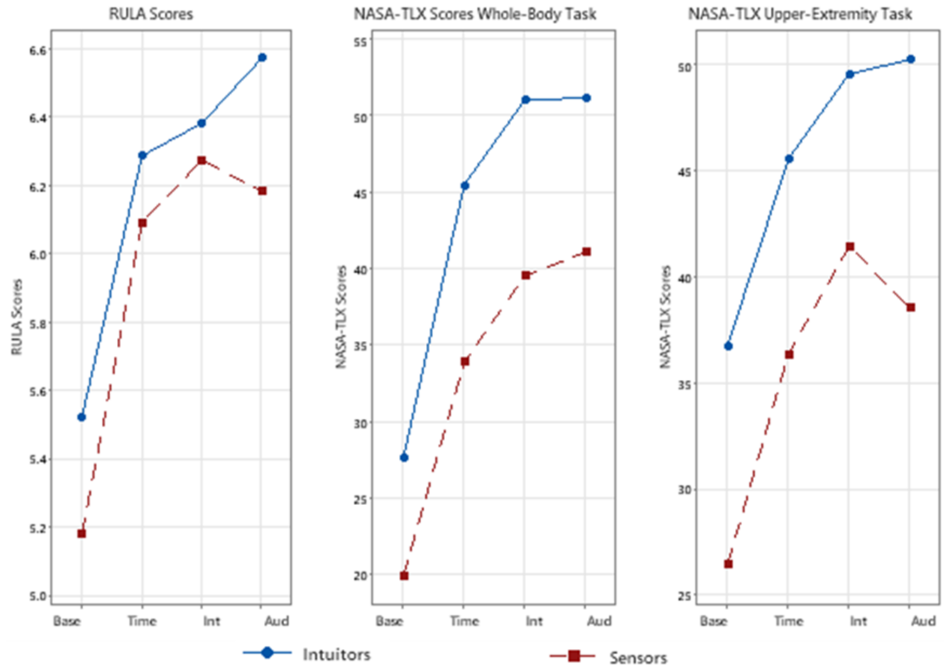


Figure 6.6 RULA, NASA-TLX interaction plot for sensors and intuitors across conditions

An effect for thinkers versus feelers was observed for NASA-TLX scores in the whole-body activity. Perception of mental workload was higher for feelers (42.3 ± 15.2) than thinkers (34.4 ± 17.4) across conditions (Figure 6.7). REBA, RULA, and NASA-TLX scores in the sitting task exhibited no change for thinkers versus feelers.

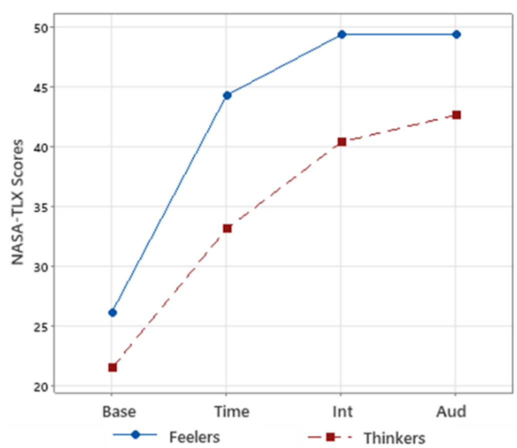


Figure 6.7 Interval plot NASA-TLX scores for feelers and thinkers across conditions

Regarding judgers versus perceivers, a main effect was only observed for NASA-TLX scores in the upper-extremity task, with a higher perception of mental workload experienced by the perceivers (47.6 ± 16.3) than the feelers (40.3 ± 14.5) across conditions (Figure 6.8).

