ERGONOMIC INVESTIGATIONS OF SIT-STAND WORKSTATIONS FOR COMPUTER-BASED WORK

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Gourab Kar

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ERGONOMIC INVESTIGATIONS OF SIT-STAND WORKSTATIONS FOR COMPUTER-BASED WORK

Gourab Kar, Ph.D.

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Increased occupational sedentary behaviors are associated with elevated risks for musculoskeletal-discomfort, cardio-metabolic and cardio-vascular diseases, and pre-mature mortality. Use of sit-stand workstations reduces sitting-time, musculoskeletal-discomfort and fatigue, without impacting productivity. However, physical activity does not increase; there is absence of an optimum sit-stand ratio.

This research investigated the potential of a sit-stand-walk intervention (SSWI) to reduce musculoskeletal-discomfort and fatigue, and increase physical activity, without impacting productivity in computer-based work. Three experiments examined efficacy of the SSWI to improve health and productivity at work.

The first two experiments with identical research designs were conducted with 80 participants in Ahmedabad, India and 100 participants in Ithaca, United States. Experiments used a between-participants design. Participants performed two-30-minute transcription-tasks after being randomly assigned to one-of-five work-conditions: sit-stand, stand-sit, sitting, standing, and the SSWI. It was hypothesized that the SSWI would reduce musculoskeletal-discomfort, physical fatigue and mental fatigue, without impacting productivity. Variables measured included: self-reported musculoskeletal-discomfort, physical-fatigue and mental-fatigue; productivity operationalized by transcription speed and error.

In the Ahmedabad-experiment, the SSWI reported significant reductions in: musculoskeletal-discomfort compared to sitting and standing; physical fatigue compared to standing; and no effect on mental fatigue and productivity. In the Ithaca-experiment, the SSWI reported significant reductions in: musculoskeletal-discomfort compared to standing; physical fatigue compared to all other work; mental fatigue compared to stand-sit and sitting; and no effect on productivity.

The third experiment compared efficacy of SSWI in two workstation-configurations: (1) Ergo-Fit - configured according to ergonomic guidelines; (2) Self-Adjusted - configured by workers according to their preference. Using a within-participants design, 36 participants performed two-30-minute transcription-tasks. Variables measured included: self-reported musculoskeletal-discomfort and fatigue; productivity operationalized by transcription speed and error; postural-risks assessed by RULA for seated-work, and REBA for standing-work. Musculoskeletal-discomfort and fatigue were similar; postural risks were significantly lower for Ergo-Fit-configuration; however, productivity was significantly higher for Self-Adjusted-configuration.

The SSWI demonstrates an optimal sit-stand-walk ratio – enabling workers to reduce sitting-time, attenuate musculoskeletal-discomfort and fatigue, and increase physical activity, without impacting productivity. Future designs of work should consider the physiological, cognitive and psychological benefits of frequent, short-bouts of standing and movement to improve worker health, well-being and productivity.

BIOGRAPHICAL SKETCH

Gourab Kar was born in Durgapur, located in the state of West Bengal, in eastern India. He lived there with his parents and elder sister until attending college at the Birla Institute of Technology, Mesra in Ranchi, Jharkhand. When Gourab was not in the architecture studio or playing cricket with friends on campus, he actively participated in inter-university quizzes and design competitions. During his undergraduate days, Gourab was an intern at an architecture firm in Kolkata, India before graduating with a professional Bachelor of Architecture degree in 2004.

Prior to beginning his doctoral studies at Cornell, Gourab was a faculty member and a coordinator of the Product Design programme at the National Institute of Design (NID), Ahmedabad where he taught theory courses on ergonomics, was the studio instructor for design projects, and mentored undergraduate (B. Des) and graduate (M. Des) theses. Before this, Gourab had earned a Master of Design (M. Des) degree in 2006, from Indian Institute of Technology Delhi, India; and a Master of Industrial Design (MID) degree with specialization in Universal Design in 2011, from Georgia Institute of Technology, Atlanta, GA. Gourab had also worked as an industrial designer in the United States and in India for four years, before embarking on his doctoral studies at Cornell.

Gourab joined Cornell's Department of Design & Environmental Analysis in 2014 to pursue a doctoral degree in Human Behavior & Design with a specialization in Human Factors & Ergonomics. His dissertation investigated the efficacy of a sit-stand-walk intervention to promote postural variability, enhance physical activity, and reduce negative health impacts of sedentary, chair-and-desk-based office work. After graduation, Gourab will join an interdisciplinary research center at a public research university in California to pursue research on interventions to improve health, well-being and productivity in the workplace.

To Ma and Baba,

For nurturing in me a sense of curiosity about the world.

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LIST OF ABBREVIATIONS

1. METs - Metabolic Equivalent Tasks
2. CMO - Chief Medical Officer of the National Health Service, United Kingdom
3. HHS - U.S. Department of Health and Human Services
4. WHO - World Health Organization
5. ILO – International Labour Organization
6. LPL - Lipoprotein Lipase
7. LIPA - Light-Intensity Physical Activity
8. DALYs - Disability Adjusted Life Years
9. SSWs - Sit-Stand Workstations
10. SSWI - Sit-Stand-Walk Intervention
11. CINHAL - Cumulative Index of Nursing and Allied Health Search Literature
12. PICO - Population, Intervention, Control, Dependents
13. PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses
14. BP - Blood Pressure
15. HR - Heart Rate
16. EE - Energy Expenditure
17. LBP - Low Back Pain
18. EMG - Electromyography
19. RCT - Randomized Controlled Trial
20. MEC - Metabolic Energy Cost
21. SIT – Seated Condition
22. STA – Standing Condition
23. VAS - Visual Analog Scale
24. ANSI - American National Standards Institute
25. HFES - Human Factors & Ergonomics Society

LIST OF ABBREVIATIONS (continued)

26. MANOVA – Multivariate Analysis of Variance
27. ANOVA - Analysis of Variance
28. BMI - Body Mass Index
29. RULA - Rapid Upper Limb Assessment
30. REBA - Rapid Entire Body Assessment
31. HVAC - Heating, Ventilation & Air-Conditioning
32. EEG - Electroencephalogram
33. HDBR - Head Down Bed Rest
34. ROI – Return on Investment

CHAPTER 1

INTRODUCTION

1.1. Sedentary Behavior

Sedentary behavior is a growing field of research which is now recognized as a public health concern (Diaz et al., 2017). The word sedentary has its roots in the Latin term “sedere,” which means “to sit.” In context of energy expenditure, sedentary behavior has been defined as *“any waking behavior characterized by an energy expenditure ≤ 1.5 METs (Metabolic Equivalent Tasks), while in a sitting, reclining or lying posture.”* (Tremblay et al., 2017). However, for the purposes of this dissertation on the ergonomic investigation of sit-stand workstations for computer-based work, sedentary behavior is defined as time spent sitting at work (CMO, 2011).

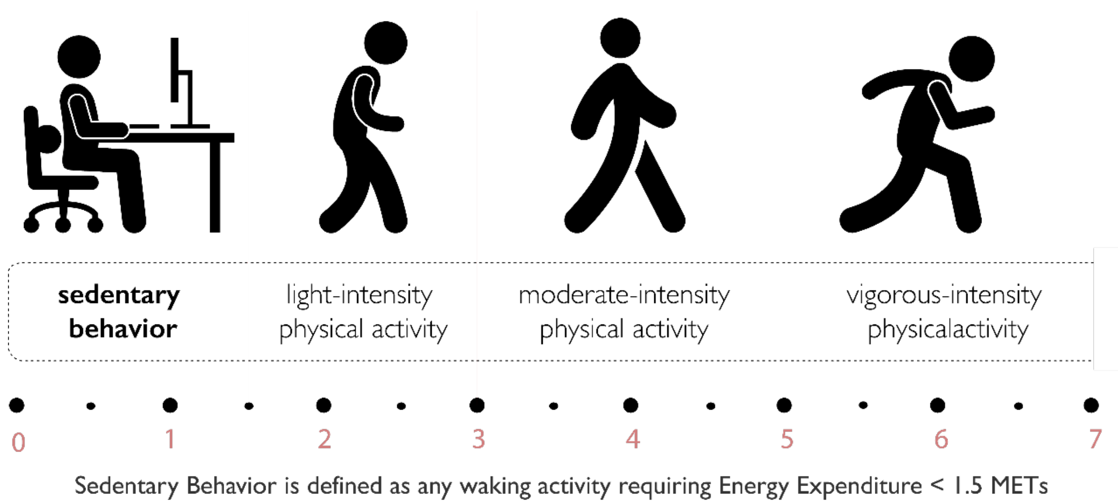

Figure 1.1. Sedentary Behavior defined in terms of Energy Expenditure

Historically, occupations recognized to be primarily sedentary in nature have been documented since the 17th century (Pope, 2004). However, over the last 50 years, the advent of computers and automation in the workplace, increase in modes of electronic communication, and individually dedicated office equipment and furniture, have all contributed to the increase in occupational sedentary behaviors (Buckley et al., 2015). Time use data from the U.S. and the U.K. indicate that working adults spend between 9.2 ~ 9.6 hour/day in sedentary behaviors, much of which involves long, uninterrupted bouts of occupational sitting (Tudor-Locke et al., 2011; Van Uffelen et al., 2010). It is estimated that by 2030, sedentary behaviors in the United States and the United Kingdom will reach 42 hour/week and 51 hour/week, respectively – an increase by 58.8% and 80.9%, respectively, when compared to 2005 baseline levels (Ng & Popkin, 2012).

1.2. Sedentary Behavior & Evolutionary Biology

In order to understand how and why sedentary behavior is so pervasive in today's world, we need to take a step back in time and consider the genesis and development of sedentary behaviors in the context of human evolution. The biological function of sitting relates to the principle of energy conservancy (Levine, 2010). As hunter-gatherers and agriculturalists, early humans needed periods of rest between highly exothermic tasks such as hunting and threshing. Sitting provided the solution - being almost as energy efficient as lying down while enabling a person to be vigilant of their surroundings. A detailed analysis of energy metabolism in agricultural work demonstrates the periodicity of exothermic and restful tasks (Coward, 1998). Sitting behaviors in moderation is not bad, but sitting in excess can be addictive and harmful (Levine, 2014).

There is evidence to suggest that there are three distinct temporal phases in humans becoming more sedentary (Levine, 2010). The first phase was the Neolithic transition, 10,000 years ago, from hunter-gatherer to agriculturalists. The second phase was during the last two centuries, coinciding with the advent of the Industrial Revolution. And the third phase covered the past 30 years, which have been impacted by rapid technological advances, particularly the adoption of computers and automation in the workplace and at home (Figure 1.1). This societal change occurred much faster than what the processes of physical and psychosocial adaptation could counteract, thereby leading to a positive balance of energy in the body which translates to harmful health consequences associated with too much sitting.

1.3. Sedentary Behavior & Health – Origins

A relation between occupational behaviors and deleterious health consequences was noted as far back as the 17th century by Bernardino Ramazzini in his seminal book on occupational diseases and industrial hygiene, *De Morbis Artificum Diatriba* – Diseases of Workers (Pope, 2004). The modern field of physical inactivity epidemiology began with the studies by Morris et al. (1958, 1953) conducted in the 1950s among employees of the London Transport Executive and Post Office employees. Their findings demonstrated that physically active men (bus conductors and postmen) had lower mortality rates from coronary heart disease than less active workers (bus drivers and switchboard operators). These pioneering studies provided evidence for a role of physical activity in averting premature mortality.

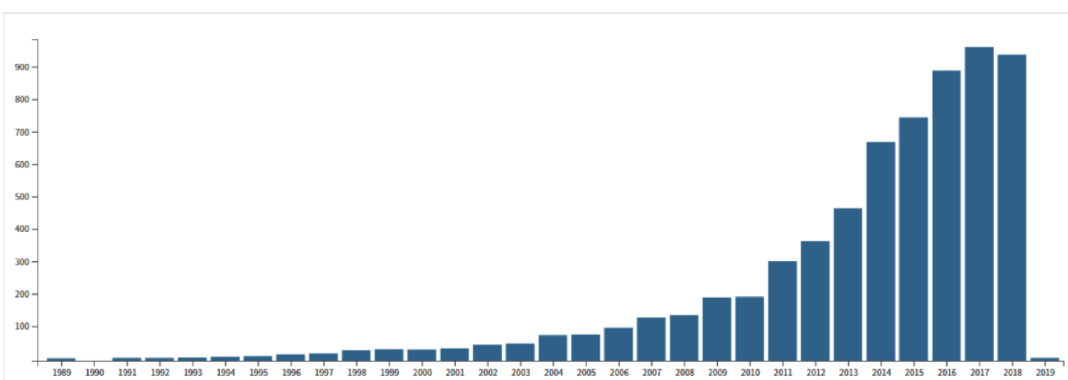

Figure 1.2. Sedentary Behavior & Health – Publications from 1988 ~ 2018

However, it has recently been hypothesized that some of these observed relationships maybe explained by differences in time spent sitting, as well as the occupational stress of driving on city roads, rather than being less active physically (i.e. bus drivers sit more than conductors) (Hamilton et al., 2007). Since the 1960s a great volume of evidence has been accumulated on the relationship between physical activity and health (Katzmarzyk, 2010; Owen et al., 2010) (Figure 1.2). This collective body of research culminated in the 1996 U.S. Surgeon General's report on *Physical Activity & Health* (Manley, 1996) and the *2008 Physical Activity Guidelines for Americans* (HHS, 2008). Recognizing the global pandemic of physical inactivity and sedentary behavior, World Health Organization has recently issued the *Global Recommendations on Physical Activity for Health* (WHO, 2010).

1.4. Sedentary Behavior & Health – Recent Findings

In recent years, researchers have begun to recognize that sedentary behaviors, independent of the level of physical activity, may lead to deleterious health consequences including lower mortality (Biddle et al., 2016). It has been hypothesized that the biological, social and environmental pathways leading to sedentary behavior and physical inactivity maybe different (Katzmarzyk, 2010). Therefore, the health effects of sedentary behavior and physical inactivity maybe the result of different biological mechanisms. In a seminal study, Hamilton and colleagues (2007) provided evidence for the fact that regulation of skeletal muscle lipoprotein lipase (LPL) for inactivity physiology (sedentary behaviors) were qualitatively different from exercise physiology (physical activity). Using a series of controlled laboratory studies, the authors provided translational evidence for a molecular reason to maintain light intensity physical activity (LIPA); experimentally reducing normal spontaneous standing and ambulatory time had much greater effect of LPL regulation, when compared to vigorous exercise.

More recent studies have shown that uninterrupted sitting for prolonged durations of time can lead to several detrimental health effects at the physiological level, such as an increased risk of developing cardio-vascular disease (Biswas et al., 2015; Wilmot et al, 2012; Healy et al., 2011; Hamilton et al., 2007), type-2 diabetes (Henson et al., 2016; Wilmot et al, 2012; Hamilton et al., 2007), obesity (Dunstan et al., 2010; Hamilton et al., 2007), some cancers (Johnsson et al., 2017; Kerr et al., 2017), and musculoskeletal disorders (Sharan et al., 2018; Daneshmandi et al., 2017). Increased sedentary behaviors also has detrimental effects at the psychological level, such as depression (Lee & Kim, 2019; Blough & Loprinzi, 2018; Stubbs et al., 2018), anxiety (Lee & Kim, 2019; Vancampfort et al., 2018; Edwards & Loprinzi, 2016;), and cognitive decline (Vancampfort et al, 2018; Magnon et al., 2018; Falck et al., 2017; Ku et al., 2017) (Figure 1.3). However, further research is needed to fully understand the implications of sedentary behavior on both physiological (de Rezende et al., 2014) and psychological health (Flack et al., 2017).

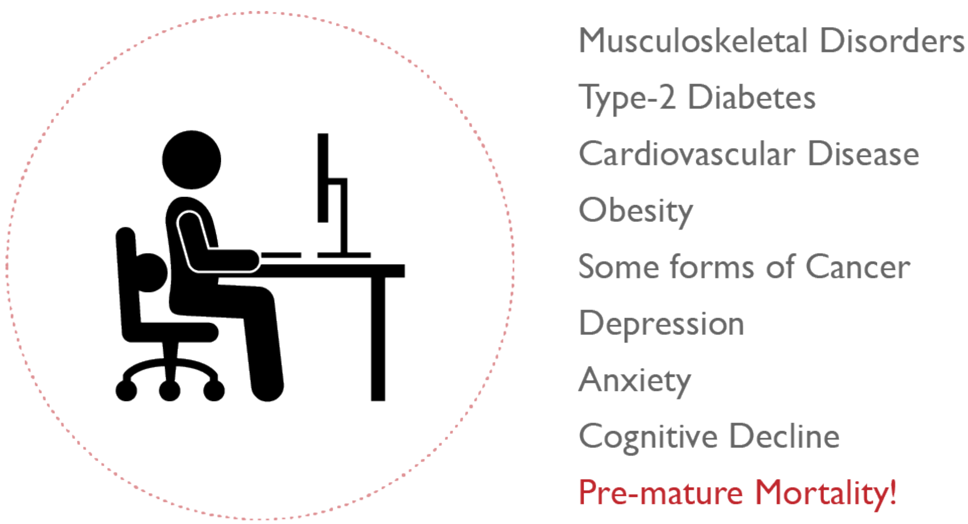

Figure 1.3. Sedentary Behavior & Health Impacts – Summary of Evidence

1.5. Sedentary Behavior & Health – Economic Burden & Trends

Sedentary behavior and physical inactivity are increasingly recognized as a major problem in public health (Dunstan et al., 2012). The WHO estimates that 3.3 million people die around the world each year due to physical inactivity, making it the fourth leading underlying cause of mortality (WHO, 2009). In context of the global pandemic of physical inactivity, Ding and colleagues (2016) estimated daily healthcare costs, productivity losses, and disability-adjusted life-years (DALYs) attributable to physical inactivity with data from 142 countries representing 93.2% of the world's population. Conservatively estimated, physical inactivity cost health-care systems $53.8 billion worldwide in 2013, with additional $13.7 billion in indirect costs attributed to productivity losses, and 13.4 million DALYs.

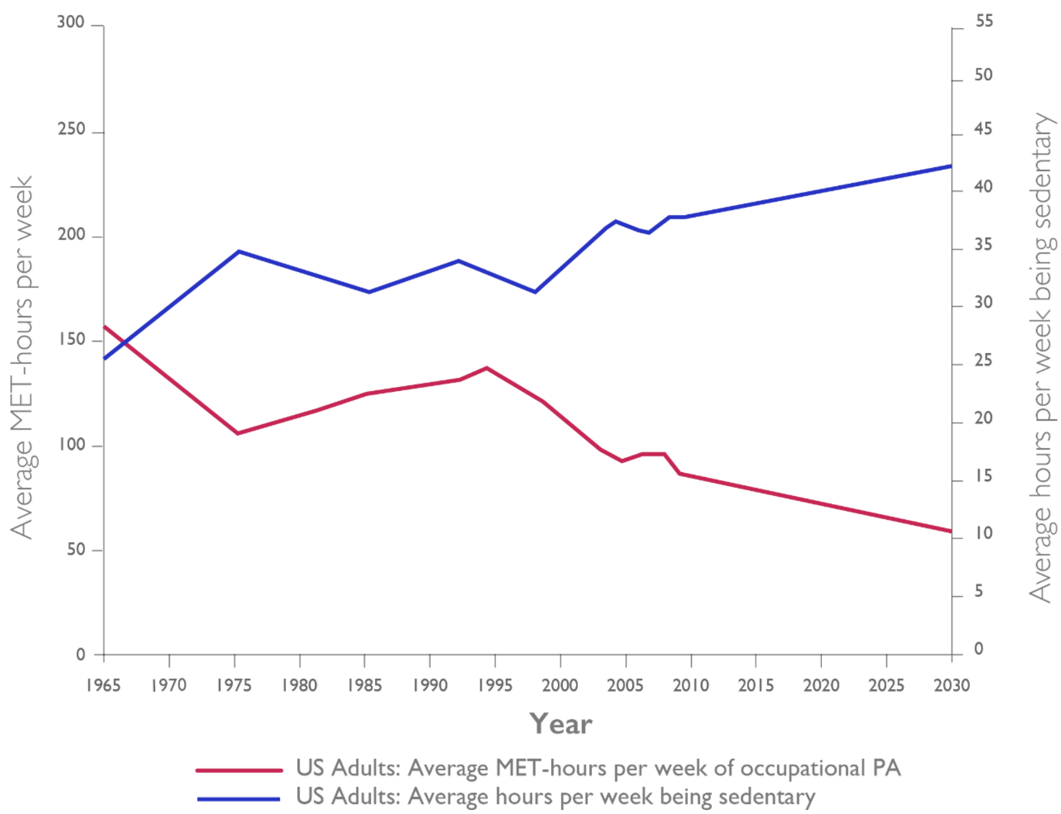

Figure 1.4. Sedentary Time & Physical Activity - Data for U.S. Adults (1965 – 2030)

To understand the future trends for sedentary behaviors, researchers have used an array of longitudinal and cross-sectional datasets to estimate average physical activity and sedentary time among adults in the U.S., the U.K., Brazil, India and China over time (Ng & Popkin, 2012). Based on the observed trends, physical activity is rapidly declining across the globe, while sedentary time is increasing simultaneously (Figure 1.4). Extrapolating these trends to the year 2030 suggest that among the five countries featured in the study, the average weekly physical activity in the U.S. will be the least at 126 METs, while sedentary time will be the highest in the U.K. at 51 hour/week. In particular, China and Brazil are projected to have the two highest declines in absolute and relative rates of total physical activity and some higher increases in sedentary time. Findings from this multi-country study represent a global call for action to reduce sedentary behavior and increase physical activity across multiple domains of daily activity, more so for occupational sitting. The reasons for focusing on occupational sedentary behaviors is elucidated in the following section.

Figure 1.5. Key Drivers of Sedentary Behaviors in the Office

1.6. Sedentary Behavior in the Office

Although there have been occupations that have been sedentary in nature, modern technological advances such as the use of computers and automation in the workplace, use of electronic communication modes, and dedicated office furniture have contributed to the increase in occupational sedentary behaviors over the past 50 years (Tudor-Locke et al., 2014) (Figure 1.5). While global trends indicate population wide increase in sedentary behavior across multiple domains of daily activity, a recent study suggests that office work may be a major contributor to the sedentary behavior. This is because office work is characterized by long, uninterrupted bouts of sitting time (> 30 minutes) and contributes significantly to the overall sedentary exposure. In a cross-sectional observational study with office workers in Australia, Parry & Straker (2013) reported that sedentary time accounted for 81.8% of work hours which was significantly greater than sedentary time during non-work hours (68.9%, $p < 0.001$). Moreover, office workers experienced significantly more sustained sedentary time (bouts > 30 minutes), and significantly fewer durations (0 – 10 minutes) of light-intensity physical activity (LIPA) during work hours compared to non-work hours ($p < 0.001$). Further, office workers had fewer breaks in sedentary time during work hours compared to non-work time ($p <0.001$). Therefore, focusing on reducing sitting time in the workplace maybe an effective strategy to tackle the pandemic of sedentary behavior. Sedentary office workers need to be informed about ills of sitting for prolonged periods of time, and introduced to benefits of engaging in standing and movement in the sedentary office (Buckley et al., 2015).

1.7. Recommendations & Expert Statement

In response to the deleterious impacts of sedentary behavior and physical inactivity on public health, there have been guidelines and recommendations to reduce sedentary behaviors and promote physical activity. The *Global Recommendations on Physical Activity for Health* issued by the World Health Organization recommends adults (18-64 years old) to perform 150-minutes per week of moderate-intensity physical activity (WHO, 2010). Similarly, the recommendations from the *American College of Sports Medicine* and the *American Heart Association* suggests that all adults need moderate-intensity physical activity for a minimum of 30-minutes each day, for five days of the week (Haskell et al., 2007). In tune with previous recommendations, the most recent edition of the *Physical Activity Guidelines for Americans* issued by the *U.S. Department of Health and Human Services* suggests that adults should engage in 150 ~ 300 minutes of moderate-intensity physical activity every week, along with recommendations to move more and sit less (Piercy et al., 2018).

Break-up seated work with standing work

Accumulate at least 2hr/day of standing and walking

Avoid prolonged static sitting or static standing

Ensure neutral posture and correct movement

Figure 1.6. Recommendations to Reduce Sedentary Behavior in the Office

In order to specifically reduce uninterrupted sitting time and increase physical activity in the sedentary office, an expert statement was recently commissioned by *Public Health England* and the *Active Working Community Interest Company* (Buckley et al., 2015). These recommendations were based on the totality of evidence from long-term epidemiological studies and intervention studies which had evaluated ways to get office workers to stand up and/or move more frequently (Figure 1.6). These guidelines are as follow: *for occupations which are predominantly desk-based, workers should aim initially to accumulate two-hours per day of standing and light-intensity physical activity (walking), eventually progressing to an accumulation of four-hours per work day. In order to achieve this goal, seated-based work should be broken-up with standing-based work – use of sit-stand desks or taking short active standing breaks are encouraged. Workers should avoid prolonged static sitting or static standing, and ensure correct movement and neutral postures at work.*

While more evidence is needed to add precision and certainty to these recommendations, the key idea is to communicate the perils of prolonged sitting to office workers, and highlight the emerging benefits of changing office environments to promote standing and movement. Employers and employees need to evaluate the best possible ways to achieve this goal, whether through changing how and when people take 'active' breaks from work, and /or use active workstations to alternate between sitting and standing work postures. The next section summarizes findings from workplace interventions that may promote standing and/or movement in the sedentary office.

1.8. Alternatives to the Sedentary Office

As office work is characterized by long, uninterrupted durations of sitting, often with fewer work breaks compared to non-work time, workplace interventions to reduce sedentary behavior can be effective in reducing sitting time and increasing standing and/or movement, without distracting office workers from their primary task (Tudor-Locke et al., 2015). Active workstations can be an important intervention to increase energy expenditure, and enhance physical activity and movement, without negatively impacting productivity in office work.

Cross-sectional and longitudinal studies on activity-oriented workplace interventions in laboratory and field settings have experimented with different strategies to reduce sedentary behaviors in the workplace. These include: *Stand-biased desks* - shifting from seated-based work to standing-based work using stand-biased desks; *Sit-Stand Workstations* - alternating between seated-based work and standing-based work by the use of height-adjustable sit-stand workstations (SSWs); *Activity-Permissive Workstations* - enabling concurrent light-intensity physical activity through use of activity permissive workstations such as treadmill desks and variants; and *Work Breaks* - changing the temporal pattern of work by incorporating short, frequent breaks from seated-based work. The evidence from each of these intervention strategies have been summarized below.

1.8.1. Stand-biased Desks

Stand-biased desks have been effective in reducing sitting time (Minges et al. 2016) and increasing energy expenditure for school children (Benden et al., 2011), and for improving cardio-metabolic health markers for adults (Healy et al., 2015). However, use of stand-biased desks does not increase physical activity when compared to seated desks (MacEwen et al., 2015). Also, prolonged occupational standing is associated with deleterious health effects including lower back and leg pain, risks for cardio-vascular disease, and musculoskeletal discomfort and fatigue of the lower limbs (Baker et al., 2018; Waters & Dick, 2015). Given the negative health impacts elucidated above, this dissertation did not pursue further research on stand-biased desks.

1.8.2. Sit-Stand Workstations

Sit-Stand Workstations (SSWs) feature height-adjustable work surfaces that enable office workers to alternate between seated-based and standing-based work. The use of SSWs for office work has been associated with reduced sitting time, lower musculoskeletal discomfort, but without any reduction in task productivity when compared to seated-based work (Chambers et al., 2019; Zhu et al., 2018; Karakolis & Callaghan, 2014). Recent research suggests that use of SSWs with short bouts of standing improves cardio-metabolic health (Healy et al., 2015) and reduces self-reported low back pain (Agarwal et al., 2018).

However, SSW use does not increase physical activity compared to seated-based work (Karakolis & Callaghan, 2014), compliance with recommended sit-to-stand protocols is low (Wilks et al., 2006), and there are perceived barriers to effective use of SSWs (Nooijen et al., 2018). The ability of change posture enabled by the use of SSWs is a recognition of the fact that humans were not created to sit all day (Grimsrud, 1990). Given the potential benefits elucidated above, this research investigated ways to increase physical activity and movement without compromising on the benefits of using SSWs for computer-based office work.

1.8.3. Activity-Permissive Workstations

Activity-permissive workstations offer office workers the opportunity to engage in light-intensity, concurrent physical activity through use of walking, pedaling or stepping while at work. Typical solutions include the treadmill desk or its variants, such as the pedal exercise machine or the elliptical machine placed below a desk and perpendicular to the work surface. Studies on activity permissive workstations have reported increased energy expenditure, reduced sedentary time and improved cardio-metabolic health makers. However, computer task performance is reported to be negatively impacted when office workers are engaged in cognitively demanding computer tasks while concurrently walking or pedaling (Funk et al., 2012; Ohlinger et al., 2011; Straker et al., 2009). Given the negative impact of activity permissive workstations on productivity in computer-based tasks, this study did not pursue further research on their suitability as an intervention to reduce sedentary behaviors.

1.8.4. Work Breaks

Another effective approach to reduce sitting time and enhance light-intensity physical activity involves changing the temporal pattern of office work through introduction of work breaks. *A work break is defined as the temporary cessation of work tasks for a short-duration of time*, *leading to physiological and psychological recovery* (Waongenngarm et al., 2018). Taking short work breaks, for durations of 30 ~ 180 seconds at intervals ranging from 10 ~ 30 minutes, have proven to lower musculoskeletal discomfort (Henning et al., 1994), attenuate physical fatigue (McLean et al., 2001), reduce low back pain (Waongenngarm et al., 2018), and improve cardio-metabolic health (Bailey & Locke, 2015), without reducing productivity at work (Sheahan et al., 2016; Galinsky et al., 2007). Work breaks relate to the cycles of work and rest that can be traced back to early humans who needed periods of rest between highly exothermic tasks such as hunting and threshing (Levine, 2010). Given the benefits elucidated above, this research investigated ways to increase physical activity and movement without compromising on the benefits of using work breaks for computer-based office work.

1.8.5. Combining Sit-Stand-Work with Active Breaks

The science of sedentary behavior and health is young and heterogeneous, there are many research gaps and opportunities, including ways to design, test and validate workplace interventions that optimize health, well-being and productivity (Tudor-Locke et al., 2014). The use of SSWs and *active* work breaks are potentially effective ergonomic interventions that can promote standing and/or movement in the sedentary office. Using a series of controlled, laboratory studies, this dissertation investigated the ergonomic challenges of SSW use for computer-based office work, specifically with respect to combining SSW use with *active* work breaks. The underlying logic was to combine sit-stand postural transitions afforded by SSWs with short bouts of LIPA enabled by active work breaks, while adhering to the expert group recommendations to promote health and productivity in the sedentary office (Buckley et al., 2015). The next section identifies research questions that guided the investigation and provided an objective framework to evaluate effectiveness of the interventions.

1.9. Research Questions

Given the ubiquity of occupational sedentary behaviors across the globe, and the evidence for negative health impacts of uninterrupted sitting - there is a critical need to design, and evaluate effective, scalable, and practical ergonomic interventions to increase standing and movement in the workplace. Potential solutions include breaking-up occupational sitting with frequent, repeated bouts of LIPA (such as self-paced walking). Specifically this dissertation investigates the ergonomic challenges of sit-stand workstations for computer-based office work. Research questions that the study seeks to address include:

- How does SSW use *impact musculoskeletal discomfort*?
- How does SSW use *impact physical fatigue*?
- How does SSW use *impact mental fatigue*?
- How does SSW use *impact productivity in computer-based office tasks*?

- What is an *optimal sit-stand ratio* for SSW use?
- What is the *role of ergonomic fit* in effective use of SSWs?
- How can *light-intensity physical activity be increased* in SSW use?
- How can *SSW use be combined with work breaks* for computer-based office work?
- Does *culture and demographics* impact health and productivity in SSW use?
- Does *gender moderate the relationship* between SSW use and dependent variables?

1.10. Research Overview

The focus of this research was to investigate a novel Sit-Stand-Walk Intervention (SSWI) that translates the expert panel recommendations on reducing sedentary behaviors in the office (Buckley et al., 2015), into practically viable workplace routine that can improve health and productivity. The SSWI has been designed by considering the ergonomic challenges of SSW from a systems perspective (Wilson, 2014) - this entails defining the context of use to include the workstation design, anthropometric fit, neutral posture, work-rest cycles, user training, and cross-cultural perspectives. The SSWI combines benefits of postural variability (afforded by SSWs use), with increased LIPA (enabled by active work breaks), to offer a sit-stand-walk routine that addresses the dual needs to reduce sitting time and increase physical activity in the sedentary office. The science behind the SSWI, and empirical studies to demonstrate its benefits in short-duration computer-based office work, can be found in the following chapters of the dissertation. The document is organized as a series of seven chapters based on laboratory-based studies that: (a) compared the use of a SSWI to seated, standing and sit-stand work for short-duration computer-based work, and (b) demonstrated benefits of the SSWI to reduce sitting time, and increase standing and movement in the sedentary office. An overview of the studies is provided below.

1.10.1. Systematic Literature Review.

The second of these seven chapters is a systematic literature review focusing on the efficacy of SSW interventions for office work. The chapter introduces the reader to the literature on SSW use, highlights the gaps in research, and thereby sets the stage for a series of laboratory-based empirical studies that follow. A qualitative synthesis of the included studies suggests that the use of SSW interventions for office work reduces musculoskeletal discomfort and fatigue, significantly lowers sitting time, and has no negative impact on productivity; however, physical activity and energy expenditure is not significantly higher compared to seated work.

1.10.2. Pilot Study.

The third chapter reports on findings from a preliminary study with participants (n = 12) in Ithaca, NY, which had evaluated effects of seated-based and standing-based work on short-duration transcription task productivity and musculoskeletal discomfort. Results suggest that for short-duration computer-based transcription tasks, standing-based work had fewer transcription errors without impacting transcription speed, when compared to seated-based work. Overall musculoskeletal discomfort for the whole body was similar for seated and standing work. However, there was an interaction of work condition and body region for musculoskeletal discomfort; upper body musculoskeletal discomfort was higher in seated-based work, while lower body musculoskeletal discomfort was higher in standing-based work.

1.10.3. Ahmedabad Cohort Study.

The fourth chapter reports on a study with participants (n = 80) in Ahmedabad, India each of whom performed two 30-minute typing transcription tasks after being randomly assigned to one of five work conditions: sit-stand, stand-sit, seated, standing and the sit–stand-walk intervention (SSWI). The SSWI was associated with significant reductions in: musculoskeletal discomfort compared to seated and standing work, and physical fatigue compared to standing work; however, there was no adverse effect on mental fatigue and productivity.

1.10.4. *Ithaca Cohort Study.*

The fifth chapter reports on a study with participants (n = 100) in Ithaca, United States, each of whom performed two 30-minute typing transcription tasks after being randomly assigned to one of five work conditions: sit-stand, stand-sit, seated, standing and the sit–stand-walk intervention (SSWI). In effect the Ithaca Study replicated the experimental design of the Ahmedabad Study; the only difference being the participant demographics and study location. The SSWI was associated with significant reductions in: musculoskeletal discomfort compared to standing work, physical fatigue compared to all other work, and mental fatigue compared to stand-sit and seated work. Also, the SSWI had no adverse effect on productivity.

1.10.5. *Workstation Fit-Study.*

The sixth chapter reports findings from a laboratory-based study with participants (n = 36) in Ithaca, United States that compared musculoskeletal discomfort, fatigue, productivity and postural risks in short-duration computer-based office work between two SSW configurations: (a) custom-designed, and configured for workers according to ergonomic guidelines (Ergo-Fit configuration); (b) commercially available, and self-adjusted by workers according to their preference (Self-Adjusted configuration). A repeated measures design was used with participants performing a 60-minute computer-based transcription task in both workstation configurations. Musculoskeletal discomfort and fatigue were similar; productivity was marginally higher for Self-Adjusted configuration; however, postural risks were significantly lower for the Ergo-Fit configuration. Findings from the study suggest that fitting the user to the workstation is essential to optimize benefits of the SSWI.

1.10.6. Discussion & Conclusion.

The seventh and concluding chapter collates findings from all studies to report on the impact of the SSWI on dependent variables, compares and contrasts findings from the four studies, discusses the strengths and limitations of the research, outlines implications for public health policy and design practice, and suggests avenues for further research at the intersection of sedentary behavior, health and design.

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CHAPTER 2

EFFECTS OF SIT-STAND WORKSTATIONS FOR OFFICE WORK – A SYSTEMATIC LITERATURE REVIEW

2.1. Abstract

Context: Increased sedentary behavior and physical inactivity in the workplace are associated with elevated risks for musculoskeletal discomfort, type-2 diabetes, cardio-vascular disease, and pre-mature mortality. Sit-stand workstations (SSWs) can reduce occupational sedentariness and physical inactivity.

Objective: The review focuses on the efficacy of SSWs for office work.

Evidence acquisition: I conducted a search of literature published before 30th June 2018 that compared SSW interventions to a sit-only control for sitting time, musculoskeletal discomfort, fatigue, productivity and physical activity.

Evidence synthesis: The search yielded 2928 articles; based on quality criteria 44 articles were eligible for full review; of these, 14 studies did not meet the inclusion criteria resulting in 30 studies which were included in the final analysis.

Conclusions: SSWs can reduce sitting time, musculoskeletal discomfort and fatigue without negatively impacting productivity; however physical activity is not increased compared to a sit-only control. Further research is needed to: determine an optimal sit-stand ratio, increase light-intensity physical activity, and evaluate effectiveness of posture-change prompts to increase sit-stand compliance.

2.2. Practitioner Summary

Sedentary behaviors in the workplace negatively impact worker health and productivity. Use of sit-stand workstations can reduce musculoskeletal discomfort, sitting time, and fatigue without decreasing productivity in office work. However, the literature does not specify an optimal sit-stand ratio, or outline strategies to increase sit-stand compliance and increase physical activity in the workplace.

2.3. Context

The advent of computers in the workplace has led office-workers to become less physically active and more sedentary (Levine, 2014; Brownson et al., 2005; Hedge & Ray, 2004). Data from the U.S. and the U.K. indicate that working adults spend between 9.2 ~ 9.6 hours/day in sedentary behaviors (Tudor-Locke et al., 2011; Van Uffelen et al., 2010), and these figures are estimated to increase by 58.8% and 80.9% respectively by 2030 (Ng & Popkin, 2012). This is a cause for concern, since sedentary behaviors, such as those ubiquitous to contemporary workplaces, are positively correlated with elevated risks for musculoskeletal discomfort, cardio-vascular disease, type-2 diabetes, obesity, metabolic syndrome, and pre-mature mortality (de Rezende et al., 2014; Owen et al., 2010; Rempel et al., 2006; Gerr et al., 2002). The direct and indirect costs of occupational sedentariness and physical inactivity are high – globally, direct costs were estimated to be $53.8 billion in 2013, with additional indirect costs of $13.7 billion (Ding et al., 2016). For employers these indirect costs include absenteeism, disability, reduced productivity and healthcare costs (Pronk & Kottke, 2009).

Given the deleterious health impacts of sedentary office work, interventions have focused on how to increase posture change and enhance physical activity in the workplace (Buckley et al., 2015). Sit-stand workstations (SSWs) that enable office-workers to easily alternate between seated and standing work, show potential to interrupt prolonged occupational sitting at work (Owen et al., 2011). Studies report that office-workers using SSWs reduce occupational sitting time, and stand for 20~30% of the workday (Vink et al., 2009; Hedge & Ray, 2004). Compared to a sit-only control, SSW interventions have shown reduced musculoskeletal discomfort, lower fatigue, and improved cardio-metabolic health markers, without adverse impacts on productivity (Agarwal et al., 2018; Healy et al., 2015; Karakolis & Callaghan, 2014). However, studies indicate that there are common perceived barriers to use of SSWs (Nooijen et al., 2018) and only 18% of office-workers use the sit-stand function at least once-a-day (Wilks et al., 2006).

This review focuses on the efficacy of SSWs for office work. Efficacy was measured for five key dependent measures - musculoskeletal discomfort, sitting time, productivity, fatigue and physical activity. Specifically, current literature on SSW interventions was systematically examined to summarize efficacy of these dependent measures compared to a sit-only control.

2.4. Evidence Acquisition

2.4.1. Search Strategy.

The following databases were searched: PubMed, CINAHL (Cumulative Index of Nursing and Allied Health Search Literature), Ergonomics Abstracts, Psych INFO, BioMed Central, Web of Science, and Science Direct. The search was limited to English language studies published in peer-reviewed academic journals and conference proceedings before 30th June 2018. The search strategy and inclusion criteria were defined using PICO – Population characteristics (P), Intervention (I), Control (C) and Dependents (O). Search words included variations of possible words and terms related to SSWs (Appendix A). Titles and abstracts of retrieved studies were saved in a database using a reference management software (Endnote, Clarivate Analytics, Philadelphia, PA). The reference lists of the articles retrieved were manually checked by the author for additional articles. The systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati et al., 2009). Table 2.1 summarizes the extracted dependent measures considered for the systematic literature review.

Physiological outcomes	- Cardio-metabolic health (B.P., H.R., Cholesterol)
	- Physical activity (standing time, stepping/walking time)
	- Movement (whole body, shoulder and neck)
	- Energy expenditure (E.E.)
	- Physical fatigue/exertion
	- Sitting time
	- Musculoskeletal discomfort
	- Physical complaints
	- Low back pain (L.B.P)
	- Spinal shrinkage
	- Foot swelling
	- Muscle activity (E.M.G)
	- Lumbar flexion
	- Postural change (sit-stand transitions)
Psychological outcomes	- Mood states
	- Workload
	- Arousal
	- Subjective sleepiness
	- Psychological well-being
	- Preferences
	- Comfort
Productivity outcomes	- Call center parameters (call handling indices)
	- Typing task performance (speed and accuracy)
	- Data entry efficiency
	- Absenteeism (no of days)
	- Injuries and illnesses

Table 2.1. Selected physiological, psychological and productivity dependent measures

2.4.2. Inclusion criteria.

Peer-reviewed studies that met the following criteria were included:

1. Intervention – Any empirical study (prospective, cross-over, quasi-experimental, cross-sectional or randomized controlled trial) that used an SSW intervention with a sit-only control.
2. Participants – Participants of working age population and of any health status.
3. Setting – Participants were office-workers in a field setting or performed simulated office work in a laboratory setting.
4. Dependent(s) – At least one relevant physiological, psychological and/or productivity dependent listed in Table 2.1 must have been evaluated.
5. Research Design – The study offered enough detail about study methods to enable authors to critically assess research quality. Such detail must have included descriptions of: sample size, participant characteristics, sit-stand intervention(s) employed, randomization and controls, and dependent measures.

Exclusion criteria comprised of published supplements, abstracts, reports, reviews, opinion articles, commentaries, magazine articles, book chapters and presentations. Studies comparing sit-only work to sit-stand were specifically included; those comparing sit-only work with dynamic workstations (treadmill workstations, bicycle ergometer etc.) were excluded.

2.4.3. Dependent Evaluation.

Studies were divided into field and laboratory studies; specific dependent measures were compared between the SSW intervention and the control. Information extracted from each study included: first author, year, country, sample characteristics (sample size, age, gender, and occupation), study design and duration, intervention characteristics (including sit-stand ratio), dependent measures and findings (Table 2.2). Search words included variations of possible words and terms related to SSWs (Appendix A).

Table 2.2. Information extracted from each article

First Author (Year), Country	Sample (n, description, gender, age)	Study Design, Duration	Intervention, Sit-Stand Ratio	Dependent Measures	Findings
Nerhood (1994), USA	Office-workers (sample size, gender and age not specified)	Prospective Study in Field Setting, 12-month intervention. Data collected 6-months pre-intervention, and 12-months post intervention.	Sit-Stand Workstation with Ergonomics Training. No Sit-Stand ratio specified.	Musculoskeletal discomfort using a body-part musculoskeletal discomfort survey. Productivity, absenteeism, injuries and illnesses.	Musculoskeletal discomfort reduced by 62.12%. Increase in productivity. No changes in absenteeism. 50% reduction in occurrence of injuries and illnesses.
Paul (1995), USA	n = 12, Office-workers, F = 9, M = 3, Mean Age = 36.5(M) /37.67 (F)	Prospective Study in Field Setting, 3-month intervention. Data collected daily at 8 am, 12 pm, 1 pm, 5 pm.	Sit-Stand Workstation with open office. Sit-Stand ratio = 3:1.	Survey on mood states (bored, sluggish, alert, tired, energetic)	Employees felt more alert, more energetic and less tired at end of workday.
Paul (1995), USA	n = 6, Office-workers, F = 5, M = 1, Mean Age = 39.0 (12.9)	Prospective Study in Field Setting. 6-Week intervention. Data collected daily at 8 am, 12 pm, 1 pm, 5 pm.	Sit-Stand Workstation with 15-min standing every hour, Sit-Stand ratio = 3:1. (45 min: 15 min)	Foot swelling measured using a foot volumeter.	Foot swelling for SSW intervention significantly lower compared to control (12.3 ml vs. 21.0 ml, p = 0.050).
Hasegawa (2001), Japan	n = 16, Male Workers, Age = 21~25 yrs. (Group A); 19~25 yrs. (Group B).	Crossover Study in Laboratory Setting. Repeated measures design with Sitting, Standing and Sit-Stand Work. Group A: 90 min duration; Group B: 60 min duration.	Sit-Stand Intervention. Sit-Stand ratio = 1:1.	Workload measured by flicker test, Self-reported Fatigue, Task Performance by errors and misses in computer task.	For 60 min task, SSW intervention reduced workload, reduced fatigue and increased performance.
Roelofs (2002), Australia	n = 30, Bank tellers, F = 24, M = 6, Mean Age = 26.5 yrs.	Crossover Study in Field Setting. Repeated measures design with	Sit-Stand Intervention with a high-chair sitting, Sit-Stand ratio = 1:1 (30 min:	Body-part musculoskeletal discomfort measured 6 times a day.	Mean musculoskeletal discomfort highest in standing, lower in sitting and

		Sitting, Standing and Sit-Stand Work. 8-hour workday, 3 separate days.	30 min).		least in Sit-Stand condition.
Hedge (2004), USA	*n* = 54, Office-workers in two locations.	Field Study; High-tech Company = RCT (*n* = 20) with control and intervention groups. Insurance Company = Cross-over study (*n* = 34). Intervention = 4 ~ 6 weeks duration. 33 employees used an SSW, 10 employees used standard workstations. M = 19, F = 14, Mean age = 38.6 (2.1).	Sit-Stand Intervention. No Sit-Stand ratio specified.	Pre-and-post survey about work patterns, work-related musculoskeletal discomfort, preferences, productivity.	Increase in standing time (8.3% vs. 21.2%, *p* = 0.001), Decrease in sitting time (87.7% vs. 71.4%, *p* = 0.000), Reduction in body-part musculoskeletal discomfort symptoms by 27.5%. 82.4% or workers preferred the SSW. Productivity ratings higher for SSW (57.5% vs. 20 %, *p* = 0.001)
Ebara (2008), Japan	*n* = 24, College students and Older Adults, F = 12, M = 12, Two age groups, College Students = 21.2 (1.1); Older Adults = 62.7 (1.6).	Crossover study in a Laboratory Setting. Three conditions - Standard Chair, High Chair, Sit-Stand. 120-minutes English transcription task.	Sit-Stand intervention. Sit-Stand ratio = 2:1 (10 min: 5 min)	Subjective Musculoskeletal discomfort using Visual Analog Scale. Subjective Sleepiness using Visual Analog Scale. Sympathetic Nerve Activity (Arousal) using R-R intervals measured with ECG. Work Performance using letters/minute.	Higher musculoskeletal discomfort in Sit-Stand compared to Standard Chair. No change in subjective sleepiness. Arousal levels higher in Sit-Stand (*p* = 0.050). No significant change in work performance.
Husemann (2009), Germany	*n* = 60, Male subjects. College Students, Age = 18 - 35 years.	Randomized Controlled Trial, Field Study. Duration = 4 hr/day for 5 days.	Sit-Stand Intervention. Sit-Stand ratio = 2:1 (30 min: 15 min). Sitting as Control. 45-min data entry task + 15 min non-data entry	Physical Complaints (GBB) and Psychological Well-being (MDBF) Surveys. Data Entry Efficiency.	Significantly fewer physical complaints in SSW Intervention. No change in psychological well-being. No change in data entry

			and break. 4hr/day for 5 days.		performance.
Davis (2014), USA	*n* = 37, Call-centre employees. F = 29, M = 8.	Prospective Study in Field Setting. Four Conditions - Sit, Sit with reminder, Sit-Stand, Sit-Stand with reminder. Duration = 2-Week break in, 2-Week observation.	Sit-Stand Intervention with or without reminder to change posture. Sit: Stand = 1:1 (30 min: 30 min)	Productivity, Body-part musculoskeletal discomfort, Postural changes.	Productivity = No change, Body-part Musculoskeletal discomfort = Lower for shoulders, lower back, upper back, No change in neck, elbows, hands and wrists, hips, knees, lower legs and feet. Increase in postural change by 40%. Decrease in sitting time by 20%.
Vink (2009), Netherlands	*n* = 10, Office Employees, F = 4, M = 6. Mean Age = 38.1 year	Crossover study in Field setting. Sit-Stand Workstation as intervention, Sitting workstation as control. Duration = 1-week break-in, 1-week observation.	Sit-Stand intervention with Sitting, Half-standing and Standing postures. Sit-Stand ratio not reported.	Local postural musculoskeletal discomfort. Questionnaire on their experience, health and movement estimate.	Significant reduction in musculoskeletal discomfort for overall body (p = 0.000), upper back (p = 0.002), neck-shoulder (p = 0.000) and low back (p = 0.004). Sitting time reduced by 23%. All employees preferred SSW.
Pronk (2012), USA	n = 34, Office-workers, Age = 22.6 (1.70) years, Gender not specified. Intervention n = 24, Control n = 10.	Time series treated as a crossover, Field Setting. Duration = 7-Weeks, 1-Week baseline (no intervention), 4-Weeks intervention, 2-Weeks post-intervention (no intervention).	Sit-Stand Intervention. Sit-Stand ratio not specified.	Sitting time using Experience Sampling Method (ESM). Body-part musculoskeletal discomfort ratings on a survey.	Sitting Time reduced by 66 min/day (p = 0.030). Decrease in upper back and neck pain (p = 0.080).

Alkhajah (2012), Australia	*n* = 32, Office-workers, Age = 20 ~ 65 years. Intervention, n = 18; Control, n = 14.	Quasi-experimental design. Duration = 3-months (baseline, 1-week follow-up, 3-month follow-up)	Sit-Stand Intervention and brief training. Sit-Stand Ratio not specified.	Sitting time = measured using activPAL3 monitor; HDL Cholesterol = whole blood sample. Self-report dependents = fatigue, musculoskeletal health, and absenteeism.	Sitting time = reduced by 2 hours ($p < 0.001$), HDL Cholesterol increased in intervention group ($p = 0.003$), self-report health and work performance dependents did not change between groups at either follow-up.
Nevala (2013), Finland	*n* = 12, Female Workers, Age = 27 ~ 53 years.	Crossover design in Laboratory Setting. Duration = 42 minutes.	Sit-Stand Intervention with low-sitting, high-sitting and standing. Sit-Stand ratio = 2:1. (28 min: 14 min).	Muscle activity = EMG, Wrist position = goniometer, Musculoskeletal discomfort = VAS-D, Productivity = Computer task.	Muscle activity = lower for *right trapezius* ($p = 0.010$) and left *extensor digitorum communis* ($p = 0.020$). Wrist extension = lower for right ($p = 0.050$) and left wrist ($p = 0.002$). Musculoskeletal discomfort = Lower in upper limbs ($p = 0.050$), Higher in lower limbs ($p = 0.010$) for intervention. Productivity = 10% higher in Intervention ($p = 0.020$)
Chau (2014), Australia	*n* = 42, Office-workers, F = 36, M = 6, Age = 38 (11).	Randomized Controlled Trial. Duration = 4-Weeks, 3/5 days per week. Assessments at 6-Weeks pre-intervention, 2-Weeks pre-intervention and 3-Weeks into	Sit-Stand intervention with training. Sit-Stand ratio not specified.	Objective monitoring of time spent sitting, standing and stepping at work using Activ-PAL activity monitor.	Sitting time = reduced by 73 min/workday (95% CI: -106, -39; $p = 0.004$). Standing time increased by 65 min/workday (95% CI: 47, 83: $p < 0.001$). No significant change in stepping time.

		intervention.			
Straker (2013), Sweden	*n* = 131, Call-centre Workers. F = 91, Age = 34.3 (10).	Cross-sectional observational study. Duration = 1-Week. Sit-Stand Intervention (*n* = 90); Sit-only Control (*n* = 40).	Sit-Stand Intervention and Ergonomics awareness interview. Sit-Stand ratio not specified.	Sitting, Standing time = Inclinometer and portable data logger. Ergonomics awareness = Interview.	Sitting time = 5.3% reduction ($p = 0.010$). Interaction of gender with workstation type. Females using SSW sit less than males ($p = 0.027$)
Davis (2014), USA	*n* = 37, Call-centre Workers. F = 29, M = 8, Age = 33.5 (8.9) years.	Quasi-experimental design; Duration = 1-month (2-week break-in, 2-week observation); Four conditions: Sit-only, Sit-only with prompt, Sit-Stand, Sit-Stand with prompt.	Sit-Stand intervention with posture change prompt. Sit-Stand ratio = 1:1.	Sitting time, standing time, sit-stand transitions measured by video analysis.	Musculoskeletal discomfort reduced significantly for shoulder, lower and upper back. Sitting time significantly reduced in Sit-stand (68.9%) and sit-stand with prompt (69.9%) compared to control (89.9%) ($p = 0.001$). Sit-stand transitions higher in sit-stand (4.05) and sit-stand with prompt (5.11) compared to control (0.5) ($p = 0.001$).
Dutta (2014), USA	*n* = 28, Office-workers, M = 9, F = 19.	Crossover Study in Field Setting. Duration = 4-Weeks (4-Week intervention, 2- Week washout, 4-Week control)	Sit-Stand Intervention with Anti-fatigue floor mats plus reminder to replace 50% sitting time with standing. Sit-Stand ratio = 1:1	Sitting Time = Accelerometer. Physical activity = Accelerometer, Productivity = Survey.	Sitting time = Reduced by 21% (95% CI: 18% ~ 25%). Physical activity = Reduction in mean sedentary time by 4.8/min/hr (95% CI: 4.14, 5.39min/hr). Productivity = No change.

Graves (2015), United Kingdom	*n* = 47, Office-workers, Intervention (n = 26), Control (n = 21). Age = 38.6 (9.5), F = 37, M = 10.	Randomized Controlled Trial. Duration = 8-Week. Assessment at Baseline (0-Week), 4-Week, 8-Week.	Sit-Stand Intervention and basic ergonomic training. No Sit-Stand Ratio specified.	Sitting, Standing/Walking time = Survey, Cholesterol = Blood Sample. Musculoskeletal discomfort = Likert scale (0 - 10).	Sitting Time = Decrease of 80 min/ 8 hr (95% CI: -129.0, -31.4; *p* = 0.002), Cholesterol = Decrease of 0.4 mmol/L (-0.79, -0.003; *p* = 0.0049), Musculoskeletal discomfort = No significant reduction in overall musculoskeletal discomfort. Beneficial reduction in upper back (*p* = 0.096), neck and shoulder.
Thorp (2014), Australia	*n* = 23, Office-workers, M = 17, F = 6. Age = 48.2 (8).	Crossover Study. Duration = 1-Week intervention, 7-day washout, 1-Week control.	Sit-Stand Intervention. Sit-Stand ratio = 1:1 (30 min: 30 min)	Fatigue = Survey, Musculoskeletal discomfort = Standard Nordic Questionnaire, Work Productivity = Survey	Fatigue = Lower for intervention (52.7 vs. 67.8, *p* < 0.001), Musculoskeletal discomfort = 31.8% reduction in lower back for intervention (*p* = 0.030). Productivity = trend towards improvement for intervention (*p* = 0.053).
Neuhaus (2014), Australia	n = 44, Office-workers, M = 16, F = 28. Multi-component Intervention (n = 16); SSW-only Intervention (n = 14); Control (n = 14).	Randomized Controlled Trial. Three Arm. Duration = 3-Months, Assessment at: baseline, 3-Month.	Multi-component intervention = SSW + Organizational Management consultation, Staff education, Manager emails) + Individual level (face-to-face coaching, telephone support); SSW-only Intervention; Control.	Sitting time and Physical activity = Accelerometer; Work performance, abseentism, musculoskeletal symptoms = online survey.	Siting time = reduced by 89 min/workday for multicomponent intervention; reduced by 33 min/workday for SSW-only intervention. Musculoskeletal symptoms = No significant changes overall. Multicomponent intervention: shoulder increased, neck, knees, ankles, feet decreased.

Karakolis (2016), Canada.	n = 24, College Students, M = 12, F = 12;	Cross-over design, Laboratory Setting. Three conditions - Sitting, Standing, Sit-Stand. Duration = 1-hour for each condition.	Sit-Stand Intervention. Sit-Stand ratio = 3: 1 (15 min: 5 min)	Lumbar flexion = Optoelectronic system, L4-L5 Loading, Shifts, drifts and fidgets = accelerometer, Musculoskeletal discomfort = VAS Productivity = typing performance.	Lumbar flexion = significantly reduced in sit-stand (p = 0.038), L4/L5 loading = no significant change, Productivity = no significant change, Shifts, drifts, fidgets = no significant change. Musculoskeletal discomfort = lower back musculoskeletal discomfort reduced for intervention. (Interaction of gender X workstation X time).
Júdice (2016), Portugal.	n = 50, College Students and Older Adults, F = 25, M = 25, Age = 20 ~ 64 years.	Cross-over design, Laboratory Setting. Three conditions - Sitting, Standing, Sit-Stand. Duration = 10 min for each condition.	Sit-Stand intervention, Sit: Stand = 1:1 (30 seconds: 30 seconds).	Energy Expenditure (EE) = indirect calorimetry.	EE = 35% increase for sit-stand transition compared to sitting (p < 0.001)
Ognibene (2016), USA	n = 46, Office-workers; M = 8, F = 38, Mean Age: Intervention = 45 years, Control = 49 years.	Randomized Controlled Study, Field Setting. Duration = 3-months. Assessments at Week-1, Week-6, Week-12.	Sit-Stand Intervention. No Sit-Stand ratio specified.	Low Back Pain Questionnaire.	Low Back Pain = Reduced in SSW-Intervention (p = 0.020)
Carr (2016), USA	n = 69, Office-workers, Age = 44.1 (10.7), Intervention, n = 31; Control, n = 38.	Cross-sectional study, Field Setting. Duration = 6 months, Assessments done for 1-Week, after 6-month in	Sit-Stand Intervention. No Sit-Stand ratio specified.	Occupational sedentary/ physical activity behaviours = Accelerometer/ Inclinometer. Cardio-metabolic health dependents.	Sitting time = reduced by 66 min/workday (p = 0.020) Standing time = increased by 60 min/workday (p =0 .010)

		intervention or control.			
Chau (2016), Australia	*n* = 31, Call-centre Workers, Intervention (n = 16); Control (n = 15); F = 14, M = 17. Age = 33 (11) years.	Quasi-experimental study, Field Setting. Duration = 19-Weeks. Assessments at Baseline, 1-Week, 4-Week, 19-Weeks.	Sit-Stand Intervention with brief training and email reminders. No Sit-Stand ratio specified.	Occupational sedentary/ physical activity behaviours = Accelerometer/ Inclinometer. Productivity = Call handling indices.	Sitting time = decreased by 100 min/workday at 19-weeks (95% CI: - 172, - 29; p = 0.009). Productivity = no changes.
Gao (2016), Finland	*n* = 24, Office-workers, F = 14, M = 10, Intervention, n = 10; Control, n = 14. Age = 37.7 (10.5) years.	Cross-sectional study, Field Setting. Duration = 3-months, Assessments during one workday.	Sit-Stand Intervention. No Sit-Stand ratio specified.	Sitting time using self-report. EMG derived muscle activity, Spinal shrinkage using stadiometer.	Sitting time = reduced (p = 0.001) Muscle activity = reduced muscle inactivity time (p = 0.014), increased light muscle activity time (p = 0.019). Spinal shrinkage = no change.
Tobin (2016), Australia	*n* = 37, Office-workers, F = 32, M = 05, Intervention (n = 18); Control (n = 19).	Cross-sectional study, Field Setting. Duration = 5-Weeks. Assessments at Week-1 and Week-5.	Sit-Stand Intervention and ergonomic assessment.	Sitting, standing and stepping time using activity monitors. Survey on self-perceived mental and physical health, work ability.	Sitting time = reduced by 99.8 min/workday, p = 0.001). No change in self-perceived mental and physical health scores. Decrease in self-reported work ability compared to lifetime best (p =0.008)
Gibbs (2016), USA	*n* = 18, Office-workers, F= 9, M = 9.	Cross-over design, Laboratory Setting. Three conditions - Sitting, Standing, Sit-Stand. Duration = 60-minutes each condition.	Sit-Stand Intervention. Sit-Stand ratio = 1:1 (30 min: 30 min)	Energy Expenditure (EE) using indirect calorimetry.	EE = increase by 7.8% (p = 0.001). Heart rate = increased

Barbieri (2017), Brazil	*n* = 24, Office-workers, F = 16, M = 8, Intervention, semi-automated (n = 12); Control, non-automated (n = 12). Age = 41.3 (8.8) years.	Prospective Study in Field Setting, 2-month intervention. Data collected for each workday, across 2-months.	SSW with Ergonomics Training. Sit-Stand ratio = 5:1. Computer-based posture-change prompts for Intervention; No prompts for control.	Sitting time and Sit-stand transitions measured by table position.	Sitting time = 85% for both conditions. Sit-stand transitions significantly higher in Intervention compared to Control (0.69 vs. 0.29 times/hour; $p < 0.001$.
Garrett (2018), USA	n = 262, Office-workers, F = 147, M = 113; Intervention, software prompts (n = 118); