Demonstrating relationships between workplace demands and exposures related to musculoskeletal disorders and stress-related health outcomes

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Musculoskeletal disorders (MSD) and outcomes related to stress, such as mental health disorders, are important sources of pain, distress, disability, and costs in Canadian workplaces. Recent initiatives have highlighted the importance of preventing MSD and stress-related outcomes at work, however they are typically treated separately, each having their own literature, prevention approaches, and programs; there has been a push to recognize their connected nature. The objectives of the thesis were therefore to: 1) develop a framework to guide measurement of physiological responses related to workplace demands in both the physical and psychosocial domain, 2) examine relationships between workplace demands (in the physical and psychosocial domain) and exposures related to MSD and stress-related health outcomes during simulated computer work, and 3) examine relationships between potentially straining aspects of call centre work and exposures related to MSD and stress-related outcomes through a field study.

The framework was developed to recognize the connected nature of work-related MSD and stress-related outcomes. It is intended that the framework be used as a guide to measure exposure and outcome variables in a comparable manner across the physical and psychosocial domains in future laboratory and field studies. The multidisciplinary approach offered a foundation to examine common workplace risk factors for physiological responses related to MSD and stress-related outcomes in the studies comprising the thesis; an approach that could make possible more effective and efficient programs to target both work-related MSD and stress-related outcomes. The integrated and multidisciplinary framework substantially contributed to a limited body of literature.

Two laboratory studies targeted the second objective of the thesis. The aim of the first was to examine the effect of mechanical demand on scapular orientation during computer work. Maximum scapular motions for rotation, protraction/retraction, and tilt were documented while participants' arms were in postures typical of computer work. The identification of these ranges permitted quantification of normalized mean position during different computer tasks, and will permit future research to better describe scapular orientation during sedentary work. Compared to a neutral posture, participants held a more laterally rotated and protracted position of the scapula when they carried out computer tasks, potentially compressing tissues in the subacromial space.

The study also illustrated it was not the change in mechanical demand that produced statistically significant differences in the mean duration and size of scapular movements during computer work, but rather the change in cognitive demand. The second laboratory study further investigated the effect of cognitive demand on physiological responses related to MSD, as well as those associated with stress-related outcomes, during computer work. Changes in cognitive demand related to perceptions of increased workload, increased sympathetic nervous system activity, and changes in the duration and size of scapular movements. Together, the findings from the two laboratory studies showed that when cognitive demand increased, both the duration and size of scapular movements decreased, as did the change in muscle activation (for the right and left upper trapezius) associated with the movements. The observed reduction in movement during mentally demanding tasks may be associated with static postures, a risk factor for discomfort and pain among computer users.

The field study was carried out in two parts. Part A explored, through semi-structured interviews, potentially straining aspects of work for call centre agents, with an emphasis on agent-client interactions, and Part B examined relationships between agent-client interactions and physiological responses monitored over a work shift. Results from Part B showed greater activation of the trapezius muscle and the sympathetic nervous system when calls were perceived to be challenging or overwhelming compared to when calls were perceived to be non-straining. Findings from Part A suggest that aspects of both the content of work, for example the regulation of emotion, and the context of work, for example workforce surveillance, condition the interactions agents have with clients every day. Future efforts should consider how these features of work might be improved to minimize agents' exposure to situations that elicit physiological stress responses.

This work provided evidence of common workplace risk factors for MSD and stress-related health outcomes: 1) cognitive demand among computer users, and 2) perceptions of psychosocial demand among call centre agents. These findings should encourage stakeholders in research and in the workplace to integrate prevention efforts for MSD and stress-related outcomes to more effectively and efficiently target primary prevention.

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Dedication

This thesis is dedicated to my family whose support and encouragement are immeasurable.

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1.0 Introduction

1.1 The need for an integrative approach

Musculoskeletal disorders (MSD) and outcomes related to stress, such as mental health disorders, are important sources of pain, distress, disability, and costs in Canadian workplaces. In Ontario, MSD account for the highest number of lost-time workers' compensation claims, and approximately 50% of lost-time days reported through the compensation system (Occupational Health and Safety Council of Ontario [OHSCO], 2007). Costs of these claims for employers between 2003 and 2007, inclusive, was estimated at over 1 billion dollars (Ministry of Labour [MOL], 2009). Furthermore, the burden of ill mental health in Canada is large and increasing. One in five individuals are affected by mental health problems/illnesses each year; related economic costs are greater than 50 billion dollars (Mental Health Commission of Canada [MHCC], 2012a). Approximately 21.4% of working individuals are affected by mental health problems/illnesses, which, for example, cost at least 6.3 billion dollars in lost productivity, as a result of absenteeism, presenteeism, and turnover, in 2011 (MHCC, 2012a). It has been noted that claims for mental health conditions make up approximately 30-40% of short-term disability claims and 30% of long-term disability claims in many Canadian companies (Sarinen, Matzanke, & Smeall, 2011).

Recent initiatives have highlighted the importance of preventing these two disorders at work. For MSD, recent reports and standards include the *MSD Prevention Guide for Ontario* (OHSCO, 2007), and the CSA standard, Z1004, dealing with MSD prevention using ergonomics in the workplace (Canadian Standards Association [CSA], 2012). For mental health, the *Mental Health Strategy for Canada* (Mental Health Commission of Canada [MHCC], 2012b), and the standard on *Psychological Health and Safety in the Workplace* (CSA

Z1003), provide an outline for workplaces to address the issues (Canadian Standards Association [CSA], 2013).

While the definition of MSD varies by study depending on the research question, in this document MSD may be considered "injuries and disorders of the musculoskeletal system, which includes the muscles, tendons, tendon sheaths, nerves, bursa, blood vessels, joints and ligaments" (Ministry of Labour [MOL], 2012). Stress-related health outcomes may include mental health disorders, MSD, cardiovascular disease, gastrointestinal disorders, or impaired immune function, however in this document an emphasis is placed on mental health disorders because they: have increased among the Canadian workforce in recent decades (Marchand, Demers, & Durand, 2005), are expected to increase among the employed over the next 30 years (MHCC, 2012a), have direct costs that top the other six major disease/injury categories in the country (Public Health Agency of Canada [PHAC], 2009), and have spurred much attention by stakeholders in recent years, evidenced by the *Mental Health Strategy for Canada*, which has a priority section for the workplace (MHCC, 2012b).

Typically, MSD and stress-related outcomes, including mental health disorders, are treated separately, each having their own literature, prevention approaches, and programs. MSD research tends to focus on hazards related to biomechanical risk and injury, whereas stress research tends to centre around workplace issues such as psychological demand or skill underutilization; each approach has a certain amount of disregard for the other (Kompier & van der Beek, 2008). MSD research may, for example, recognize that contributions from both the physical and psychosocial domain are important, however psychosocial hazards are often treated as confounding variables that obscure associations between biomechanical demands and MSD (Feuerstein, Shaw, Nicholas, & Huang, 2004). This approach ignores possible interaction effects between domains (Feuerstein et al., 2004), and disregards the recent call to acknowledge that exposures related to MSD and stress-related outcomes have common workplace hazards (Kompier & van der Beek, 2008). It is believed that considering these two disorders separately lessens prevention effectiveness and increases resources required for implementing workplace prevention programs.

Models have been developed to examine specific psychosocial hazards at work (Siegrist et al., 2004; Karasek et al., 1998), and more holistically job stress and wellness (LaMontagne, Keegel, & Vallance, 2007; Carayon, Smith, & Haims, 1999; Shehadeh & Shain, 1990; Hurrell & McLaney, 1988), as well as work-related MSD (Wells, Van Eerd, & Hägg, 2004; Armstrong et al., 1993; Moore, Wells, & Ranney, 1991), some of which include psychosocial hazards (Feuerstein et al., 2004; Lundberg, 2002a; National Research Council [NRC], 2001; Sauter & Swanson, 1996; Bongers, de Winter, Kompier, & Hildebrandt, 1993). For example, Bongers et al. (1993) suggest interactions between physical, psychosocial, and individual factors at work are important for development of chronic musculoskeletal symptoms. The conceptual model proposed by the NRC (2001) focuses largely on the person by suggesting individual factors influence biomechanical loading, internal tolerances, and outcomes. This model demonstrates links between the workplace and the person by highlighting scientific disciplines that have aimed to demonstrate associations between them (NRC, 2001). The NRC (2001) model has, however, received some criticism since it does not address the mediating effect individual factors may have on workplace risk factors (Feuerstein et al., 2004). Feuerstein et al. (2004) propose the workstyle model, which suggests that *how* a worker carries out his or her duties in the face of increasing demands is important for development of musculoskeletal symptoms. Furthermore, the often-described ecological model (Sauter & Swanson, 1996) suggests that work technology influences both physical demand and work organization. In this model, work organization can then affect physical demand, through various means, such as increased repetition, but can also affect psychological strain (Sauter & Swanson, 1999). Psychological strain might then affect biomechanical strain through increased muscular tension, but may also mediate the pathway between biomechanical strain and MSD outcome (Sauter & Swanson, 1999). These models of MSD causation that include work organization and psychosocial demand, in addition to mechanical demand, provide the theoretical foundation necessary to develop an integrative approach to simultaneously study exposures related to MSD and stress-related health outcomes.

Few models (Lundberg, 2002a; Carayon et al., 1999) comprehensively address the connected nature of exposures related to MSD and stress-related health outcomes at work. The job stress model developed by Carayon et al. (1999) suggests that work organization determines both physical/ergonomic and psychosocial risk, which consequently affects three stress reactions: psychobiological, psychological, and behavioural. Psychobiological reactions may include changes in heart rate (HR), stress hormone levels, and muscular tension; psychological reactions may involve changes in mood; and behavioural reactions may result in absenteeism. These reactions can then lead to strain outcomes including but not limited to work-related MSD and mental health disorders (Carayon et al., 1999). It is important to note that individual characteristics including personality type, perceptions, and ability to cope, might influence these pathways (Carayon et al., 1999). The biopsychosocial model proposed by Lundberg (2002a) for work-related upper extremity MSD emphasizes the importance of an integrated approach to examine loads on the body. It is suggested that biomechanical load, ergonomic factors, mental stress, and psychosocial factors at work induce both physiological stress responses and muscular activity, important for the development of sustained stress and muscular tension (Lundberg, 2002a). These models provide further groundwork to propose in-depth analysis of relationships between workplace demands and physiological exposures related to both MSD and stress-related health outcomes.

1.2 Objectives of the thesis

The overall aim of the thesis is to demonstrate relationships between workplace demands and exposures related to MSD and stress-related health outcomes in the laboratory and in the field. More specifically, objectives are to: 1) develop a framework to guide measurement of physiological responses related to workplace demands in both the physical and psychosocial domain, 2) examine relationships between workplace demands (in the physical and psychosocial domain) and exposures related to MSD and stress-related health outcomes during simulated computer work, and 3) examine relationships between potentially straining aspects of call centre work and exposures related to MSD and stress-related health outcomes through a field study. Figure 1.1 provides an overview of the thesis. The result of this work will be the exploration of an integrated approach to help inform development of new prevention activities to simultaneously target two common sources of workplace pain and disability: MSD and mental health disorders.

Two laboratory studies targeted the second objective of the thesis (Figure 1.1). The aim of the first laboratory study (chapter 3) was to examine the effect of mechanical demand on scapular orientation during computer work, and the aim of the second laboratory study (chapter 4) was to investigate the effect of cognitive demand on physiological responses related to MSD and stress-related outcomes (scapular orientation, electromyography, and heart rate) during computer work. The laboratory studies will provide a better understanding of the links between workplace demands and exposures related to MSD and stress-related outcomes, which might provide evidence of a common workplace risk factor for MSD and stress-related outcomes during computer work.

The field study targeted the third objective of the thesis (Figure 1.1), and was conducted in two Ontario call centres: one within an insurance company and one within the provincial government. The mixed methods design had two parts: Part A (chapter 5) explored, through semi-structured interviews, potentially straining situations/tasks for call centre agents, with an emphasis on agent-client interactions, and Part B (chapter 6) examined relationships between agent-client interactions and physiological responses related to MSD and stress-related outcomes (electromyography, heart rate, and electrodermal activity) monitored over a work shift. Part A was conducted first and guided Part B. Findings from the case study will help to inform prevention activities that could simultaneously target MSD and stress-related health outcomes in the call centre environment.

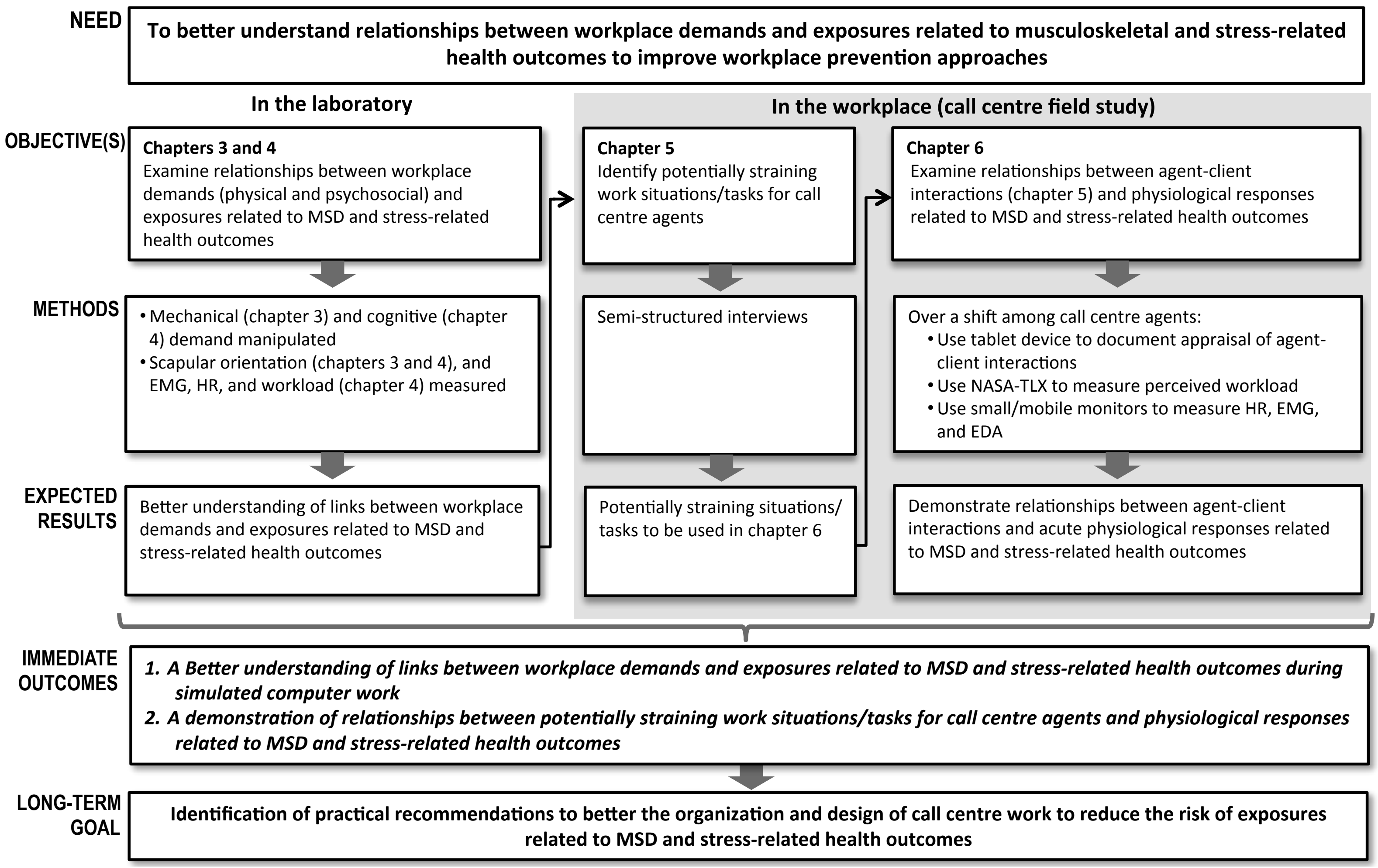


Figure 1.1. Overview of the thesis.

2.0 A framework to guide measurement of physiological responses related to workplace demands in both the physical and psychosocial domain

Although recent peer-reviewed literature has urged researchers to address the connected nature of musculoskeletal disorders (MSD) and stress-related health outcomes at work (Kompier & van der Beek, 2008), generally speaking, research regarding etiology and prevention remain separate. With an overall aim in this thesis to demonstrate relationships between workplace demands and exposures related to both MSD and stress-related outcomes, the development of a framework to guide measurement of variables across the physical and psychosocial domains is necessary, since, to the knowledge of the author, the MSD and stress literatures have not been combined for this purpose.

Evidence from the ergonomics and biomechanics literature has shown associations between mechanical demands and MSD (National Institute for Occupational Safety and Health [NIOSH], 1997), and there is support for associations between cognitive and emotional demands and exposures related to MSD (Lundberg et al., 2002b; Marras, Davis, Heaney, Maronitis, & Allread, 2000; Lundberg et al., 1994). In the laboratory, mechanical demand may be manipulated using changes to workstation design (Dennerlein & Johnson, 2006a; Delisle, Lariviere, Plamondon, & Imbeau, 2006; Aarås, Fostervold, Ro, Thoresen, & Larsen, 1997). For example, shoulder posture and electromyography (EMG) depend on computer mouse position (Dennerlein & Johnson, 2006a). Furthermore, cognitive demand may be replicated using tasks such as mental arithmetic or the Stroop colour-word test (Larsman et al., 2009; Laursen, Jensen, Garde, & Jørgensen, 2002; Lundberg et al., 2002b), and emotional demand using exposure to unsupportive language, video surveillance, or disturbing images (Poh, Swenson, & Picard, 2010; Blangsted, Søgaard, Christensen, & Sjøgaard, 2004; Marras et al., 2000). A non-postural load in the trapezius muscle has been observed as a result of performing the Stroop colour-word test (Laursen et al., 2002), and increased load in the low back has been seen as a result of contact with interpersonal strife (Marras et al., 2000). Although these demands likely fall in both the physical and psychosocial domain, evidence suggests a relationship between speed of task during computer work and exposures related to MSD; both increased time pressure (typing speed) and workload (mental arithmetic) increased key strike force (Hughes, Babski-Reeves, & Smith-Jackson, 2007).

Furthermore, literature supports associations between perceptions of psychosocial demand, for example low control or high effort-reward imbalance, and exposures for stress-related health outcomes (Juster, McEwen, & Lupien, 2010). In the laboratory it has been shown that performing mental arithmetic or the Stroop colour-word test increases stress hormone concentrations, as well as heart rate (HR) and blood pressure (BP), compared to baseline (Krantz, Forsman, & Lundberg, 2004; Lundberg et al., 1994). In the field, it has been shown that the concentration of these hormones, namely adrenalin, noradrenalin, and cortisol, as well as HR and BP, increase during work time compared to non-work time (Rissén, Melin, Sandsjö, Dohns, & Lundberg, 2000). Relationships between perceived job stress and the diurnal variation of cortisol are also reported (Chida & Steptoe, 2009; Alderling, Theorell, de la Torre, & Lundberg, 2006; Eller, Netterstrøm, & Hansen, 2006). More specifically, positive associations between the cortisol awakening response, i.e. the change in cortisol concentration from the moment after waking up to 30 minutes after waking up, when salivary levels increase between 50% and 160% (Clow, Thorn, Evans, & Hucklebridge, 2004), and job stress have been shown (Chida & Steptoe, 2009; Alderling et al., 2006).

A variety of demands in one's environment may increase catecholamine excretion from the sympathetic-adrenal-medullary (SAM) axis, i.e. adrenalin and noradrenalin, including noise, crowded areas, radial acceleration, and parachute jumping (Frankenhaeuser, 1986). According to Frankenhaeuser (1986), it is the psychological aspects of these situations, as opposed to the physical ones, that fundamentally govern the sympathetic response. For example, both physical underload and physical overload trigger catecholamine release. These two situations are very different with regard to physical demand, but both may be departures from what an individual is psychologically set to deal with (Frakenhaeuser, 1980). It is important to make this point because when examining jobs with low physical demand, for example computer or call centre work, it is likely the psychosocial aspects of these jobs that will govern the sympathetic response.

As outlined in chapter 1, models have been developed that provide essential groundwork to propose in-depth analysis of relationships between workplace demands and exposures related to both MSD and stress-related outcomes. The biopsychosocial model proposed by Lundberg (2002a) emphasizes the importance of a multi-system approach for examining loads on the body by suggesting that demands in both the physical and psychosocial domain contribute to sustained stress and muscular tension. Perceived stress initiates activation of neuroendocrine and immune mediators, including the stress hormones cortisol, adrenalin, and noradrenalin, which exert effects at the cellular level to achieve allostasis (McEwen, 2003). Allostasis refers to the body achieving “stability though change” (Sterling & Eyer, 1988, p. 636) in reaction to external demands. According to Sterling and Eyer (1988), who pioneered the term, allostasis “provides for continuous re-evaluation of need and for continuous readjustment of all parameters toward new setpoints” (Sterling & Eyer, 1988, p. 637). Almost all physiological measures within the human body vary with behaviour (Sterling & Eyer, 1988), save some that must be kept in close check, for example body temperature or pH (McEwen, 2004).

The allostatic response should shut off once the external demand is gone, however a physiological load may ensue if the response is chronically overactive or underactive (McEwen, 1998). McEwen's allostatic load (AL) model (1998) for chronic stress describes how exposure to stressful situations from life events, trauma, abuse, and environmental stressors, can, over time, result in an AL. AL involves shifting of various biomarkers out of their "regular" operating zones (McEwen, 2000), for example elevated BP referred to as a secondary outcome (Juster et al., 2010). AL has been linked to various health problems including burnout (Juster et al., 2011), cardiovascular disease, and obesity (McEwen, 1998).

The AL model is based on the concept that measurement of variables from multiple regulatory systems is required to understand total load (Juster et al., 2010). This approach provides rationale to study physiological responses in the physical and psychosocial domain resulting from contact with workplace demands so total load can be better understood for prevention purposes. The framework is presented in Figure 2.1. It may be read vertically from intrinsic job demands to health outcomes within each domain, or may be read horizontally to show conceptually equivalent measures across domains. It should be noted that the framework provides examples of variables for measurement within each category (i.e. intrinsic job demands, perceptions of demand, physiological responses, and health outcomes), however this is *not* meant to be a comprehensive list. Furthermore, the framework should *not* be read as a causative model. Rather, it is intended as a guide for measurement of variables across both risk factor domains.

Work organization
E.g. quotas, time standards, scheduling, staffing, margin of manoeuvre

PHYSICAL DOMAIN		PSYCHOSOCIAL DOMAIN
Physical demands • Mechanical (e.g. force, repetition, posture)	**Intrinsic job demands**	**Psychosocial demands** • Cognitive (e.g. task complexity, multiple tasks); emotional (e.g. emotion display rules, risk of harassment)
Ratings of physical demand • Borg perceived exertion	**Perceptions of demand**	**Ratings of psychosocial demand** • Copenhagen Psychosocial Questionnaire
Acute reactions • Muscle activation, tissue loads	**Physiological responses**	**Acute reactions**[1] • Release of stress hormones and inflammatory cytokines; electrodermal activity responses
Longer-term reactions • Tissue creep, vertebral disc fluid loss		**Longer-term reactions**[1] • Cardiovascular, metabolic, immune changes
Musculoskeletal disorders • Tenosynovitis, disc herniation, myalgia	**Health outcomes**	**Stress-related outcomes** • Mental health disorders, musculoskeletal disorders, cardiovascular disease

[1]Adapted from McEwen, 1998

Figure 2.1. A framework to guide measurement of physiological responses related to intrinsic job demands in the physical and psychosocial domain (with *possible* variables of interest); the framework should *not* be read as a causative model.

2.1 Framework scope, terminology, and considerations

Various disciplines contributed to the literature reviewed in the generation of the framework, and thus clarification around terminology and scope is necessary.

2.1.1 Intrinsic job demands and perceptions of demands

Intrinsic job demands imply any situation inherent to work that could cause harm to a worker. Unlike demands in the physical domain, which may be regarded as mechanical*,* such as force, repetition, posture, vibration, or some combination (NRC, 2001; NIOSH, 1997), directly measureable in the work environment, demands in the psychosocial domain are loosely defined (NIOSH, 1997; Sauter & Swanson, 1996) because they may be related to objective aspects of the work environment or to workers' perceptions. Risk related to psychosocial demand is often judged through self-reports, for example through the Job Content Questionnaire (Karasek, 1979), however there has been a push to acknowledge that tools are needed to more objectively capture information about the psychosocial work environment (Persson & Kristiansen, 2012). In their review of available instruments for measuring psychosocial demands, Tabanelli et al. (2008) indicate there are a number of observational tools available; many are not in English.

In the context of the framework, *psychosocial demands* are those psychological and social aspects of work that, theoretically, can be quantified in the work environment using job descriptions or similar tools. Psychosocial demands may be cognitive or emotional in nature. It might be more straightforward to draw a line between the two in the laboratory versus the field. For example, a complex task at work may require a high degree of mental effort but may also require use of emotional display rules, and teasing these demands apart may be difficult. The framework aims to guide measurement in both laboratory and field settings, and thus depending on the study, psychosocial demand may or may not be separated into components.

Similarly, *physical demands* are inherent to the job, for example mechanical demands related to lifting a certain number of boxes of measurable weight. Perceptions of mechanical demands are possible, for instance using the Borg scale to rate perceived exertion (Borg, 1982), however it is more typical for objective measures, such as weights, heights, and distances, to be used to examine intrinsic demands in this domain (NIOSH, 1997). Furthermore, *work organization* is "the way in which work is structured, supervised and processed" (Kuorinka & Forcier, 1995, p. 11), which incorporates factors such as quotas and staffing levels, and may influence intrinsic job demands in both domains.

2.1.2 The concept of stress and the cognitive appraisal process

Although the term stress is not explicitly used in the framework, the concept should be considered. Selye (1984), a pioneer in the area of the physiological stress response, considered stress "the state manifested by a specific syndrome which consists of all the nonspecifically-induced changes within a biological system" (Selye, 1984, p. 64). According to this definition, any environmental factor could cause stress, but stress itself was a reaction inside the human body (Selye, 1984). Today it is considered conceptually limiting to define stress in these medical terms (Cox & Griffiths, 2005).

Engineering terms have been used, which consider stress a hazard in the work environment, but they too have been criticized for, among other things, ignoring the worker-environment relationship (Cox & Griffiths, 2005). Widely used are psychological approaches, which may be interactional or transactional in nature (Cox & Griffiths, 2005). Interactional refers to the structure of the worker-environment interaction, demonstrated for example by Karasek's Demand-Control model (Karasek, 1979), and transactional refers to the cognitive and emotional processes underlying these interactions (Tabanelli et al., 2008), demonstrated for example by the psychological stress and coping theory (Lazarus & Folkman, 1986). According to this theory, "psychological stress refers to a relationship with the environment that the person appraises as significant for his or her well-being and in which the demands tax or exceed coping resources" (Lazarus & Folkman, 1986, p. 63). In this sense, psychological stress fits into the *perceptions of demand* category in the framework, as it is the perception or appraisal of the external demand that is important. It is this meaning of stress that is used in the document.

Suppose an individual is presented with a mental arithmetic task. Through transaction with his or her environment, the individual would go through a process of primary appraisal, and, if necessary, processes of secondary appraisal and coping (Folkman, Lazarus, Dunkel-Schetter, DeLongis, & Gruen, 1986). Primary appraisal would be used to determine if something is at stake, for example harm to self-esteem or goals. Should something be at stake, secondary appraisal would be used to consider options to prevent adverse outcomes. At this time coping strategies would be considered, for example accepting the situation (Folkman et al., 1986). Primary and secondary appraisal depend on one another in that a demand considered stressful at one point in time may be considered irrelevant at a later date if coping strategies turn out to be adequate (Folkman & Lazarus, 1985). Cox (1988) suggests that the appraisal process involves perceptions of: 1) demands, 2) individual characteristics and resources for coping, 3) constraints around coping, and 4) support for coping. Likewise, perception of demand in the physical domain could operate through an "appraisal" process where a worker examines the demand, the strength or endurance he or she has to cope with the demand, the constraints that might exist, and the support that might be available.

Appraisal might be one of challenge, i.e. as possibly having some sort of benefit, or might be one of threat, i.e. as possibly inducing some sort of harm (Folkman et al., 1986), or might be some combination of the two (Nelson & Simmons, 2005). This is important to consider because it has been shown that the nature of the stress response depends on the state elicited by the person-environment transaction (Nelson & Simmons, 2005; Frankenhaeuser, 1986; Ekman, Levenson, & Friesen, 1983; Lundberg & Frankenhaeuser, 1980). For example, release of adrenalin from the SAM axis and cortisol from the hypothalamic-pituitary-adrenal (HPA) axis depends on activity (active versus passive state) and affectivity (positive versus negative state)

(Frankenhaeuser, 1991). Adrenalin, a hormone more responsive to mental demand than physical demand (Frankenhaeuser, 1986), tends to increase during active states, whether positive or negative, whereas cortisol tends to increase during negative states only, whether active or passive (Frankenhaeuser, 1991; Frankenhaeuser, 1986). Details of the person-environment transaction are important to consider because physiological variables commonly measured in stress research may show similar profiles even though they may be elicited by different transactions.

2.1.3 Physiological responses

The framework is intended as a tool to guide measurement of *physiological responses* to intrinsic job demands, or perceptions of those demands, in the physical and psychosocial domain. As previously mentioned, stress reactions may also be psychological and/or behavioural in nature (Carayon et al., 1999). Psychological reactions may involve changes in mood, and behavioural reactions may involve absenteeism or changes to diet (Carayon et al., 1999). Coping would likely combine physiological, psychological, and behavioural reactions since the concept refers to "the person's constantly changing cognitive and behavioral efforts to manage specific external and/or internal demands that are appraised as taxing or exceeding the person's resources" (Folkman et al., 1986, p. 993). While it is important to acknowledge that psychological and behavioural reactions occur, and not separate from physiological reactions, it is the intent of the framework to guide measurement of intrinsic job demands, perceptions of demands, and physiological responses across the two domains.

Acute reactions refer to initial physiological responses from contact with workplace demands, for example release of stress hormones in response to an appraisal of threat, or internal mechanical reactions, such as muscle activation or tissue loading in the low back, in response to lifting a heavy box. Acute reactions may lead to *longer-term reactions*. For example, AL may result if the allostatic response (Sterling & Eyer, 1988) is chronically overactive (McEwen, 1998), and vertebral disc fluid loss may be an outcome of continued tissue loading in the low back.

2.1.4 Health outcomes

In the physical domain *health outcomes* include MSD, such as tenosynovitis, disc herniation, or myalgia, and in the psychosocial domain health outcomes include mental health disorders among others, such as MSD, cardiovascular disease, gastrointestinal disorders, and impaired immune function. Outcomes ranging from pain to case definitions are used when examining MSD (NIOSH, 1997). Like MSD, mental health disorders, which include but are not limited to conditions such as anxiety and depression, are often examined using case definitions or data from standardized questionnaires.

2.2 Examples to demonstrate the utility of the framework

2.2.1 Performing a mental arithmetic task

Suppose an individual is asked to count backward out loud from 1079 by 13s within a restricted time period. This task is objectively quantifiable and in the context of the framework would be a psychosocial demand. Through transaction with his or her environment, the individual would go through a process of primary appraisal, and, if necessary, would consider coping strategies (Folkman et al., 1986). Assuming that the individual determines something is at stake, for example he or she is concerned about completing the task within the non-negotiable time period, coping strategies, such as making light of the situation or accepting the situation, would be considered (Folkman et al., 1986). This appraisal process fits into the category perceptions of demand, and may result in physiological, psychological, and behavioural reactions, such as activation of the sympathetic nervous system, a negative mood change, or more forceful vocalizations of the answer, respectively (Carayon et al., 1999).

The physiological response may be measured through changes in stress hormone levels or HR (acute reactions), and the response should "shut off" once the task is complete (McEwen, 1998). However, if the individual is asked to perform similarly difficult tasks throughout the day, and for weeks or months, chronic overactivity of the allostatic response (Sterling & Eyer, 1988) could result in an AL (McEwen, 1998). AL, which involves shifting of various biomarkers out of their regular operating zones (McEwen, 2000), is represented by *longer-term reactions* in the framework, and has been linked to *health outcomes* such as burnout (Juster et al., 2011), and structural changes in the brain associated with the disorders anxiety and depression (McEwen, 2004).

2.2.2 Lifting a box

Suppose an individual is asked to lift a box from the floor, carry it to a knee-height shelf 10 meters away, and place it on the shelf. The mechanical demands associated with this task are quantifiable and in the context of the framework present a physical demand. To parallel the psychology literature (Cox, 1988), perceptions of demand could operate through an appraisal process where the worker examines the demand, for example whether it is easy or difficult and whether the weight of the box exceeds his or her ability to lift it once or continuously. A trial lift may be used to gain further information. Also appraised would be the constraints that might exist, for example the box must be moved within the next 5 minutes, and the support that might exist to cope with the situation, for example a co-worker who can help, or a trolley that can be used (Cox, 1988). These factors would contribute to the individual's perception of task difficulty. Aspects of this perception process are comparable to the appraisal seen during psychophysical load adjust studies (Ciriello, Snook, Buck, & Wilkinson, 1990).

Suppose the individual lifts the box. This lift would result in muscle activation and tissue loading (acute reactions) in the low back, among other body regions. If the individual is asked to repeat the lift and carry throughout the day, and for weeks or months, there may be resulting longer-term reactions such as tissue creep, vertebral disc fluid loss, or micro-damage to vertebral endplates due to loading of the spine. Injury may result without adequate rest and repair time (health outcomes).

2.3 Chapter summary

The first objective of the thesis was to develop an integrative framework to recognize the connected nature of work-related MSD and stress-related outcomes. It is intended that the framework be used as a guide to measure exposure and outcome variables in a comparable manner across the physical and psychosocial domains in future laboratory and field studies. The framework provided a foundation to examine common workplace risk factors for acute reactions related to MSD and stress-related outcomes in subsequent chapters of the thesis, which might make possible more efficient and effective prevention programs targeting both MSD and stress-related outcomes.

3.0 The effect of mechanical demand on scapular orientation during computer work

3.1 Background

Computer use in the workplace has increased in recent decades, and mechanical demands related to its use have been associated with upper extremity musculoskeletal symptoms and disorders (Hanse, 2002; Marcus et al., 2002; Aarås, Horgen, & Ro, 2000; Szeto, Straker, Raine, & Kirtley, 2000; Punnett & Bergqvist, 1997). The prevalence of symptoms among users tends to be highest in the neck and shoulder region compared to other parts of the upper extremity (Jenkins et al, 2007; Chang et al., 2007; Karlqvist, Tornqvist, Hagberg, Hagman, & Toomingas, 2002). For example, among undergraduate student computer users (N=127), pain was most prevalent in the neck (72%), followed by the shoulder (56%), wrist (51%), hand (36%), fingers (28%), and so on (Jenkins et al., 2007). Karlqvist et al. (2002) found that among 785 female computer users of various occupations, 59% reported pain in the neck/shoulders on at least 3 days in the month prior to the study, 32% in the shoulder joint/upper arms, and 40% in the elbow/forearm/hands; the prevalence was highest for all body parts among call centre workers (Karlqvist et al., 2002).

Evidence from the epidemiological literature suggests mechanical demands during computer work are related to musculoskeletal symptoms of the neck and shoulder (Hanse, 2002; Marcus et al., 2002; Punnett & Bergqvist, 1997). Marcus et al. (2002) conducted a prospective study among 632 computer users, and found that, for example, an elbow angle of greater than 121° (keyboard) was associated with lower odds of presenting with neck/shoulder symptoms and disorders compared to an elbow angle of less than or equal to 121°. Though cross sectional design, Hanse (2002) found that white-collar workers (N=201) who reported four hours per day or more of computer use were more likely to have had aches, pain, or discomfort in their shoulder in the year preceding the study than those who reported less than four hours of computer use per day.

The literature links awkward postures to risk of developing MSD of the shoulder (NIOSH, 1997). As outlined in the NIOSH review (1997), a neutral shoulder posture is one where the upper arm hangs beside the torso, and awkward postures are those where the upper arm is flexed and/or abducted over 60 degrees. In these awkward postures the subacromial space decreases, i.e. the area between the acromion and the humeral head, which places pressure on tissues located in and around this space (NIOSH, 1997). During computer work it would be rare for the arm to be flexed or abducted to such an extent. However, protraction of the scapula, which may be seen through changes in computer workstation design (Straker et al., 2008), is associated with decreased subacromial space (Solem-Bertoft, Thuomas, & Westerberg, 1993). A reduction in subacromial space is linked to shoulder pathologies such as impingement syndrome, and it is noted that situations that decrease this space are unfavorable for disorder progression (Ludewig & Cook, 2000). It is possible that a protracted shoulder posture during computer work would act to aggravate a pre-existing condition or increase an individual's susceptibility to develop a condition.

Laboratory studies have examined changes in scapular and upper extremity posture as a result of changes to workstation design (Straker et al., 2008; Kotani, Barrero, Lee, & Dennerlein, 2007). For example, Kotani et al. (2007) found that shoulder flexion increased and shoulder abduction decreased as the distance between the keyboard and user increased. Straker et al. (2008) found that shoulder flexion and abduction increased, by 6-13° and 12-17°, respectively, as did scapular protraction (2-3°) and elevation (4-7°), when a user worked at a desk that provided forearm support compared to a desk that did not provide forearm support.

This study measured scapular protraction and elevation using only one scapular marker (on the acromion) and therefore was not able to examine three-dimensional scapular orientations and movements.

Furthermore, computer users tend to adopt non-neutral scapular and upper extremity postures while working (Gerr et al., 2000; Kleine, Schumann, Bradl, Grieshaber, & Scholle, 1999). Gerr et al. (2000) found that, among 379 computer users in a variety of companies, 61% assumed non-neutral shoulder postures while typing, which was operationalized as greater than 25° shoulder flexion. Kleine et al. (1999) quantified changes in acromion position among secretaries over three hours of computer work and found that the distance between the 7th cervical vertebra (C7) and the left acromion, and C7 and the right acromion, decreased during each working hour. More specifically, on average, C7, the right acromion, and the left acromion lowered by 5.5mm, 3.3mm, and 1.7mm, respectively, during one hour of work. Changes in the distance between C7 and the right and left acromion accounted for 31% (right) and 33% (left) of the variance in trapezius muscle root mean square (RMS) value. Higher RMS values were associated with smaller distances between C7 and each acromion. It was concluded that the increase in trapezius muscle activity was in part a result of the shoulders lifting to compensate for a slouching back (Kleine et al., 1999).

While laboratory studies have examined changes in scapular and upper extremity posture in relation to changes in workstation design (Straker et al., 2008; Kotani et al., 2007), and in relation to computer work (Gerr et al., 2000; Kleine et al., 1999), to the author's knowledge three-dimensional changes in scapular orientation, i.e. quantification of scapula medial/lateral rotation, protraction/retraction, and anterior/posterior tilt, have not been documented during computer work.

3.2 Objective and hypotheses

The aims of this study were to: 1) quantify maximum scapular motion (rotation, protraction/retraction, tilt) when the arms are in postures typical of computer work, 2) determine the orientation of the scapula within this range during neutral posture and five computer tasks of varying mechanical demand, and 3) document scapular movement during the five computer tasks (Figure 3.1). Hypotheses related to aim 3) were: a) the number, duration, and size of scapular movements (section 3.4.1) will be different across computer tasks, and b) the time-weighted average slope describing change in orientation over time (section 3.4.1) will be different across computer tasks.

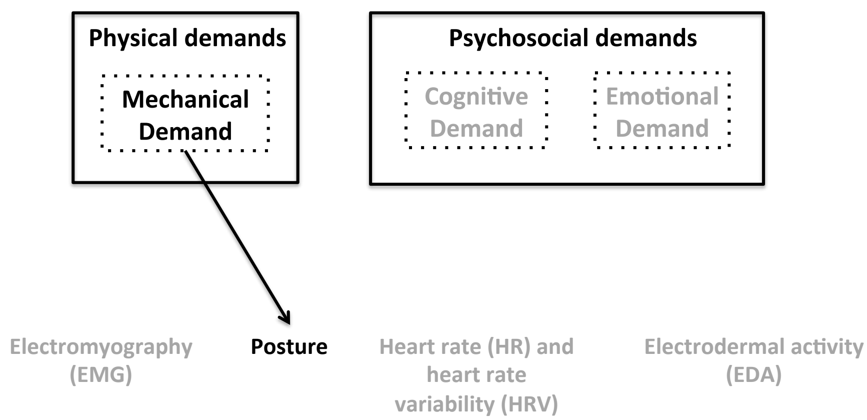


Figure 3.1. General layout showing independent (physical demands and psychosocial demands) and dependent (EMG, posture, HR/HRV, EDA) variables monitored in at least one study of the thesis; the arrow demonstrates the relationship focused on in chapter 3.

3.3 Methods

3.3.1 Participant population

16 right-hand dominant touch-typists were recruited from the University of Waterloo to participate (8 female and 8 male). Potential participants who reported having injury or discomfort to their shoulders or neck in the week prior to the study, or who had an allergy or

sensitivity to ethanol, were excluded. Trunk and scapular kinematics were collected while participants took part in five computer tasks of varying mechanical demand.

3.3.2 Instrumentation

Eight Vicon MX20 cameras (Vicon Motion Systems, Oxford, UK) were used to collect scapular and trunk kinematics at a sampling rate of 50 Hz. Cameras tracked the location of 8 markers (Wu et al., 2005) and 1 marker cluster (van Andel, van Hutten, Eversdijk, Veeger, & Harlaar, 2009; Karduna, McClure, Michener, & Sennett, 2001) placed over the trunk and right upper extremity: 7th cervical vertebra (C7), 8th thoracic vertebra (T8), suprasternal notch (SN), xiphoid process (XP), acromial angle (AA), root of scapular spine (SS), inferior angle (IA) (markers), and posterior-lateral acromion (marker cluster). The markers that were placed over the scapula are shown in Figure 3.2.

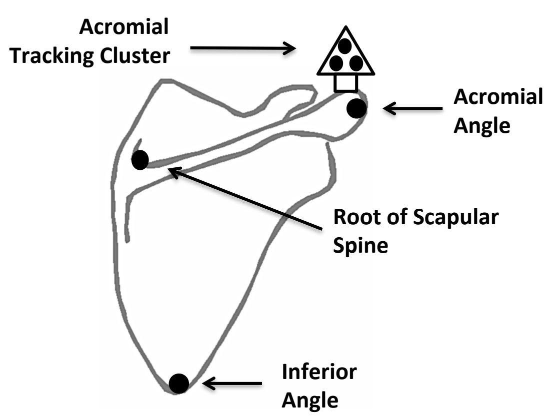


Figure 3.2. Location of markers placed over the scapula.

Markers were placed over the specified anatomical landmarks so thorax and scapular local coordinate systems could be established in accordance with International Society of Biomechanics (ISB) recommendations (Wu et al., 2005). The acromial marker cluster was used to track the location of the scapula during experimental conditions to minimize error from skin movement. The accuracy of this “acromial method” (Karduna et al., 2001, p. 185) was assessed by Karduna et al. (2001) who concurrently measured three-dimensional kinematics during shoulder activity using the acromial method, i.e. with a receiver placed over the posterior-lateral acromion, and the gold-standard method, i.e. with a receiver placed on bone pins secured to the scapula. The acromial method was found to be accurate for shoulder activity below 120° of upper arm elevation, and differences between the two methods were related to skin movement (Karduna et al., 2001). van Andel et al. (2009) also examined the accuracy of the acromion method using a marker cluster similar to that used in the current study and found it to be a valid method to examine scapular orientation when the upper arm was below 100° of elevation. The authors indicated, however, that the comparison method (a scapular locator device) would be ideal since the cluster method had a maximum mean difference of 8.4° (van Andel et al., 2009). However, the locator device cannot be used without a researcher/observer to regularly change its orientation. The acromion method was therefore used in the current study.

3.3.3 Collection protocol

Participants were seated at a computer workstation (height adjustable desk) in a height-adjustable chair (no armrests). The location of the computer monitor was adjusted such that it was approximately one arm’s length from the participant, and the height of the monitor was adjusted such that the top of the screen was at eye level. When the participant placed his or her fingers over the home row of the keyboard, the upper arms hung beside the torso, the elbows were bent slightly greater than 90°, the knees were bent approximately 90°, and the feet lay flat on the floor. The position of the chair was marked with tape so it was kept consistent from one condition to the next.

A static calibration trial was collected to establish a relationship between the acromial marker cluster and the three markers placed on the scapula (Figure 3.2). This allowed the marker cluster to be used to track the location of the three scapular markers during the experimental conditions. Participants performed five test conditions. Trunk and scapular kinematics were collected continuously during each condition. Each condition lasted 8 minutes, and the order of the conditions followed a Latin square design to minimize any order effect. A 10-minute walking break was given between conditions.

Condition 1: Watch video (with hands resting on thighs)

Participants positioned themselves at the computer workstation with their hands resting on their thighs, and a nature video was shown on the computer screen. Their task was to watch the video and to keep their hands resting on their thighs.

Condition 2: Watch video (with fingers resting over keyboard)

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists), and a nature video was shown on the computer screen (same clip as in condition 1). Their task was to watch the video and to keep their fingers on the home row of the keyboard.

Condition 3: Verbalize answer to computer task (with hands resting on thighs)

Participants positioned themselves at the computer workstation with their hands resting on their thighs. Once each second the written word blue, green, red, or yellow was presented on the computer screen in blue, green, red, or yellow font, respectively (i.e. the colour of the text matched the colour of the word as it was written), while that same word was heard through the earphones. Their task was to verbalize the word each second and to keep their hands resting on their thighs.

Condition 4: Verbalize answer to computer task (with fingers resting over keyboard)

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists). The task outlined in condition 3 was presented. Their task was to verbalize the word each second and to keep their fingers on the home row of the keyboard.

Condition 5: Key answer to computer task

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists). The task outlined in condition 3 was presented. Their task was to indicate the word each second by pressing the corresponding key on the keyboard (d=red, f=green, j=blue, and k=yellow). Prior to this condition participants were given one minute or more of practice.

Mechanical demand changed across conditions 1 and 2, and across conditions 3 and 4, by the change in hand/arm position. Condition 5 added an additional mechanical demand to conditions 2 and 4 as participants typed their answer.

Once the test conditions were complete participants were asked to perform 4 extreme motions with their shoulders: maximum elevation, maximum depression, maximum protraction, and maximum retraction. These motions were carried out with participants' arms in positions typical of computer work. This was a position that was most comfortable for participants to elicit the maximum with the restriction that their hands were either on their lap, by their side (upper arms hanging beside torso), or just over the keyboard/desk. The neutral starting position was one where the participants' upper arms hung relaxed beside their torso. The extreme motions were demonstrated for participants and they were able to practice if needed. Trunk and scapular kinematics were collected during each 5-second trial.

3.4 Analysis

3.4.1 Data processing

A model constructed in Visual 3D was used to quantify scapular motion, namely changes in medial/lateral rotation, protraction/retraction, and posterior/anterior tilt (Figure 3.3).

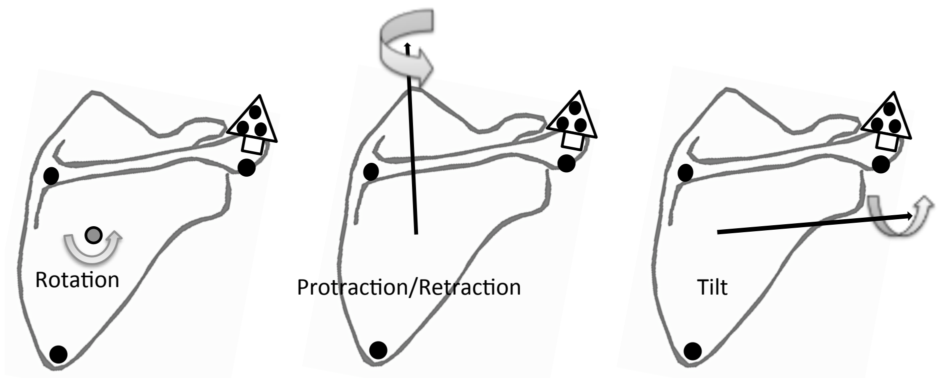


Figure 3.3. Movement of the scapula.

The model's thorax and scapular local coordinate system were constructed in accordance with Wu et al. (2005). The thorax segment had a +Y axis defined by the unit vector running from the distal segment end (midpoint of markers XP and T8) to the proximal segment end (midpoint of markers SN and C7) (pointing up), a +Z axis defined by the unit vector perpendicular to the +Y axis and the plane formed by the markers SN, C7, XP, and T8 (pointing to the participant's right), and a +X axis formed by the cross product of the +Y and +Z axes (pointing forward). The segment was tracked using the SN, C7, XP, and T8 markers.

The scapular segment had a +Z axis defined by the unit vector running from the distal segment end (midpoint of markers SS and IA) to the proximal segment end (midpoint of marker AA and a landmark marker created to construct the scapular local coordinate system) (pointing to the participant's right), a +X axis defined by the unit vector perpendicular to the

+Z axis and the plane formed by SS, IA, AA, and the landmark marker (pointing forward), and a +Y axis formed by the cross product of the +Z and +X axes (pointing up). The segment was tracked using the 3 markers on the acromion marker cluster.

Motion of the scapula was expressed relative to the thorax; the first rotation described protraction (positive)/retraction (negative), the second rotation described medial (positive)/lateral (negative) rotation, and the third rotation described posterior (positive)/anterior (negative) tilt (Wu et al., 2005). Kinematic data was low-pass filtered using a dual pass Butterworth filter with a cutoff frequency of 4Hz (Chopp, Fischer, & Dickerson, 2011; Fischer, 2011). Kinematic signals in units of degrees were exported from Visual3D for each test condition, each extreme motion trial, and a standing neutral position trial.

To address objective 3, three-dimensional changes in scapular orientation were quantified for each of the five computer tasks. First, the derivative of each kinematic signal (medial/lateral rotation, protraction/retraction, and posterior/anterior tilt) was taken producing three new signals in units of degrees/second. The standard deviation (degrees/second) of the middle 7 minutes of task 1 was taken to quantify baseline noise for each axis of rotation. Task 1 was chosen because it was the most restful trial, and the middle 7 minutes was used to minimize any effect related to the start or end of the task. For each test condition and each axis of rotation, time points were documented when the signal exceeded twice the documented standard deviation (2SD) and when the signal passed below this threshold; time windows with exceeded threshold values on a given axis of rotation were merged if they occurred less than one second apart. “Scapular movements” were said to occur when time windows with exceeded threshold values overlapped on at least two of the three axes of rotation; the duration of a movement was the duration of the overlapping windows. The original kinematic signals (units of degrees) were used to quantify the size of the scapular movements for each axis of rotation. Figure 3.4 illustrates a scapular movement. Simple linear regression was used to quantify the change in orientation between movements, and a time-weighted average of the slopes was calculated for medial/lateral rotation, protraction/retraction, and posterior/anterior tilt. This analysis was carried out using LabChart 7.1 and Excel.

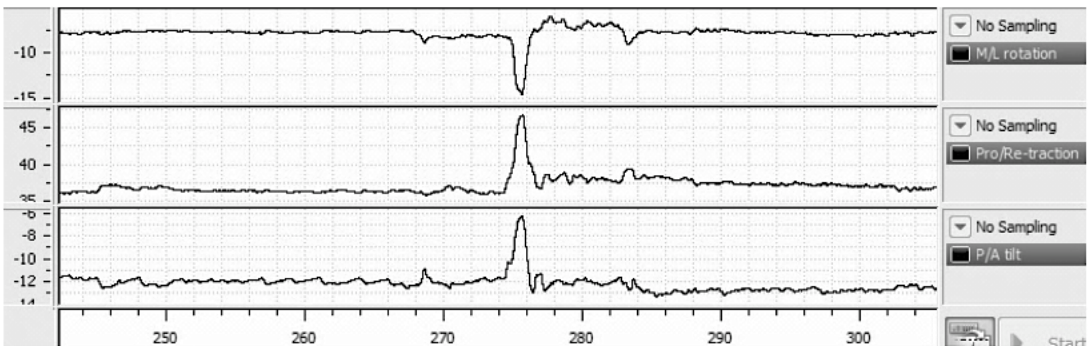


Figure 3.4. Example of a scapular movement: medial lateral rotation (top window), protraction/retraction (middle window), and posterior/anterior tilt (bottom window); angle (degrees) on the Y-axis and time (s) on the X-axis. *Note: graphic generated using LabChart 7.1.

3.4.2 Statistical analysis

Normality of the data was examined using q-q plots and p-p plots. An alpha level of 0.05 was used in all analyses. To address objectives 1 and 2, data from the extreme motion trials were used to calculate the maximum scapular motion seen during computer work, and data from the five computer tasks (mean of middle 7 minutes) was normalized to each participant's maximums (medial/lateral rotation, protraction/retraction, and posterior/anterior tilt). Box plots were used to describe the position of the scapula within the participants' maximum ranges during a neutral standing trial (anatomical position) and during the five computer tasks. A one-way repeated measures analysis of variance (ANOVA) was used to compare the six normalized positions. Mauchly's test was used to determine whether the sphericity assumption was met. If the assumption was violated the effect (condition) and error degrees of freedom were adjusted based on the Huynh-Feldt epsilon value (ε). Post hoc examination of group differences was made using Tukey's HSD test for multiple comparisons.

To address the first hypothesis for objective 3, the number, duration, and size of scapular movements present during each computer task was quantified (section 3.4.1). The middle 7 minutes of each 8-minute condition was used to minimize any effect related to the start and/or end of a trial. For each participant, a mean value for each test condition was generated for the duration of movements and the size of movements (along each axis of rotation). One-way repeated measures ANOVA was used to compare the number, mean duration (seconds), and mean size (degrees) of movements across computer tasks. To address the second hypothesis for objective 3, one-way repeated measures ANOVA was used to compare the time-weighted average slope (section 3.4.1) across tasks. Mauchly's test was used to determine whether the sphericity assumption was met for each repeated measures ANOVA. If the assumption was violated, the effect (condition) and error degrees of freedom were adjusted based on the Huynh-Feldt epsilon value (ε). Post hoc examination of group differences was carried out using Tukey's HSD test for multiple comparisons.

3.5 Results

3.5.1 Maximum scapular motion during computer work

Mean values and standard deviations for all participants for maximum scapular rotation, protraction/retraction, and tilt are presented in Table 3.1.

	Rotation (degrees)				Protraction/Retraction (degrees)				Tilt (degrees)			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
All	31.7	6.4	42.8	21.5	39.8	13.4	66.9	23.7	17.5	5.5	27.6	10.3
Female	31.4	6.8	41.0	21.5	36.6	10.8	51.5	23.7	19.3	5.2	25.7	12.1
Male	32.1	6.4	42.8	23.8	43.1	15.6	66.9	25.0	15.7	5.6	27.6	10.3

Table 3.1. Maximum range of motion for rotation, protraction/retraction, and tilt, with arms are in postures typical of computer work (N=16).

3.5.2 Scapular position during neutral and computer work

Box plots describing mean normalized position for medial/lateral rotation, protraction/retraction, and posterior/anterior tilt, during a standing neutral trial and during each of the five computer tasks, are presented below (Figures 3.5 to 3.7). Figures 3.5 and 3.6 demonstrate that, compared to neutral, participants held a more laterally rotated and protracted position of the scapula during computer work. Participants also tended to hold a more laterally rotated, protracted, and posteriorly tilted position of the scapula during computer tasks where their hands rested over the keyboard's home row (or typed) compared to tasks where their hands rested on their lap (Figures 3.5 to 3.7).

Mauchly's test indicated that the sphericity assumption was violated (χ^2 (14)=39.33, p=0.0003) for the one-way ANOVA examining the dependent measure normalized mean position for rotation, and therefore the Huynh-Feldt Epsilon (ε=0.54) was used to modify the degrees of freedom. The main effect of condition was statistically significant: F(2.68,40.20)=14.53, p<0.001. Means and standard deviations for neutral, task 1, task 3, task 2, task 4, and task 5 were 88.41% (8.38), 78.61% (11.42), 78.82% (9.05), 72.45% (13.53), 71.90% (13.24), and 72.15% (14.68), respectively (Figure 3.5). Post hoc analyses demonstrated that the neutral position was statistically different (p<0.05) from each task.

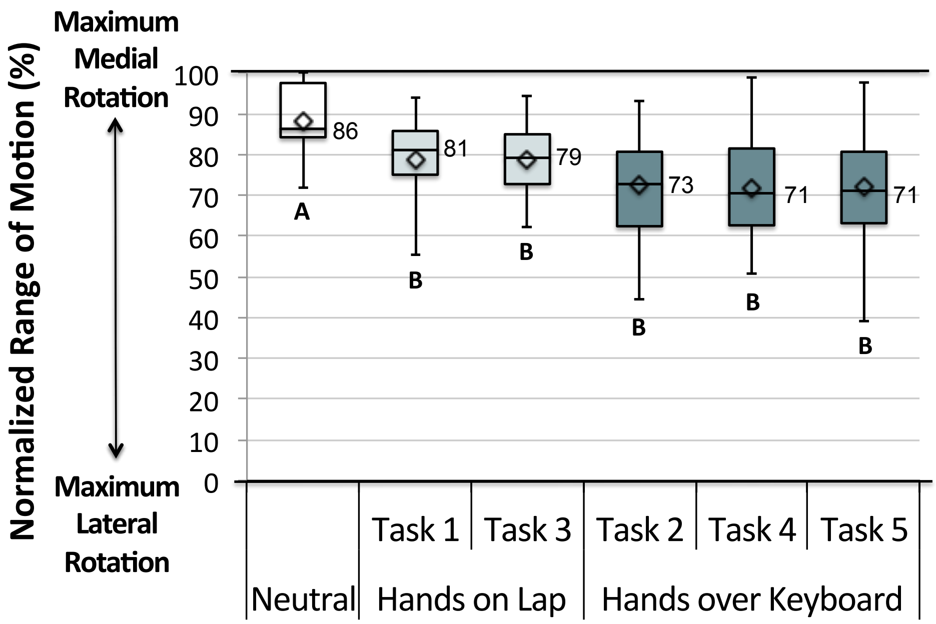


Figure 3.5. Box plots for medial/lateral rotation (N=16) showing the minimum, 25th percentile, median (value indicated), mean (signified by ◆), 75th percentile, and maximum for normalized mean position during neutral and each of the five test conditions. Box plots with different letters have significantly different means (p<0.05).

Mauchly's test indicated the sphericity assumption was violated (χ^2 (14)=46.98, p<0.0001) for the one-way ANOVA examining the dependent measure normalized mean position for protraction/retraction, and therefore the Huynh-Feldt Epsilon (ε=0.44) was used to modify the degrees of freedom. The main effect of condition was statistically significant: F(2.22,33.34)=15.65, p<0.001. Means and standard deviations for neutral, task 1, task 3, task 2, task 4, and task 5 were 48.08% (10.35), 62.25% (9.88), 63.55% (11.10), 67.39% (12.95), 65.50% (10.87), and 66.52% (11.51), respectively (Figure 3.6). Post hoc analyses demonstrated that the neutral position was statistically different (p<0.05) from each task.

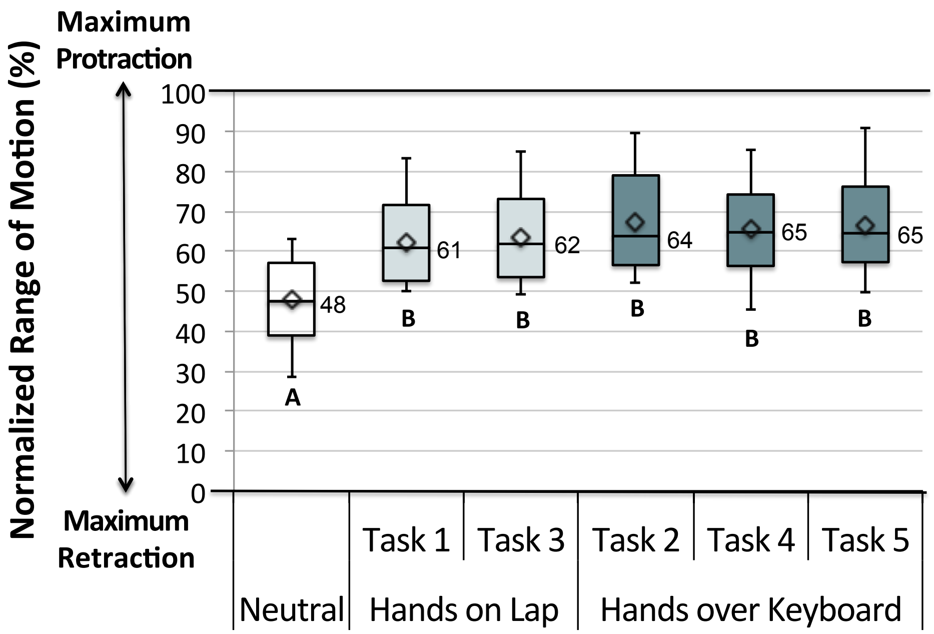


Figure 3.6. Box plots for protraction/retraction (N=16) showing the minimum, 25th percentile, median (value indicated), mean (signified by ◆), 75th percentile, and maximum for normalized mean position during neutral and each of the five test conditions. Box plots with different letters have significantly different means (p<0.05).

Mauchly's test indicated the sphericity assumption was not violated (χ^2 (14)=19.55, p=0.145) for the one-way ANOVA examining the dependent measure normalized mean position for tilt. The main effect of condition was statistically significant: F(5,75)=4.31, p=0.002. Means and standard deviations for neutral, task 1, task 3, task 2, task 4, and task 5 were 54.31% (22.06), 53.37% (21.96), 52.44% (21.28), 62.42% (19.58), 60.11% (22.90), and 60.09% (22.79), respectively (Figure 3.7). Post hoc analyses demonstrated that tasks 1 and 3 were statistically different from task 2 (p<0.05).

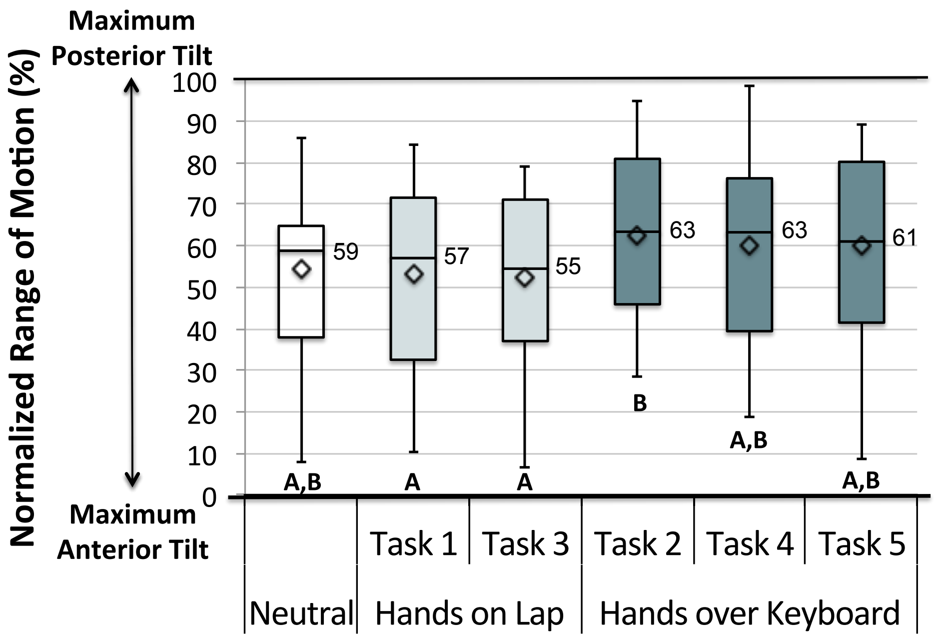


Figure 3.7. Box plots for posterior/anterior tilt (N=16) showing the minimum, 25th percentile, median (value indicated), mean (signified by ◆), 75th percentile, and maximum for normalized mean position during neutral and each of the five test conditions. Box plots with different letters have significantly different means ($p<0.05$).

3.5.3 Scapular movement during computer work

Results from the one-way repeated measures ANOVAs indicate the main effect of computer task was significant for mean duration of movements ($p<0.001$), and for mean size of movements for medial/lateral rotation ($p=0.049$), protraction/retraction ($p=0.048$), and posterior/anterior tilt ($p=0.037$) (Table 3.2). F values were not statistically significant for the time-weighted average of slopes with means across conditions for all three axes of rotation being close to 0 degrees/second.

Measure	Mauchly's Test (χ^2 (df), *p*-value)	Huynh-Feldt Epsilon (ε)	F value (df_{task}, df_{error})	*p*-value
Number of movements	22.96(9), 0.006	0.74	0.71 (2.97,44.51)	0.551
Mean duration (s)	3.59(9), 0.936	-	7.71 (4,60)	**<0.001**
Mean size of movements (°):				
medial/lateral rotation	26.97(9), 0.001	0.59	3.11 (2.34,35.16)	**0.049**
protraction/retraction	33.85(9), <0.001	0.67	2.99 (2.66,39.97)	**0.048**
posterior/anterior tilt	16.06(9), 0.066	0.70	3.18 (2.79,41.88)	**0.037**
Time-weighted average of slopes (°/s):				
medial/lateral rotation	56.72(9), <0.001	0.63	0.96 (2.54,38.12)	0.408
protraction/retraction	168.22(9), <0.001	0.28	1.00 (1.13,17.02)	0.342
posterior/anterior tilt	97.57(9), <0.001	0.34	1.45 (1.36,20.40)	0.251

Table 3.2. One-way repeated measures ANOVA results for measures of scapular movement across the five computer tasks. Statistically significant F values denoted by bolded *p*-values ($p<0.05$). N=16.

Figure 3.8 illustrates the statistically significant group differences for multiple comparisons examining duration of movements. With hands on lap, watching the video (task 1) involved scapular movements of statistically greater duration (mean=4.26 s, SD=1.69) than did vocalizing answers to the interactive computer task (task 3) (mean=2.77 s, SD=1.62). Likewise, with hands on keyboard, watching the video (task 2) involved scapular movements of statistically greater duration (mean=4.72 s, SD=1.69) than did vocalizing answers to the interactive computer task (task 4) (mean=3.23 s, SD=2.18). Typing answers to the computer task (task 5) resulted in scapular movements of duration (mean=5.19 s, SD=1.63) similar to those observed during both video viewing tasks (tasks 1 and 3).

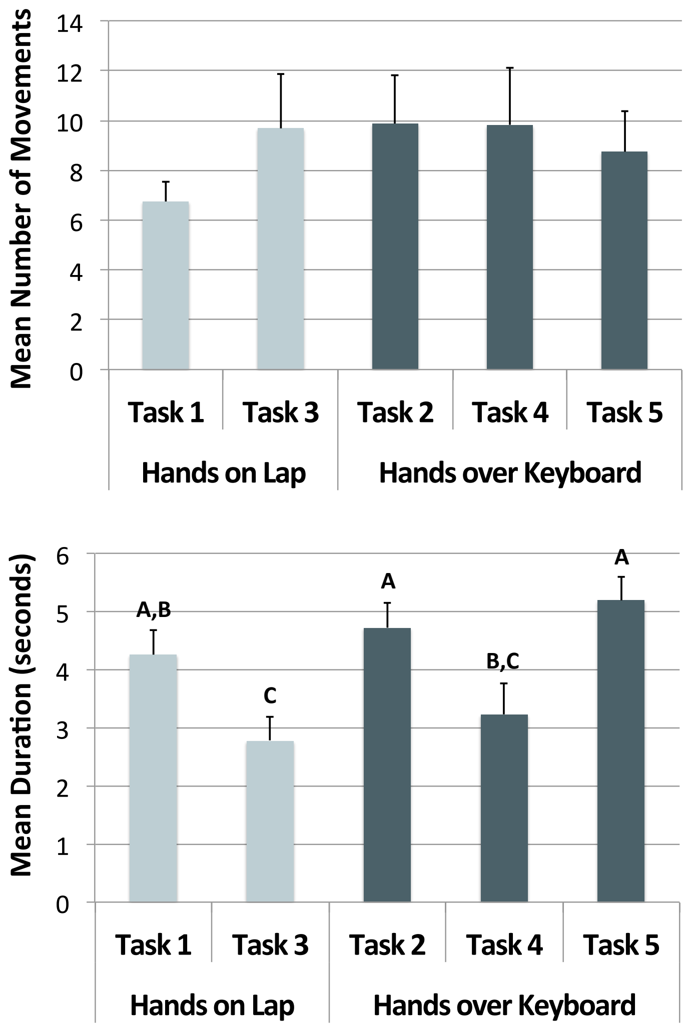


Figure 3.8. Mean number and duration of scapular movements during each of the five computer tasks. Bars with different letters have significantly different means (p<0.05). N=16.

Figure 3.9 illustrates the statistically significant group differences for multiple comparisons examining size of scapular movements along each axis of rotation. For medial/lateral rotation, with hands on lap, watching the video (task 1) resulted in statistically larger scapular movements (mean=2.02°, SD=2.26) than did vocalizing answers to the interactive computer task (task 3) (mean=0.79°, SD=0.91). Although not statistically significant, a similar trend was seen for hands over keyboard; watching the video (task 2) resulted in larger movements (mean=1.58°, SD=1.39) than did vocalizing answers to the interactive computer task (task 4) (mean=1.03°, SD=0.87). Typing answers to the computer task (task 5) involved medial/lateral rotation movements similar in size (mean=1.73°, SD=1.10) to those seen during both video viewing tasks (tasks 1 and 3) (Figure 3.9).

Furthermore, with hands on lap, watching a video (task 1) resulted in larger protraction/retraction movements (mean=2.25°, SD=2.80) than did vocalizing answers to the interactive computer task (task 3) (mean=1.34°, SD=2.17), though this difference was not statistically significant. Likewise, with hands over keyboard, watching the video (task 2) resulted in larger movements (mean=1.88°, SD=2.06) than did vocalizing answers to the interactive computer task (task 4) (mean=0.90°, SD=0.69). Again, this difference was not statistically significant. Typing answers to the computer task (task 5) involved protraction/retraction movements that were statistically larger (mean=2.35°, SD=2.34) than those observed when the answers were vocalized (task 4) (Figure 3.9).

The multiple comparisons test did not show statistically significant group differences for size of scapular movements along the axis of rotation for posterior/anterior tilt. This said, trends were similar to those seen for medial/lateral rotation and for protraction/retraction with means and standard deviations for task 1, task 3, task 2, task 4, and task 5 being 1.67° (1.36), 1.01° (0.95), 1.41° (1.01), 0.92° (0.60), and 1.58° (0.69), respectively (Figure 3.9).

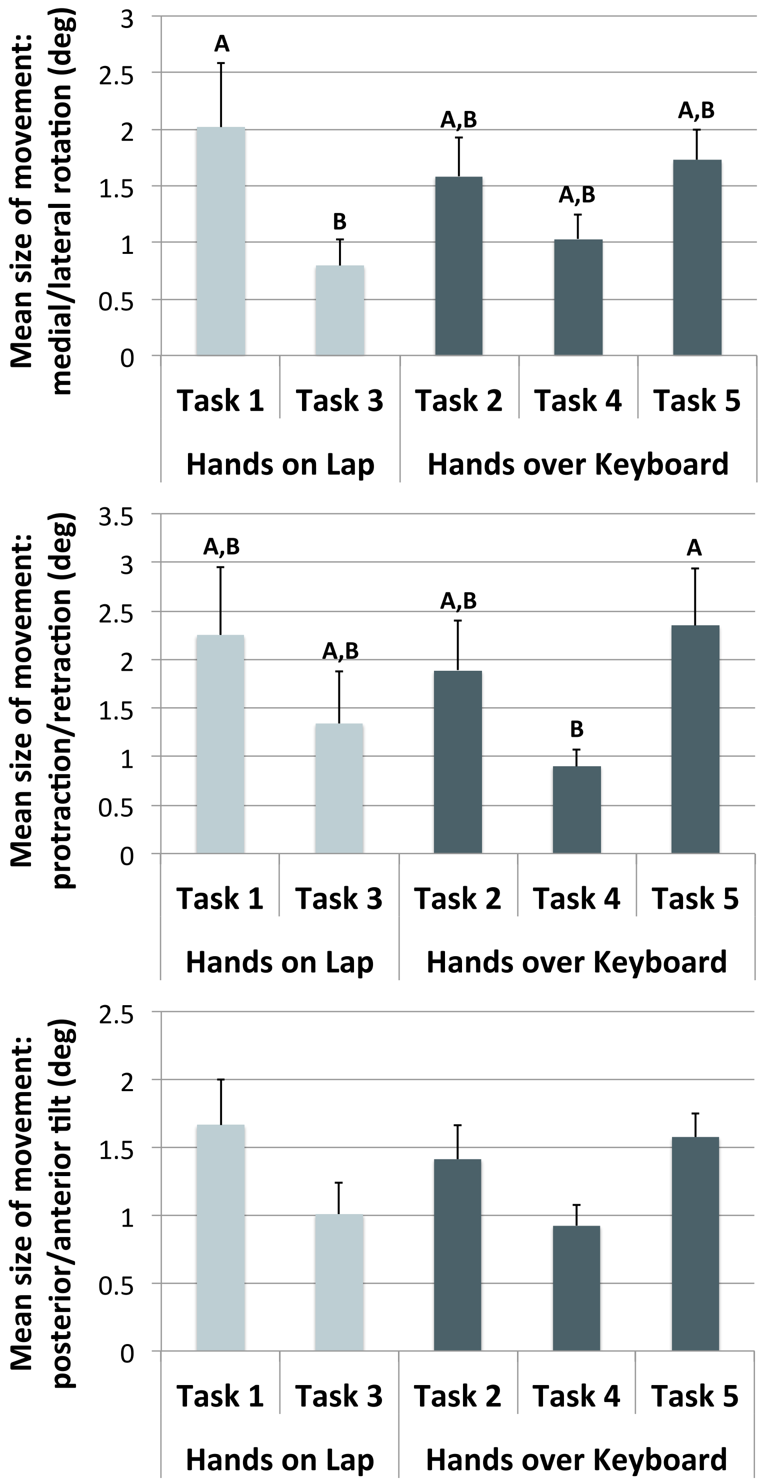


Figure 3.9. Mean size of movements (along the three axes of rotation) in each of the five computer tasks. Bars with different letters have significantly different means ($p<0.05$). N=16.

3.6 Discussion

This study quantified maximum scapular rotation, protraction/retraction, and tilt during computer work, and described the position of the scapula within this range during computer tasks of varying mechanical demand. Studies have examined scapular kinematics during arm elevation in the scapular plane (Ebaugh, McClure, & Karduna, 2005; McClure, Michener, Sennett, & Karduna, 2001; Ludewig, Cook, & Nawoczenski, 1996), with values of 50°, 24°, and 30° reported for rotation, protraction/retraction, and tilt, respectively (McClure et al., 2001), however these values do not provide a good sense of maximal possible range during computer work. This study revealed a mean range of 39.8° for protraction/retraction while the arms were in postures typical of computer work. The smaller range for protraction/retraction seen in the arm raising studies is due to motion being constrained to the scapular plane. The identification of these maximum ranges will permit future research to better describe scapular orientation during computer work.

Results from the current study indicated that, compared to neutral, participants held a more laterally rotated and protracted position of the scapula during computer work. More specifically, participants tended to assume a more laterally rotated and protracted position during computer tasks where their hands were over the keyboard compared to tasks where their hands were resting on their lap. These findings are of possible significance for health since protraction of the scapula is associated with decreased subacromial space (Solem-Bertoft et al., 1993), which in turn is related to should pathologies. Ludewig & Cook (2000) have suggested that small changes in protraction (4-6°) are important given the size of the subacromial space. Changes in orientation of 7° can reduce the space by roughly 25%, contributing to tissue compression and perhaps irritation and pain (Riek, Ludewig, & Nawoczenski, 2008). In the current study, the normalized mean scapular position during neutral was 48%, and during computer tasks this value ranged from 61 to 65 % (Figure 3.6); these values corresponded to a mean difference of 6.6° when examining neutral and the typing task. Thus, computer work is associated with scapular positions that may be sufficiently protracted to increase the compression of tissues in the subacromial space.

Clinicians suggest patients with work-related neck and upper extremity musculoskeletal disorders have "[a] 'forward head posture' (lower cervical flexion and upper cervical extension/head tilt to extension) and 'rounded shoulders' (scapular protraction and elevation)" (Szeto et al., 2000, p. 601). Though the cause and effect debate exists, it has been suggested this forward head posture may be a risk factor for MSD among computer users (Szeto et al., 2002). Szeto, Straker, and Raine (2002) examined movement patterns during computer work and found that individuals with neck/shoulder discomfort had greater protraction and elevation of the acromion than did individuals without neck/shoulder discomfort. This study, however, examined acromion position in two-dimension and did not assess the frequency of movements. The current study examined three-dimensional changes in scapular orientation during computer work. Although there were no statistically significant differences for number of movements across computer tasks, with the exception of typing, there were shorter and smaller scapular movements during computer activities that required more attention, regardless of hand position. During typing the duration and size of movements was similar to that found during video watching, however a limitation of the current study is that there was only one typing task so the effect of cognitive demand during typing could not be assessed.

Nonetheless, results indicated that measures of scapular movement differed across cognitive demand. Although muscle activity was not monitored, which may also be considered a limitation, previous work has demonstrated a non-postural load in the shoulder region during mentally demanding tasks (Laursen et al., 2002; Lundberg, et al., 2002b; Lundberg et al., 1994). For example, Lundberg et al. (1994) found that trapezius activity increased in response to the Stroop colour-word test and to mental arithmetic. Tense postures, observed in the current study through shorter and smaller scapular movements, may be a reflection of increased muscle loading in the neck/shoulder region during mentally demanding tasks (Laursen et al., 2002).

Computer users tend to experience prolonged low-level activation of muscles in the upper extremity (Szeto, Straker, & O'Sullivan, 2005; Peper et al., 2003); as well they experience sympathetic arousal and periods of immobility (Peper et al., 2003). Individuals tend to tighten muscles required to and not required to execute work tasks, and are often not aware of these efforts (Peper, Booiman, Tallard, & Takebayashi, 2010). The term dysponesis is used to describe these "misplaced and misdirected efforts" (Harvey & Peper, 2012, p. 147), with the bracing effort being one type (Whatmore & Kohli, 1974): "efforts to hold the body, or a part of the body, rigid or 'or guard'" (Peper et al., 2010, p.6). The bracing effort is sustained for "fight or flight" (Peper et al., 2010), and therefore it is likely rigid postures are more prevalent in tasks where cognitive demand, or psychological stress, is present. It may be hypothesized that the reduction in duration and size of scapular movements, seen in the current study during tasks that require more attention, is associated with the bracing effort (Whatmore & Kohli, 1974) and higher static activity in muscles involved in scapulothoracic movement, i.e. the trapezius, pectoralis major, serratus anterior, and others that cannot be monitored using surface EMG (rhomboids, levator scapulae, and pectoralis minor) (Jobe, Phipatanakul, & Coen, 2009), as well as other muscles of the upper extremity.

While it may be a limitation that this work was conducted among a restricted university sample, and thus caution with regard to transferability is warranted, to the knowledge of the authors this work provides first evidence of maximum scapular motion during computer work, and of where the scapula lies within these ranges during various tasks. This information will permit future research to better describe scapular orientation during computer work. Further, although laboratory studies have examined changes in scapular and upper extremity posture in relation to changes in workstation design (Straker et al., 2008; Kotani et al., 2007), and in relation to computer work (Gerr et al., 2000; Kleine et al., 1999), to the author's knowledge this is the first study to examine three-dimensional measures of scapular movement during computer work.

3.7 Implications for health in the workplace

This study provides a better understanding of the link between job demands and shoulder posture during computer work. Compared to neutral, computer work resulted in protracted postures large enough to somewhat compress tissues in the subacromial space and either aggravate a pre-existing shoulder condition or increase one's susceptibility to develop a condition. Interestingly, it was not the change in mechanical demand that notably changed the mean duration and size of scapular movements during computer work, but rather the change in cognitive demand. These findings contribute to the literature that emphasizes the importance of considering both the physical and psychosocial work environment when studying worker health. Chapter 4 will examine the effect of cognitive and mechanical demand on exposures related to both MSD and stress-related outcomes during computer work.

4.0 The effect of cognitive demand on musculoskeletal and stress-related exposures during computer work

4.1 Background

Computer use at work has increased in recent decades, and mechanical demands related to its use have been associated with upper extremity musculoskeletal symptoms and disorders (Hanse, 2002; Marcus et al., 2002; Aarås et al., 2000; Szeto et al., 2000; Punnett & Bergqvist, 1997). As previously emphasized, demands in both the physical and psychosocial domain are important to consider when studying musculoskeletal disorders (MSD) (Kompier & van der Beek, 2008; NIOSH, 1997; Smith & Carayon, 1996; Faucett & Rempel, 1994). In general, mechanical demands among computer users are low to moderate, and workplace hazards beyond those in the physical domain, in other words those related to the psychosocial work environment, are important for understanding and preventing MSD. According to Punnett and Bergqvist (1997), upper extremity MSD among visual display unit (VDU) users are more so a factor of work organization than narrowly the mechanical demands of the job.

Associations are well documented between mechanical demands during computer work and muscle activity (Hughes et al., 2007; Kotani et al., 2007; Dennerlein & Johnson, 2006b). For example, activity of the forearm flexor and extensor muscles, as well as trapezius and deltoid muscles, vary across computer task performed, including typing, form filling, text editing, graphing, and web-based tasks (Dennerlein & Johnson, 2006b). In addition, Hughes et al. (2007) have shown that increased typing speed during computer work, likely a combination of mechanical and psychosocial demand, results in increased activity of forearm muscles.

Links have been made between psychosocial demands and muscle activity during computer work (Larsman et al., 2009; Waersted & Westgaard, 1996). A non-postural load in the shoulder region is observed during cognitively demanding tasks (Laursen et al., 2002;

Lundberg, et al., 2002b; Lundberg et al., 1994). For example, Lundberg et al. (1994) found that trapezius muscle activity increased in response to the Stroop colour-word test and mental arithmetic (separately), and that muscle activity during a test contraction was higher when carried out concurrently with the Stroop test compared to when carried out alone. In addition, it has been shown that a mentally demanding and a physically demanding task may (separately) activate the same motor units, which has implications for certain types of work since breaks may not provide the respite needed if psychological stress persists past a task/event (Lundberg et al., 2002b). Many of these studies have concentrated on the trapezius muscle; it is located in an area commonly associated with musculoskeletal symptoms among computer users (Karlqvist et al., 2002).

Perception of demand is part of the cognitive appraisal process and is important for understanding physiological loads on the body. Reports of workload, which involve perceptions of both mechanical and psychosocial demand, measured for example using the NASA – Task Load Index (TLX) (Hart & Staveland, 1988), are important to consider since perception of high workload, even if demands are low, can influence psychological and physiological well being (Hart & Staveland, 1988).

Psychological stress can lead to a variety of physiological responses (McEwen, 1998), in addition to increased trapezius activity (Lundberg et al., 1994). In the laboratory, it has been shown that stress conditions simulated through mental arithmetic and the Stroop colour-word test increase stress hormone concentrations, as well as increase heart rate (HR) and blood pressure (BP), compared to baseline (Krantz et al., 2004; Lundberg et al., 1994). Perceived job stress is associated with low heart rate variability (HRV) (Thayer, Yamamoto, & Brosschot, 2010). Parameters commonly used to assess HRV include power in the low frequency (LF)

(0.04-0.15 Hz) range, an indication of sympathetic and parasympathetic activity, power in the high frequency (HF) (0.16-0.40 Hz) range, an indication of parasympathetic activity, and the LF/HF ratio, an indication of balance between the two systems (Eller, Kristiansen, & Hansen, 2011). Mulder, Mulder, Meijman, Veldman, and van Roon (2000) specify that power in the signal's 0.07-0.14 Hz range (i.e. LF range) is "an index of task-related mental effort" (Mulder et al., 2000, pg. 143).

Chapter 3 provided detail on laboratory studies that have examined changes in scapular and upper extremity posture in relation to computer work (Gerr et al., 2000; Kleine et al., 1999). Kleine et al. (1999) showed that changes in acromion position over time during VDU work linked to trapezius muscle activity. These changes in acromion position (Kleine et al., 1999) occurred during regular computer work, and to the knowledge of the author links between psychosocial demand during computer work and scapular position have not been well elucidated. Findings from chapter 3 suggest an effect of cognitive demand on the duration and size of scapular movements during work. Reduced scapular movement during tasks that require more attention may be a reflection of increased muscle loading in the neck/shoulder region since trapezius activity is higher during mentally demanding tasks (Lundberg et al., 1994).

4.2 Objective and hypotheses

The overall aim of this study was to document perceived workload and acute reactions in the physical and psychosocial domain during computer tasks of varying cognitive demand (Figure 4.1). More specifically, hypotheses were: 1) measures from the NASA-TLX will be different across levels of cognitive demand; 2) the number, duration, and size of scapular movements will be different across levels of cognitive demand; 3) a) the change in muscle activation which corresponds to scapular movements (for select scapulothoracic muscles) will be different across levels of cognitive demand, and b) trapezius activity, including measures of rest time and % maximum voluntary contraction (MVC), will be different across levels of cognitive demand; and 4) HR and the LF/HF ratio will be different across levels of cognitive demand.

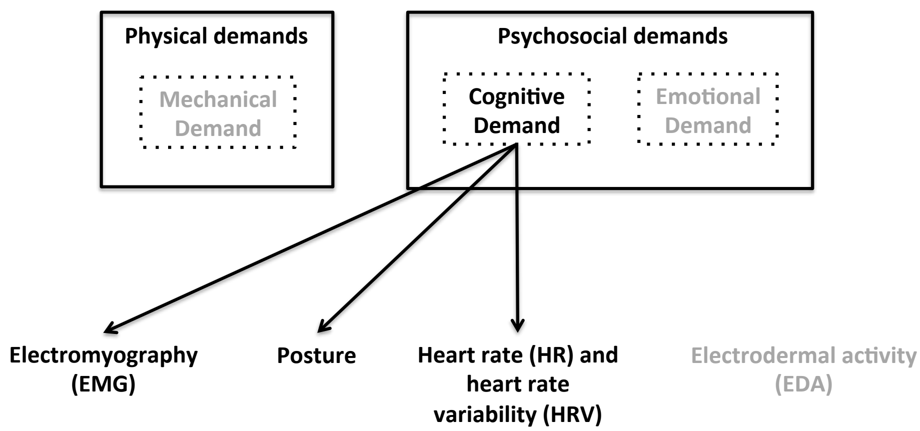


Figure 4.1. General layout showing independent (physical demands and psychosocial demands) and dependent (EMG, posture, HR/HRV, EDA) variables monitored in at least one study of the thesis; arrows demonstrate relationships focused on in chapter 4.

4.3 Methods

4.3.1 Participant population

Eight right-hand dominant touch-typists (female) were recruited from the University of Waterloo to participate. Potential participants who reported having injury or discomfort to their shoulders or neck in the week prior to the study, or who had an allergy or sensitivity to ethanol, were excluded. Trunk and scapular kinematics, electromyography (EMG), HR, and perceived workload were monitored while participants took part in eight computer tasks.

4.3.2 Instrumentation

4.3.2.1 NASA-Task Load Index (TLX)

The NASA-TLX was used to collect six measures of perceived workload: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988) directly after each test condition. Each of the measures was collected using a visual-analog scale that ranged from 0 (*low*) to 10 (*high*) (Appendix A).

4.3.2.2 Kinematic data

Refer to section 3.3.2 for a description of trunk and scapular kinematic data collection.

4.3.2.3 Electromyography

Bilateral EMG was collected from the upper and lower trapezius, the pectoralis major (clavicular insertion), and the serratus anterior. The trapezius was chosen since activation of this muscle is related to both physical and cognitive demand during computer work (Dennerlein & Johnson, 2006a; Laursen et al., 2002). The pectoralis major and the serratus anterior were also examined because these muscles, together with the trapezius and other muscles of the shoulder region that cannot be monitored using surface EMG (i.e. the rhomboids, the levator scapulae, and the pectoralis minor), are involved in scapulothoracic movement (Jobe et al., 2009). The trapezius acts to retract the scapula as well as elevate the lateral angle; the pectoralis major indirectly aids to depress the lateral angle; and the serratus anterior acts in scapular protraction, and with the levator scapulae, in upward rotation (Jobe et al., 2009).

Pairs of silver-silver chloride electrodes (Ambu® Blue Sensor N, 20mm inter-electrode distance) were affixed over the muscles parallel to the muscle fibers. A reference electrode was placed over the clavicle. Table 4.1 provides a description of electrode placement. The skin was prepared by cleansing with a solution of water and ethanol at each electrode site to minimize impedance. EMG signals were collected using the Noraxon Telemyo 2400 T G2 telemetered system (Noraxon, Arizona, USA). The raw signal was differentially amplified to produce maximum amplification of the signal (common-mode rejection ratio of >100 dB and input impedance of 100MΩ), bandpass filtered from 10-500Hz, and analog/digital converted at 1500 samples per second (16-bit analog/digital card with +/- 3.5V range). Before the collection procedure began, three MVCs were collected for each muscle (Table 4.1) so data from the experimental conditions could be normalized.

Muscle	**Electrode placement (Cram & Kasman, 1998)**	**Maximum voluntary contraction (similar to Brookham, 2008; Cram & Kasman, 1998)**
Upper Trapezius	Placed “along the ridge of the shoulder, slightly lateral to and one half the distance between the cervical spine C-7 and the acromion” (Cram & Kasman, 1998, p. 273).	Participant lies prone with their head turned to the side of the MVC; researcher resists abduction of the shoulder at 90° (elbow extended and thumb pointing toward floor).
Lower Trapezius	Placed “next to the medial edge of the scapula at a 55-degree oblique angle” (Cram & Kasman, 1998, p. 277) 5 cm below spine of scapula (Cram & Kasman, 1998).	Participant lies prone with their head turned to the side of the MVC; researcher resists shoulder retraction (backward and downward) with arm abducted at 90° (elbow extended and thumb pointing toward ceiling).
Pectoralis Major (clavicular insertion)	Placed “on the chest wall at an oblique angle toward the clavicle, approximately 2 cm below the clavicle, just medial to the axillary fold” (Cram & Kasman, 1998, p. 293).	Participant sits and flexes both shoulder and elbow to 90°; researcher resists horizontal adduction and flexion of the shoulder.
Serratus Anterior	Placed “just below the axillary area, at the level of the inferior tip of the scapula, and just medial of the latissimus dorsi” (Cram & Kasman, 1998, p. 281).	Using a horizontal bar in a fixed location, participant pushes to protract the shoulders.

Table 4.1. Electrode placements and maximum voluntary contractions.

4.3.2.4 Heart rate and the LF/HF ratio

The Burdick EK10 (Siemens, Wisconsin, USA) was used for single-lead ECG monitoring continuously during each condition. One ECG pad (Positrace® Adult) was placed over the right 5^{th} intercostal space (between the 5^{th} and 6^{th} rib) at the mid-clavicular line (ground electrode), a second ECG pad was placed over the left 5^{th} intercostal space at the mid-clavicular line (positive electrode), and a third ECG pad was placed over the manubrium of the sternum (negative electrode), as suggested by Brubaker, Kaminsky, and Whaley (2002). The signal was unfiltered and sampled at 1500Hz.

4.3.3 Collection protocol

Participants were seated at a computer workstation (height adjustable desk) in a height-adjustable chair (no armrests). The location of the computer monitor was adjusted such that it was approximately one arm's length from the participant, and the height of the monitor was adjusted such that the top of the screen was at eye level. When the participant placed his or her fingers over the home row of the keyboard, the upper arms hung beside the torso, the elbows were bent slightly greater than 90°, the knees were bent approximately 90°, and the feet lay flat on the floor. The position of the chair was marked with tape so it was kept consistent from one condition to the next.

A static calibration trial was collected to establish a relationship between the acromial marker cluster and the three markers placed on the scapula (Figure 3.2). This allowed the marker cluster to be used to track the location of the three scapula markers during the experimental conditions. Eight conditions were performed; trunk and scapular kinematics, EMG, and HR were collected continuously during each. Each condition lasted 8 minutes, and the order of the conditions followed a Latin square design to minimize any order effect. A 10-minute walking break was given between conditions.

Condition 1: Watch video (with hands resting on thighs)

Participants positioned themselves at the computer workstation with their hands resting on their thighs, and a nature video was shown on the computer screen. Their task was to watch the video and to keep their hands resting on their thighs.

Condition 2: Watch video (with fingers resting over keyboard)

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists), and a nature video was shown on the computer screen (same clip as in condition 1). Their task was to watch the video and to keep their fingers on the home row of the keyboard.

Condition 3: Verbalize answer to baseline computer task (with hands resting on thighs)

Participants positioned themselves at the computer workstation with their hands resting on their thighs. Once each second the written word blue, green, red, or yellow was presented on the computer screen in blue, green, red, or yellow font, respectively (i.e. the colour of the text matched the colour of the word as it was written). Their task was to verbalize the word each second and to keep their hands resting on their thighs.

Condition 4: Verbalize answer to baseline computer task (with fingers resting over keyboard)

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists). The task outlined in condition 3 was presented. Their task was to verbalize the word each second and to keep their fingers on the home row of the keyboard.

Condition 5: Verbalize answer to Stroop colour-word test (with hands resting on thighs)

Participants positioned themselves at the computer workstation with their hands resting on their thighs. A computerized version of the Stroop colour-word test (MacLeod, 1991) presented them with contradictory information once each second. For example, the written word red was presented on the screen in yellow font. Their task was to verbalize the answer, i.e. the colour of the text, each second (in the example, the answer would be "yellow") and to keep their hands resting on their thighs.

Condition 6: Verbalize answer to Stroop colour-word test (with fingers resting over keyboard)

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists). The task outlined in condition 5 was presented. Their task was to verbalize the answer each second, and to keep their fingers on the home row of the keyboard.

Condition 7: Type answer to baseline computer task

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists). The task outlined in condition 3 was presented. Their task was to indicate the word each second by pressing the corresponding key on the keyboard (d=red, f=green, j=blue, and k=yellow). Prior to this condition participants were given one minute or more of practice.

Condition 8: Type answer to Stroop colour-word test

Participants positioned themselves at the computer workstation with their fingers resting over the home row of the keyboard (without resting their wrists). The task outlined in condition 5 was presented. Their task was to indicate the answer each second by pressing the corresponding key on the keyboard (d=red, f=green, j=blue, and k=yellow).

4.4 Data analysis

Mechanical demand was kept constant across conditions 1, 3, and 5 (hands resting on thighs) and across conditions 2, 4, and 6 (fingers resting over home row of keyboard), however cognitive demand increased across each of these groupings. Cognitive demand also increased across conditions 7 and 8, during which time mechanical demand likely remained constant. Conceptually it did not fit to add a ninth condition where participants would type answers while watching a video. Since the design was not full factorial (Figure 4.2), a two-way repeated measures analysis of variance (ANOVA) was used to examine dependent measures across conditions 1 through 6, and a paired t-test was used to compare measures across conditions 7 and 8. For each repeated measures ANOVA, Mauchly's test was used to determine whether the sphericity assumption was met; if the assumption was violated then the effect and error degrees of freedom were adjusted based on the Huynh-Feldt epsilon value (ε). Post hoc examination of group differences was made using Tukey's HSD test for multiple comparisons. Normality of the data was examined using q-q plots and p-p plots. An alpha level of 0.05 was used in all analyses.

		Cognitive demand		
		Video watching	**Baseline computer task**	**Stroop computer task**
Mechanical demand	**Hands on lap**	Condition 1	Condition 3	Condition 5
	Hands over keyboard	Condition 2	Condition 4	Condition 6
	Typing	-	Condition 7	Condition 8

Figure 4.2. Outline of experimental conditions in chapter 4.

4.4.1 Perceived workload

Data from the paper and pencil NASA-TLX were scored and recorded electronically. To test the first hypothesis, a two-way repeated measures ANOVA was used to compare conditions 1 through 6, and a paired t-test was used to compare conditions 7 and 8.

4.4.2 Kinematic data

The Visual3D model described in section 3.4.1 was used to process kinematic data and to examine changes in scapular orientation, i.e. medial/lateral rotation, protraction/retraction, and posterior/anterior tilt (Figure 3.3). The number, duration, and size of scapular movements were quantified using the procedure outlined in section 3.4.1. To test the second hypothesis, a two-way repeated measures ANOVA was used to compare conditions 1 through 6, and paired t-test was used to compare conditions 7 and 8.

4.4.3 Electromyography

As with the kinematic data, the middle 7 minutes of each 8-minute condition was used for analysis to minimize any effect related to the start or end of a trial. Both % MVC and EMG gaps (Veiersted, Westgaard, & Andersen, 1990) were examined for the right and left trapezius. Prior to converting EMG signals to a percent of maximum, data was linear enveloped through full wave rectification and low-pass filtering (Winter, 2005) using a single-pass digital Butterworth filter with cutoff frequency of 4Hz (Fischer, 2011). A one-second moving average was used to determine the highest second within each MVC trial. The highest value from the three MVCs was used to express the linear enveloped data as a percent of maximum. Mean % MVC over consecutive 1-minute windows was calculated for each condition resulting in seven data points; an average value was generated for each condition. EMG gaps analysis provided an indication of muscular rest (Veiersted et al., 1990). A gap was defined as muscle activity below 1 % MVC for 0.2 seconds or more (Mathiassen, Burdorf, van der Beek, & Hansson, 2003). Rest time expressed as a fraction of total time was calculated for each condition using 1-minute consecutive windows; an average value was generated for each condition. To test the second part of the third hypothesis, a two-way repeated measures ANOVA was used to compare conditions 1 through 6, and a paired t-test was used to compare conditions 7 and 8.

Change in % MVC associated with scapular movements was calculated for the right upper trapezius, the right lower trapezius, the right serratus anterior, and the right pectoralis major (clavicular insertion). For each scapular movement, a 5-second mean was calculated for the window just before the movement, and a mean value was calculated for the duration of the movement; the difference provided the change in % MVC. An average delta, or change, was generated for each condition. To test the first part of the third hypothesis, a two-way repeated measures ANOVA was used to compare conditions 1 through 6, and a paired t-test was used to compare conditions 7 and 8. All EMG analysis was conducted using MATLAB®, LabChart 7.1, and Excel.

4.4.4 Heart rate and the LF/HF ratio

ECG data was missing for two of eight participants, and therefore inter-beat-interval (IBI) data was extracted from the left serratus anterior (LSA) EMG signal for each participant using LabChart 7.1. LabChart was also used to extract IBI values from the ECG signal for the six participants with this data. For these six participants, IBI data for condition 1 from the LSA signal and from the ECG signal were put into a linear regression model; ECG IBI data was the independent variable and LSA IBI data was the dependent variable. The intercept parameter estimate was 0.0 and the slope parameter estimate was 1.0. The R-square value was 1.0. A linear model using IBI data from condition 8 produced the same results. Thus, IBI data extracted from the LSA EMG signal was used to estimate HR and LF/HF ratios for all participants.

HR and LF/HF ratios were calculated by Kubios HRV version 2.1; Kubios HRV uses MATLAB® to run (Tarvainen, Niskanen, Lipponen, Ranta-aho, & Karjalainen, 2014). Upon import, IBI data was converted to a signal with equidistant samples using cubic spline interpolation (4Hz) so time and frequency domain parameters could be calculated for each condition. Detrending of the signal was carried out to remove "slow nonstationary trends" (Tarvainen, Ranta-aho, & Karjalainen, 2002, pg. 172), such as those related to thermoregulation or the renin-angiotensin system (Berntson et al., 1997), using the smoothness prior method (Lambda = 500) (Tarvainen et al., 2002). As outlined by Tarvainen et al. (2014) this method "is basically a time-varying high-pass filter and its cut-off frequency can be adjusted with the Lambda parameter" (Tarvainen et al., 2014, pg. 215). The frequency spectrum was estimated using Fast Fourier Transform (FFT) (Tarvainen et al., 2014).

Power in units of ms^2 was estimated for the LF (0.04-0.15 Hz) and HF (0.15-0.40 Hz) bands in order to calculate the $LF[ms^2]/HF[ms^2]$ ratio, which is said to reflect the balance between the sympathetic and parasympathetic systems (Cerutti, Bianchi, & Mainardi, 1995). At least two minutes of data is required to examine power in the LF band (Task Force of The European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). Therefore, for each condition, the number of beats per minute (BPM) and the LF/HF ratio was calculated over consecutive 2-minute windows; these windows were used to generate an average for each dependent measure. To test the fourth hypothesis, a two-way repeated measures ANOVA was used to compare conditions 1 through 6, and a paired t-test was used to compare conditions 7 and 8.

4.5 Results

4.5.1 Perceived workload

Figure 4.3 illustrates ratings of workload across the eight computer tasks/conditions. Results from the two-way repeated measures ANOVA (Table 4.2) indicate that the main effect of mechanical demand, which had 2 levels (hands on lap and hands over keyboard), was statistically significant for the NASA-TLX measure physical demand (p=0.015); the mean rating for hands on lap was 1.79 (SE=0.59) and the mean rating for hands over keyboard was 3.12 (SE=0.57).

The ANOVA results also indicate that the main effect of cognitive demand, which had 3 levels (video watching, baseline tasks, and Stroop colour-word tasks), was statistically significant for the NASA-TLX measures mental demand (p<0.001), temporal demand (p<0.001), effort (p=0.004), performance (p<0.001), and frustration (p=0.041) (Table 4.2). Post-hoc analysis for mental demand indicated that all three levels of cognitive demand were different from one another (p<0.05); the mean rating for video watching was 1.00 (SE=0.41), the mean rating for baseline tasks was 3.56 (SE=0.92), and the mean rating for Stroop colour-word tasks was 6.37 (SE=0.62). Likewise, post-hoc analysis for temporal demand indicated that all three levels were different from one another (p<0.05); the mean rating for video watching was 0.56 (SE=0.28), the mean rating for baseline tasks was 3.31 (SE=0.72), and the mean rating for Stroop colour-word tasks was 6.16 (SE=0.70). Post-hoc analysis for effort showed that ratings were statistically different (p<0.05) for video watching (mean=2.56, SE=0.59) and the Stroop colour-word tasks (mean=6.28, SE=0.57), and for baseline tasks (mean=3.34, SE=0.74) and the Stroop colour-word tasks. Similarly, post-hoc analysis for performance showed that ratings were statistically different (p<0.05) for video watching (mean=1.31, SE=0.37) and the Stroop colour-word tasks (mean=4.34, SE=0.73), and for baseline tasks (mean=1.16, SE=0.41) and the Stroop colour-word tasks. Lastly, post-hoc analysis for frustration indicated a statistically significant difference ($p<0.05$) between video watching (mean=1.41, SE=0.36) and Stroop colour-word tasks (mean=4.06, SE=0.87).

Although the workload measures did not differ statistically across the two typing tasks (Table 4.3), it can be seen from Figure 4.3 that each of the six workload measures was higher for the Stroop task (task 8) compared to the baseline task (task 7). If effect sizes are examined, it can be seen that there is at least a medium effect (Cohen, 1992) for effort (Cohen's d=0.663).

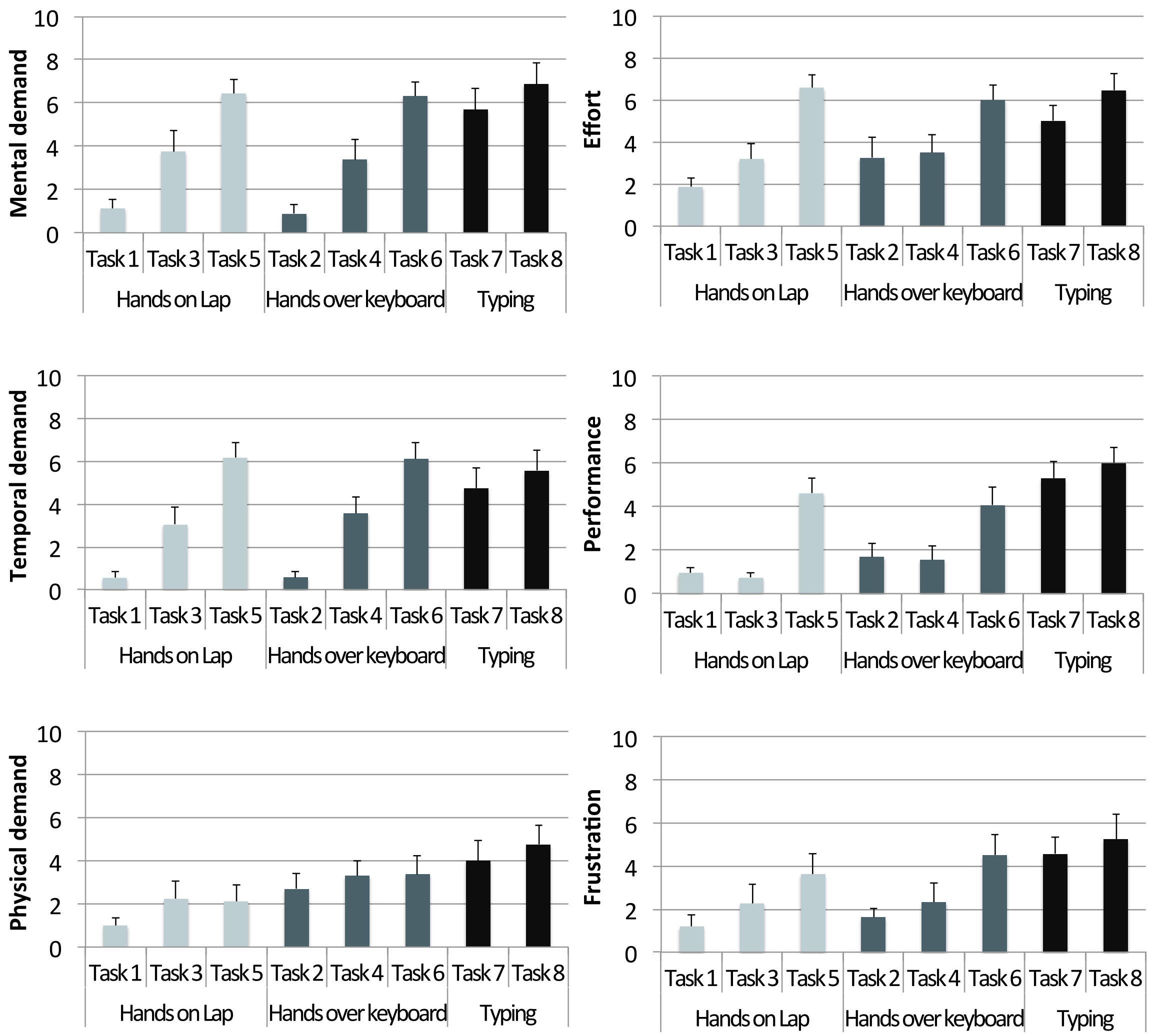


Figure 4.3. Mean NASA-TLX ratings for each of the eight computer tasks. N=8.

Measure and source of variation	**Mauchly's Test (χ^2 (df), *p*-value)**	**Huynh-Feldt Epsilon (ε)**	**F value (df_{task}, df_{error})**	***p*-value**	**Partial eta Squared (η_p^2)**
Mental demand					
Mech	-	-	1.05 (1,7)	0.340	0.130
Cog	0.23(2), 0.891	-	19.58 (2,14)	**<0.001**	0.737
*Mech*Cog*	7.07(2), 0.029	0.64	0.12 (1.28,8.97)	0.799	0.017
Physical demand					
Mech	-	-	10.12 (1,7)	**0.015**	0.591
Cog	2.04(2), 0.361	-	1.66 (2,14)	0.225	0.192
*Mech*Cog*	2.34(2), 0.311	-	0.23 (2,14)	0.796	0.032
Temporal demand					
Mech	-	-	0.38 (1,7)	0.557	0.051
Cog	3.21(2), 0.201	-	18.40 (2,14)	**<0.001**	0.724
*Mech*Cog*	4.54(2), 0.103	-	0.32 (2,14)	0.732	0.044
Effort					
Mech	-	-	0.86 (1,7)	0.386	0.109
Cog	2.08(2), 0.353	-	8.21 (2,14)	**0.004**	0.540
*Mech*Cog*	4.14(2), 0.126	-	1.97 (2,14)	0.176	0.220
Performance					
Mech	-	-	1.38 (1,7)	0.278	0.165
Cog	4.19(2), 0.123	-	12.56 (2,14)	**<0.001**	0.642
*Mech*Cog*	0.01(2), 0.994	-	1.87 (2,14)	0.191	0.210
Frustration					
Mech	-	-	1.93 (1,7)	0.207	0.216
Cog	0.47(2), 0.789	-	4.06 (2,14)	**0.041**	0.367
*Mech*Cog*	0.04(2), 0.978	-	0.37 (2,14)	0.699	0.050

Table 4.2. Two-way repeated measures ANOVA results for measures of workload across conditions 1 through 6. Mech=mechanical demand and has 2 levels (hands on lap and hands over keyboard). Cog=cognitive demand and has 3 levels (video watching, baseline computer tasks, Stroop colour-word tasks). Statistically significant F values denoted by bolded *p*-values ($p<0.05$). N=8.

Measure	**Mean difference (condition 7 - 8)**	**Standard Error**	**t value (df)**	***p*-value**	**Cohen's *d***
Mental demand	-1.19	0.74	-1.60 (7)	0.154	0.424
Physical demand	-0.75	0.33	-2.29 (7)	0.056	0.287
Temporal demand	-0.81	0.40	-2.03 (7)	0.082	0.298
Effort	-1.44	0.75	-1.91 (7)	0.098	0.663
Performance	-0.69	0.77	-0.90 (7)	0.400	0.324
Frustration	-0.69	0.80	-0.86 (7)	0.419	0.248

Table 4.3. Results from the paired t tests comparing workload measures across conditions 7 and 8. Statistically significant t values denoted by bolded *p*-values ($p<0.05$). N=8.

4.5.2 Scapular movements

Figure 4.4 illustrates the mean number, duration, and size of scapular movements across the eight computer tasks/conditions. Results from the two-way repeated measures ANOVA (Table 4.4) indicate that the interaction effect was statistically significant for number of movements (p=0.001). As seen in Figure 4.4, with hands on lap, there was an increase in the mean number of scapular movements as cognitive demand increased (from task 1 to task 5). Post-hoc analysis indicated that the mean number of scapular movements in task 1 (mean=5.75, SE=1.10) was statistically different ($p<0.05$) from the mean number in task 5 (mean=11.00, SE=3.05). However, with hands over keyboard, the opposite trend was seen. There was a decrease in the mean number of scapular movements as cognitive demand increased (from task 2 to task 6); post-hoc analysis did not reveal statistically significant group differences. It is noteworthy that the main effect of cognitive demand had a large effect (Richardson, 2011) for mean duration of scapular movements ($\eta_p^2 = 0.246$). Measures of movement did not differ statistically across the two typing tasks (Table 4.5).

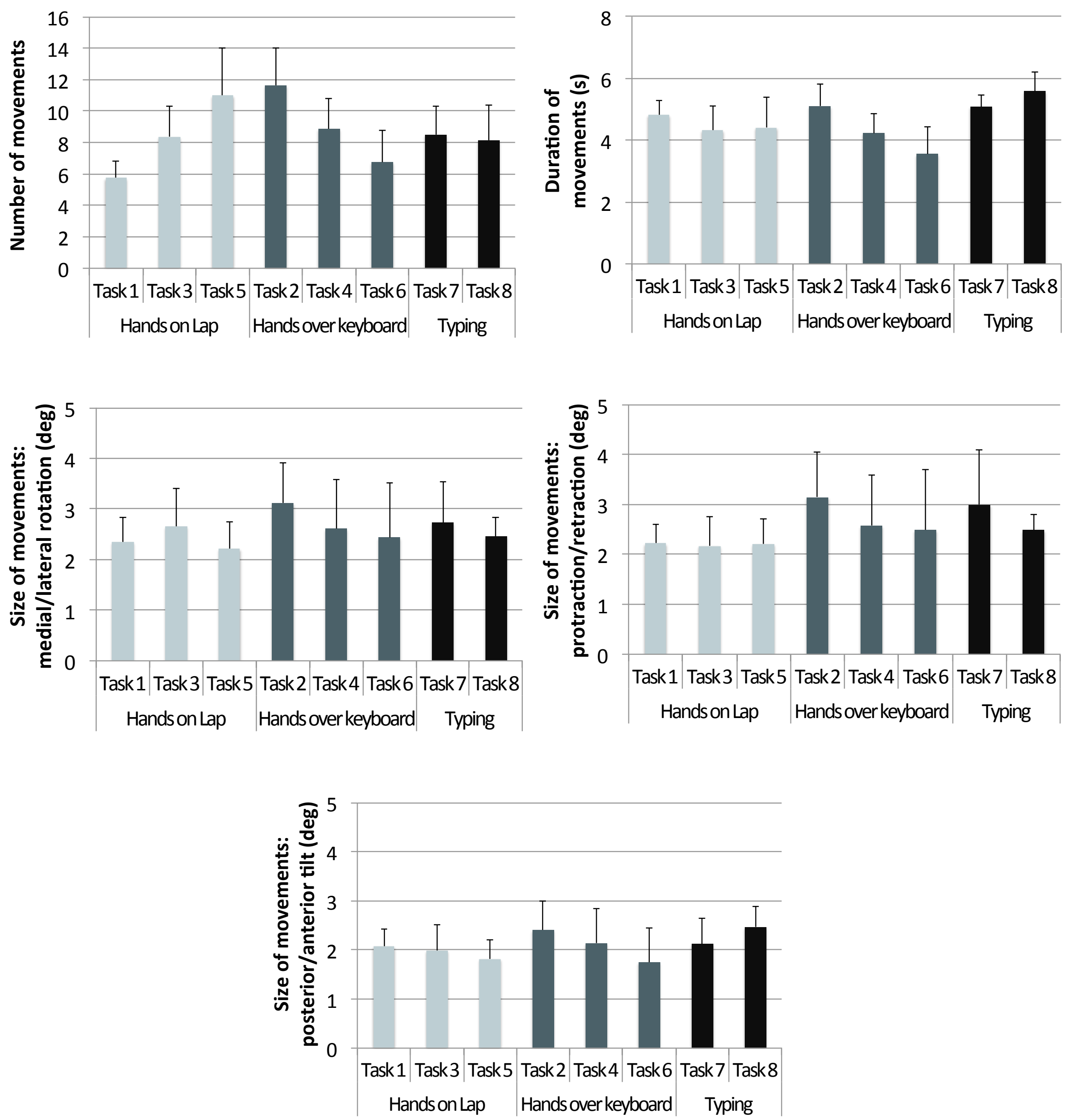


Figure 4.4. Mean number, duration, and size of scapular movements (along the three axes of rotation) for each of the eight computer tasks. N=8.

Measure and source of variation	**Mauchly's Test (χ^2 (df), *p*-value)**	**Huynh-Feldt Epsilon (ε)**	**F value (df_{task}, df_{error})**	***p*-value**	**Partial eta Squared (η_p^2)**
Number of movements					
Mech	-	-	0.27 (1,7)	0.619	0.037
Cog	5.23(2), 0.073	-	0.01 (2,14)	0.994	0.001
*Mech*Cog*	1.89(2), 0.389	-	10.80 (2,14)	**0.001**	0.607
Duration of movements (s)					
Mech	-	-	0.38 (1,7)	0.560	0.051
Cog	0.10(2), 0.951	-	2.28 (2,14)	0.139	0.246
*Mech*Cog*	2.41(2), 0.299	-	0.83 (2,14)	0.458	0.106
Size of movement (°): *medial/lateral rotation*					
Mech	-	-	0.17 (1,7)	0.692	0.024
Cog	2.91(2), 0.233	-	0.58 (2,14)	0.574	0.076
*Mech*Cog*	0.48(2), 0.787	-	0.61 (2,14)	0.556	0.081
Size of movement (°): *protraction/retraction*					
Mech	-	-	0.41 (1,7)	0.543	0.055
Cog	2.36(2), 0.308	-	0.52 (2,14)	0.604	0.069
*Mech*Cog*	0.20(2), 0.905	-	0.97 (2,14)	0.403	0.122
Size of movement (°): *posterior/anterior tilt*					
Mech	-	-	0.11 (1,7)	0.748	0.016
Cog	0.84(2), 0.657	-	2.19 (2,14)	0.149	0.238
*Mech*Cog*	1.40(2), 0.497	-	0.74 (2,14)	0.495	0.096

Table 4.4. Two-way repeated measures ANOVA results for measures of scapular movement across conditions 1 through 6. Mech=mechanical demand and has 2 levels (hands on lap and hands over keyboard). Cog=cognitive demand and has 3 levels (video watching, baseline computer tasks, Stroop colour-word tasks). Statistically significant F values denoted by bolded *p*-values ($p<0.05$). N=8.

Measure	Mean difference (condition 7 - 8)	Standard Error	t value (df)	*p*-value	Cohen's *d*
Number of movements	0.37	1.43	0.26 (7)	0.800	0.065
Duration of movements (s)	-0.50	0.51	-0.98 (7)	0.360	0.342
Size of movement (°): *medial/lateral rotation*	0.27	0.76	0.36 (7)	0.730	0.156
Size of movement (°): *protraction/retraction*	0.50	0.98	0.51 (7)	0.624	0.220
Size of movement (°): *posterior/anterior tilt*	-0.34	0.44	-0.78 (7)	0.462	0.250

Table 4.5. Results from the paired t tests comparing measures of scapular movement across conditions 7 and 8. Statistically significant t values denoted by bolded *p*-values ($p<0.05$). N=8.

4.5.3 Electromyography associated with scapular movements

Figure 4.5 illustrates the mean change in % MVC associated with scapular movements across the eight computer tasks. Results from the two-way repeated measures ANOVA (Table 4.6) indicate that the main effect of cognitive demand, which had 3 levels (video watching, baseline tasks, and Stroop colour-word tasks), was statistically significant for the right lower trapezius (p=0.042). Post-hoc analysis indicated that the change in % MVC was statistically different ($p<0.05$) for video watching (mean=1.15 % MVC, SE=0.54) and the Stroop colour-word tasks (mean=0.60 % MVC, SE=0.33). Although not statistically significant, there was a large effect (Richardson, 2011) for the right upper trapezius ($\eta_p^2 = 0.140$).

Results from Table 4.6 also indicate that the main effect of mechanical demand, which had 2 levels (hands on lap and hands over keyboard), was statistically significant for the right lower trapezius (p=0.036), the right serratus anterior (p=0.019), and the right pectoralis major (p=0.003). For the right lower trapezius, the mean change in % MVC with hands on lap was 0.76 (SE=0.42) and with hands over keyboard was 0.95 (SE=0.44). For the right serratus anterior, the mean change in % MVC with hands on lap was 0.37 (SE=0.23) and with hands over keyboard was 0.67 (SE=0.25). Lastly, for the right pectoralis major, the mean change in % MVC with hands on lap was 0.16 (SE=0.07) and with hands over keyboard was 1.17 (SE=024). Although the main effect of mechanical demand was not statistically significant for the right upper trapezius, there was a large effect (Richardson, 2011) ($\eta_p^2 = 0.224$). Change in % MVC did not differ statistically across the two typing tasks (Table 4.7).

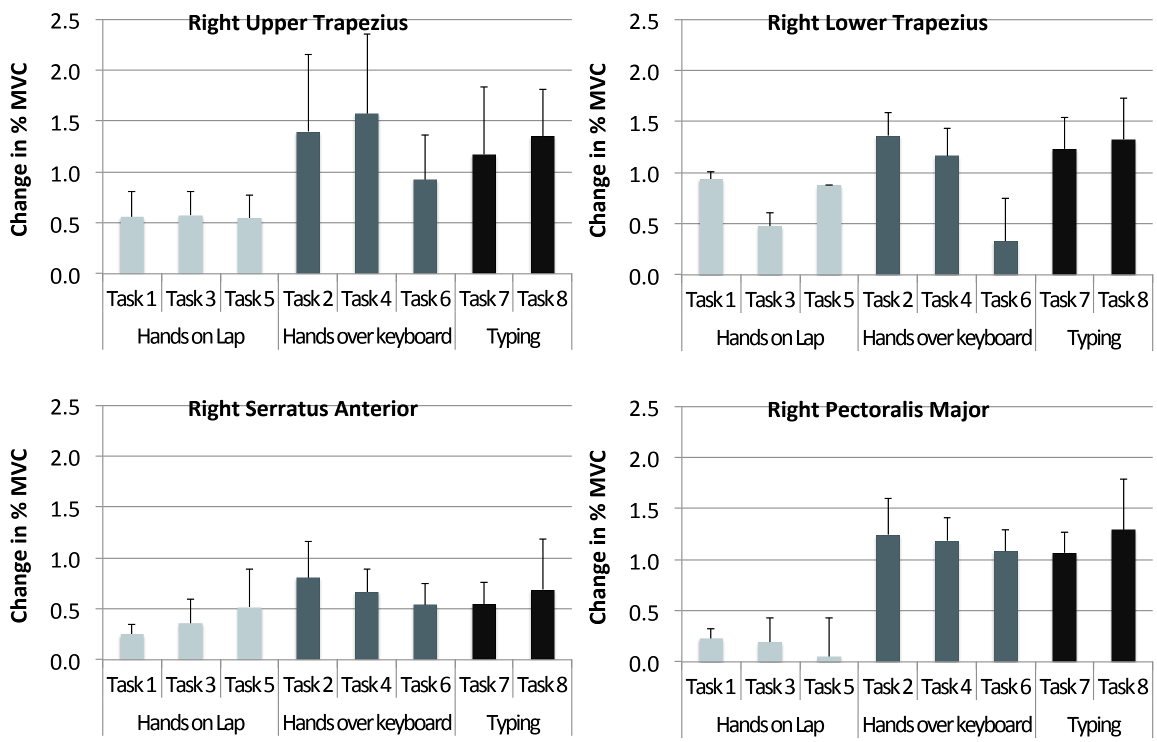


Figure 4.5. Mean change in % MVC associated with scapular movements for each of the eight computer tasks. N=8.

Measure (change in % MVC) and source of variation	**Mauchly's Test (χ^2 (df), *p*-value)**	**Huynh-Feldt Epsilon (ε)**	**F value (df_{task}, df_{error})**	***p*-value**	**Partial eta Squared (η_p^2)**
Right upper trapezius					
Mech	-	-	2.02 (1,7)	0.198	0.224
Cog	8.22(2), 0.016	0.61	1.14 (1.22,8.57)	0.331	0.140
*Mech*Cog*	5.38(2), 0.068	-	1.29 (2,14)	0.307	0.155
Right lower trapezius					
Mech	-	-	6.72 (1,7)	**0.036**	0.490
Cog	8.17(2), 0.017	0.61	5.35 (1.23,8.58)	**0.042**	0.433
*Mech*Cog*	13.23(2), 0.001	0.54	0.87 (1.09,7.62)	0.390	0.110
Right serratus anterior					
Mech	-	-	9.16 (1,7)	**0.019**	0.567
Cog	3.21(2), 0.201	-	0.03 (2,14)	0.968	0.005
*Mech*Cog*	11.20(2), 0.004	0.56	1.04 (1.13,7.90)	0.350	0.129
Right pectoralis major					
Mech	-	-	18.95 (1,7)	**0.003**	0.730
Cog	10.23(2), 0.006	0.58	0.47 (1.15,8.06)	0.635	0.063
*Mech*Cog*	1.92(2), 0.382	-	0.01 (2,14)	0.994	0.001

Table 4.6. Two-way repeated measures ANOVA results for mean change in % MVC associated with scapular movements across conditions 1 through 6. Mech=mechanical demand and has 2 levels (hands on lap and hands over keyboard). Cog=cognitive demand and has 3 levels (video watching, baseline computer tasks, Stroop colour-word tasks). Statistically significant F values denoted by bolded *p*-values ($p<0.05$). N=8.

Measure (change in % MVC)	**Mean difference (condition 7 – 8)**	**Standard Error**	**t value (df)**	***p*-value**	**Cohen's *d***
Right upper trapezius	-0.18	0.33	-0.55 (7)	0.602	0.112
Right lower trapezius	-0.09	0.50	-0.18 (7)	0.859	0.051
Right serratus anterior	-0.14	0.31	-0.44 (7)	0.670	0.130
Right pectoralis major	-0.23	0.18	-1.26 (7)	0.247	0.229

Table 4.7. Results from the paired t tests comparing mean change in % MVC associated with scapular movements across conditions 7 and 8. Statistically significant t values denoted by bolded *p*-values ($p<0.05$). N=8.

4.5.4 Trapezius electromyography

4.5.4.1 Gaps

Figure 4.6 illustrates mean rest time as a fraction of total time (using EMG gaps) across the eight computer tasks. Results from the two-way repeated measures ANOVA (Table 4.8) indicate that the main effect of mechanical demand, which had 2 levels (hands on lap and hands over keyboard), was statistically significant for the right upper trapezius (p=0.033), the right lower trapezius (p=0.001), and the left lower trapezius (p=0.003). For the right upper trapezius, rest time as a fraction of total time with hands on lap was 0.51 (SE=0.16) and with hands over keyboard was 0.21 (SE=0.11). For the right lower trapezius, rest time as a fraction of total time with hands on lap was 0.64 (SE=0.09) and with hands over keyboard was 0.17 (SE=0.09). For the left lower trapezius, rest time as a fraction of total time with hands on lap was 0.44 (SE=0.10) and with hands over keyboard was 0.08 (SE=0.05). Although the main effect of cognitive demand was not statistically significant for any muscle, there was a large effect (Richardson, 2011) for the right upper trapezius (η_p^2 = 0.339), the left upper trapezius (η_p^2 = 0.284), and the left lower trapezius (η_p^2= 0.237). Rest time did not differ statistically across the two typing tasks (Table 4.9).

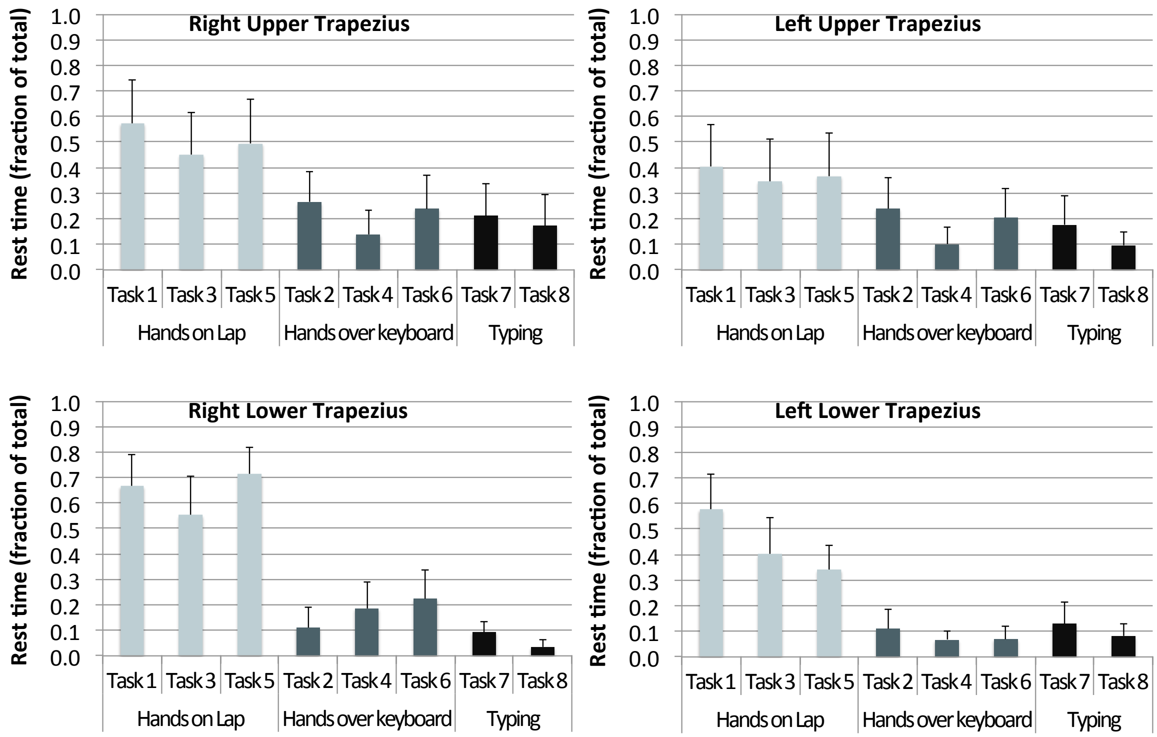


Figure 4.6. Mean rest time as a fraction of total time for each of the eight computer tasks. N=8.

Measure (rest time as fraction of total time) and source of variation	**Mauchly's Test (χ^2 (df), *p*-value)**	**Huynh-Feldt Epsilon (ε)**	**F value (df_{task}, df_{error})**	***p*-value**	**Partial eta Squared (η_p^2)**
Right upper trapezius					
Mech	-	-	7.04 (1,7)	**0.033**	0.501
Cog	1.33(2), 0.514	-	3.59 (2,14)	0.055	0.339
*Mech*Cog*	0.10(2), 0.952	-	0.27 (2,14)	0.768	0.037
Right lower trapezius					
Mech	-	-	26.30 (1,7)	**0.001**	0.790
Cog	3.79(2), 0.150	-	0.52 (2,14)	0.607	0.069
*Mech*Cog*	0.52(2), 0.769	-	0.86 (2,14)	0.442	0.110
Left upper trapezius					
Mech	-	-	4.25 (1,7)	0.078	0.378
Cog	2.22(2), 0.329	-	2.78 (2,14)	0.096	0.284
*Mech*Cog*	0.77(2), 0.680	-	0.44 (2,14)	0.652	0.059
Left lower trapezius					
Mech	-	-	18.83 (1,7)	**0.003**	0.729
Cog	0.09(2), 0.955	-	2.17 (2,14)	0.151	0.237
*Mech*Cog*	0.53(2), 0.766	-	0.80 (2,14)	0.470	0.102

Table 4.8. Two-way repeated measures ANOVA results for rest time as a fraction of total time for the right and left trapezius across conditions 1 through 6. Mech=mechanical demand and has 2 levels (hands on lap and hands over keyboard). Cog=cognitive demand and has 3 levels (video watching, baseline computer tasks, Stroop colour-word tasks). Statistically significant F values denoted by bolded *p*-values ($p<0.05$). N=8.

Measure (rest time as fraction of total time)	**Mean difference (condition 7 - 8)**	**Standard Error**	**t value (df)**	***p*-value**	**Cohen's d**
Right upper trapezius	0.039	0.037	1.05 (7)	0.331	0.111
Right lower trapezius	0.059	0.046	1.29 (7)	0.238	0.593
Left upper trapezius	0.079	0.066	1.19 (7)	0.271	0.319
Left lower trapezius	0.049	0.038	1.29 (7)	0.238	0.252

Table 4.9. Results from the paired t tests comparing rest time as a fraction of total time for the right and left trapezius across conditions 7 and 8. Statistically significant t values denoted by bolded *p*-values ($p<0.05$). N=8.

4.5.4.2 Percent of Maximum Voluntary Contraction

Figure 4.7 illustrates mean % MVC across the eight computer tasks. Results from the two-way repeated measures ANOVA (Table 4.10) indicate that the main effect of mechanical demand, which had 2 levels (hands on lap and hands over keyboard), was statistically significant for the left lower trapezius (p=0.019); with hands on lap the mean % MVC was

1.47 (SE=0.31) and with hands over keyboard the mean % MVC was 3.26 (SE=0.66). Although not statistically significant, the same trend was seen for the other three muscles; there was a large effect (Richardson, 2011) for the right upper trapezius ($\eta_p^2 = 0.304$), the right lower trapezius ($\eta_p^2 = 0.326$), and the left upper trapezius ($\eta_p^2 = 0.172$). It should be noted that the main effect of cognitive demand showed a large effect (Richardson, 2011) for the right upper trapezius ($\eta_p^2 = 0.257$). % MVC did not differ statistically across the two typing tasks for any one muscle (Table 4.11), however from Figure 4.7 it can be seen that muscle activity was greater during the Stroop task compared to the baseline task for the right and left upper trapezius.

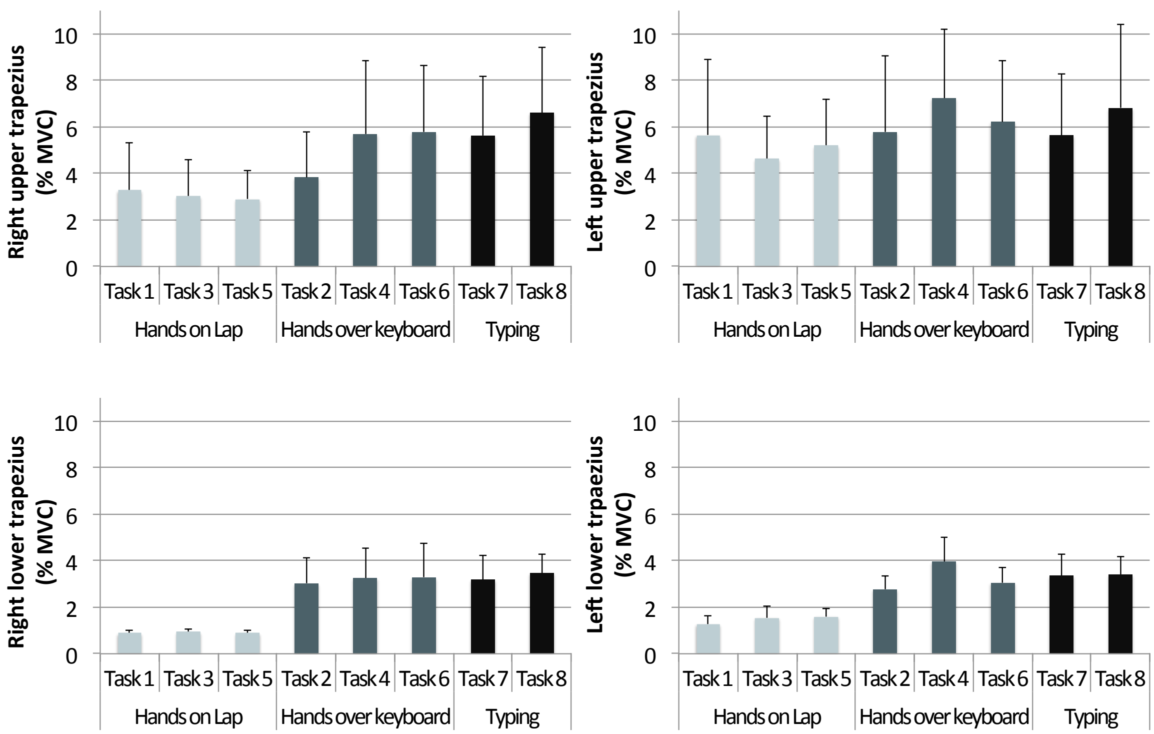


Figure 4.7. Mean % MVC for each of the eight computer tasks. N=8.

Measure (% MVC) and source of variation	Mauchly's Test (χ^2 (df), *p*-value)	Huynh-Feldt Epsilon (ε)	F value (df_{task}, df_{error})	*p*-value	Partial eta Squared (η_p^2)
Right upper trapezius					
Mech	-	-	3.06 (1,7)	0.124	0.304
Cog	0.07(2), 0.966	-	2.43 (2,14)	0.124	0.257
*Mech*Cog*	9.22(2), 0.010	0.59	1.40 (1.18,8.29)	0.278	0.167
Right lower trapezius					
Mech	-	-	3.38 (1,7)	0.108	0.326
Cog	3.76(2), 0.153	-	0.29 (2,14)	0.756	0.039
*Mech*Cog*	5.59(2), 0.061	-	0.14 (2,14)	0.870	0.020
Left upper trapezius					
Mech	-	-	1.45 (1,7)	0.267	0.172
Cog	13.29(2), 0.001	0.54	0.02 (1.09,7.62)	0.917	0.002
*Mech*Cog*	2.20(2), 0.333	-	3.55 (2,14)	0.057	0.337
Left lower trapezius					
Mech	-	-	9.13 (1,7)	**0.019**	0.566
Cog	0.91(2), 0.633	-	1.10 (2,14)	0.359	0.136
*Mech*Cog*	1.33(2), 0.514	-	1.28 (2,14)	0.309	0.155

Table 4.10. Two-way repeated measures ANOVA results for mean % MVC for the right and left trapezius across conditions 1 through 6. Mech=mechanical demand and has 2 levels (hands on lap and hands over keyboard). Cog=cognitive demand and has 3 levels (video watching, baseline computer tasks, Stroop colour-word tasks). Statistically significant F values denoted by bolded *p*-values (p<0.05). N=8.

Measure (% MVC)	Mean difference (condition 7 - 8)	Standard Error	t value (df)	*p*-value	Cohen's d
Right upper trapezius	-0.99	0.65	-1.52 (7)	0.173	0.131
Right lower trapezius	-0.28	0.61	-0.46 (7)	0.659	0.107
Left upper trapezius	-1.16	1.07	-1.08 (7)	0.314	0.131
Left lower trapezius	-0.05	0.36	-0.13 (7)	0.902	0.019

Table 4.11. Results from the paired t tests comparing mean % MVC for the right and left trapezius across conditions 7 and 8. Statistically significant t values denoted by bolded *p*-values (p<0.05). N=8.

4.5.5 Heart rate and the LF/HF ratio

Figure 4.8 illustrates mean HR (BPM) and LF//HF ratio across the eight computer tasks. Results from the two-way repeated measures ANOVA (Table 4.12) indicate that the main effect of cognitive demand, which had 3 levels (video watching, baseline tasks, and Stroop colour-word tasks), was statistically significant for HR (*p*=0.041) and the LF/HF ratio (*p*=0.015). Post-hoc analysis indicated that HR was statistically different (*p*<0.05) for video watching (mean=73.30, SE=4.43) and the baseline tasks (mean=76.76, SE=4.15). Although not statistically different from video watching (*p*=0.096), the Stroop colour-word tasks had a mean (mean=76.28, SE=4.25) similar to the baseline tasks. Post-hoc analysis also indicated that the LF/HF ratio was statistically different (*p*<0.05) for video watching (mean=1.21, SE=0.38) and the baseline tasks (mean=2.10, SE=0.54), as well as for video watching and the Stroop colour-word tasks (mean=2.04, SE=0.57).

Results from Table 4.12 indicate the interaction effect was statistically significant for HR (*p*=0.009). With hands on lap, there was an increase in heart rate between video watching and the other two tasks (Figure 4.8); post-hoc analysis indicated that mean HR during video watching (71.49, SE=4.20) was statistically different (*p*<0.05) from mean heart rate during baseline tasks (mean=76.41, SE=4.29) and from mean HR during Stroop colour-word tasks (mean=76.00, SE=4.17). However, with hands over keyboard, these differences were less pronounced (Figure 4.8) and were not statistically significant. HR and the LF/HF ratio did not differ statistically across the two typing tasks (Table 4.13).

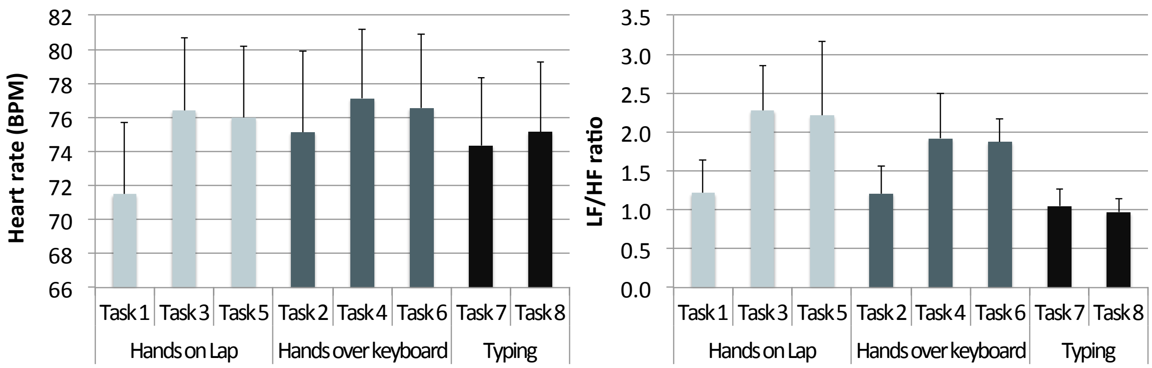


Figure 4.8. Mean HR (BPM) and LF/HF ratio for each of the eight computer tasks. N=8.

Measure and source of variation	Mauchly's Test (χ^2 (df), *p*-value)	Huynh-Feldt Epsilon (ε)	F value (df_{task}, df_{error})	*p*-value	Partial eta Squared (η_p^2)
Heart rate (BPM)					
Mech	-	-	3.89 (1,7)	0.089	0.357
Cog	4.51(2), 0.105	-	4.05 (2,14)	**0.041**	0.366
*Mech*Cog*	4.56(2), 0.102	-	6.64 (2,14)	**0.009**	0.487
LF/HF ratio					
Mech	-	-	0.59 (1,7)	0.469	0.077
Cog	8.30(2), 0.016	0.61	8.52 (1.22,8.54)	**0.015**	0.549
*Mech*Cog*	6.31(2), 0.043	0.66	0.14 (1.33,9.31)	0.790	0.019

Table 4.12. Two-way repeated measures ANOVA results for HR (BPM) and the LF/HF ratio across conditions 1 through 6. Mech=mechanical demand and has 2 levels (hands on lap and hands over keyboard). Cog=cognitive demand and has 3 levels (video watching, baseline computer tasks, Stroop colour-word tasks). Statistically significant F values denoted by bolded *p*-values ($p<0.05$). N=8.

Measure	Mean difference (condition 7 - 8)	Standard Error	t value (df)	*p*-value	Cohen's d
Heart rate (BPM)	-0.82	1.43	-0.57 (7)	0.586	0.071
LF/HF ratio	0.08	0.22	0.36 (7)	0.727	0.138

Table 4.13. Results from the paired t tests comparing HR (BPM) and the LF/HF ratio across conditions 7 and 8. Statistically significant t values denoted by bolded *p*-values ($p<0.05$). N=8.

4.6 Discussion

This study quantified perceived workload, three-dimensional changes in scapular orientation, trapezius muscle activity, and HR/HRV during eight computer tasks of varying cognitive and mechanical demand. Ratings of workload provided verification that the independent measures were correctly manipulated. As expected, the main effect of mechanical demand was statistically significant for NASA-TLX ratings of perceived physical demand. In addition, for each level of mechanical demand (hands on lap and lands over keyboard), perceived physical demand increased with increased cognitive demand (video watching, baseline tasks, and Stroop tasks), though the main effect of cognitive demand was not significant. Ratings of perceived exertion (RPE) are important to consider, since, for example, perceived exertion of the shoulder is lower in neutral postures compared to non-neutral postures during computer work (Karlqvist et al., 1998). In addition, RPE values have good agreement with ergonomists' evaluation of postures (Lindegård, Karlberg, Tornqvist, Toomingas, & Hagberg, 2005).

As discussed in chapter 2, perceptions of psychosocial demand may result in physiological, psychological, and behavioural stress reactions, such as activation of the sympathetic nervous system, a negative mood change, and/or more forceful vocalization of an answer, respectively (Carayon et al., 1999). The current study examined physiological reactions to changes in cognitive demand, which, according to the NASA-TLX ratings, elicited statistically significant changes in perceived mental demand, temporal demand, effort, performance, and frustration. More specifically, changes in HR and the LF/HF ratio were examined as an indication of sympathetic nervous system activity. The main effect of cognitive demand was statistically significant for both HR and the LF/HF ratio, with higher values observed during tasks that required more attention.

It has been shown that stress conditions simulated through mental arithmetic and the Stroop colour-word test increase stress hormone concentrations, as well as increase HR and BP, compared to baseline (Krantz et al., 2004; Lundberg et al., 1994). In the field it has been shown that HR and BP are higher during work time compared to non-work time (Rissén et al., 2000). Furthermore, the LF/HF ratio is shown to be higher during cognitively demanding tasks (Hjortskov et al. 2004; Delaney & Brodie, 2000). For example, Hjortskov et al. (2004) demonstrated that the LF/HF ratio was statistically greater during a laboratory session that involved cognitive demand and lack of social support compared to a control session. Delaney & Brodie (2000) showed that, among 15 individuals in an experimental group, the combination of the Stroop colour-word test and mental arithmetic produced an increase in the LF/HF ratio from a mean of 6.3 in the baseline condition to a mean of 8.1 in the treatment condition. These values are higher than those found in the current study possibly because of a more challenging treatment session. However, overall, findings from the current study are consistent with those found in the literature.

In chapter 3 it was demonstrated that measures of scapular movement, namely the duration and size of movements, differed across levels of cognitive demand. In the current study, the main effect of cognitive demand from the ANOVA was not statistically significant for any measure of scapular movement. The trends, however, were in the same direction as those found in chapter 3. For example, when cognitive demand increased the duration of movements tended to decrease ($\eta_p^2 = 0.246$). Furthermore, there was a large effect (Richardson, 2011) for mean size of movements for posterior/anterior tilt ($\eta_p^2 = 0.246$); as cognitive demand increased the size of movements decreased. A medium effect size (Richardson, 2011) was found for size of movements along the other two axes of rotation. When the two typing tasks are considered, some trends are in the anticipated direction. For example, increased cognitive demand resulted in smaller movements along two of the three axes of rotation. It may be that the physical demands of typing wash out effects observed when postures are more static. In addition, there were eight participants in the current study and 16 in the study presented in chapter 3, so it may be that the sample size of the current study was not large enough to detect statistical significance for measures of scapular movement.

Novel to the current study was the observed change in % MVC associated with scapular movements. Movements resulted in changes of up to 1.6 % MVC for the right upper trapezius, 1.4 % MVC for the right lower trapezius, 0.8 % MVC for the right serratus anterior, and 1.3 % MVC for the right pectoralis major. When considering tasks 1 through 6, the main effect of cognitive demand was statistically significant for the right lower trapezius, and there was a large effect (Richardson, 2011) for the right upper trapezius ($\eta_p^2 = 0.140$); as cognitive demand increased the size of the change in % MVC typically decreased. This reduction in change in % MVC, along with shorter and smaller scapular movements, may relate to more static postures during mentally demanding computer work, a risk factor for discomfort and pain of the upper extremity.

As suggested in chapter 3, it might be that tense postures, evidenced by shorter and smaller scapular movements, are a reflection of increased muscle loading in the neck/shoulder region during mentally demanding tasks (Laursen et al., 2002). Individuals tend to tighten muscles that are required for and not required for work tasks, and are often unaware of unnecessary efforts (Peper et al., 2010). Dysponesis is a term used to describe these “misplaced and misdirected efforts" (Harvey & Peper, 2012, p. 147). The bracing effort is one type (Whatmore & Kohli, 1974): "efforts to hold the body, or a part of the body, rigid or 'or guard'" (Peper et al., 2010, p.6). This effort is sustained for "fight or flight" (Peper et al., 2010), which suggests that rigid postures may be more prevalent during mentally demanding tasks. A reduction in scapular movement may be associated with the bracing effort and higher static activity in muscles of the neck/shoulder region.

The current study examined upper and lower trapezius activity across the eight computer tasks. The main effect of mechanical demand was statistically significant for rest time as a fraction of total time for the right upper and lower trapezius, and for the left lower trapezius; as expected, rest time decreased as mechanical demand increased. The main effect of cognitive demand, however, was not statistically significant. As previously discussed, it may that the sample size was not adequate to detect statistical significance. Nevertheless, there was a large effect (Richardson, 2011) for right upper trapezius rest time ($\eta_p^2 = 0.339$) and for left upper trapezius rest time ($\eta_p^2 = 0.284$); mean rest time for attention-related tasks (baseline tasks and Stroop tasks) was less than mean rest time for video watching tasks. For example, for the right upper trapezius, mean rest times for video watching, baseline tasks, and Stroop tasks were 0.42, 0.29, and 0.37, respectively.

It may seem surprising that mean rest time was higher for Stroop tasks than baseline tasks, since the literature would suggest otherwise (Schleifer et al., 2008; Laursen et al., 2002), however, the mean % MVC for these two task types was similar (Figure 4.7), and perhaps the difference in cognitive demand between the baseline and Stroop tasks was not sufficient to produce the expected effect. For example, in a study by Schleifer et al. (2008), a researcher sat beside each participant during the "stressful" task to provide negative verbal and behavioural feedback, and in a study by Laursen et al. (2002), an alarm sounded each time an incorrect answer was provided, likely increasing demands. The NASA-TLX and HR results emphasize this point. Average ratings of mental demand for the Stroop tasks reached only approximately six on 10, and post hoc analysis for the main effect of cognitive demand on HR showed statistically significant differences only between video watching (mean=73.30) and the baseline tasks (mean=76.76), though the Stroop tasks had a mean (mean=76.28) similar to the baseline tasks.

It may be a limitation that this study was conducted among a small university sample, and thus caution is necessary with regard to interpretation of results and transferability, however this work builds on chapter 3 and provides further evidence that the duration and size of scapular movements during computer work is likely related to level of cognitive demand present. Static posture, evidenced by the observed reduction in movement, is a risk factor for musculoskeletal discomfort and pain in the neck/shoulder region.

4.7 Implications for health in the workplace

This work provides a better understanding of links between psychosocial demands during computer work and exposures related to MSD and stress-related health outcomes. Changes in cognitive demand during computer work related to: perceptions of increased temporal demand, effort, and frustration; changes in sympathetic nervous system activity; and changes in the duration and size of scapular movements, perhaps an indication of increased static shoulder posture. The observed physiological responses across both domains (Figure 2.1) suggest the presence of a common workplace risk factor for exposures related to MSD and stress-related outcomes among computer users: cognitive demand. Future research and prevention activities should consider common risk factors so MSD and stress outcomes may be simultaneously targeted in the workplace.

5.0 Field study Part A: Potentially straining situations/tasks for call centre agents

5.1 Background and objective

Health outcomes including MSD, burnout, fatigue, anxiety, and depression are well documented among call centre workers (Castanheira & Chambel, 2010; d'Errico et al., 2010; Krause, Burgel, & Rempel, 2010; Charbotel et al., 2009; Norman, Floderus, Hagman, Toomingas, & Tornqvist, 2008; Sprigg & Jackson, 2006; Toomingas, Nilsson, Hagberg, Hagman, & Tornqvist, 2003; Holman, Chissick, & Totterdell, 2002). It is therefore not surprising that a mixture of workplace demands linked to MSD and mental health problems are present in these workplaces. Call centre workers tend to: conduct computer work with few breaks (Norman et al., 2008); conduct their work in poorly designed spaces (d'Errico et al., 2010); experience time pressure (d'Errico et al., 2010; Kjellberg et al., 2010); perceive high effort-reward imbalance (Krause et al., 2010), high psychological demand, low decision latitude, and low social support (Norman et al., 2008); feel troubled by dialogue scripting (Sprigg & Jackson, 2006); face performance monitoring (Sprigg & Jackson, 2006; Holman et al., 2002); and encounter difficult interactions with clients (Lin, Chen, & Lu, 2009). Considering the selection of demands present in the call centre environment, there is need to understand those situations/tasks perceived as difficult for agents within the participating organizations so relationships between workplace demands and physiological responses can be examined.

Work demands in call centres are often documented through use of questionnaires, for example the Job Content Questionnaire, which targets the demand-control model of job strain (Croidieu et al., 2008; Norman et al., 2008), or other questionnaires aimed at specific job demands and/or aspects of work organization (d'Errico et al., 2010; Kjellberg et al., 2010;

Norman et al., 2008; Sprigg & Jackson, 2006). Lin et al. (2009) asked call centre workers to report the three most important job stressors from a list, and "encountering difficult customers" (Lin et al., 2009, p. 564), "difficulty in serving customers well while maintaining a consistent average work time" (Lin et al., 2009, p. 564), and "calls taking a long time to process" (Lin et al., 2009, p. 564) came out on top. Each of these stressors is either directly or indirectly related to the agent-client interaction. In addition, studies have been carried to better understand call centre work through interviews (Renton, Lightfoot, & Maar, 2011; Scholarios & Taylor, 2010; Connell & Hannif, 2009; Grandey, Dickter, & Sin, 2004; Hyman, Baldry, Scholarios, & Bunzel, 2003). Many of these efforts, however, target general aspects or troubles of call centre work, for example promotion of physical activity in the workplace (Renton et al., 2011) or work-life balance (Hyman et al., 2003), and few (Grandey et al., 2004) target perceptions of stressors.

The aim of Part A was, through use of semi-structured interviews, to better understand potentially straining aspects of call centre work with an emphasis on agent-client interactions. This knowledge will provide insight into aspects of the job that may be associated with physiological responses over a work shift (Part B).

5.2 Methods

5.2.1 Participant population

Individuals were recruited from two Ontario call centres to participate in Part A (Table 5.1). Data collection for call centre 1 (CC1) was carried out at one worksite in Southern Ontario, and data collection for call centre 2 (CC2) was carried out at two worksites in Southern Ontario. Despite the two geographical locations, all participants from CC2 performed the same job and worked under the same management.

	Call centre 1	Call centre 2
Type	Insurance	Government
Call content	Support for medical, dental, and drug claims	Support for public service (e.g. pay and benefits)
Worksites	1	2
Hours of operation	Weekdays 8am-7pm	Weekdays 8am-5pm
Duration of work shifts	8 hours	8 hours
Inbound/outbound calls	Inbound	Inbound
Unionization	No	Yes
Number of front line agents	80	45
Number of team leads/supervisors	8	7

Table 5.1. Characteristics of the two participating call centres.

Participants were recruited from each call centre using information sessions and recruitment flyers. Front line agents, union representatives, and team leads/supervisors were eligible to participate. There was no exclusion criterion. Given the ratio of call centre agents to team leads/supervisors (Table 5.1), and the aim of Part A, which was to understand perceived stressors for agents, it was decided that, for each call centre, a purposive sample of approximately 80% front line agents to 20% team leads/supervisors would be targeted. This selection held true for CC1, however there were no team leads/supervisors who volunteered to participate from CC2. 10 individuals from CC1 (P1 to P10) and 15 individuals from CC2 (P11 to P25) were interviewed (Table 5.2). All study participants were permanent, full-time workers. Participants were provided with a 25-dollar gift card for remuneration. The Office of Research Ethics at the University of Waterloo approved the study.

	Call centre 1		Call centre 2	
	Number (female/male)	Mean job tenure (yrs.)	Number (female/male)	Mean job tenure (yrs.)
All participants	10 (9/1)	5.9	15 (10/5)	8.4
Agents	8 (7/1)	4.2	14 (10/4)	8.1
Agent union rep	-	-	1 (0/1)	12.0
Team leads/supervisors	2 (2/0)	12.9	0	-

Table 5.2. Characteristics of Part A study participants.

5.2.2 Interview guide

An interview schedule was developed for agents (Appendix B) and for team leads/supervisors (Appendix C) in consultation with the literature that targeted 5 aspects of call centre work: 1) physical/biomechanical, including issues of workspace design and the repetitive nature of the job; 2) psychosocial, including issues of job control, social support, and challenging interactions with clients; 3) work organizational, including issues of workload, workplace monitoring, break time, and sitting time; 4) environmental, including issues related to the physical work environment such as noise, lighting, and air quality; and 5) employment conditions, including whether agents worked full or part time, and whether agents were permanent workers or on contract.

For each of these five sections, generally speaking, lines of questioning followed the structure: does [insert potentially straining situation/task] occur in your work environment; does [insert potentially straining situation/task] affect your ability to do your work; does [insert potentially straining situation/task] affect you in any other way; how might you be able to change [insert potentially straining situation/task]; and do you think it would be possible to make this/these changes? The interview guides were piloted twice: once with a member of the research team and once with a call centre agent known to the research team but who was otherwise not involved in the project. This process resulted in few minor changes to the interview guides.

5.2.3 Data collection, transcription, and analysis

Interviews were carried out in a private meeting room at the participating call centres in June and July of 2013. Interviews lasted 17 to 61 minutes (mean 42 minutes) and were audio recorded to ensure accuracy and completeness of the data collected. The semi-structured guide was followed closely, however deviations from the guide were made to clarify the questions and in some cases the responses given. Interviews were transcribed verbatim using Express Scribe (NCH Software), and were sent to participants to provide them an opportunity to clarify any points they thought necessary.

Transcripts were imported into NVivo10 (QSR International) for data management, and thematic analysis was carried out. The interview guides served as a basis for developing the preliminary structural coding scheme. A structural coding scheme uses every question in a guide as a structural code that corresponds to a theme (Guest, MacQueen, & Namey, 2012). Separately, two members of the research team read over all interviews once to generate a refined coding scheme that included not only structural codes but also emergent content codes (Guest et al., 2012) relevant to the research objective; differences were discussed and resolved. Independently, each researcher then used the refined coding scheme to code the first three of 10 interviews from CC1 and the first four of 15 interviews from CC2. To ensure reliability in the analysis, intercoder agreement was assessed through detailed examination of the two sets of coded transcripts, and if differences existed, they were discussed and resolved by either changing the coding scheme or the concept of the code. This reliability check acted to minimize bias either researcher may have brought to the coding process (Guest et al., 2012), and resulted in a final coding scheme, which was used to identify passages that described and/or discussed situations/tasks perceived as difficult for call centre agents.

5.3 Results

Although the interview guide targeted 5 aspects of call centre work, the focus in the remainder of this chapter is on better understanding challenging interactions with clients since this feature of call centre work will be further studied in chapter 6. The aim of chapter 6 is to examine relationships between perceptions of call difficulty and physiological responses in the physical and psychosocial domain monitored over a work shift. Challenging interactions were described or alluded to by participants as being potentially important for wellbeing, i.e. in these situations demands may exceed coping resources (Lazarus & Folkman, 1986), which may result in physiological, psychological, and/or behavioural reactions (Carayon et al., 1999). Findings suggest that various features of both the *content* and *context* of call centre work condition the interactions agents have with their clients every day. These features of job content included the *regulation of emotion,* the *extent of knowledge required to do the job*, and the *unrelenting nature of the work*, and these features of context included the *pressure to be productive* and *workforce surveillance*.

5.3.1 Content of call centre work

Features of the content of agents' work, i.e. what they do during work, were discussed by participants, and included the regulation of emotion, the extent of knowledge required to do the job, and the unrelenting nature of the work. These aspects of job content shape agents' perception of call difficulty, which will be explored in this section.

5.3.1.1 Regulation of emotion

Agents in the participating organizations take up to 80 calls per shift. CC1 is in the insurance industry and deals with clients who have questions about their medical, dental, and drug coverage. These questions come from a small proportion clients who have complicated inquires or troubles with their claims:

> The problem with us is that we're on the very tip, the sharp end of the iceberg. And we get 45 million claims a year. So we obviously don't take 45 million calls a year. We get on the order of thousands of calls. So those are the very, very rare occasions when a

> claim isn't assessed correctly or when somebody doesn't understand. So 99.9 percent of the time, everything is fine. But those 0.1 percent, those are the people that we talk to. So to start off with, those people are [the] very, very small minority but they're the small minority of people who can be very upset. (P6)

CC2 is part of the Ontario government and provides assistance to the public service when they have questions related to, for example, pay and benefits or vacation. Like agents in CC1, agents in CC2 are the first point of contact for client inquiries, which can be demanding because they sometimes feel they are "a shield to get hit [on] for all the inadequacies of the government." (P13)

Whether an interaction with a client is pleasant or challenging, agents are required to smile with their words and to impose business-like boundaries around their conversations. Management monitors both the quality and accuracy of agent-client interactions through workforce surveillance. Observation of tone and body language is common: "They can hear my attitude when they're walking by… they call you into the [office] and say, 'Listen, you need to smile when you're on the phone.' [Many of] our managers can hear everything in here and it sucks." (P9) Although agents are aware that their attitude and level of emotional involvement are assessed through quality audits, they find it difficult to present as "detached" when there is an emotional caller:

> Like it's really hard when you have people crying on the telephone and things like that; 'My husband died.' Or 'My wife died.' Or 'My husband's got cancer,' and things like that. You're trying to balance a lot of things and we're not supposed to be emotionally involved but sometimes it's hard. (P3)

Withholding information from clients for quality purposes was also described as an emotional stressor for agents because as customer service representatives, agents seek to help clients the best they can. One participant from CC1 explained: “Sometimes you want to be able to give them more information, but you can’t. So I think people sometimes feel a little restricted. ‘I want to help them, but I can’t.’ You know?” (P2) Another agent from CC2 explained the struggle with these boundaries:

> So when the person on the phone says, ‘Well can you tell me what such and such is?’ And it’s right there in our face. We can’t tell them we see it. So I don’t like to do it, but I lie to the person. (P21)

5.3.1.2 Extent of knowledge required to do the job

Agents require a certain amount of knowledge to do their job, and to feel comfortable doing it. Classroom training is provided before agents are put on the phone, however being inexperienced is associated with some level of anxiety. One participant from CC1 considered the struggle of being new to the job: “I think when I first started, probably my nervousness and my un-sureness would have shone through, so people probably took advantage of that. So I think I had more difficult calls before.” (P6) With seniority agents become cross-trained, i.e. they are trained to answer new call types, which increases the knowledge they require to do their job. Certain queues are associated with more complex inquiries, and thus with cross training comes the possibility of greater cognitive demand during work. For example, in CC1, inquiries regarding drug claims are considered more complex than inquiries regarding dental claims. So, the number of queues assigned not only influences the likelihood of receiving a challenging call, but also the agents’ workload:

> If you're only trained on one benefit, and there are no calls coming in on your line, then you have a little bit of a breather. Or, if you're cross-trained on some other things, then the chance of you continually getting calls is higher. So, I mean, it's good because you want to get trained on all the benefits because that increases your job level, which increases your pay. But it also usually means that you're going to get a lot of calls. (P2)

The irregular frequency of certain inquiries can also prove troubling for agents because the knowledge they require to answer the question may not be available: "And sometimes it's something out of the blue and [I haven't] had that question for… six years. That takes a long time to really go in and figure out," (P14) said a participant from CC2. Similarly, agents can be troubled by a lack of communication from management when new policies or procedures are put in place that influence call content:

> We're still told these things [e.g. changes to procedures] late even though they [management] know it ahead of time. They still don't give it to us in time… Optimally in an organization the bosses should be saying, 'Hey, by the way, batten down the hatches, there's a storm coming!" (P16)

Although irregular inquires can be frustrating and can take time to figure out, another participant from CC2 indicated the troubleshooting helps with future calls: "You're looking for how to get to the steps that are needed to be able to resolve this situation so you have the experience and the knowledge for the next call that comes in." (P23) In fact, although participants described strategies to enhance information gathering, for example refining the "art of probing" or using the knowledge centre (a line agents can call for help), it was indicated that experience on the job provides much of the knowledge needed:

> It's like the learning curve was just straight up for six months, that's what I used to say. Straight up for six months till you actually kind of felt comfortable with answering [the questions], and then still the anxiety was there for a lot of years because you never know what they're going to ask you when you answer the phone… And I just faked it till I made it, that's what I said. I just kind of faked the whole thing and said, 'Oh yeah, I can do this for you.' And then you're like stressed out. Because it is stressful. It's stressful just even gathering information; knowing what questions to ask. That took years to get to that point where you understood the process enough to know what to say to get the information that you want. (P24)

5.3.1.3 Unrelenting nature of the work

Over the course of their workday agents interact with clients continuously and have few breaks. Although call content varies to some extent, agents described the monotonous process of managing inquiries: "Log tickets, open screen, close screen, go into different screens, post ticket, change the icon [and repeat]" (P14). Another participant described the repetitive computer work associated with handling calls all day: "Oh yes, it's all very repetitive. You know, press this button to answer the phone, press this button to… and too much clicking. The clicking is killing us all." (P24)

This said, agents considered the sedentary and monotonous nature of the job something they had to accept: "[It] can be difficult and draining to be tied to the desk. But I guess that's just the way that the job is." (P4) Another participant from CC2 indicated: "I don't really see how [it could be different] considering the nature of the work. You just have to find ways to do your stretching or whatever at your desk because that's what you're chained to." (P15)

Participants indicated that sitting all day is uncomfortable and makes then feel lethargic. There is a breaking point where they have to get up and move:

> I've got to walk. I've got to get up and move. Sometimes the days are crazy and you can do 50 or 60 calls in a day. Other days it's quiet enough that you can change positions… and get some alleviation. But when it's non-stop, it's like 'Ok, I need a break,' and you've got to stop. And it's an unscheduled break. (P18)

This breaking point may be linked to both the physical and psychosocial demands of the job. A participant from CC2 discussed the mental strain associated with taking calls all day:

> I go home and I'm thinking, 'My god, I'm not doing a marathon.' But I feel it's the mental demand on your brain, your hearing, [and] your vision… And I suppose when you're stressed it does bear on your vision and your hearing because you're listening to somebody all day on the phone. (P22)

Although most agents indicated they experience challenging interactions daily, there was a sense the number could fluctuate: "There [are] a lot of days where everybody is happy and nobody is crabby or grumpy or unhappy. But then the next day you might get everyone [who is upset]. It's totally random, it's very random." (P1) Participants provided examples of challenging interactions, including issues with difficult personalities, abusive language, and emotional callers. To cope with these situations, agents use a variety of strategies, including taking a walk or seeking co-worker/supervisor support.

However, the rigidity of break times in the call centre environment makes it difficult to take a walk to relieve frustration or discomfort. A participant from CC2 described the strictness of the work schedule: "We were told to follow [the break times] really, really close. Like if your break is at 10, then you have to go exactly at 10, right. So I feel that this is [a] restriction and stress to your system." (P14) Participants mentioned a desire for additional break time to cope with the physical and psychosocial aspects of the job:

> I think that we probably should have maybe another 15, or maybe even two extra 10-minute breaks just because of what we do. It just gives you a chance to get away and not only let your body just have a second but also your mind to have a second. And sometimes that [is] kind of important – just that little bit [of time] to go away and walk around. But I don't know if that would ever happen [laughs]. (P3)

5.3.2 Context of call centre work

Features of the context of agents' work, i.e. the setting in which their work occurs, were discussed by participants, and included the pressure to productive and workforce surveillance. These aspects of context shape agents' perceptions of call difficulty, which will be explored in this section.

5.3.2.1 Pressure to be productive

Production pressure was a work organization factor commonly discussed by participants. Agents find it difficult to balance expectations for number of calls taken per day with delivery of accurate information:

> So what's more important? I have 80 calls a day, consistently; I'm just a wizard. Or is it more important to give accurate information, be kind to the person, [and] listen to what their problem is as opposed to get them off the phone and keep my numbers up high? (P1)

The pressure to provide accurate information within a restricted time period can leave little leeway to get the job done: "You have to watch the tone of voice while you're providing accurate information, while you're accessing all parts of the system, and doing it all under 5 minutes… and accurately. Did I mention accurately?" (P4) Participants emphasized the need to get "it" right: "Yeah, on the phone, it has be to 100%. It can't be 'I think' or 'Maybe.' It can't be like that. You have to say 'Ok, this is the process, this is it.' You have to be 100% sure." (P11) The struggle to ensure information is correct within a restricted time period may create psychological stress if agents feel they are not doing their job well. Or, if time is taken to ensure information is correct, for example by calling the knowledge centre, call durations will increase which may cause frustration. If incorrect information is provided, agents in CC1 receive deductions on their quality review, which affects their performance appraisal.

There is little time for agents to do work between calls. Balancing quotas with time required for wrap-up between calls is also a frustration:

> I can't type and talk, I use my hands to talk. So when I'm talking to people I'm doing this [hands in air] and I'm not doing this [typing]… So after I've put them on hold or whatever, or put myself on post call I'll type it up. And then I'll be not even finished and the team lead will come and if the queues are busy [will] say '[Name], there's a call you have to take.' So you just leave that ticket and you just keep leaving tickets open and not closing [them] because you've got to take the next call, the next call, the next call. (P11)

Perceptions of call difficulty may be heightened when tickets are left open because the work is left unfinished, and because agents may feel unprepared to handle a new call if their thoughts remain with the previous call.

5.3.2.2 Workforce surveillance

Agents are familiar with surveillance for performance purposes, aspects of which include accuracy of information given, and statistics on call duration and number of calls taken. In

CC1 every call is audio recorded: “So I never know which calls are being listened to, but all of my calls are potentially being listened to. So there’s always a third person on the phone calls, so that’s stressful.” (P6) Knowing a call could be scored for quality during a challenging interaction may heighten psychological stress; more so with agents who are new to the job. In CC2, a software program is placed on every computer to monitor call durations, time between calls, lunch breaks, unscheduled breaks etc. Every time an agent changes his/her task he/she must indicate so with a code: “Team leads always know what you’re doing at any given time. I call it an umbilical cord.” (P12) Another participant from CC2 described the frustration with “pop-ups”, i.e. instant messages sent from supervisors to agents (through the computer system) to tell them to take a call:

> I guess it is offensive for me because I know how I work and I feel like there are some people that don’t get those [pop-ups] and there are some people who do get them. So there are the issues with the social part of [the] organization. And I feel, actually I don’t feel, I know, I’m a hard worker and a good worker. (P22)

Participants described taking a walk or “breather” as a means to cope with the sedentary nature of the job, or with having had a difficult call, however production pressures along with surveillance do not act in favour of this coping strategy: “Other times it just feels like if you’re joking with your colleague or something, somebody will come over and go, ‘What are you guys doing?’ Breathing. What’s the problem? Come on, we don’t have to be that crazy rigid.” (P18) Participants from CC2 also described co-worker support as a means to cope with challenging calls, however participants from CC1 did not. Instead, CC1 agents indicated this type of support is discouraged for fear it will compromise call quality:

> We're actually not allowed to ask other people around us any questions, just in case they give incorrect information… because if they screw up and tell you something wrong and then you turn around and tell a customer, it's you that gets in trouble… so it's frustrating that we're not allowed, because we do get in trouble. They [supervisors] hear you. It's like [frustrated sigh]. They need to wear earplugs around here. (P9)

5.4 Discussion

Challenging agent-client interactions is a stressor commonly reported in the call centre literature (Lin, Chen, Hong, & Lin, 2010; Charbotel et al., 2009; Lin et al., 2009; Goldberg & Grandey, 2007; Grandey et al., 2004). Lin et al. (2009) asked call centre workers to report the three most important job stressors from a list, and "encountering difficult customers" (Lin et al., 2009, p. 564) came out on top. Charbotel et al. (2009) found that "situations of tension with clients" (Charbotel et al., 2009, p. 752) was a risk factor for psychological distress among workers (OR=2.08). Findings from the current study suggest aspects of both the content and context of call centre work shape the interactions agents have with their clients every day. For job content, the regulation of emotion, the extent of knowledge required to do the job, and the unrelenting nature of the work, emerged as features that condition these interactions. Aspects of context, including the pressure to be productive and workforce surveillance, influence the work that is done and ultimately the agents' perception of call difficulty.

Agents discussed the requirement to "smile through" calls regardless of a client's mood. Previous work has shown that individuals exposed to emotion display rules report more emotional exhaustion than individuals who have autonomy over their display of emotion; this difference can be attributed to amount of surface acting, i.e. behaviours aimed at faking emotion (Goldberg & Grandey, 2007). Interactions with hostile customers/clients produce surface acting whether emotion display rules are present or not (Goldberg & Grandey, 2007), suggesting that interactions with difficult clients will elicit greater emotional exhaustion than baseline or non-straining interactions. These more challenging interactions likely involve relay of difficult information, difficult personalities, emotional issues, and so on, and are likely longer in duration than non-straining interactions. Production pressures may weigh on agents. Croidieu et al. (2008) found that decision latitude was low when there were enforced call durations, and when agents took incoming calls only, as was the case in the participating call centres. With incoming calls, agents cannot prepare for the content or tone of the conversation beforehand, and must adjust during the call. Surveillance may also influence perceptions of challenge in these situations if agents fear their surface acting is not adequate, and their quality review will be affected.

Agents build the knowledge they require to carry out their work through training and experience; this can take years. Situations may present over the workday that make agents feel unprepared to do their job. Being unable to quickly handle an inquiry as a result of being new to the job, being recently cross-trained, or having missed updates from management regarding call content, are examples. Perception of challenge in some of these situations might stem from the complexity of the inquiry, for example those related to changes in drug coverage, and more experienced agents may find the inquiry difficult. However, if agents have yet to build the knowledge they require to do their job comfortably, aspects of the context of work may play a prominent role in shaping the perception of interactions. If agents take the time required to ensure information is accurate, for example by seeking supervisor or co-worker support, call durations will increase which will affect performance. However, if agents neglect to ensure information is accurate, and incorrect information is provided, workforce surveillance will pick up errors and performance will also be affected. There is a tight balance to be held.

Workforce surveillance for performance purposes is considered a risk factor for MSD and stress-related outcomes (Castanheira & Chambel, 2010; Charbotel et al., 2009; Norman et al., 2008; Goldberg & Grandey, 2007; Sprigg et al., 2006; Holman et al., 2002). Charbotel et al. (2009) found that struggles to meet quality and quantity demands was a risk factor for psychological distress (OR=1.61), and Norman et al. (2008) found that call monitoring was a risk factor for neck/shoulder (OR=1.56) and hand/arm (OR=1.68) symptoms among call centre workers. Interestingly, Holman et al. (2002) demonstrated that the purpose and perceived intensity of surveillance are important to consider. Specifically, if surveillance is related to performance development, i.e. aimed at improving skills, or if surveillance is perceived as useful, i.e. to ensure standards, it is positively linked to wellbeing. However, if the intensity of surveillance is perceived to be high, it is negatively linked to wellbeing; assessed using measures of exhaustion, anxiety, depression, and job satisfaction (Holman et al., 2002). Agents in the participating call centres discussed their anxiety and frustration related to second-to-second surveillance, which might have implications for health.

Participants discussed that, in theory, they should take a break every hour to cope with the physical and psychosocial demands of the job, however many indicated that in practice this does not occur. Due to production pressures and surveillance, agents find it difficult to take unscheduled walking breaks or “breathers” to talk with or vent to co-workers. In one of the call centres co-worker support is discouraged for fear inaccurate information will be distributed and quality standards will be jeopardized. Support in the workplace is important for health (Kjellberg et al., 2010; Norman et al., 2008), and difficulties utilizing this resource may heighten psychological stress. Times of high workload are almost unavoidable in call centres due to the unpredictable nature of call numbers and content, and therefore successful coping strategies are necessary (Sprigg, Stride, Wall, Holman, & Smith, 2007).

Perceptions of agent-client interactions fit in the *perceptions of demand* category in the framework developed to guide measurement of physiological responses related to job demands and perceptions of demands in the physical and psychosocial domain (Figure 2.1). Should interactions with clients be appraised as important for wellbeing, i.e. where demands exceed available resources or coping strategies (Lazarus & Folkman, 1986), there may be resulting physiological, psychological, and/or behavioural reactions (Carayon et al., 1999). It is the aim of Part B (Chapter 6) to examine the relationship between agents' perceptions of interactions and physiological responses related to MSD and stress-related health outcomes.

5.5 Implications for health in the workplace

Findings from Part A suggest that aspects of both the content and context of call centre work condition the interactions agents have with clients every day. For job content, the regulation of emotion, the extent of knowledge required to do the job, and the unrelenting nature of the work, emerged as features that shape these interactions. Aspects of context, including pressure to be productive and workforce surveillance, influence the work done and ultimately the agents' perception of call difficulty. Future research and workplace efforts might consider a work system design approach to minimize agents' exposure to potentially straining situations. Part B aims to examine relationships between agents' perceptions of interactions and physiological responses. A better understanding of how the body reacts to challenging interactions will provide rational to examine how exposure to these situations can be mitigated and how secondary prevention can be ramped up (Sprigg et al., 2007) to enhance the effectiveness of coping strategies.

6.0 Field study Part B: Relationships between agent-client interactions and physiological responses related to musculoskeletal disorders and stress-related outcomes in call centres

6.1 Background and objective

In Part A agents described how aspects of both the content and context of call centre work condition the interactions they have with clients every day. Challenging interactions occur daily, though various factors influence this frequency, including the variability of call type from day to day, the agents' knowledge and training, and individual perceptions. Challenging interactions tend to elicit feelings of distress and frustration, however for some they were perceived as positive. Research has highlighted the agent-client interaction as a stressor in call centres (Lin et al., 2010; Charbotel et al., 2009; Lin et al., 2009; Goldberg & Grandey, 2007; Grandey et al., 2004). For example, Lin et al. (2009) asked call centre workers to report the three most important job stressors from a list, and "encountering difficult customers" (Lin et al., 2009, p. 564) came out on top. Charbotel et al. (2009) found that "situations of tension with clients" (Charbotel et al., 2009, p. 752) was a risk factor for psychological distress (OR=2.08). Findings from Part A provide an explanation as to why and how challenging interactions occur, which is instrumental to better understanding how these situations might be mitigated in the future.

Each workday agents evaluate the interactions they have with clients through primary and secondary appraisal (Folkman et al., 1986). If, through primary appraisal, the agent determines something is at stake, for example not being able to answer the question, or potential emotional harm, secondary appraisal would take place to consider coping strategies (Folkman et al., 1986). Possible coping strategies were discussed in Part A. Challenging interactions appraised as significant, in other words as important for wellbeing and where demands exceed coping resources (Lazarus & Folkman, 1986), may result in physiological reactions (Carayon et al., 1999) in the physical and psychosocial domain (Figure 2.1).

This part of the field study aimed to demonstrate relationships between agents' appraisal of their interactions with clients and physiological responses from the physical and psychosocial domain monitored over a work shift (Figure 6.1). Considering the literature around trapezius muscle activity and its response to mechanical and psychosocial demand (Dennerlein & Johnson, 2006a; Laursen et al., 2002; Lundberg et al., 2002b; Lundberg et al., 1994), as well as its anatomical position in an area commonly associated with musculoskeletal symptoms among computer users (Karlqvist et al., 2002), electromyography (EMG) of this muscle was a chosen measure from the physical domain. Furthermore, heart rate variability (HRV) is suggested to be more sensitive than blood pressure in terms of responding to mental stress (Hjortskov et al., 2004). Perceived job stress is associated with low HRV (Thayer et al., 2010), and power in the signal's 0.07-0.14 Hz range is considered "an index of task-related mental effort" (Mulder et al., 2000, pg. 143). Like EMG, heart rate (HR) can be collected continuously over a work shift, and is less obtrusive to measure than, say, stress hormone levels. In addition, electrodermal activity (EDA) is considered a good measure of emotional strain (Boucsein & Thum, 1997). A previous study used EDA as a means to distinguish between stressful and non-stressful calls in a call centre (Hernandez, Morris, & Picard, 2011). Therefore both HR and EDA were chosen measures from the psychosocial domain. It is suggested these three physiological signals (EMG, HR, and EDA) are suitable for examining physical, mental, and emotional strain on the body (Boucsein & Thum, 1997).

6.2 Objective and hypothesis

Part B aimed to demonstrate relationships between agents' appraisal of their interaction with clients and acute reactions monitored over a work shift (EMG, HR, and EDA) (Figure 6.1). The hypothesis was that interactions appraised as significant would result in greater trapezius muscle activity and sympathetic nervous system activity compared to baseline or non-straining interactions.

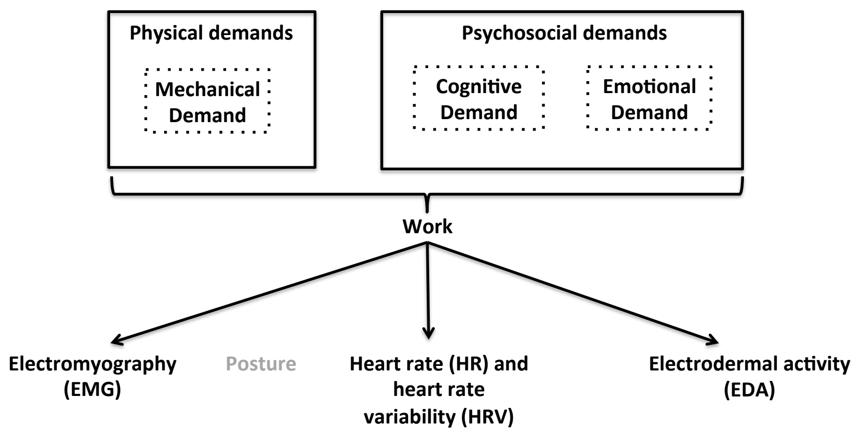


Figure 6.1. General layout showing independent (physical demands and psychosocial demands) and dependent (EMG, posture, HR/HRV, EDA) variables monitored in at least one study in the thesis; arrows demonstrate relationships focused on in chapter 6.

6.3 Methods

6.3.1 Participant population

Individuals were recruited from two Ontario call centres to participate in Part B (Table 6.1). Data collection for call centre 1 (CC1) was carried out at one worksite in Southern Ontario, and data collection for call centre 2 (CC2) was carried out at two worksites in Southern Ontario. All participants at CC2 performed the same job.

	Call centre 1	Call centre 2
Type	Insurance	Government
Call content	Support for medical, dental, and drug claims	Support for public service (e.g. pay and benefits)
Worksites	1	2
Hours of operation	Weekdays 8am-7pm	Weekdays 8am-5pm
Duration of work shifts	8 hours	8 hours
Inbound/outbound calls	Inbound	Inbound
Unionization	No	Yes
Number of front line agents	80	45

Table 6.1. Characteristics of the two participating call centres.

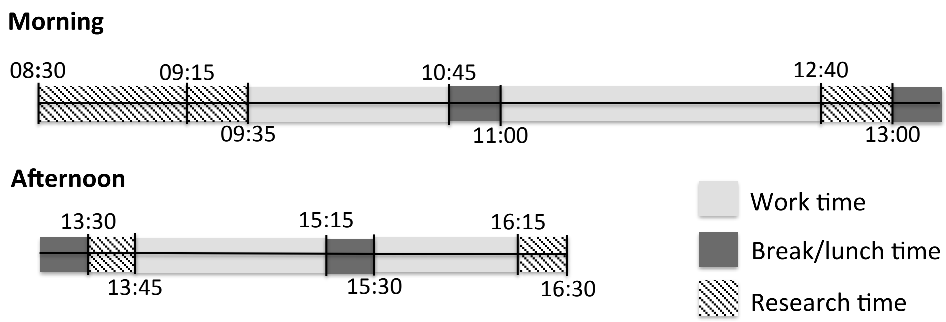
Participants were recruited using information sessions and recruitment flyers. Exclusion criteria included: 1) an allergy or sensitivity to ethanol, 2) any ongoing pain or injury to the neck or shoulder that prevented work or activities of daily living in the month prior to the study, 3) a pacemaker, and 4) use of any medication for the heart, such as beta-blocker medication. In total 24 individuals participated, 12 from CC1 and 12 from CC2 (Table 6.2). All participants were permanent, full-time workers. Participants were provided with a 25-dollar gift card for remuneration. The Office of Research Ethics at the University of Waterloo approved the study.

	All participants	**Participants from call centre 1**	**Participants from call centre 2**
Number (female/male)	24 (18/6)	12 (11/1)	12 (7/5)
Mean tenure (yrs.) (min-max)	7.0 (0.2-19.5)	6.2 (0.9-19.5)	7.8 (0.2-12.4)
Mean age (yrs.) (min-max)	42.3 (25.0-63.0)	41.0 (25.0-60.0)	43.6 (33.0-63.0)
Mean height (cm) (min-max)	167.7 (150.0-183.0)	166.2 (150.0-180.0)	169.3 (157.0-183.0)
Mean weight (kg) (min-max)	80.7 (52.3-127.3)	80.0 (52.3-106.8)	81.4 (63.6-127.3)

Table 6.2. Characteristics of Part B study participants.

6.3.2 Data collection

Participation began at the start of each participant's work shift and was complete at the end of his/her shift. Participants took their regular break(s) and lunch with equipment set-up and additional research activities occurring during what would have otherwise been work time. Participants met the researchers in private meeting room at the start of their shift, at which time the protocol was explained (Figure 6.2) and written consent was obtained. Only one participant took part on any given day due to resource limitations.



08:30 - 09:15	**Information consent and equipment set-up**
08:30 – 08:45	Information and consent; explanation of collection protocol
08:45 – 09:00	Electrode placement (EMG, ECG) and ECG signal test
09:00 – 09:15	Don monitors for EMG, ECG, and EDA collection
09:15 – 09:35	**Signal calibration and rest 1**
09:15 – 09:20	Maximum voluntary contractions for EMG data normalization
09:20 – 09:30	Reference contractions for data synchronization 1 and rest 1
09:30 – 09:35	Set-up at agent's workstation for morning collection
12:40 – 13:00	**Rest 2 and download EMG data**
12:40 – 12:50	Reference contractions for data synchronization 2 and rest 2
12:50 – 13:00	Download EMG data, re-don monitor, and conduct reference contractions for data synchronization 3
13:30 – 13:45	**Rest 3 and re-calibrate signals**
13:30 – 13:40	Rest 3
13:40 – 13:45	Set-up at agent's workstation for afternoon collection
16:15 – 16:30	**Rest 4 and remove monitors/electrodes**
16:15 – 16:25	Reference contractions for data synchronization 4 and rest 4
16:25 – 16:30	Remove monitors and electrodes and provide remuneration

Figure 6.2. Timeline for a typical collection day.

6.3.2.1 Appraisal of agent-client interactions

Participants used a touch screen computer tablet placed beside their workstation to appraise every call they took over their work shift. The following two questions were answered immediately after each call: 1) how much of a challenge did that call pose for you (answers ranging form 1 to 7 with anchors of *not at all*, *moderately challenging*, and *extremely challenging*), and 2) how overwhelmed did you feel by that call (i.e. how much did it overwhelm your ability to cope) (answers ranging from 1 to 7 with anchors of *not at all*, *moderately overwhelming*, and *extremely overwhelming*)? Figure 6.3 displays the application's interface. At the end of each collection day, the participant's call log, i.e. the file with the start and end time of every call taken, was provided by the employer to the researcher so it could be matched with the participant's call ratings.

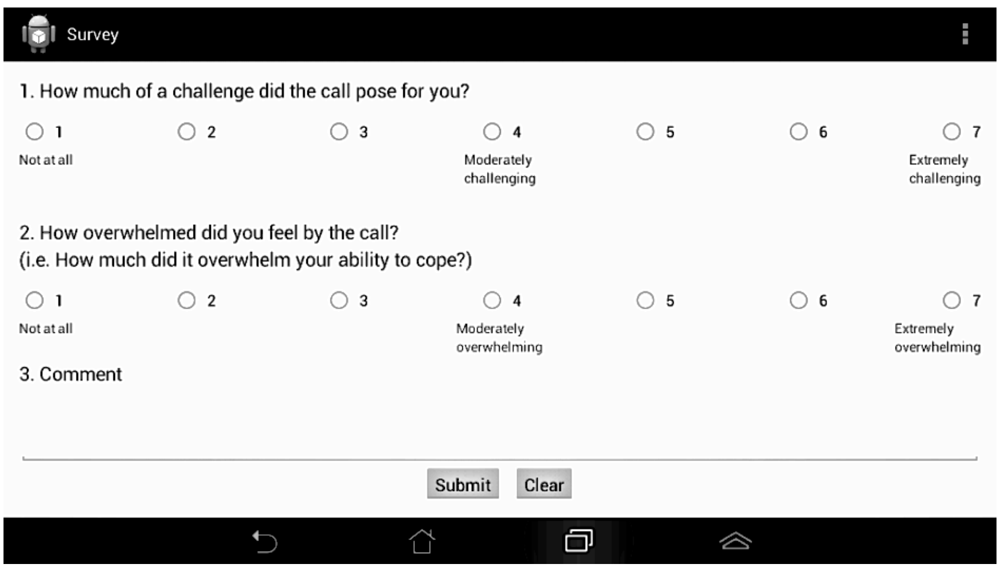


Figure 6.3. Tablet application used to rate calls.

In addition, every 45 minutes during work participants were asked to rate the call they just took using the NASA-Task Load Index (TLX), a workload scale that provides information on perceived mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988). Each of the measures was collected using a visual-analog scale that ranged from 0 (*low*) to 10 (*high*) (Appendix A). Participants filled out this workload scale at least five times during their work shift.

6.3.2.2 Physiological responses

A pair of silver-silver chloride electrodes (Ambu® Blue Sensor N) were placed 20mm apart (centre-to-centre) over the right and left upper trapezius (Table 4.1). EMG signals were collected using a belt-worn EMG data-logger (Mega, 3000P, Mega Electronics, Finland). Raw EMG signals were differentially amplified (common-mode rejection ratio of >130 dB and input impedance of 10GΩ), sampled at 1000 Hz, bandpass filtered from 20-500Hz, and fed into an analog/digital converter. Data was collected in averaged mode; the raw signal was rectified then averaged. A sampling period of 0.1s was used, thus 100 samples were averaged for each data point. The signals were collected continuously over the work shift. Three 5-second maximum voluntary contractions (MVCs) were collected for each muscle before the start of the workday (Figure 6.2) so the EMG signal amplitude could be normalized.

To determine HR and HRV parameters, a lightweight (less than 10 grams) HR monitor (Actiheart, CamNtech, Cambridgeshire, UK) was used for continuous monitoring. One ECG pad (Positrace® Adult) was placed over the left 5th intercostal space (at the mid-clavicular line), with the round end of the monitor fastened to it, and a second pad was placed 10 cm horizontal to the first pad at the anterior axillary line, with the other end of the monitor fastened to it (CamNtech, 2010). HR was sampled at 1000Hz and every inter-beat interval (IBI) was recorded over the work shift. A signal test was performed at the start of the workday to ensure proper electrode placement and integrity of the signal.

A wrist-worn wireless device (Affectiva, Waltham, Massachusetts) was used to continuously monitor skin conductance (SC). The device created a small direct current over the skin on the ventral side of the distal forearm using two silver plated electrodes (12mm in diameter), which allowed for detection of electrical changes due to sweat gland activity

(Affectiva, 2012). Sweat glands are exclusively innervated by the sympathetic nervous system (Boucsein, 1992). Firing of postganglionic sudomotor nerve fibres results in skin conductance responses (SCRs) (Benedek & Kaernbach, 2010). The wrist-worn device recorded SC in µSiemens at a sampling rate of 32Hz. The lightweight unit (22.7 grams) was placed on participants' non-dominant wrist to minimize motion artifact during data collection.

6.3.2.3 Siting and walking time

A video recorder (SONY Handycam® HDR-SR11) was used to document walking and standing time so these time windows could be excluded from call data. The video recorder was placed on a small tripod on participants' desks and images from keyboard height down were recorded continuously over the work shift. Audio was not recorded.

6.3.2.4 Steps to ensure data synchronization

At various points during the collection (Figure 6.2) steps were taken to ensure data could later be synchronized for analysis. It was critical that the call log provided by the employer could be time-matched to the physiological/video signals, and that the physiological/video signals could be time-matched to one another (section 6.3.3.1). The EDA monitor and the HR monitor were both synchronized to the time on the researcher's computer and data collected was time stamped. Data from the EMG monitor was not time stamped. However, the EDA monitor and the EMG monitor were both equipped with a "mark" button capable of placing a stamp in their dataset when the button was pressed. Thus, once all three monitors (EMG, EDA, and HR) were running, the "mark" button on the EDA and EMG monitors were pressed at the same time in front of the video camera (at the participant's desk) so the EMG and video signals could later be time-matched to the other two (EDA and HR). This process was done in the morning and in the afternoon because EMG data was downloaded at the lunch hour.

Reference voluntary contractions (RVEs) were conducted four times during the work shift: at the start and end of the morning and at the start and end of the afternoon. The RVEs required both arms to be abducted to 90 degrees in the scapular plane; participants were instructed to hold their arms up for 10 seconds and then to rest their arms beside their torso for 10 seconds, and to repeat three times. The EDA monitor (worn on wrist) contained a three-axis accelerometer, which meant that the RVEs could be used to verify synchronization of EDA and EMG data since activity data from the EDA monitor would time-match to trapezius activity. Furthermore, when participants took their first call, i.e. at the very moment they said hello, the mark button on the EDA monitor was pressed to verify that the call centre's computer time was the same as the researcher's computer time.

6.3.3 Data synchronization, coding, and pre-processing

All data including call logs, raw physiological signals, and video was imported into The Observer® XT 8.0 (Noldus) and a project file was created for each participant (Figure 6.4). The Observer® XT allowed integration of observational data (call logs and video recordings) and physiological signals (EMG, HR, and EMG) so data could be synchronized, coded, and exported for analysis.

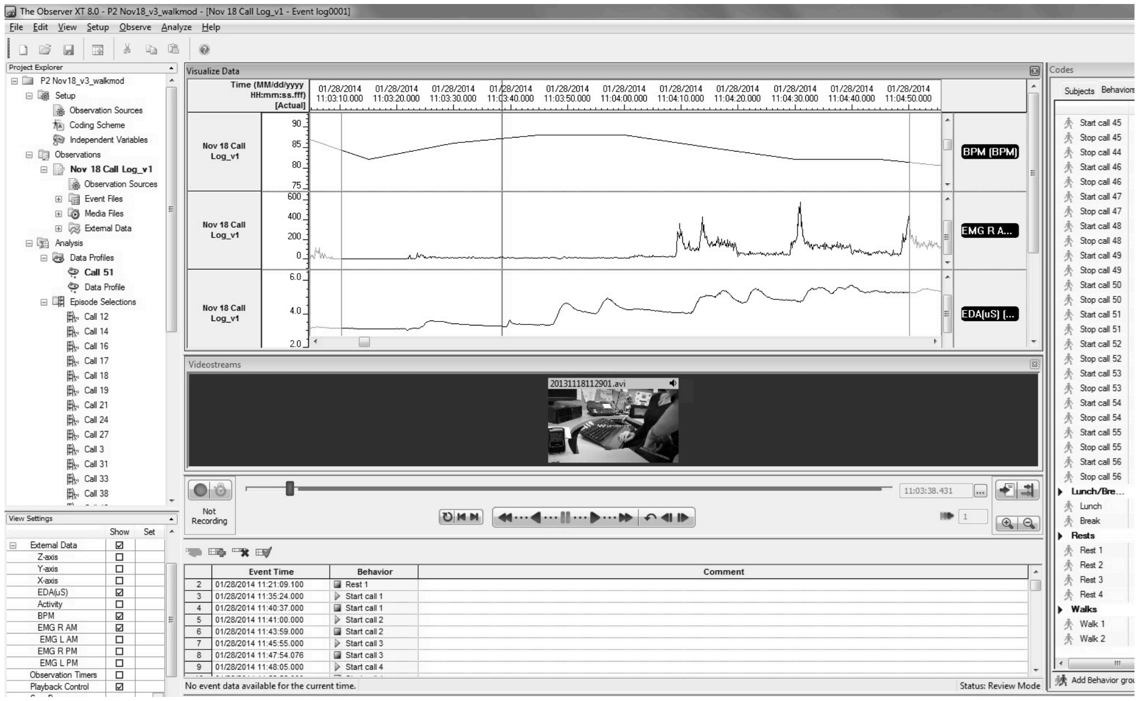


Figure 6.4. Example of a participant file in The Observer® XT 8.0.

6.3.3.1 Data synchronization

Synchronization of the EMG, HR, EDA, and video data was verified four ways: 1) by examining the four sets of RVEs (section 6.3.2.4), 2) by verifying that arm reaches seen in the video corresponded to expected trapezius activity during work, 3) by verifying that walks and stands seen in the video corresponded to expected activity from the HR monitor (which also contained an accelerometer), and 4) by verifying that the time on the digital clock placed on the participant's desk in front of the video camera changed at the same moment the project time changed in The Observer® XT.

6.3.3.2 Data coding

Once the data was synchronized, observational data was coded into each participant file, including the start and end time of every call, walks, stands, breaks, lunch, and the four rests taken over the work shift (Figure 6.2).

6.3.3.3 Selecting challenging, overwhelming, and baseline calls

Calls appraised as significant were identified in order to address the hypothesis that significant interactions would result in greater trapezius muscle activity and sympathetic nervous system activity compared to baseline interactions. As outlined in section 6.3.2.1, the following two questions were answered by participants immediately after every call: 1) how much of a challenge did that call pose for you (answers ranging form 1 to 7), and 2) how overwhelmed did you feel by that call (i.e. how much did it overwhelm your ability to cope) (answers ranging from 1 to 7)? Challenging and overwhelming calls were examined separately because there was a large spread in each participant's spearman correlation coefficient for ratings of challenging and ratings of overwhelming (Figure 6.5). The box plot shows that the lowest correlation coefficient was 0.12, the 25th percentile was 0.56, the median was 0.72, the 75th percentile was 0.88, and the largest was 1.00.

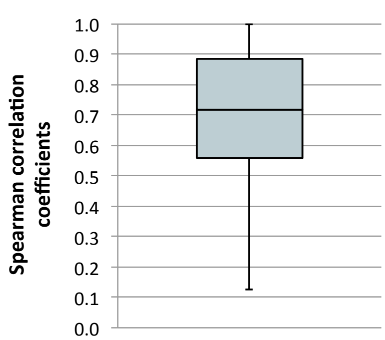


Figure 6.5. Box plot for spearman correlation coefficients for ratings of challenging and ratings of overwhelming. N=24.

For each participant, a call was considered *challenging* when ratings for question 1) were above the 80th percentile in the call rating frequency distribution. Likewise, a call was considered *overwhelming* when the same criterion was met for question 2) above. For most participants this meant that six calls were appraised as challenging and six calls were appraised as overwhelming. However, if more than 6 calls were scored above the 80th percentile on either scale, then the highest rated six calls were used, and if fewer than six calls were scored above the 80th percentile, then calls below the 80th percentile were used unless that meant taking baseline calls (those rated 1 on the Likert scale). Randomization was used when multiple calls with the same rating could have been chosen. If fewer than six calls were rated above 1 on either scale then that participant had fewer than six challenging (or overwhelming) calls.

Calls appraised as significant were compared with *baseline calls*. Baseline calls were calls with ratings of 1 on both the scale for challenging and the scale for overwhelming. To take into account possible time of day effects in the physiological signals, for example changes in skin conductance level (SCL) related to ambient temperature (Boucsein et al., 2012) or changes in HR due to caffeine or nicotine consumption (Gilbert, Dibb, Plath, & Hiyane, 2000), each challenging call was time-matched to a baseline call, and each overwhelming call was time-matched to a baseline call. The first baseline call that preceded a given challenging (or overwhelming) call was considered its time-match. Baseline calls occurred just before challenging (or overwhelming) calls, as opposed to just after, to minimize any carry-over effects from the straining agent-client interaction. When two or more challenging (or overwhelming) calls occurred in a row they shared the same time-matched baseline.

All challenging calls, and their corresponding baseline calls, and all overwhelming calls, and their corresponding baseline calls, were required to be at least 30 seconds in duration for data analysis purposes. However, to examine certain HRV parameters in the frequency domain at least 2 minutes of data are required (Task Force of The European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). Thus, challenging and overwhelming calls that were at least 2 minutes in duration, i.e. the large majority, required baseline matches that were also at least 2 minutes for comparisons to be made with HRV. If a given baseline match did not meet this criterion, a second "best" time-matched baseline was used. Thus, some challenging (and overwhelming) calls had two baseline matches: one that was used for all analyses except HRV, and one that was used for HRV alone. It might be said that the baseline calls used in the HRV analysis were not as well time-matched as the baseline calls used in all other analyses, however this is a limitation that was required in order to examine HRV. Table 6.3 provides a description of: 1) all calls taken by participants over their work shift, and 2) all calls selected for analysis.

	Mean Number (min-max)	Mean Duration* (min-max)
All calls	36.7 (20.0-60.0)	4.6 (2.8-8.3)
Analyzed calls		
Challenging	5.7 (2.0-6.0)	9.1 (4.7-20.1)
Baseline (for challenging)	5.8 (3.0-9.0)	3.1 (1.2-5.1)
Overwhelming	5.3 (2.0-6.0)	8.7 (4.6-18.8)
Baseline (for overwhelming)	5.4 (1.0-9.0)	3.1 (1.2-5.4)

* Values based on each participant's average

Table 6.3. Number and duration of all calls taken over the work shift and of all calls selected for analysis.

6.3.3.4 Selecting the lowest rest

Each participant performed four 10-minute rest trials throughout his/her work shift (Figure 6.2). For each dependent measure, the rest trial that produced the lowest average over minutes five to nine was used.

6.3.3.5 Extracting physiological data from calls and rest

For each participant raw EMG and EDA data was extracted from every challenging call, overwhelming call, baseline call, and lowest rest using The Observer® XT. IBI data could not be imported into The Observer® XT because it had no fixed sampling rate, and therefore IBI data required for HRV parameter calculation, and used for HR calculation, was extracted from the time-stamped IBI file (downloaded directly from the HR monitor). Time spent reaching to start or end a call, and time spent walking or standing was excluded from call data.

6.4 Data analysis

6.4.1 Processing physiological data

The ratings made for agent-client interactions were made for each call as a whole, and it cannot be determined whether a challenging or overwhelming circumstance occurred at the start, in the middle, at the end, or throughout a call. Therefore, when analyzing the physiological signals, two values were extracted from every call for each dependent measure: 1) an average for the entire call using means from consecutive windows, and 2) the highest value from a series of overlapping windows that spanned the entire call.

6.4.1.1 Upper trapezius muscle activity

The highest level of muscle activation from the 3 MVC trials for each muscle was used to normalize the EMG signal amplitude. For each call, mean % MVC was calculated for consecutive 30-second windows; these windows were used to generate an average % MVC. In addition, mean % MVC was calculated for overlapping 30-second windows; the 30-second window was moved forward by 10 seconds at a time thus producing four 30-second windows for each minute of data. The highest value from the series of overlapping windows was used. EMG data from the lowest rest was processed in the same manner using minutes five to nine of the 10-minute trial. All calculations were made in LabChart 7.1.

6.4.1.2 Heart rate (HR) and heart rate variability (HRV)

IBI data for every call was imported into Kubios HRV version 2.1 for analysis; Kubios HRV is a program that uses MATLAB® (MathWorks) to run (Tarvainen et al., 2014). Upon import, IBI data was converted to a signal with equidistant samples using cubic spline interpolation (4Hz) so time and frequency domain parameters could be calculated. For each call, the number of beats per minute (BPM) was calculated over consecutive 30-second windows; these windows were used to generate an average. BPM was also calculated for overlapping 30-second windows as described for the EMG analysis; the highest value from this series of overlapping windows was used. Data from the lowest rest was processed in the same manner using minutes five to nine of the 10-minute trial.

Detrending of the signal was carried out to remove “slow nonstationary trends” (Tarvainen et al., 2002, pg. 172), such as those related to thermoregulation or the renin-angiotensin system (Berntson et al., 1997), using the smoothness prior method (Lambda = 500) (Tarvainen et al., 2002). As outlined by Tarvainen et al. (2014) this method “is basically a time-varying high-pass filter and its cut-off frequency can be adjusted with the Lambda parameter” (Tarvainen et al., 2014, pg. 215). The frequency spectrum was estimated using Fast Fourier Transform (FFT) (Tarvainen et al., 2014). Power in units of ms^2 was estimated for the low frequency (LF) (0.04-0.15 Hz) and high frequency (HF) (0.15-0.40 Hz) bands in order to calculate the $LF[ms^2]/HF[ms^2]$ ratio which is said to reflect balance between the sympathetic and parasympathetic systems (Cerutti et al., 1995). As previously mentioned, at least two minutes of data is required to examine power in the LF band (Task Force of The European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996).

Therefore, for each call that was at least two minutes in duration, the LF/HF ratio was calculated over consecutive 2-minute windows; these windows were used to generate an average. The LF/HF ratio was also calculated over overlapping 2-minute windows; the 2-minute window was moved forward by 10 seconds at a time thus producing, for example, seven 2-minute windows for three minutes of data. The highest value from this series of overlapping windows was used. Data from the lowest rest was processed in the same manner using minutes five to nine of the 10-minute trial.

6.4.1.3 Electrodermal activity

SC data for each call was imported into Ledalab version 3.4.6 for analysis; Ledalab runs using MATLAB® (MathWorks) (Benedek & Kaernbach, 2010). Upon import, the raw signal was visually inspected for artifacts, which may have resulted from body movements or mechanical pressure on the wrist-worn recording device. Artifacts were corrected using cubic spline interpolation; one second of data on either side of the artifact was used to interpolate. Raw data was then low pass filtered (3Hz) using a 1^{st} order Butterworth filter to reduce noise (Poh et al., 2010). Tonic and phasic components of the SC signal were assessed separately. The tonic component refers to the slow changing SCL, and the phasic component refers to the quick changes in SC, i.e. the SCR (Boucsein et al., 2012). Continuous decomposition analysis (CDA) using standard deconvolution was used to separate the signal into its continuous tonic and phasic parts, an approach that is shown to provide a better estimate of SCR amplitude compared to typical trough-to-peak SCR amplitude analyses, and that provides a continuous phasic measure that closely mirrors sudomotor nerve activity (Benedek & Kaernbach, 2010).

As previously mentioned, it was not known at what point an agent's interaction with a client became straining, if it did, as ratings were made for each call as a whole. Measures of phasic activity, such as number of SCRs, are generally examined within a response window, in other words after a known stimulus has occurred. SCRs that occur in the absence of a known external stimulus are called nonspecific SCRs (NS.SCRs) and are considered a part of tonic activity (Boucsein et al., 2012). However, when a call was rated as challenging or overwhelming, an assumption was made that a stimulus was present, though that stimulus could not be traced to a specific moment in time. Boucsein et al. (2012) suggest that self-reports (i.e. call ratings) should be used when recording SC in ambulatory settings so SC fluctuations can be attributed to known stimuli. Thus, the assumption was made that SCRs observed during calls were related to aspects of the agent-client interaction, and to phasic rather than tonic activity.

Two phasic and one tonic measure were examined for each call: the number of SCRs with a threshold value of 0.03 μS; the integrated phasic driver activity, also called the integrated skin conductance response (ISCR), which accounts for temporal features of SCRs (and not just their amplitudes), and which mirrors sudomotor nerve activity (Benedek & Kaernbach, 2010); and SCL. For each call the dependent measures were calculated over consecutive 30-second windows; these windows were used to generate an average. Each dependent measure was also calculated for overlapping 30-second windows as described for the EMG analysis; the highest value from this series of overlapping windows was used. Data from the lowest rest was processed in the same manner using minutes five to nine of the 10-minute trial.

6.4.2 Statistical analysis

A generalized linear model (GLM) with a cumulative logit link function (multinomial distribution), also known as a proportional odds regression model, was used to examine the effect of: 1) workload on ratings of challenging, and 2) workload on ratings of overwhelming.

Two preliminary models were created with the six measures from the NASA-TLX (mental demand, physical demand, temporal demand, performance, effort, and frustration) as explanatory variables and ratings of challenging/overwhelming as the response variable. For each participant, the first 5 calls that were rated using the NASA-TLX were used. A blocking (explanatory) variable for workplace (CC1 or CC2) was also included in each preliminary model. Explanatory variables with a *p*-value less than or equal to 0.05 were included in the final models. The workplace (blocking) variable was not statistically significant in either model.

As previously mentioned, since it could not be determined at what point during a call a challenging or overwhelming situation occurred (if it did), from each call, and from the lowest rest, two values were extracted for each dependent measure: 1) an average value using means from consecutive windows (AvgCW), and 2) the highest value from a series of overlapping windows (HighOW). For each dependent measure, a box plot was generated to describe the data using means from both AvgCW and HighOW values. The analyses described in the following two paragraphs were carried out separately for AvgCW and HighOW values.

To address the hypothesis that challenging/overwhelming calls resulted in greater trapezius activity and sympathetic nervous system activity compared to baseline calls, for each dependent measure, the difference was taken between each challenging call and its time-matched baseline (baseline values subtracted from challenging values), and between each overwhelming call and its time-matched baseline (baseline values subtracted from overwhelming values). Then, for each participant, a mean difference was calculated for each dependent measure for: 1) challenging calls compared to their time-matched baseline calls, and 2) overwhelming calls compared to their time-matched baseline calls. Each participant's mean difference for each dependent measure was then used in a paired *t*-test (related samples) to test the null hypothesis that the mean differences came from a population with a mean of zero (alpha set to 0.05). As mentioned in section 6.3.3.3, when two or more challenging (or overwhelming) calls occurred in a row, they shared the same time-matched baseline. This analysis approach will not be influenced by different numbers of each call type as might be mean values due to possible time of day effects.

In addition, for each dependent measure the difference was taken between each baseline call and the lowest rest (rest value subtracted from baseline value). Then, for each participant, a mean difference was calculated for each dependent measure for: 1) baseline calls (matched to challenging calls) compared to rest, and 2) baseline calls (matched to overwhelming calls) compared to rest. Each participant's mean difference for each dependent measure was then used in a paired *t*-test (related samples) to test the null hypothesis that the mean differences came from a population with a mean of zero (alpha set to 0.05). This analysis was carried out to determine if non-straining calls were different from non-work time.

6.5 Results

6.5.1 The effect of workload on tablet ratings

The final proportional odds regression model examining the effect of workload on ratings of challenging included the explanatory variables mental demand ($p<0.001$), performance ($p=0.045$), and effort ($p=0.001$), with mental demand having the largest effect on ratings of challenging with a parameter estimate of 0.75 (Table 6.4). Likewise, the final proportional odds regression model examining the effect of workload on ratings of overwhelming included the explanatory variables mental demand ($p<0.001$), performance ($p=0.001$), and frustration ($p<0.001$), with frustration having the largest effect on ratings of overwhelming with a parameter estimate of 0.51 (Table 6.5).

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	*p*-value
Mental demand	0.75	0.15	25.23	<0.001
Performance	0.20	0.10	4.00	0.045
Effort	0.44	0.13	11.57	0.001

Table 6.4. Final proportional odds regression model for effect of workload on ratings of challenging.

Variable	Parameter Estimate	Standard Error	Wald Chi-Square	*p*-value
Mental demand	0.47	0.11	17.86	<0.001
Performance	0.33	0.10	10.84	0.001
Frustration	0.51	0.11	21.00	<0.001

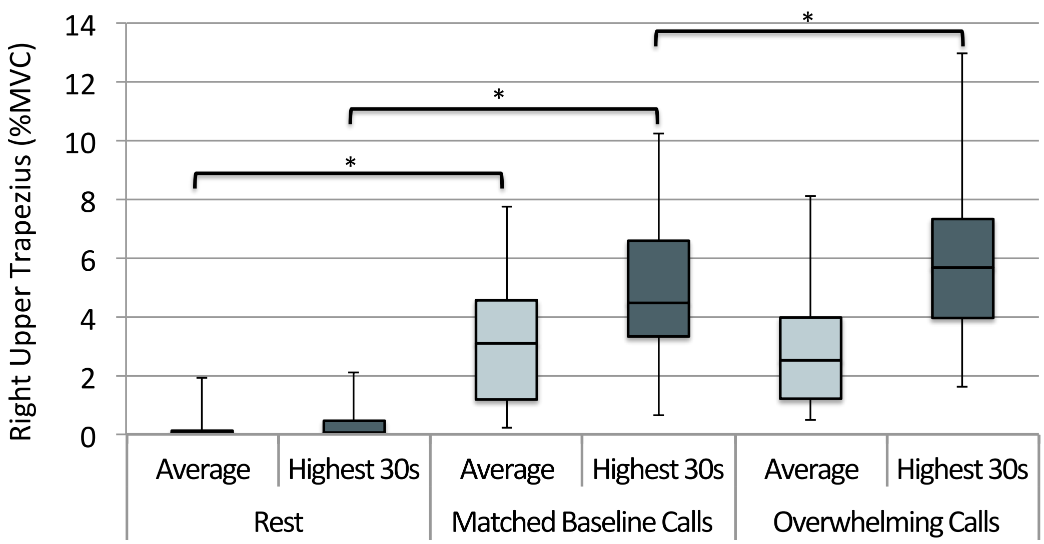
Table 6.5. Final proportional odds regression model for effect of workload on ratings of overwhelming.

6.5.2 Trapezius activity during overwhelming calls, baseline calls, and rest

For the right upper trapezius (Figure 6.6), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.0, 0.1, and 1.9 % MVC, respectively, for the lowest rest, was 0.2, 1.2, 3.1, 4.6, and 7.7 % MVC, respectively, for baseline calls, and was 0.5, 1.2, 2.5, 4.0, and 8.1 % MVC, respectively, for overwhelming calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.1, 0.5, and 2.1 % MVC, respectively, for the lowest rest, was 0.6, 3.3, 4.5, 6.6, and 10.2 % MVC, respectively, for baseline calls, and was 1.6, 4.0, 5.7, 7.3, and 12.9 % MVC, respectively, for overwhelming calls.

Results from the paired *t*-tests (Table 6.6) were used to indicate on the box plot (Figure 6.6) where the average mean difference was statistically different from zero. For the right upper trapezius, when using HighOW values, the average mean difference was 1.20 % MVC (p<0.001) when comparing overwhelming calls to their time-matched baselines, and was 4.55

% MVC (p<0.001) when comparing baseline calls to rest. When using AvgCW values, the average mean difference was 3.12 % MVC (p<0.001) when comparing baseline calls to rest (Table 6.6). Refer to Appendix D for results using challenging calls, their time-matched baselines, and rest.

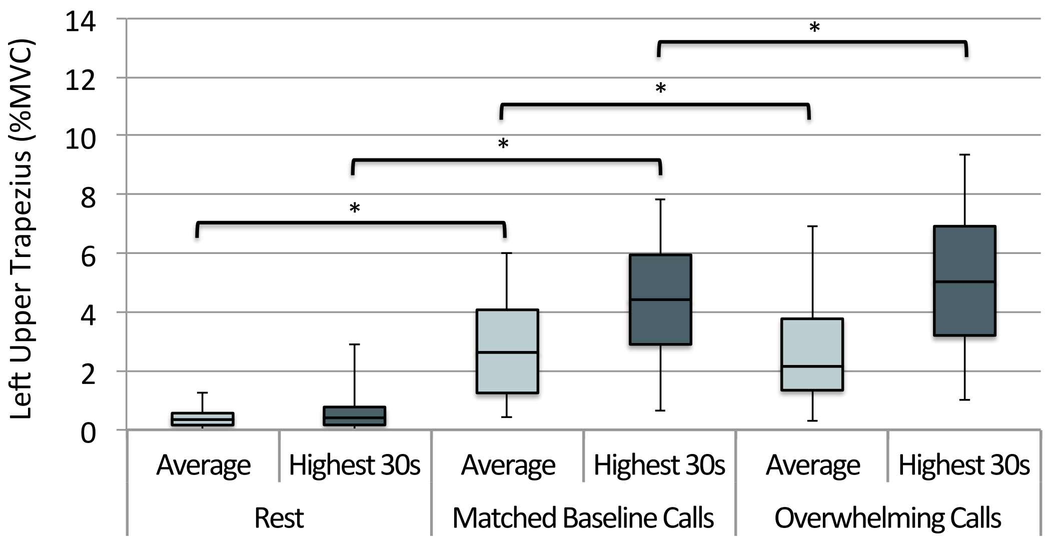


*Average mean difference (Table 6.6) is statistically significant

Figure 6.6. Box plots for the right upper trapezius (% MVC) (N=24) showing minimum, 25th percentile, median, 75th percentile, and maximum values for overwhelming calls, time-matched baselines, and rest.

For the left upper trapezius (Figure 6.7), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.2, 0.3, 0.6, and 1.3 % MVC, respectively, for the lowest rest, was 0.4, 1.2, 2.6, 4.1, and 6.0 % MVC, respectively, for baseline calls, and was 0.3, 1.3, 2.2, 3.8, and 6.9 % MVC, respectively, for overwhelming calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.2, 0.4, 0.7, and 2.9 % MVC, respectively, for the lowest rest, was 0.6, 2.9, 4.4, 6.0, and 7.9 % MVC, respectively, for baseline calls, and was 1.0, 3.2, 5.0, 6.9, and 9.4 % MVC, respectively, for overwhelming calls.

Results from the paired *t*-tests (Table 6.6) were used to indicate on the box plot (Figure 6.7) where the average mean difference was statistically different from zero. For the left upper trapezius, when using HighOW values, the average mean difference was 0.74 % MVC (p=0.002) when comparing overwhelming calls to their time-matched baselines and was 3.73 % MVC (p<0.001) when comparing baseline calls to rest. When using AvgCW values, the average mean difference was -0.28 % MVC (p=0.043) when comparing overwhelming calls to their time-matched baselines, and was 2.48 % MVC (p<0.001) when comparing baseline calls to rest (Table 6.6). Refer to Appendix D for results using challenging calls, their time-matched baselines, and rest.



*Average mean difference (Table 6.6) is statistically significant

Figure 6.7. Box plots for the left upper trapezius (% MVC) (N=24) showing minimum, 25th percentile, median, 75th percentile, and maximum values for overwhelming calls, time-matched baselines, and rest.

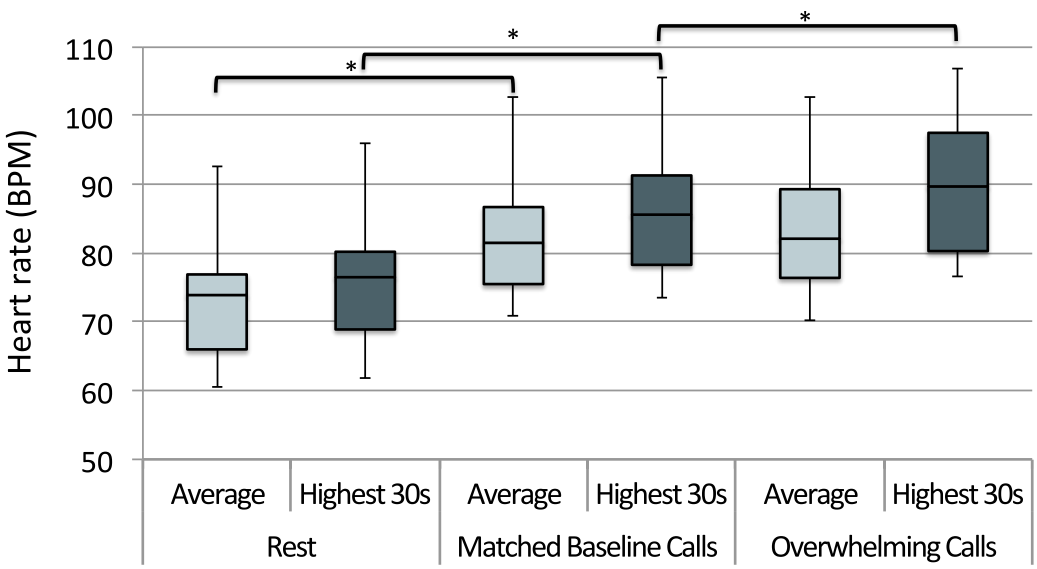
Measure	Mean difference between	Average mean difference (95% CL)	Standard Error	*p*-value
Right trapezius (%MVC)	**Overwhelming and time-matched baseline calls**			
	Using call average (AvgCW)	-0.29 (-0.78 to 0.20)	0.24	0.237
	Using highest 30s (HighOW)	1.20 (0.76 to 1.64)	0.21	**<0.001**
	Baseline calls and rest			
	Using call average (AvgCW)	3.12 (2.22 to 4.03)	0.44	**<0.001**
	Using highest 30s (HighOW)	4.55 (3.48 to 5.61)	0.51	**<0.001**
Left trapezius (%MVC)	**Overwhelming and time-matched baseline calls**			
	Using call average (AvgCW)	-0.28 (-0.56 to -0.01)	0.13	**0.043**
	Using highest 30s (HighOW)	0.74 (0.30 to 1.18)	0.21	**0.002**
	Baseline calls and rest			
	Using call average (AvgCW)	2.48 (1.73 to 3.22)	0.36	**<0.001**
	Using highest 30s (HighOW)	3.73 (2.85 to 4.60)	0.42	**<0.001**

Table 6.6. Average mean differences (right and left trapezius activity) for overwhelming calls compared to their time-matched baselines, and for baseline calls compared to rest (N=24). Bolded *p*-values are statistically significant.

6.5.3 Heart rate and LF/HF ratio during overwhelming calls, baseline calls, and rest

For heart rate (Figure 6.8), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 60.5, 66.0, 73.9, 76.9, and 92.7 BPM, respectively, for the lowest rest, was 70.8, 75.5, 81.5, 86.7, and 102.6 BPM, respectively, for baseline calls, and was 70.2, 76.4, 82.1, 89.3, and 102.6 BPM, respectively, for overwhelming calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 61.8, 68.9, 76.5, 80.2, and 95.9 BMP, respectively, for the lowest rest, was 73.5, 78.3, 85.6, 91.3, and 105.6 BPM, respectively, for baseline calls, and was 76.6, 80.3, 89.7, 97.5, and 106.8 BPM, respectively, for overwhelming calls.

Results from the paired *t*-tests (Table 6.7) were used to indicate on the box plot (Figure 6.8) where the average mean difference was statistically different from zero. When using HighOW values, the average mean difference was 3.35 BPM (p<0.001) when comparing overwhelming calls to their time-matched baselines, and was 9.67 BPM (p<0.001) when comparing baseline calls to rest. When using AvgCW values, the average mean difference was 9.39 BPM (p<0.001) when comparing baseline calls to rest (Table 6.7). Refer to Appendix E for results using challenging calls, their time-matched baselines, and rest.

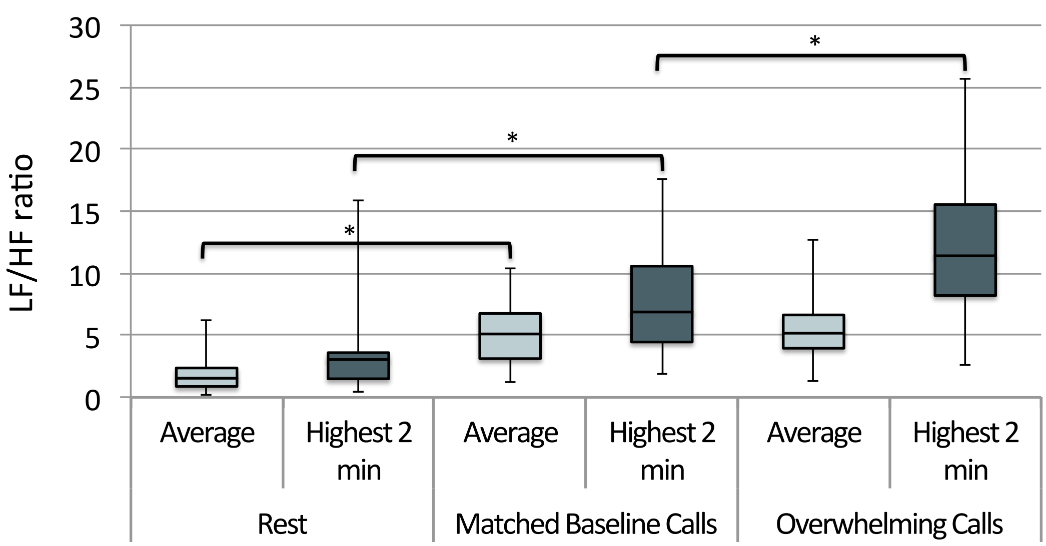


*Average mean difference (Table 6.7) is statistically significant

Figure 6.8. Box plots for heart rate (BPM) (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for overwhelming calls, time-matched baselines, and rest.

For the LF/HF ratio (Figure 6.9), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.2, 0.9, 1.5, 2.4, and 6.2, respectively, for the lowest rest, was 1.2, 3.1, 5.1, 6.8, and 10.4, respectively, for baseline calls, and was 1.3, 4.0, 5.2, 6.6, and 12.7, respectively, for overwhelming calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.4, 1.5, 3.1, 3.6, and 15.9, respectively, for the lowest rest, was 1.9, 4.5, 6.9, 10.6, and 17.6, respectively, for baseline calls, and was 2.5, 8.2, 11.4, 15.5, and 25.6, respectively, for overwhelming calls.

Results from the paired *t*-tests (Table 6.7) were used to indicate on the box plot (Figure 6.9) where the average mean difference was statistically different from zero. When using HighOW values, the average mean difference was 4.56 ($p<0.001$) when comparing overwhelming calls to their time-matched baselines, and was 4.18 ($p<0.001$) when comparing baseline calls to rest. When using AvgCW values, the average mean difference was 3.33 ($p<0.001$) when comparing baseline calls to rest (Table 6.7). Refer to Appendix E for results using challenging calls, their time-matched baselines, and rest.



*Average mean difference (Table 6.7) is statistically significant

Figure 6.9. Box plots for the LF/HF ratio (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for overwhelming calls, time-matched baselines, and rest.

Measure	Mean difference between	Average mean difference (95% CL)	Standard Error	*p*-value
Heart rate (BPM)	**Overwhelming and time-matched baseline calls**			
	Using call average (AvgCW)	0.79 (-0.45 to 2.04)	0.60	0.200
	Using highest 30s (HighOW)	3.35 (1.79 to 4.91)	0.75	**<0.001**
	Baseline calls and rest			
	Using call average (AvgCW)	9.39 (7.18 to 11.60)	1.07	**<0.001**
	Using highest 30s (HighOW)	9.67 (7.17 to 12.17)	1.21	**<0.001**
LF/HF ratio	**Overwhelming and time-matched baseline calls**			
	Using call average (AvgCW)	0.38 (-0.48 to 1.25)	0.42	0.365
	Using highest 2min (HighOW)	4.56 (3.04 to 6.08)	0.73	**<0.001**
	Baseline calls and rest			
	Using call average (AvgCW)	3.33 (2.52 to 4.14)	0.39	**<0.001**
	Using highest 2min (HighOW)	4.18 (2.56 to 5.79)	0.78	**<0.001**

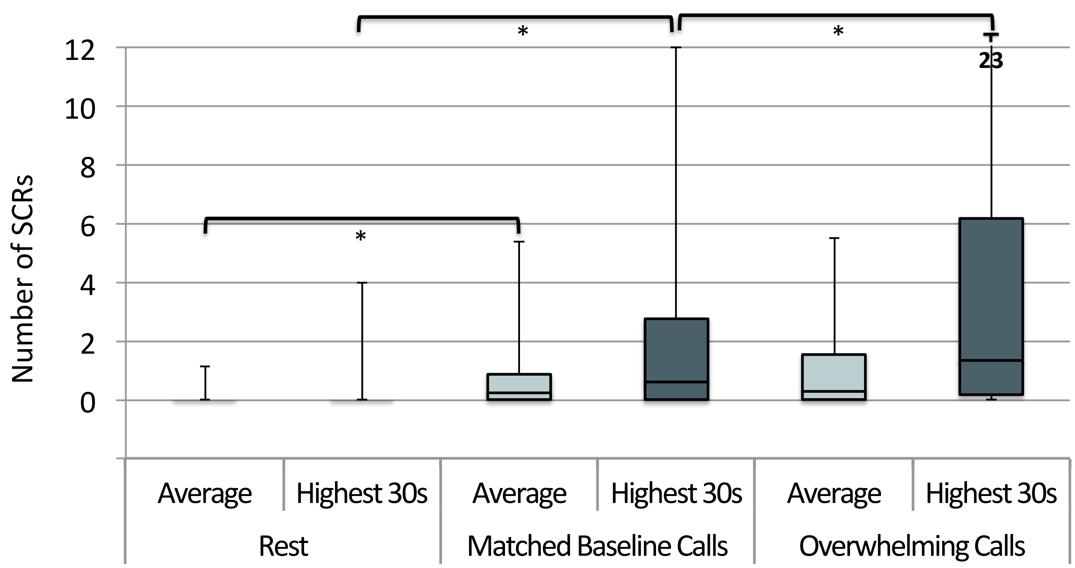
Table 6.7. Average mean differences (heart rate and the LF/HF ratio) for overwhelming calls compared to their time-matched baselines, and for baseline calls compared to rest (N=23). Bolded *p*-values are statistically significant.

6.5.4 Electrodermal activity during overwhelming calls, baseline calls, and rest

For number of SCRs (Figure 6.10), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.0, 0.0, and 1.1, respectively, for the lowest rest, was 0.0, 0.0, 0.2, 0.9, and 5.4, respectively, for baseline calls, and was 0.0, 0.0, 0.3, 1.5, 5.5, respectively, for overwhelming calls. Likewise, when using the means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.0, 0.0, 4.0, respectively, for the lowest rest, was 0.0, 0.0, 0.6, 2.8, 12.0, respectively, for baseline calls, and was 0.0, 0.2, 1.3, 6.2, and 23.0, respectively, for overwhelming calls.

Results from the paired *t*-tests (Table 6.8) were used to indicate on the box plot (Figure 6.10) where the average mean difference was statistically different from zero. When using

HighOW values, the average mean difference was 2.02 (p=0.008) when comparing overwhelming calls to their time-matched baselines, and was 1.70 (p=0.007) when comparing baseline calls to rest. When using AvgCW values, the average mean difference was 0.74 (p=0.016) when comparing baseline calls to rest (Table 6.8). Refer to Appendix F for results using challenging calls, their time-matched baselines, and rest.

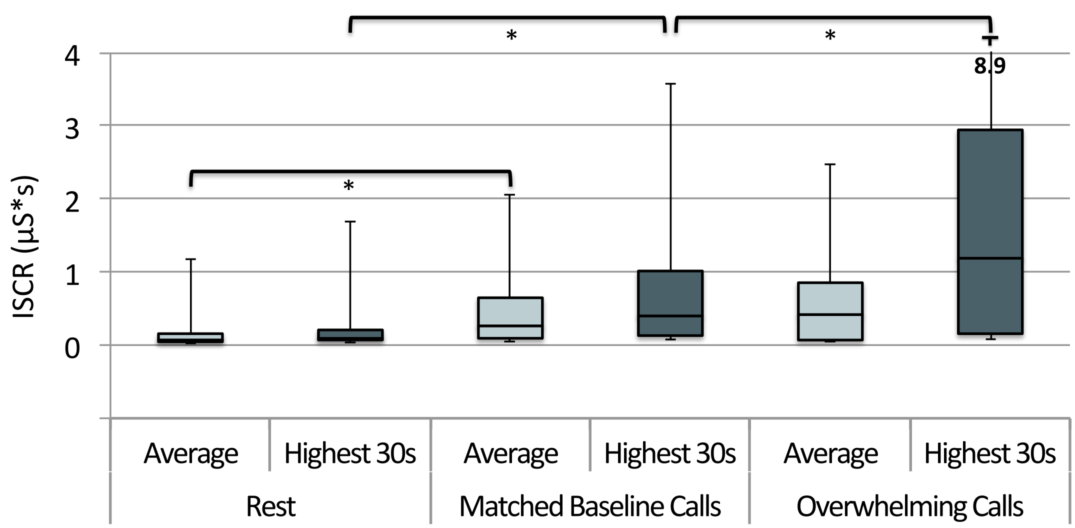


*Average mean difference (Table 6.8) is statistically significant

Figure 6.10. Box plots for number of SCRs (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for overwhelming calls, time-matched baselines, and rest.

For the ISCR (Figure 6.11), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.1, 0.2, and 1.2 µS*s, respectively, for the lowest rest, was 0.0, 0.1, 0.3, 0.6, and 2.1 µS*s, respectively, for baseline calls, and was 0.0, 0.1, 0.4, 0.9, and 2.5 µS*s, respectively, for overwhelming calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.1, 0.1, 0.2, and 1.7 µS*s, respectively, for the lowest rest, was 0.1, 0.1, 0.4, 1.0, and 3.6 µS*s, respectively, for baseline calls, and was 0.1, 0.2, 1.2, 2.9, and 8.9 µS*s, respectively, for overwhelming calls.

Results from the paired *t*-tests (Table 6.8) were used to indicate on the box plot (Figure 6.11) where the average mean difference was statistically different from zero. When using HighOW values, the average mean difference was 1.09 µS*s (p=0.006) when comparing overwhelming calls to their time-matched baselines, and was 0.61 µS*s (p=0.001) when comparing baseline calls to rest. When using AvgCW values, the average mean difference was 0.33 µS*s (p=0.001) when comparing baseline calls to rest (Table 6.8). Refer to Appendix F for results using challenging calls, their time-matched baselines, and rest.

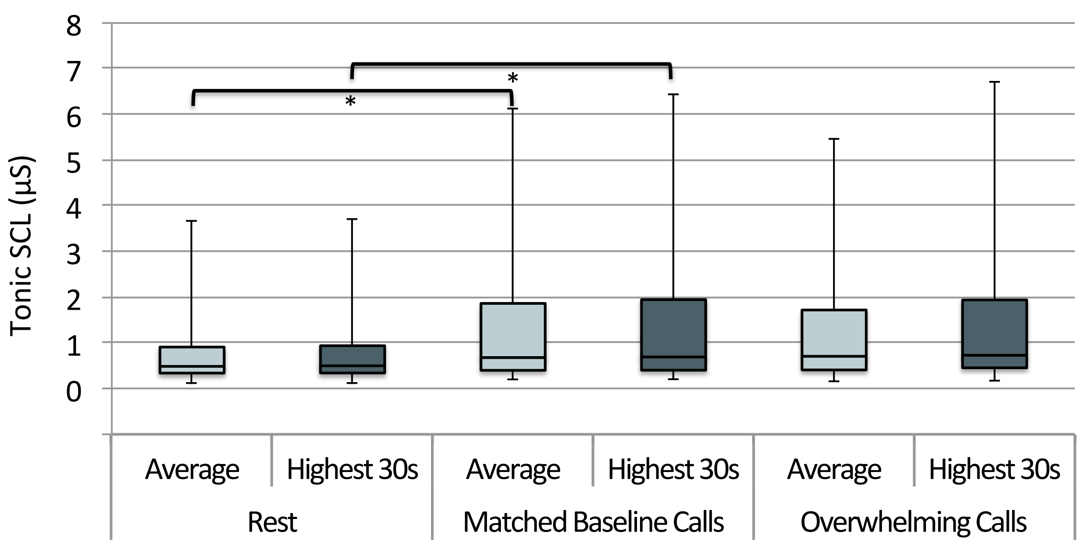


*Average mean difference (Table 6.8) is statistically significant

Figure 6.11. Box plots for ISCR (µS*s) (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for overwhelming calls, time-matched baselines, and rest.

For SCL (Figure 6.12), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.1, 0.3, 0.5, 0.9, and 3.7 µS, respectively, for the lowest rest, was 0.2, 0.4, 0.7, 1.9, and 6.1 µS, respectively, for baseline calls, and was 0.2, 0.4, 0.7, 1.7, and 5.5 µS, respectively, for overwhelming calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.1, 0.3, 0.5, 0.9, and 3.7 µS, respectively, for the lowest rest, was 0.2, 0.4, 0.7, 1.9, and 6.4 µS, respectively, for baseline calls, and was 0.2, 0.5, 0.7, 1.9, and 6.7 µS, respectively, for overwhelming calls.

Results from the paired *t*-tests (Table 6.8) were used to indicate on the box plot (Figure 6.12) where the average mean difference was statistically different from zero. When using HighOW values, the average mean difference was 0.54 µS ($p<0.001$) when comparing baseline calls to rest. When using AvgCW values, the average mean difference was 0.50 µS ($p<0.001$) when comparing baseline calls to rest (Table 6.8). Refer to Appendix F for results using challenging calls, their time-matched baselines, and rest.



*Average mean difference (Table 6.8) is statistically significant

Figure 6.12. Box plots for SCL (µS) (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for overwhelming calls, time-matched baselines, and rest.

Measure	Mean difference between	Average mean difference (95% CL)	Standard Error	*p*-value
Number of SCRs	**Overwhelming and time-matched baseline calls**			
	Using call average (AvgCW)	0.18 (-0.02 to 0.38)	0.09	0.073
	Using highest 30s (HighOW)	2.02 (0.59 to 3.44)	0.69	**0.008**
	Baseline calls and rest			
	Using call average (AvgCW)	0.74 (0.15 to 1.33)	0.28	**0.016**
	Using highest 30s (HighOW)	1.70 (0.52 to 2.89)	0.57	**0.007**
ISCR (μS*s)	**Overwhelming and time-matched baseline calls**			
	Using call average (AvgCW)	0.08 (-0.01 to 0.17)	0.04	0.083
	Using highest 30s (HighOW)	1.09 (0.35 to 1.82)	0.35	**0.006**
	Baseline calls and rest			
	Using call average (AvgCW)	0.33 (0.15 to 0.51)	0.09	**0.001**
	Using highest 30s (HighOW)	0.61 (0.27 to 0.94)	0.16	**0.001**
Tonic SCL (μS)	**Overwhelming and time-matched baseline calls**			
	Using call average (AvgCW)	-0.09 (-0.18 to 0.002)	0.04	0.054
	Using highest 30s (HighOW)	0.01 (-0.05 to 0.08)	0.03	0.655
	Baseline calls and rest			
	Using call average (AvgCW)	0.50 (0.23 to 0.77)	0.13	**<0.001**
	Using highest 30s (HighOW)	0.54 (0.24 to 0.83)	0.14	**<0.001**

Table 6.8. Average mean differences (number SCRs, ISCR, tonic SCL) for overwhelming calls compared to their time-matched baselines, and for baseline calls compared to rest (N=23). Bolded *p*-values are statistically significant.

6.6 Discussion

The aim of Part B was to examine relationships between ratings of agent-client interactions and physiological responses monitored over a work shift among call centre agents. The hypothesis was that interactions appraised as significant would result in greater physiological reactions compared to baseline interactions, which was found true. Both challenging and overwhelming calls, separately, resulted in greater trapezius muscle activity, higher HR, higher LF/HF ratio, greater number of SCRs, and higher ISCR, compared to baseline calls. In addition, each of these measures was higher during baseline calls compared to rest, suggesting that non-straining work conditions alone increase the physiological response.

As outlined in chapter 5, every day agents encounter potentially straining interactions. Various factors influence the frequency of these interactions, including the variability of call type from day to day, the agents' knowledge and training, and individual perceptions. Individual perceptions are at the centre of the cognitive appraisal process. Whether aware of it or not, agents evaluate each interaction they have with clients through primary and secondary appraisal (Folkman et al., 1986). If, through primary appraisal, the agent determines something is at stake, for example not being able to answer an inquiry or potential emotional strife, secondary appraisal would take place to consider coping strategies (Folkman et al., 1986).

When work demands exceed coping resources (Lazarus & Folkman, 1986), or barriers exist that prevent use of these resources, there may be resulting physiological, psychological, and behavioural reactions (Carayon et al., 1999). This study focused on acute reactions related to interactions appraised as challenging and those appraised as overwhelming. An interaction might be challenging but not overwhelming if an agent has adequate coping resources. Thus, it was expected that calls appraised as overwhelming would elicit the greatest physiological response. However, both challenging and overwhelming calls resulted in similar acute responses compared to baseline calls. For example, when HighOW values were used to examine right trapezius activity, the mean difference between overwhelming calls and their time-matched baseline calls was 1.20 % MVC, and the mean difference between challenging calls and their time-matched baseline calls was 1.31 % MVC. Similarly, for HR, the mean difference between overwhelming calls and baseline calls was 3.35 BPM, and the mean difference between challenging calls and baseline calls was 3.13 BPM. In fact, the dependent measures with statistically significant mean differences were essentially the same whether challenging or overwhelming calls were examined.

The similarity in results may be a reflection of participants not distinguishing between the concept of challenging and the concept of overwhelming when tablet ratings were made. For some participants there was a high correlation between the two rating scales (Figure 6.5). However, the proportional odds regression models suggest that different aspects of workload drove ratings for these two measures; mental demand had the largest effect on ratings of challenging, and frustration had the largest effect on ratings of overwhelming. These finding suggest, as previously mentioned, that an agent-client interaction might be challenging, due to, say, high mental demand, but that the interaction might only become overwhelming if one's ability to cope is overwhelmed, perhaps leading to feelings of frustration. Participants in Part A indicated that they have feelings of distress and frustration during these calls.

Overwhelming calls resulted in higher trapezius activity, higher HR and LF/HF ratio, greater number of SCRs, and a higher ISCR, compared to baseline calls. As previously discussed, it could not be determined at what point during a call an overwhelming (or challenging) situation occurred (if it did), so two values were extracted from each call for each dependent measure: an average value using means from consecutive windows (AvgCW) and a highest value from a series of overlapping windows (HighOW). HighOW values were those that resulted in statistically significant mean differences. Using HighOW values was the best way to ensure that physiological reactions related to the challenging/overwhelming part of a call were not washed out by the call as a whole. For example, difficulties related to an emotional or abusive client may surface only after upsetting information is provided. It may be considered a limitation that HighOW values were those that produced statistical significance, however the same approach was taken for both baseline and challenging/overwhelming calls, and mean differences were statistically significant.

Results indicated a statistically significant mean difference of 1.20 % MVC for the right trapezius and 0.74 % MVC for the left trapezius when HighOW values were used to compare overwhelming and baseline calls. The trapezius muscle responds to mechanical and mental demand (Dennerlein & Johnson, 2006a; Laursen et al., 2002; Lundberg et al., 2002b; Lundberg et al., 1994), and thus it is reasonable to suggest this increased activity was the result of both physical and psychosocial work factors. For example, mental demand to respond to an inquiry might be combined with a requirement to reach for resources in the workspace. Although video data was available, it was not feasible to tease apart these demands by coding arm position throughout the work shift for all participants.

Nonetheless, a median value of 4.5 % MVC and 5.7 % MVC was found for the right upper trapezius during baseline and overwhelming calls, respectively. These values are in-line with upper trapezius activity typically seen during computer work (Delisle et al., 2006; Dennerlein & Johnson, 2006a; Karlqvist et al., 1998; Aaras et al., 1997). For example, Delisle et al. (2006) found that, among 18 computer users, the 50^{th} percentile activity ranged of 4 to 5 % of MVC during keyboarding tasks. Dennerlein & Johnson (2006a) found the 50^{th} percentile activity to range from 5 to 7 % MVC during computer work that incorporated different mouse configurations. Mean differences reported in this study, although small, add to the level of activity seen during regular or non-straining work, which may lead to increased tissue loading and discomfort among call centre agents.

Results showed a statistically significant mean difference of 3.35 BPM and of 4.56 for LF/HF ratio when HighOW values were used to compare overwhelming and baseline calls.

Results also demonstrated a mean difference of approximately 9 BPM when comparing baseline calls to rest, suggesting that non-straining work conditions alone increase sympathetic activity. The literature has shown that HR is higher during work time compared to non-work time (Rissén et al., 2000). The literature also shows that the LF/HF ratio is higher during cognitively demanding tasks (Hjortskov et al. 2004; Delaney & Brodie, 2000; Sloan et al., 1994). For example, Sloan et al. (1994) found that self-reported stress, examined hourly using four affect measures, was associated with significantly higher LF/HF ratios during the day. Delaney & Brodie (2000) found that the combination of the Stroop colour-word test and mental arithmetic produced an increase in the LF/HF ratio from a mean of 6.3 in a baseline condition to a mean of 8.1 in a treatment condition. These numbers are similar to median values found in the current study during baseline (LF/HF=6.9) and overwhelming (LF/HF=11.4) calls. The slightly higher values in the current study may be attributed to higher cognitive demand during real work conditions.

The mean differences found in HR and the LF/HF ratio are an indication of increased sympathetic activity during overwhelming calls. As previously discussed (section 2.0), this physiological response should shut off once the external demand is gone, i.e. the overwhelming call ends, however a load may result if this allostatic response is chronically overactive (McEwen, 1998). McEwen (1998) outlines four situations that lead to allostatic load (AL), one of which is “repeated ‘hits’ from multiple stressors” (McEwen, 1998, p.174). Arguably not one client inquiry is the same, as mentioned by participants in Part A. If overwhelming interactions are considered “hits”, and these hits activate the sympathetic nervous system, increasing HR and the LF/HF ratio, then over time they may be associated with an AL, which has been linked to various health outcomes including burnout (Juster et al.,

2011) and cardiovascular disease (McEwen, 1998), as well as structural changes in the brain associated with the disorders anxiety and depression (McEwen, 2004).

EDA is a good measure of emotional strain (Boucsein & Thum, 1997). Since sweat glands are innervated exclusively by the sympathetic nervous system (Boucsein, 1992), it follows that measures of EDA should be heightened during overwhelming calls. Results indicated statistically significant mean differences of 1.09 μS*s for the ISCR and of 2.02 for number of SCRs when HighOW values were used to compare overwhelming and baseline calls. These trends are consistent with the literature (Farrow et al., 2013; Lajante, Droulers, Amarantini, & Dondaine, 2012; Steptoe, Evans, & Fieldman, 1997; Renaud & Blondin, 1997; Boucsein & Thum, 1997). For example, the ISCR, which is said to closely mirror sudomotor nerve activity (Benedek & Kaernbach, 2010), has been used to examine differences in emotional arousal during commercial viewing, with mean values ranging from approximately 0.4 μS*s to 0.8 μS*s (Lajante et al., 2012). The median values reported in the current study were 0.4 μS*s and 1.2 μS*s for baseline and overwhelming calls, respectively. Furthermore, Renaud & Blondin found mean SCR rates close to 4/minute and 6/minute during baseline and Stroop tasks, respectively, for a group of 16 participants performing the task at fast pace. Steptoe et al. (1997) found a mean SCR rate of approximately 6/minute for a computer task that was self-paced, and of approximately 2.5/minute for a recovery period. Median values of 0.6 and 1.3 for baseline and overwhelming calls, respectively, were reported in the current study. These values are smaller than those reported in the literature, however this is likely because the values in the current study were based on 30 seconds of data and not 1 minute.

Furthermore, results indicated a mean difference of 0.01 μS for tonic SCL when HighOW values were used to compare overwhelming and baseline calls. This value was not statistically significant. However, mean differences when comparing baseline calls (those matched to overwhelming calls) and rest were statistically significant whether AvgCW or HighOW values were used. The literature confirms the expected effect; SCL should increase with increased demand (Collet, Averty, & Dittmar, 2009; Sjörs, Larsson, Dahlman, Falkmer, & Gerdle, 2009; Cramer, 2003; Steptoe, Cropley, & Joekes, 1999). For example, Steptoe et al. (1999) monitored 162 teachers during a baseline task and two computer tasks and found that SCL rose from a mean of 3.19 μS during baseline to a mean of 4.03 μS during the Stroop colour-word test. Sjörs et al. (2009) found that, among a control group of 30 individuals, SCL rose from approximately 5 μS in baseline to approximately 12 μS during low force work to approximately 14 μS during a standardized task with psychosocial demand. These SCLs are higher than those reported in the current study. This difference may be the result of equipment used. There is high correlation between skin conductance measured at the finger and the wrist, though the magnitude of the response is lower at the wrist (Poh et al., 2010). It would not have been possible to use a traditional skin conductance monitor with finger electrodes in the field, and thus the wrist monitor was used.

It may be considered a limitation that correlations between physiological signals were not examined in this study, however it is not expected that the highest 30 seconds for, say, trapezius activity would necessarily time-match to the highest 30 seconds for HR and number of SCRs. The three signals monitored in this study were chosen because they target different aspects of workload. As outlined by Boucsein & Thum (1997), EMG, HR, and EDA are suitable for examining physical, mental, and emotional strain on the body, respectively. For example, EMG and HR might have increased at the start of a call because of a mentally demanding question, and measures of EDA might have increased only after upsetting information was provided. Further work would be needed to explain these relationships.

6.7 Implications for health in the workplace

Part B of the field study demonstrated relationships between agent-client interactions and acute responses related to MSD and stress-related outcomes among call centre agents. There was greater activation of the trapezius muscle and sympathetic nervous system when calls were perceived to be challenging or overwhelming compared to when calls were perceived to be non-straining. The observed physiological changes across both the physical and psychosocial domain (Figure 2.1) suggest the presence of a common workplace risk factor for MSD and stress-related outcomes among call centre agents: challenging and overwhelming calls. As seen in chapter 5, aspects of both the content and context of call centre work condition the interactions agents have with clients every day. Future research and workplace efforts should consider how these features of work might be improved, for example through job design or participatory ergonomics, to minimize agents' exposure to challenging/overwhelming calls, which would in turn target prevention of both MSD and stress-related outcomes.

7.0 Thesis overview, contributions, and implications

7.1 Thesis objectives and major contributions

The overall objective of the thesis was to demonstrate relationships between workplace demands and exposures related to two disorders that are important sources of pain, disability, and costs in the workplace: musculoskeletal disorders (MSD) and stress-related health outcomes.

7.1.1 Integrative framework

The first objective of the thesis was to develop an integrative framework to recognize the connected nature of work-related MSD and stress-related outcomes, with an intention that the framework be used to guide measurement of exposure and outcome variables in a comparable manner across the physical and psychosocial domains (Figure 2.1). This integrative approach offered a foundation to examine common workplace risk factors for acute reactions related to MSD and stress-related outcomes in chapters 3, 4, and 7. To the knowledge of the author the MSD and stress literatures had not previously been combined for this purpose. The integrated and multidisciplinary framework substantially contributed to a limited body of literature.

Major contribution #1

The framework was found useful in structuring and interpreting the empirical studies of this thesis. Future research could consider this multidisciplinary approach to common workplace risk factors for MSD and stress-related outcomes. Such an approach could help to design and implement more effective and efficient workplace prevention programs for these common disorders.

7.1.2 Relationships between workplace demands and physiological responses related to MSD and stress-related outcomes during computer work

The second objective of the thesis was to examine relationships between workplace demands in the physical and psychosocial domains and acute reactions related to MSD and stress-related health outcomes during computer work. The two laboratory studies (chapters 3 and 4) targeted this objective. The aim of chapter 3 was to examine the effect of mechanical demand on scapular orientation during computer work. Maximum scapular motion for rotation, protraction/retraction, and tilt were documented while participants' arms were in postures typical of computer work (section 3.5.1). The identification of these maximum ranges permitted quantification of normalized mean scapular position during work (section 3.5.2). Findings suggested that, compared to neutral, participants held a more laterally rotated and protracted position when they carried out computer tasks; postures may have been sufficiently protracted to increase the compression of tissues in the subacromial space.

Major contribution #2

The identification of these maximum ranges will permit future research to better describe scapular orientation during computer work.

In this study (chapter 3), it was not the change in mechanical demand that notably changed the mean duration and size of scapular movements during computer work, but rather the change in cognitive demand. Chapter 4 aimed to further investigate the effect of cognitive demand on acute reactions related to MSD, as well as those associated with stress-related outcomes, during computer work. Changes in cognitive demand related to: perceptions of increased workload; increased sympathetic nervous system activity observed through increases in HR and the LF/HF ratio; and changes in the duration and size of scapular movements. More specifically, when cognitive demand increased, both the duration and size of scapular movements tended to decrease (sections 3.5.3 and 4.5.2), as did the change in % MVC (for the right and left upper trapezius) associated with the movements (section 4.5.3). This reduction in scapular movement during mentally demanding tasks may be associated with the bracing effort (Whatmore & Kohli, 1974) and higher static activity in muscles of the neck/shoulder region. It is well known that static posture during computer work is a risk factor for discomfort and pain.

Major contribution #3

Together, findings from the two laboratory studies (chapters 3 and 4) provide evidence for a common workplace risk factor for acute reactions related to MSD and stress-related health outcomes among computer users: cognitive demand (Figure 7.1). This finding contributes to the literature emphasizing the importance of the physical and psychosocial work environment when considering worker health during computer work.

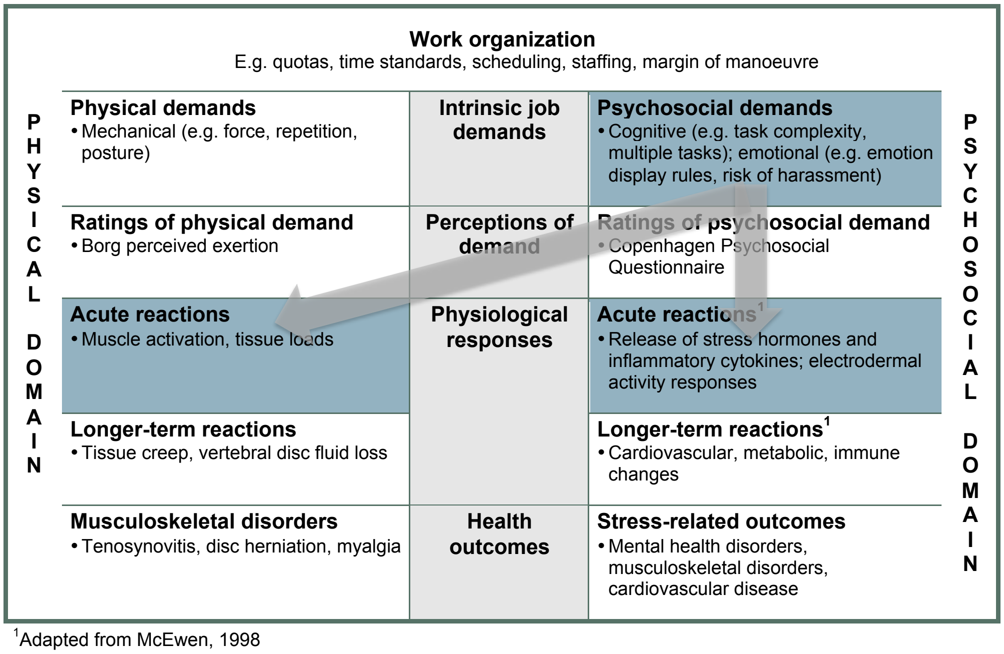


Figure 7.1. Main findings from chapters 3 and 4 suggest a common workplace risk factor for acute reactions related to MSD and stress-related outcomes among computer users: cognitive demand.

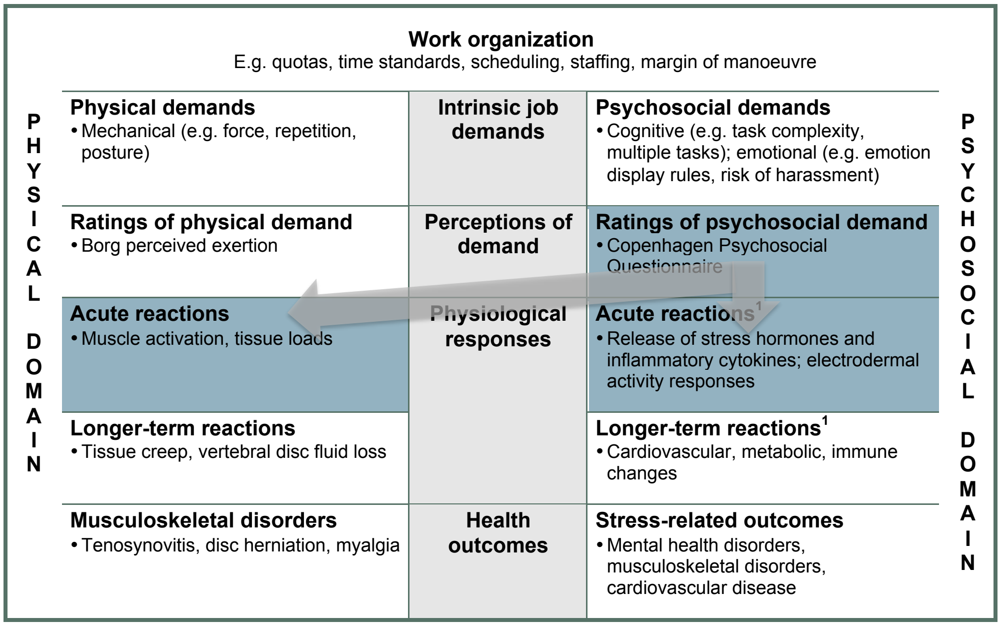
7.1.3 Relationships between potentially straining aspects of call centre work and acute reactions related to MSD and stress-related health outcomes

The third objective of the thesis was to examine relationships between potentially straining aspects of call centre work and physiological responses related to MSD and stress-related health outcomes through a field study. The field study was carried out in two parts. Part A explored, through semi-structured interviews, potentially straining aspects of work for call centre agents, with an emphasis on agent-client interactions, and Part B examined relationships between agent-client interactions and acute reactions monitored over a work shift. Findings from Part B showed there was greater activation of the trapezius muscle and sympathetic nervous system when calls were perceived to be challenging/overwhelming compared to when calls were perceived to be non-straining. Findings are in line with the literature which suggests a relationship between cognitive demand and a non-postural load in the shoulder region

(Laursen et al., 2002; Lundberg, et al., 2002b; Lundberg et al., 1994), as well as increased sympathetic activity when perceptions of stress are high (Sloan et al., 1994) and when intrinsic demands are present in the psychosocial domain (Sjörs et al., 2009; Hjortskov et al. 2004; Delaney & Brodie, 2000; Steptoe et al., 1999; Renaud & Blondin, 1997).

Major contribution #4

The observed physiological responses across the physical and psychosocial domain suggest the presence of a common workplace risk factor for MSD and stress-related outcomes among call centre agents: challenging and overwhelming calls (Figure 7.2). This finding is supported by results from chapters 3 and 4, which point to cognitive demand as a risk factor among computer users. The findings further highlight the importance of both the physical and psychosocial work environment when considering worker health.



[1]Adapted from McEwen, 1998

Figure 7.2. Main findings from Part B of the field study (chapter 6) suggest a common workplace risk factor for acute reactions related to MSD and stress-related outcomes among call centre agents: challenging and overwhelming calls.

Findings from Part A of the field study provided a good sense of what was challenging/overwhelming about agent-client interactions, and of where workplaces might intervene to minimize their occurrence and effects. Features of both the content and context of call centre work were shown to condition the interactions agents have with their clients every day. For example, being unable to quickly handle an inquiry as a result of being new to the job, or being recently cross-trained, might drive stress responses due to the complexity of the inquiry, or due to features of the context of work including pressure to be productive and surveillance. If agents take time to ensure information is correct, for example by seeking supervisor support, call durations will increase which will affect productivity. However, if agents neglect to ensure information is accurate, and incorrect information is provided, workforce surveillance will pick up errors and performance will be affected. There is a tight balance that must be maintained.

Since features of both the content and context of work contribute to perceptions of challenge during agent-client interactions, a work system design approach might be most appropriate to mitigate risk of exposure to straining situations. The Balance Theory describes five components of the work system: person, technology, task, environment, and organization (Smith & Sainfort, 1989). According to the theory, components of the work system "interact to determine the way in which work is done and the effectiveness of the work in achieving individual and organizational needs and goals" (Smith & Sainfort, 1989, pg. 75). Positive aspects of one component may counter the negative aspects of another; the theory reasons to balance production pressure with psychological load during work (Smith & Sainfort, 1989). For example, loosening restrictions on call durations might counteract psychological stress related to being new to the job or recently cross-trained.

Other considerations that might better balance the work system: additional training and coaching prior to agents being put on the phone; greater access to information and resources while agents are on the phone; easing on production expectations; allowing short breaks every hour, shown to improve productivity and wellbeing among computer users (Henning, Jacques, Kissel, Sullivan, & Alteras-Webb, 1997); and changing workstation design, for example by using a sit-stand workstation with training (Robertson, Ciriello, & Garabet, 2013). Even with good prevention efforts, challenging and overwhelming interactions will occur during work since agents have little, if any, control over the mood of a client when they pick up the phone. Secondary prevention efforts would also be necessary to enhance the effectiveness of coping strategies (Sprigg et al. 2007). A participatory ergonomics (PE) program might be one way to consider solutions to for the physical, cognitive, and emotional demands of the job. A PE program would involve a team of employees, union representatives, management, and other stakeholders, that would receive training in ergonomics and generate solutions to mitigate risk of adverse health outcomes (Yazdani et al., 2015). Recent work, however, has suggested that PE programs are not easily integrated into organizations' health and safety management systems due to differences in both structure and language (Yazdani et al., 2015).

Major contribution #5

> Future workplace efforts should consider a work system design approach to address features of the content and context of call centre work to minimize agents' exposure to situations that elicit physiological stress responses. Efforts to reduce the occurrence of challenging/overwhelming interactions will minimize acute reactions related to MSD and stress-related health outcomes among call centre workers.

7.2 Complementary study designs

Study-specific limitations have been discussed in previous chapters. More generally, it is pertinent to mention that the quantitative study designs, i.e. the laboratory studies (chapters 3 and 4) and Part B of the field study (chapter 6), each with their own strengths and limitations, complimented one another in that they both produced similar results. Threats to internal validity in the laboratory studies were minimized through rigorous experimental design and use of gold-standard equipment for data collection, however, as noted in each study's discussion, external validity may have been lacking and results not necessarily transferable outside the young and healthy student population during simulated work. On the contrary, all efforts were made to preserve internal validity in Part B of the field study, for example through careful adherence to the study protocol for each participant, however given that the study was carried out in the field, there was unpredictability, for example with regard to the frequency of challenging or overwhelming interactions per day. Results from Part A provided context for the findings in Part B. Since Part B was carried out among 24 call centre agents during real work conditions, the results are perhaps more transferable to other workplaces than the results from the laboratory studies. It should be noted, however, that the design of the field study was focused on acute reactions, and so the examination of long-term chronic health outcomes was not possible. Future work may examine these longer-term health outcomes, which are represented in the integrated framework, but may also consider other outcome variables, such as productivity. A better understanding of the competing demands of call centre work, for example productivity versus safety, might provide insight into how the job can be better designed to minimize exposure to straining work conditions. Regardless of the noted strengths and limitations, both the laboratory and field studies identified common workplace risk factors for acute reactions in the physical and psychosocial domain.

7.3 Overall implication for future work

This work provides support for common workplace risk factors for MSD and stress-related health outcomes: 1) cognitive demand among computer users, and 2) perceptions of psychosocial demand among call centre agents. These findings should encourage stakeholders in work and health research and in the workplace to integrate prevention efforts for MSD and stress-related outcomes, such as anxiety and burnout, in order to more effectively and efficiently target primary prevention of these costly and common disorders.

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Appendices

Appendix A – NASA-Task Load Index (TLX)

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix B – Interview Schedule for agents

Section 1: Physical/Biomechanical

1A: Is there anything about your workstation that affects your ability to do your work? (Prompt: Some examples might be your chair, keyboard, computer, and phone.)

i. Do you work at different workstations? If yes, does this affect your ability to do your work?

ii. Are there any ways in which your workstation could be changed? What would be the reason to make this change?

iii. How likely is it that this change could occur?

1B: Are there times you find yourself doing repetitive work? Repetitive means to continually do the same motions or activities.

i. [If yes] Does this affect your ability to do your work?

ii. [If yes] How might your work be different so it is less repetitive?

iii. How likely is it that this change could occur?

Section 2: Job (Psychosocial)

2A: How much choice do you have in how you do your job? (For example, how to answer clients' questions.)

i. Can you think of some examples of ways in which you are and are not able to choose how you do your job?

ii. Are there ways in which this amount of choice affects your ability to do your work?

iii. [If yes] How might your job be different so you have more choice in how you do it?

iv. How likely is it that this change could occur?

2B: Are you observed while you work?

i. [If yes] Can you describe how this occurs? Does this occur occasionally, frequently, or somewhere in between?

ii. Does this observation affect your ability to do your work?

2C: Do you feel you get support from management?

i. What are some of the ways this is shown?

ii. Does [this] affect your ability to do your work?

iii. [If yes] How?

2D: Do you feel you get support from your co-workers?

i. What are some of the ways this is shown?

ii. Does [this] affect your ability to do your work?

iii. [If yes] How?

2E: Could you describe what makes an interaction with a client challenging, and could you provide some examples?

i. How often do these challenging interactions occur (occasionally, frequently, or somewhere in between)? Are you able to estimate the number of these interactions on a typical day?

ii. Could you describe how these challenging interactions make you feel?

iii. Have you developed any strategies that help you to deal with these interactions?

iv. Does management ever get involved when you have a challenging interaction?

Section 3: Job (Organizational)

I'm interested in some features of what I'll call the organization of your work.

3A: Let's start with your workload, that is, the amount of work you have to do.

i. Does workload affect your productivity? [Prompt if needed: productivity might be thought of as efficiency during work hours.]

ii. [If yes] Are there ways your workload could be different so you could be more productive?

iii. How likely is it that this change could occur?

3B: Would you say you have sufficient breaks of sufficient length? [Pause] Please describe your break time on a typical day.

i. [If no] Does this affect your ability to do your work?

ii. [If yes] Could your breaks be organized differently so you could be more productive?

iii. How likely is it that this change could occur?

3C: Do you find that sitting for long periods of time affects your ability to do your work?

i. [If yes] How?

ii. Are there ways in which this could be different?

iii. How likely is it that this change could occur?

Section 4: Environmental

4A: Are there things about your physical environment that affect your ability to do your work? Some examples might be light, noise, or air quality.

i. [If yes] What are they and how do they affect your work?

ii. How likely might it be to change these conditions?

Section 5: Employment Conditions

5A: Are you a full-time or part-time worker?

i. For part-time workers: would you like to work full time?

ii. [If yes] Why?

5B: Are you a permanent or contract worker?

i. For contract workers: would you like to be a permanent worker?

ii. [If yes] Why?

Appendix C – Interview Schedule for Supervisors and Managers

Section 1: Physical/Biomechanical

1A: Are you aware of anything about the agents' workstations that might affect their ability to do their work? (Prompt: Some examples might be their chair, keyboard, computer, and phone.)

i. Do they work at different workstations? If yes, do you think this affects their ability to do their work?

ii. Are you aware of ways in which their workstations could be improved?

iii. How feasible is it that this change could occur?

1B: Is the agents' work repetitive? Repetitive means to continually do the same motions or activities.

i. [If yes] Do you think this affects their ability to do their work?

ii. [If yes] Are you aware of ways in which their work could be less repetitive?

iii. How feasible is it that this change could occur?

Section 2: Job (Psychosocial)

2A: How much choice do agents have in how they do their job? (For example, how to answer clients' questions.)

i. Can you provide some examples of ways in which agents are and are not able to choose how they do their job?

ii. Do you think [this] affects their ability to do their work?

iii. Are you aware of ways in which their job could be different so they could have more choice in how they do it?

iv. How feasible is it that this change could occur?

2B: Are agents observed while they work?

i. [If yes] Could you describe how this occurs? Does this occur occasionally, frequently, or somewhere in between?

ii. [If yes] Do you think this observation affects their ability to do their work?

iii. [If yes] Are you aware of ways this could be different so it does not affect their work?

iv. How feasible is it that this change could occur?

2C: Does management provide support to agents?

i. [If yes] What are some of the ways this is shown?

ii. [If yes] Do you think this support affects the agents' ability to do their work?

iii. Are you aware of ways in which more support could be provided by management?

2D: Are you aware of co-workers providing support to one another?

i. [If yes] What are some of the ways this is shown?

ii. [If yes] Do you think this support affects their ability to do their work?

iii. Are you aware of ways in which co-workers could provide more support to one another?

2E: Could you describe what you think makes an agent's interaction with a client challenging, and could you provide some examples?

i. How often would you say these interactions occur (occasionally, frequently, or somewhere in between)? Are you able to estimate the number of these interactions for an agent on a typical day?

ii. How do you think these challenging interactions make the agents feel?

iii. Are you aware of any strategies agents have developed to help them deal with challenging interactions?

iv. Does management ever get involved when an agent has a challenging interaction with a client?

Section 3: Job (Organizational)

I'm interested in some features of what I'll call the organization of work.

3A: Let's start with the agents' workload, that is, the amount of work they have to do.

iv. Are you aware of ways in which the agents' workload affects their productivity? [Prompt if needed: productivity might be thought of as efficiency during work hours.]

i. If yes, are there ways their workload could be different so they could be more productive?

ii. How feasible is it that this change could occur?

3B: Would you say the agents have sufficient breaks of sufficient length? [Pause] Please describe break time on a typical day.

i. [If no] Do you think this affects their ability to do their work?

ii. [If yes] Are you aware of ways their breaks could be organized so they could be more productive?

iii. How feasible is it that this change could occur?

3C: Are you aware of ways in which sitting for long periods of time affects the agents' ability to do their work?

i. [If yes] Are there ways in which this could be different?

ii. How feasible is it that this change could occur?

Section 4: Environmental

4A: Are you aware of anything about the physical environment that affects the agents' ability to do their work? Some examples might be light, noise, or air quality.

i. [If yes] What are they and how do you think they affect their work?

ii. Are there ways the physical work environment could be improved?

iii. How feasible is it that this change could occur?

Section 5: Employment Conditions

5A: Are there both full-time and part-time agents in this workplace?

i. Do you believe part-time agents would like to work full time?

ii. [If yes] Why?

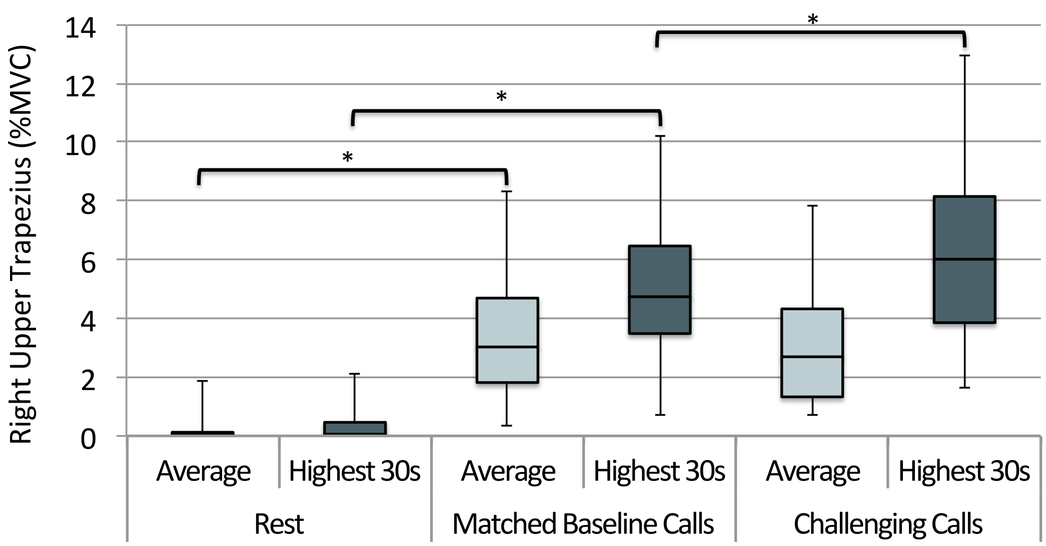
5B: Are there both permanent and contract agents in this workplace?

i. Do you believe contract agents would like to be permanent?

ii. [If yes] Why?

Appendix D – Trapezius activity during challenging calls, baseline calls, and rest

For the right upper trapezius (Figure D1), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.0, 0.1, and 1.9 % MVC, respectively, for the lowest rest, was 0.3, 1.8, 3.0, 4.7, and 8.3 % MVC, respectively, for baseline calls, and was 0.7, 1.3, 2.7, 4.3, and 7.8 % MVC, respectively, for challenging calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.1, 0.5, and 2.1 % MVC, respectively, for the lowest rest, was 0.7, 3.5, 4.7, 6.5, and 10.2 % MVC, respectively, for baseline calls, and was 1.6, 3.8, 6.0, 8.1, and 12.9 % MVC, respectively, for challenging calls.

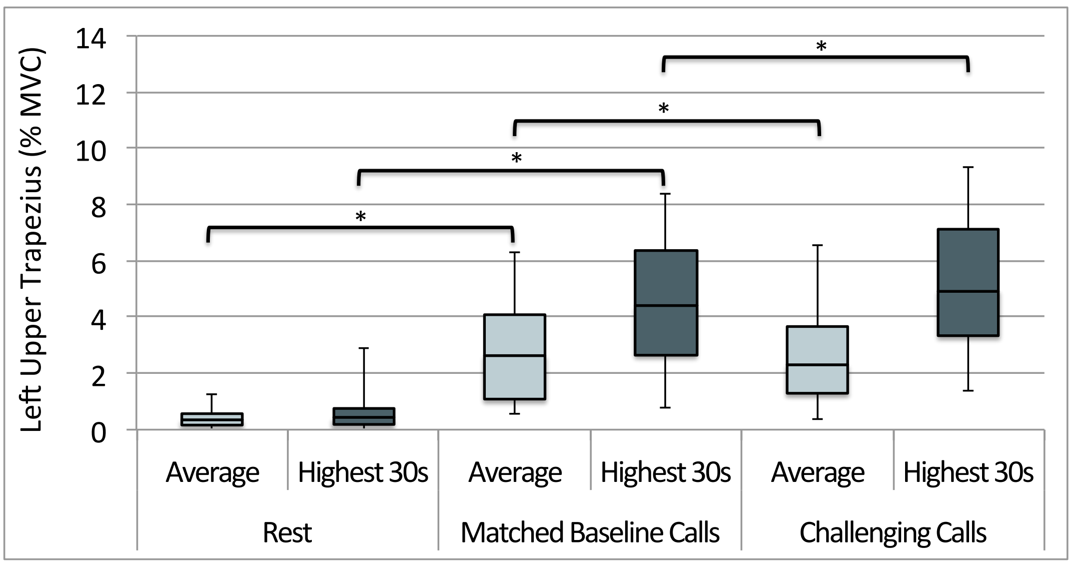


*Average mean difference (Table D) is statistically significant

Figure D1. Box plots for the right trapezius (%MVC) (N=24) showing minimum, 25th percentile, median, 75th percentile, and maximum values for challenging calls, time-matched baselines, and rest.

For the left upper trapezius (Figure D2), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.2, 0.3, 0.6, and 1.3

% MVC, respectively, for the lowest rest, was 0.5, 1.1, 2.6, 4.1, and 6.3 % MVC, respectively, for baseline calls, and was 0.4, 1.3, 2.3, 3.7, and 6.6 % MVC, respectively, for challenging calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.2, 0.4, 0.7, and 2.9 % MVC, respectively, for the lowest rest, was 0.8, 2.6, 4.4, 6.3, and 8.3 % MVC, respectively, for baseline calls, and was 1.4, 3.3, 4.9, 7.1, and 9.3 % MVC, respectively, for challenging calls.



*Average mean difference (Table D) is statistically significant

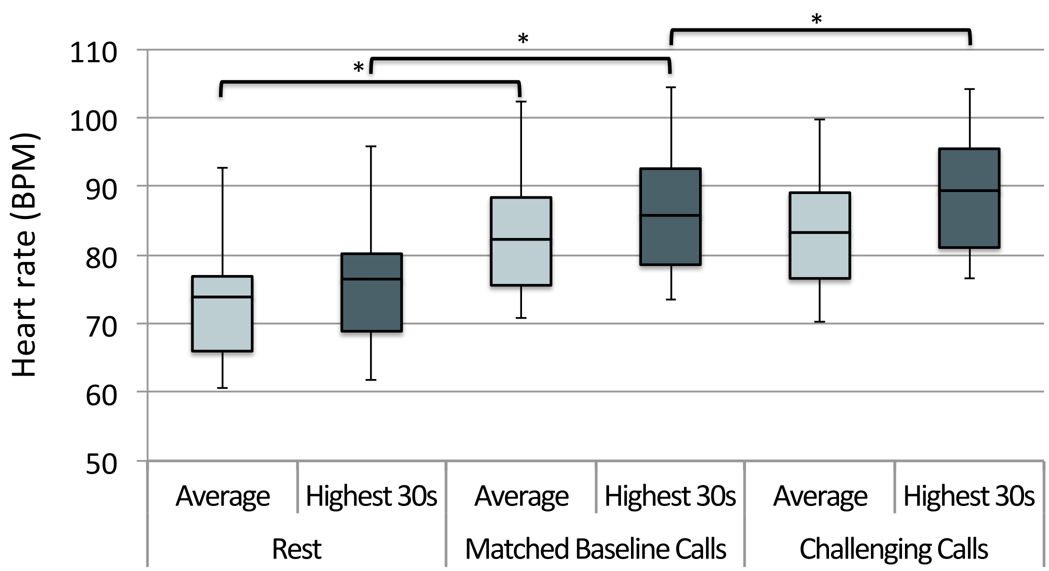
Figure D2. Box plots for the left trapezius (%MVC) (N=24) showing minimum, 25th percentile, median, 75th percentile, and maximum values for challenging calls, time-matched baselines, and rest.

Measure	Mean difference between	Average mean difference (95% CL)	Standard Error	*p*-value
Right trapezius (% MVC)	**Challenging and time-matched baseline calls**			
	Using call average (AvgCW)	-0.26 (-0.71 to 0.19)	0.22	0.240
	Using highest 30s (HighOW)	1.31 (0.87 to 1.74)	0.21	**<0.001**
	Baseline calls and rest			
	Using call average (AvgCW)	3.16 (2.34 to 3.98)	0.40	**<0.001**
	Using highest 30s (HighOW)	4.62 (3.56 to 5.68)	0.51	**<0.001**
Left trapezius (% MVC)	**Challenging and time-matched baseline calls**			
	Using call average (AvgCW)	-0.30 (-0.58 to -0.01)	0.14	**0.043**
	Using highest 30s (HighOW)	0.88 (0.45 to 1.31)	0.21	**<0.001**
	Baseline calls and rest			
	Using call average (AvgCW)	2.50 (1.77 to 3.23)	0.35	**<0.001**
	Using highest 30s (HighOW)	3.70 (2.80 to 4.61)	0.44	**<0.001**

Table D. Average mean differences (trapezius activity) for challenging calls compared to their time-matched baselines, and for baseline calls compared to rest (N=24). Bolded *p*-values are statistically significant.

Appendix E – Heart rate and the LF/HF ratio during challenging calls, baseline calls, and rest

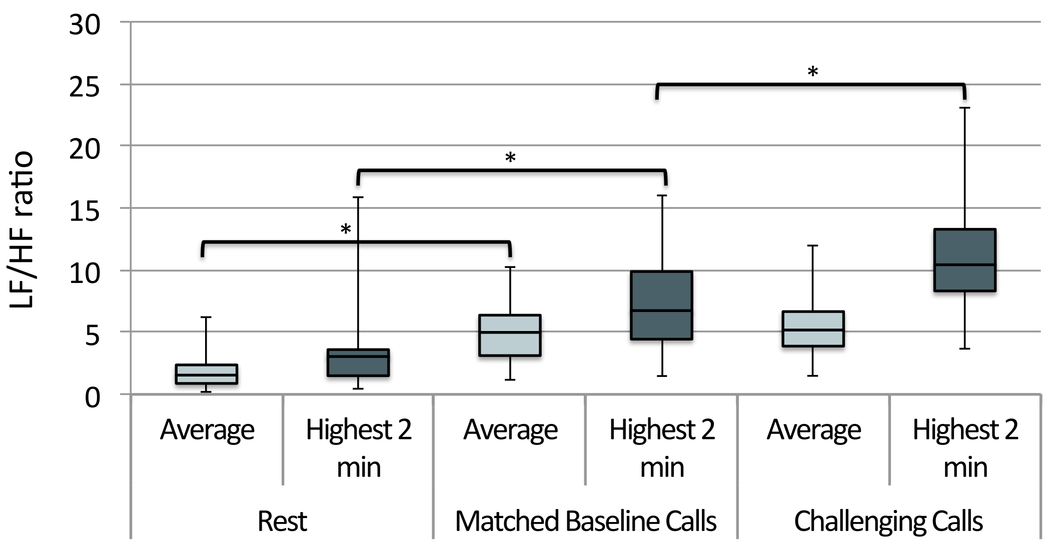
For heart rate (Figure E1), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 60.5, 66.0, 73.9, 76.9, and 92.7 BPM, respectively, for the lowest rest, was 70.8, 75.6, 82.3, 88.4, and 102.3 BPM, respectively, for baseline calls, and was 70.2, 76.6, 83.3, 89.1, and 99.9 BPM, respectively, for challenging calls. Likewise, when using the means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 61.8, 68.9, 76.5, 80.2, and 95.9 BMP, respectively, for the lowest rest, was 73.5, 78.6, 85.8, 92.6, and 104.5 BPM, respectively, for baseline calls, and was 76.6, 81.1, 89.4, 95.5, and 104.3 BPM, respectively, for challenging calls.



*Average mean difference (Table E) is statistically significant

Figure E1. Box plots for heart rate (BPM) (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for challenging calls, time-matched baselines, and rest.

For the LF/HF ratio (Figure E2), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.2, 0.9, 1.5, 2.4, and 6.2, respectively, for the lowest rest, was 1.1, 3.1, 5.0, 6.4, and 10.2, respectively, for baseline calls, and was 1.5, 3.9, 5.2, 6.7, and 11.9, respectively, for challenging calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.4, 1.5, 3.1, 3.6, and 15.9, respectively, for the lowest rest, was 1.5, 4.4, 6.7, 9.9, and 16.1, respectively, for baseline calls, and was 3.7, 8.3, 10.4, 13.3, and 23.0, respectively, for challenging calls.



*Average mean difference (Table E) is statistically significant

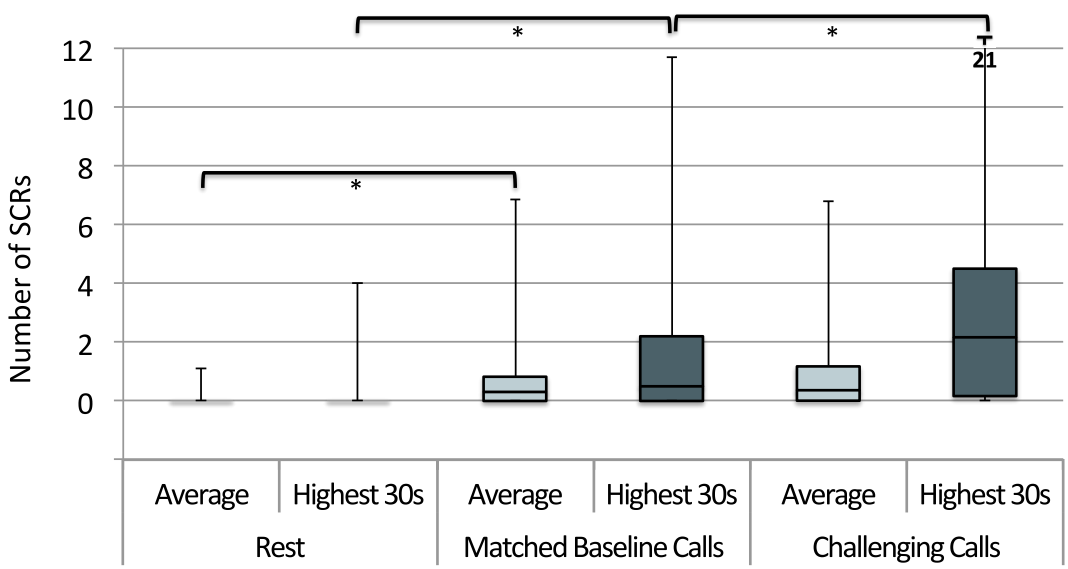
Figure E2. Box plots for the LF/HF ratio (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for challenging calls, time-matched baselines, and rest.

Measure	Mean difference between	Average mean difference (95% CL)	Standard Error	*p*-value
Heart rate (BPM)	**Challenging and time-matched baseline calls**			
	Using call average (AvgCW)	0.66 (-0.57 to 1.91)	0.60	0.278
	Using highest 30s (HighOW)	3.13 (1.66 to 4.60)	0.71	**<0.001**
	Baseline calls and rest			
	Using call average (AvgCW)	9.72 (7.70 to 11.74)	0.97	**<0.001**
	Using highest 30s (HighOW)	9.81 (7.48 to 12.14)	1.12	**<0.001**
LF/HF ratio	**Challenging and time-matched baseline calls**			
	Using call average (AvgCW)	0.29 (-0.52 to 1.09)	0.39	0.470
	Using highest 2min (HighOW)	4.06 (2.60 to 5.52)	0.70	**<0.001**
	Baseline calls and rest			
	Using call average (AvgCW)	3.19 (2.40 to 3.98)	0.38	**<0.001**
	Using highest 2min (HighOW)	3.90 (2.43 to 5.36)	0.71	**<0.001**

Table E. Average mean differences (heart rate and the LF/HF ratio) for challenging calls compared to their time-matched baselines, and for baseline calls compared to rest (N=23). Bolded *p*-values are statistically significant.

Appendix F – Electrodermal activity during challenging calls, baseline calls, and rest

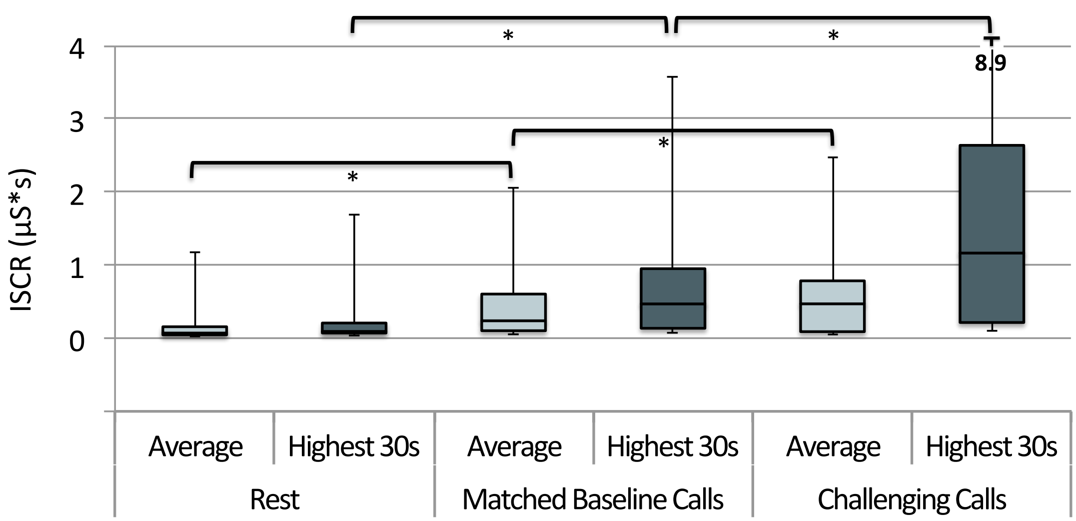
For number of SCRs (Figure F1), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.0, 0.0, and 1.1, respectively, for the lowest rest, was 0.0, 0.0, 0.3, 0.8, and 6.8, respectively, for baseline calls, and was 0.0, 0.0, 0.4, 1.2, 6.8, respectively, for challenging calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.0, 0.0, 4.0, respectively, for the lowest rest, was 0.0, 0.0, 0.5, 2.2, 11.7, respectively, for baseline calls, and was 0.0, 0.2, 2.2, 4.5, and 21.0, respectively, for challenging calls.



*Average mean difference (Table F) is statistically significant

Figure F1. Box plots for number of SCRs (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for challenging calls, time-matched baselines, and rest.

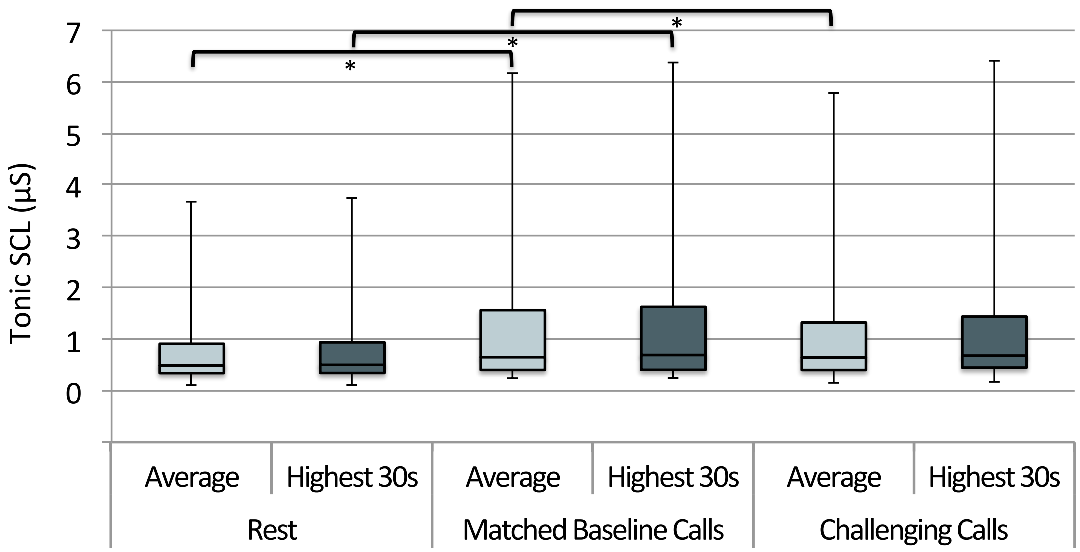
For the ISCR (Figure F2), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.0, 0.1, 0.2, and 1.2 µS*s, respectively, for the lowest rest, was 0.1, 0.1, 0.2, 0.6, and 2.1 µS*s, respectively, for baseline calls, and was 0.1, 0.1, 0.5, 0.8, and 2.5 μS*s, respectively, for challenging calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.0, 0.1, 0.1, 0.2, and 1.7 μS*s, respectively, for the lowest rest, was 0.1, 0.1, 0.5, 1.0, and 3.6 μS*s, respectively, for baseline calls, and was 0.1, 0.2, 1.2, 2.6, and 8.9 μS*s, respectively, for challenging calls.



*Average mean difference (Table F) is statistically significant

Figure F2. Box plots for ISCR (μS*s) (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for challenging calls, time-matched baselines, and rest.

For SCL (Figure F3), when using means from AvgCW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.1, 0.3, 0.5, 0.9, and 3.7 μS, respectively, for the lowest rest, was 0.2, 0.4, 0.7, 1.6, and 6.2 μS, respectively, for baseline calls, and was 0.2, 0.4, 0.6, 1.3, and 5.8 μS, respectively, for challenging calls. Likewise, when using means from HighOW values, the minimum, 25th percentile, median, 75th percentile, and maximum was 0.1, 0.3, 0.5, 0.9, and 3.7 μS, respectively, for the lowest rest, was 0.2, 0.4, 0.7, 1.6, and 6.4 μS, respectively, for baseline calls, and was 0.2, 0.4, 0.7, 1.4, and 6.4 μS, respectively, for challenging calls.



*Average mean difference (Table F) is statistically significant

Figure F3. Box plots for SCL (μS) (N=23) showing minimum, 25th percentile, median, 75th percentile, and maximum values for challenging calls, time-matched baselines, and rest.

Measure	Mean difference between	Average mean difference (95% CL)	Standard Error	*p*-value
Number SCRs	**Challenging and time-matched baseline calls**			
	Using call average (AvgCW)	0.15 (-0.06 to 0.36)	0.10	0.1491
	Using highest 30s (HighOW)	1.83 (0.69 to 2.97)	0.55	**0.0031**
	Baseline calls and rest			
	Using call average (AvgCW)	0.82 (0.06 to 1.59)	0.37	**0.0350**
	Using highest 30s (HighOW)	1.65 (0.40 to 2.89)	0.60	**0.0118**
ISCR (µS*s)	**Challenging and time-matched baseline calls**			
	Using call average (AvgCW)	0.09 (0.002 to 0.18)	0.04	**0.0461**
	Using highest 30s (HighOW)	1.01 (0.37 to 1.65)	0.31	**0.0033**
	Baseline calls and rest			
	Using call average (AvgCW)	0.32 (0.14 to 0.50)	0.09	**0.0015**
	Using highest 30s (HighOW)	0.55 (0.24 to 0.88)	0.15	**0.0014**
Tonic SCL (µS)	**Challenging and time-matched baseline calls**			
	Using call average (AvgCW)	-0.11 (-0.21 to -0.01)	0.05	**0.0352**
	Using highest 30s (HighOW)	-0.04 (-0.12 to 0.05)	0.04	0.3729
	Baseline calls and rest			
	Using call average (AvgCW)	0.49 (0.20 to 0.78)	0.14	**0.0020**
	Using highest 30s (HighOW)	0.52 (0.21 to 0.83)	0.15	**0.0019**

Table F. Average mean differences (number SCRs, ISCR, tonic SCL) for challenging calls compared to their time-matched baselines, and for baseline calls compared to rest (N=23). Bolded *p*-values are statistically significant.