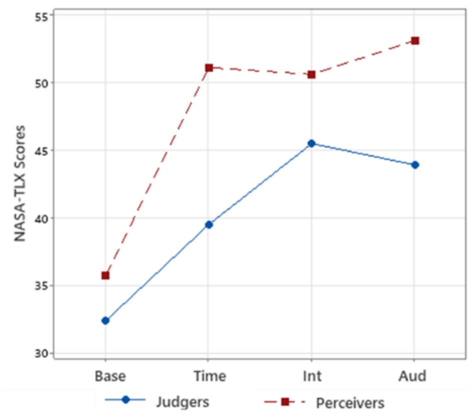


Figure 6.8 Interaction plot NASA-TLX scores for judgers and perceivers across conditions

A main effect of anxiety was observed for NASA-TLX scores for the whole-body activity (Table 6.2). In general, higher perceptions of mental workload were observed for participants with higher anxiety trait ratings (coefficient for anxiety = + 0.241 anxiety rating) (Figures 6.9).

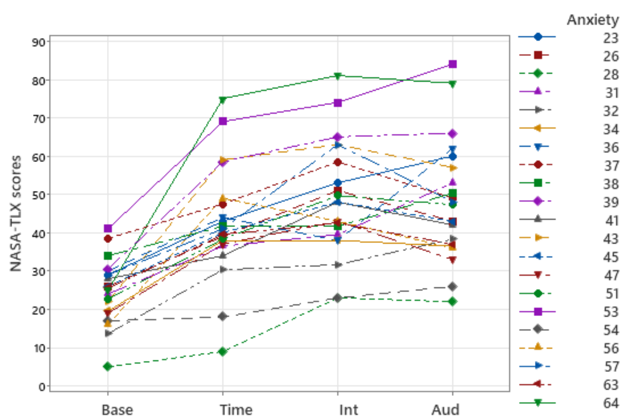


Figure 6.9 Interaction plot NASA-TLX whole-body task scores for anxiety (Lower anxiety scores associated with lower anxiety)

A main effect of age was observed for NASA-TLX scores in the upper-extremity task (Table 6.2). Perception of mental workload was higher for younger participants (coefficient for age = -0.387 years) (Figure 6.10).

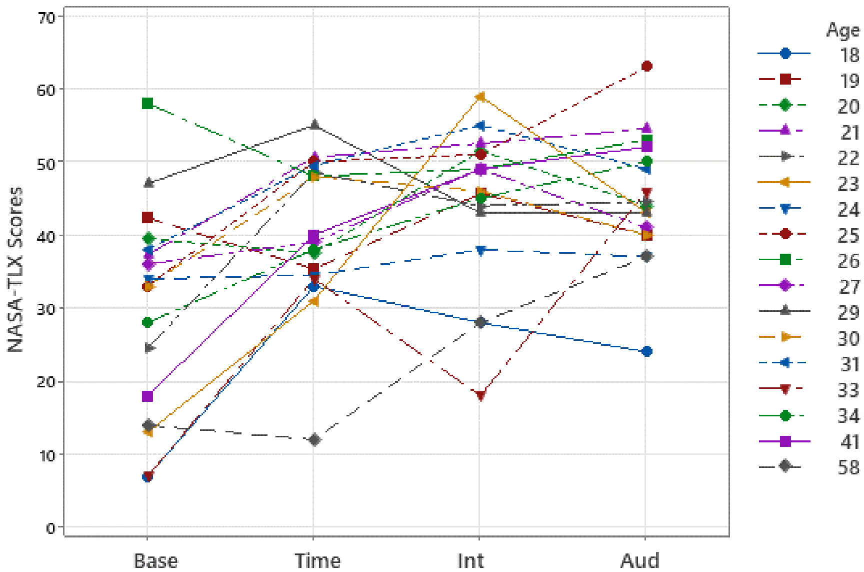


Figure 6.10 Interaction plot NASA-TLX scores upper-extremity task for age across conditions

Forward selection stepwise general linear models were performed to identify the relative ability of the individual characteristics to explain the variance in the response variables. When studying the NASA-TLX scores for the *whole-body task*, factors of condition, sensors/intuitors, sex, and anxiety were statistically significant (in decreasing significant order), resulting in the model that explained 44.24% of the variability in the data. Personality traits such as extroverts/ introverts were not independently significant (p = 0.077). Personality traits thinkers/feelers, judgers/perceivers, and individual factors such as age were not even part of the model (Table 6.3).

Table 6.3 General Linear Model NASA-TLX Whole-Body Task Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Values	P-Value
Anxiety	1	923.7	2.46%	1457.2	1457.2	8.85	0.004
Condition	3	10760.3	28.68%	10760.3	3586.8	21.78	0.000
Sex	1	1604.5	4.28%	2879.8	2879.8	17.48	0.000
Extraverts-Introverts	1	944.5	2.52%	524.4	524.4	3.18	0.077
Sensors-Intuitors	1	3517.0	9.37%	3517.0	3517.0	21.35	0.000
Error	120	19765.9	52.69%	19765.9	164.7		
Total	127	37515.9	100.00%				

The model that explained 24.90% of the variability for the NASA-TLX scores in *the upper-extremity task* included factors (in decreasing significant order) such as condition, sensors/intuitors, and age. In this case, sex, anxiety, and the rest of the personality traits thinkers/feelers, extroverts/introverts, judgers/perceivers, were not part of the model (Table 6.4).

Table 6.4 General Linear Model NASA-TLX Upper-Extremity Task Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Values	P-Value
Age	1	1176	3.89%	1865	1865.2	10.43	0.002
Condition	3	3771	12.46%	3771	1256.9	7.03	0.000
Sensors-Intuitors	1	3480	11.51%	3480	3480.4	19.46	0.000
Error	122	21824	72.14%	21824	178.9		
Total	127	30251	100.00%				

REBA scores variability exhibit an interesting behavior by being explained (R^2 = 27.14%) by only one factor, judgers/perceivers in addition to condition. Anxiety, age, sex, and thinkers/feelers, extroverts/introverts, and sensors/intuitors were not present in this model (Table 6.5).

Table 6.5 General Linear Model REBA Scores Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Values	P-Value
Condition	3	78.031	27.17%	78.031	26.010	15.79	0.000
Judgers-Perceivers	1	6.510	2.27%	6.510	6.510	3.95	0.049
Error	123	202.677	70.57%	202.677	1.648		
Total	127	287.219	100.00%				

The RULA model explained 31.96% of the variability in the data and considers condition, extroverts/introverts, sensors/intuitors, and thinkers/feelers (in decreasing significant order). Factors such as sex, age, anxiety, and judgers/perceivers were not part of the model (Table 6.6).

Table 6.6 General Linear Model RULA Scores Analysis of Variance

Source	**DF**	**Seq SS**	**Contribution**	**Adj SS**	**Adj MS**	**F-Values**	**P-Value**
Condition	3	21.398	26.20%	21.398	7.1328	16.30	0.000
Extraverts-Introverts	1	3.146	3.85%	5.236	5.2365	11.97	0.001
Sensors-Intuitors	1	2.938	3.60%	2.362	2.3619	5.40	0.022
Thinkers-Feelers	1	1.250	1.53%	1.250	1.2500	2.86	0.094
Error	121	52.947	64.82%	52.947	0.4376		
Total	127	81.680	100.00%				

Discussion

This study sought to understand how individual characteristics such as sex, anxiety rating, age, and personality traits can explain differences in how people respond to changes in mental workload. The results showed no interaction effects between individual factors and conditions therefore individual characteristics did not influence how people responded to changes in mental workload induced by psychosocial factors. However, individual characteristics were associated with differences in perceived mental workload (NASA-TLX scores) and body postures (REBA and RULA scores). The effects of these individual factors on the NASA-TLX, REBA, and RULA scores are important because they could help to get a more informed and complete picture when interpreting their values and estimating potential thresholds.

Perceived mental workload appears to depend on anxiety trait ratings. The NASA-TLX scores for the whole-body task were higher for participants with higher anxiety, following what has been expressed in previous studies that people who have high trait anxiety tend to perceive more situations as threatening or dangerous than people who have lower trait anxiety ratings (Barnes et al., 2002; Spielberger, 2010). This is an important discovery because anxiety is becoming a common mental health disorder (Booth, Sharma, & Leader, 2016; Merikangas et al., 2010) and studies have also found that females are twice more likely to reach the cut-off for high anxiety levels than men (Zsido, Teleki, Csokasi, Rozsa, & Bandi, 2020). This study demonstrates that individual factors such as anxiety could influence perceived mental workload which in turn could increase the possibility of developing WMSDs (Carayon et al., 1999; Eatough et al., 2012; Kompier & van der Beek, 2008; Neupane & Nygård, 2017).

Another interesting finding associated with this study was that personality traits might affect perceived mental workload and body postures. Different personality traits help explain part of the variability observed in the response variables. For instance, introverts tend to internalize their thoughts and feelings and when facing new or unfamiliar situations they are very likely to mishandle the situation (Myers & Myers, 2010) which could explain the higher perception of mental workload observed in these participants across conditions. Intuitors, for example, have difficulty performing repetitive tasks (Myers & Myers, 2010), an aspect that might explain why this personality trait (S/N) was observed as a main effect factor for NASA-TLX scores in both activities and REBA scores. Although RULA scores were worse for introverts (5.9 ± 0.8) than extroverts (6.3 ± 0.7), and for intuitors (6.2 ± 0.8) than for sensors (5.9 ± 0.8), all groups are still in the medium-risk range of development of musculoskeletal disorders, indicating that further investigation and changes are required soon. RULA scores were statistically significant between the personality trait dichotomies, however, there were no clinically significant because they correspond to the same musculoskeletal risk.

These findings suggest that people with different personality traits perceived mental workload differently and assumed different body postures when performing tasks. Personality can interfere by manipulating somatic sensations and interpretation. For instance, an activity could be considered stressful to one person and might generate higher mental workload and body postures scores, while the same activity may be considered as a challenge to achieve and on the contrary would generate a feeling of joy or motivation in the person which could reduce mental workload scores and not generate changes on body postures (Mehta & Agnew, 2015; Myers & Myers, 2010).

Regarding the effect of sex, the results show that perceived mental workload is affected by sex. NASA-TLX scores for the whole-body activity were 18.7% higher for females compared to males. Sex was a contributing factor explaining the variability of NASA-TLX scores for the whole-body activity, indicating that this individual factor should be considered when analyzing perceptions of mental workload as has also been stated by Cole and Rivilis (2004) who point out that individual factors such as sex affect personal responses to workplace exposure. However, sex was not significantly associated with changes in body postures and NASA-TLX scores for the upper-extremity task. Therefore, research is needed to understand the nuances of this relationship, because of the inconsistencies between the response variables.

Age was a significant factor for NASA-TLX scores for the upper-extremity task. Perceived mental workload was higher in younger participants. This behavior of age regarding significance on variance explained in each of the responses could be attributable to the fact that age is a difficult variable to de-construct. For instance, it could be a measure of cumulative exposure, decrease tolerance, greater experience, different skills, different biomechanical exposures, among other factors (Cole & Rivilis, 2004; Collins & O'Sullivan, 2015; Heiden, Weigl, Angerer, & Müller, 2013; Shan et al., 2011).

The study shows a lack of interaction effects between the individual factors (age, sex, anxiety, personality traits) and condition (baseline, time constraint, alarm, interruption). While the individual characteristics (age, sex, anxiety, and personality traits) influenced perceived mental workload and body postures, these effects do not seem to be condition-specific. These results are contradictory with previous studies that have demonstrated interaction effects of individual factors with mental workload conditions (Kermit G Davis et al., 2002; Marras et al., 2000). However, the psychosocial factors included in this study to manipulate perceived mental workload are substantially different from those used in the studies mentioned before. Therefore, this is an interesting finding that provides additional insight into the role of these individual factors on perceived mental workload generated by psychosocial factors such as time, alarm, and interruptions.

The individual factors considered in the study (sex, age, anxiety, personality) exhibit a low contribution in explaining variability on perceived mental workload for the whole-body activity (18.7 %) with higher contributions observed in different personality trait dichotomies, sex, and anxiety. Individual factors have a low contribution for perceived mental workload for the upper-extremity task (15.4%) with higher contributions from age and sensors/intuitors. In terms of variability in body postures, individual factors do not explain a good portion of the variance in REBA scores. The model was able to explain only about 28% of the variability. REBA scores seem to be less affected by individual characteristics, yet higher scores were observed on perceivers. Meanwhile, the contribution of the individual factors on explaining the variability on RULA scores was interesting, since almost all the personality trait dichotomies resulted in an important contributor factor. The model for RULA was able to explain just about 32% of the variability of the data. These results indicate that more research is needed to expand our understanding of the influence of individual factors on perceived mental workload, body postures, and the potential association with work-related musculoskeletal disorders (WMSDs).

These results should be interpreted with caution because the current study is exploratory in nature and therefore not sufficiently powered to detect personality traits, anxiety, sex, or age differences after controlling for multiple comparisons. Future studies could be done by focusing the assessment on only two levels of mental workload and ensuring the recruitment of enough participants representative of each of the personality traits dichotomies to be able to identify specific associations between the personality traits and perception of mental workload and their influence on body postures. Future studies may be better able to assess the impact of personality traits by using The Big Five Inventory (FBI) model (John, Donahue, & Kentle, 1991) of personality traits which has been shown to remain stable throughout most of one's lifetime (Cobb-Clark & Schurer, 2012; Raad & Perugini, 2002) and due to the psychometric limitations pertaining to the reliability and validity of the MBTI that have raised concerns about its use by practitioners (Boyle, 1995). Likewise, studies can be performed by having enough representation of participants with high and low anxiety levels and from both sex groups (male and female) to evaluate in a more precise way the influence of anxiety ratings on the perception of mental workload and the potential effect on body postures. Similarly, much is still unknown regarding the age effect on perceived mental workload and body postures. Future studies investigating aspects of this factor are necessary.

Conclusion

The results of the current study suggest that individual characteristics such as age, sex, anxiety level, and personality have a modifying role on perceived mental workload and body postures. The study provides evidence that perceived mental workload is influenced to a higher extent by individual characteristics such as anxiety, sex, and personality traits. On the other hand, body postures seem to be influenced by different individual factors depending on the nature of the activity. For the whole-body activity, body postures are influenced to a greater extent by anxiety ratings and personality traits. The body postures for the upper-extremity task are more influenced by personality traits. Out of the individual factors considered in the study, the one with higher influence in almost all the response variables is sensors/intuitors, followed by extroverts/introverts, age, and sex. Based on the results, it seems that factors related to the individual should be clearly distinguished and addressed separately since they can interfere by manipulating somatic sensations and interpretations. Collectively, these results suggest that individual factors should be considered when attempting to evaluate all the risk factors that occurred during work and their possible influence on the perception of the task and hand, postures assumed to perform a task, and their potential influence on the development of WMSDs.

CHAPTER SEVEN

GENERAL DISCUSSION AND CONCLUSION

The current study examined the effects of distinct types of psychosocial factors in the presence of a constant level of physical demands. The primary objective was to determine whether there was a differential effect of various types of psychosocial factors on perceived mental workload that therefore will lead to changes in body postures. It was hypothesized that psychosocial factors such as time available, interruptions, and alarms would lead to higher perceptions of mental workload and consequently to worse body postures.

In general, participants' perceptions of mental workload and body postures were assessed and objectively compared under four different conditions of two physical activities (sitting and standing) in which the physical demands were kept constant and the workstation design was the same. Manipulations of psychosocial factors included a time constraint to complete the tasks, an alarm, and interruptions. These psychosocial factors were introduced to manipulate and control the perception of mental workload to determine the effects on body postures assumed by the participants to perform the experimental activities. Effects of individual characteristics such as age, sex, anxiety, and personality traits on perceived mental workload and body postures were also explored.

Figure 7.1 presents the research overview and its contributions. Based on the three primary contributions of the study, a number of key findings were noted:

Contribution 1: Psychosocial factors generated higher perceptions of mental workload when compared against the baseline condition for whole-body and upper-extremity tasks, differences between the time constraint with the interruption and auditory conditions were also observed for the whole-body activity.

Contribution 2: Higher mental workload perceptions were associated with worse body postures when compared with a baseline condition. There were no differences for body postures between the higher mental workload conditions.

Contribution 3: Differences were noted between participants in their perceptions of mental workload and body postures which varied markedly when different individuals were subjected to the conditions of the experiment. Individual characteristics such as personality traits dichotomies such as sensors/intuitors and extroverts/introverts, and sex seem to be key variables in helping explain such differences.

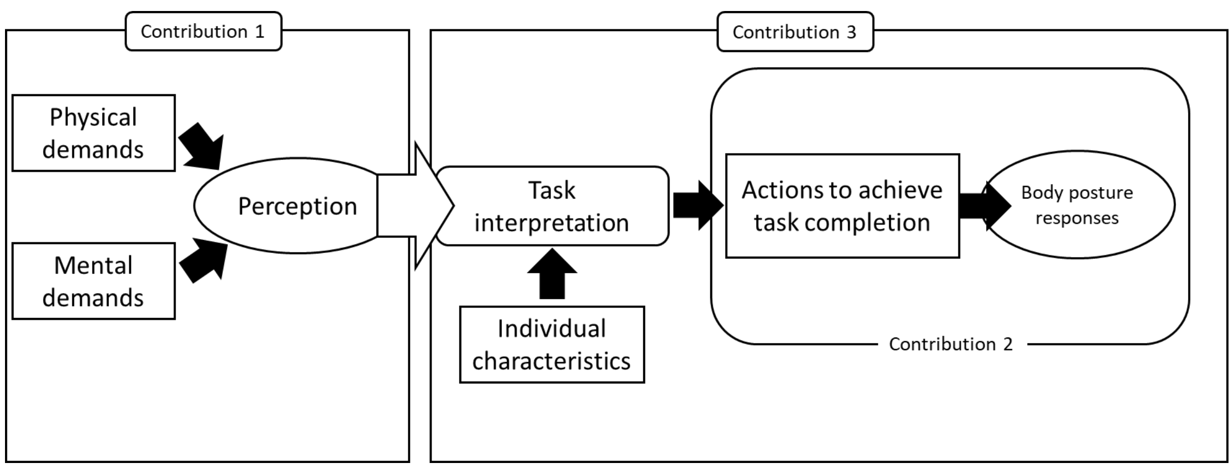


Figure 7.1 Research contributions

The data generated from this research project support the hypothesis that perceived mental workload is affected by psychosocial factors even when the physical demands of the task and the design of the workstation are the same. The results showed that mental workload perception was successfully increased between the baseline condition and the time constraint, alarm, and interruption conditions. Furthermore, the study provides evidence that high mental workload is related to worse body postures that consequently could lead to work-related musculoskeletal disorders (WMSDs); however, further research is needed to clearly establish a relationship with WMSD risk. These results demonstrated that factors other than those related to the physical or mental demands of the task itself, such as psychosocial work factors, could alter the perception of mental workload which also generates changes in body postures. These results provide a piece of evidence and help support the effect of psychosocial work factors on the perception of the task at hand as has been previously suggested in other studies (Marras & Hancock, 2014; Mehta, 2016; Rubio et al., 2004). Additionally, the results of the present study demonstrated that perceptions, actions, and/or reactions of the participants to overcome psychosocial factors could be more related to WMSDs than the psychosocial characteristics themselves as previously stated by Davis and Heaney (2000).

The results also support the hypotheses that perceived mental workload affects body postures, showing that there is a positive association between higher mental workload and worse body postures. The current study imposed higher loads of mental demands by changing psychosocial characteristics and has found that increases in REBA and RULA scores (worse body postures) occurred in response to higher perceptions of mental workload.

A possible mechanism by which body postures are worse (increased REBA and RULA scores), as shown in this study, is through alterations in perceived mental workload originated by psychosocial work factors such as time pressure, interruptions, and alarms. Previous studies have suggested that this psychosocial-perceived mental workload link might exist. Those who assess reactions of mental and physical demands on perceived mental workload have reported that psychosocial factors for instance concentration demand, job rotation, and responses to the psychosocial environment influence subjective mental workload scores (Bao et al., 2016; Cullen & Agnew, 2016; DiDomenico & Nussbaum, 2008; DiDomenico & Nussbaum, 2011; Mehta, 2016; Mehta & Agnew, 2011, 2015).

Also, a perceived mental workload-body behavior (changes in posture, influence on muscle load, movement, and exerted forces) link might exist. Studies have reported that reactions to psychosocial work characteristics (e.g. mental stress, high concentration demands, low job control, social support, job satisfaction, time pressure) influence muscle activity (Bongers et al., 1993; Carayon et al., 1999; Davis et al., 2002; Marras et al., 2000; Marras & Hancock, 2014; Qiu & Helbig, 2012; Yu et al., 2015). These studies certainly support the association between worse body postures and higher perceived mental workload identified in the present study. These changes in body postures in presence of mental demands could help improve the design of ergonomics interventions to reduce WMSDs by following a more holistic approach that calls for the consideration of the physical demands of the task but also mental demands that in turn could be affected by psychosocial factors.

The findings from the fourth and fifth research questions regarding the potential influence of individual factors in perceived mental workload and body postures show that anxiety, personality traits, and sex are the individual characteristics with higher contributions in the response variables. Perceived mental workload for the *whole-body task* increased by an average of 66.0% when comparing baseline against the time constraint condition. Across conditions, larger increases in perceived mental workload were observed for certain types of individuals (e.g., females (69.2%) and feelers (69.3%)). NASA-TLX scores for the *upper-extremity task* increased by an average of 27.7% between the baseline and time constraint conditions. Consistently across conditions, NASA-TLX scores exhibited larger increases for perceivers (43%). RULA scores increased on average by 13.1% between baseline and time constraint conditions. Larger differences were observed on certain individuals (e.g., introverts (19.7%) and intuitors (13.8%)) across conditions. Sensors/intuitors turned out to be a key factor in explaining variability in perceived mental workload and body postures. This personality trait dichotomy was the only individual characteristic present in almost all the models developed to explain the outcomes on the response variables. In general, intuitors exhibited higher NASA-TLX scores for both tasks and RULA scores.

Collectively, the results suggest that the associations between psychosocial factors, individual characteristics, perceived mental workload, and body postures are complex. Perceived mental workload and body postures are mixed reactions to the work environment influenced by psychosocial factors such as time, alarms, and interruptions, and the person's unique attributes. Based on the study results, it can be said that there is an association between psychosocial factors and perceived mental workload that defines and has an effect on the body postures assumed to perform a task. In addition, perceived mental workload and body posture are associated with individual characteristics. The findings of the study are a clear demonstration of the importance of factors beyond the physical demands of work in determining the onset of WMSDs.

The assessment of mental workload is crucial in the design and evaluation of occupational tasks to reduce the risk of WMSDs (DiDomenico & Nussbaum, 2011; Mehta & Agnew, 2015). Past research in this area has focused predominantly on assessing the influence of different physical workload parameters on perceived mental workload. This study is novel and contributes to overcoming an important shortcoming in the field of mental workload by considering the influence of psychosocial factors, keeping the physical load constant, on the perception of mental workload and its influence on body postures.

Future Directions

A central limitation of this research is that it was focused on outcomes obtained from university students performing the experimental tasks. Since the perception of mental workload may differ between groups, such as university students and industrial operators or workers, for instance, healthcare workers. Future work should build on the findings from the current study by extending the investigation to recruiting an actual workforce in this case, sterile processing department (SPD) staff, performing the occupational tasks in a more realistic environment, perhaps using the actual trays utilized in the SPD.

The findings also indicate areas for future exploration to determine the impacts of mental workload on muscle-specific tasks, with additional information from biomechanical responses considering for instance forces exerted, duration of exertions, and muscle activities to identify connections with body postures and the risk of developing WMSDs. The use of ergonomic assessment tools such as REBA and RULA that yield discrete results could present some complications when doing statistical analyses like ANOVA and mixed effect models. Additionally, recent studies have evaluated REBA and RULA methods identifying some issues related to reliability, sensitivity, discrepancies, and validity, and have proposed some changes on the methods to overcome those limitations (Ghasemi & Mahdavi, 2020; Golabchi, Han, & Fayek, 2016; Joshi & Deshpande, 2020, 2021; Manghisi et al., 2017; Mumani, Stone, & Momani, 2021). Future studies could consider the use of these improved REBA and RULA methods (Ghasemi & Mahdavi, 2020; Golabchi et al., 2016; Manghisi et al., 2017; Mumani et al., 2021) that result in continuous values and overcome some of the deficiencies of the methods.

Because mental workload could be affected by psychosocial demands that could include factors others than physical demands, temporal demands, performance, or effort, future work is needed to evaluate whether other subjective tools, such as SURG-TLX, can identify the presence of psychosocial work factors and get a more accurate perception of mental workload due to the consideration of factors such as distractions, situational stress, and task complexity into the mental workload assessment.

The present study did not consider performance as a response variable that might be affected by changes in perceived mental workload originated by psychosocial factors or the potential relationships with the body postures assumed to perform a task. Future research could be done by incorporating performance measures other than the own participants' perceptions (collected by the NASA-TLX) but including for instance time to complete the tasks, the number of errors based on objects in wrong positions or wrong locations, objects missed, accuracy on the response to experimental questions.

Since the current study was not powered enough or perhaps the design of the study was not suited to evaluate the causal influence of individual factors, more research is needed to fully determine how factors such as age, sex, anxiety, and personality traits, and the interactions between these factors may influence the risk to workers who are exposed to different work environments. In addition, factors such as right or left-handed may be included to evaluate any potential influence or effect on the body posture assumed to perform the activities. Likewise, future studies could avoid some limitations due to the reliability and validity of the MBTI by using the Big Five Inventory model instead, to identify personality traits. The way individuals respond to workplace conditions is a second important group of characteristics that should be considered in future research. The consideration of individual factors is important to identify links with risk injury and also because the impact of ergonomics interventions can be substantially modified by individual factors such as responsiveness, attitudes, anthropometric variables, mental health status, and others.

Future research should take into account the interrelationships between the factors considered in this study such as psychosocial factors, individual characteristics, perceived mental workload, and body postures, and the effect of those interrelationships on the risk of development WMSDs. Addressing these gaps in the ergonomics and human factors fields is critical to detail risk profiles for various occupations and workforces and could offer recommendations to establish thresholds to reduce risk. Likewise, continuing to incorporate and examine the influence of psychosocial and organizational work factors on perceived mental workload, body postures, and human behavior may lead to suggesting or identifying possible paths to create and/or improve safety cultures in the workplace with a reasonable expectation of reducing occupational disorders and diseases. It will be interesting to evaluate the effect of favorable psychosocial and/or organizational work conditions on perceived mental workload, body postures, and its consequences.

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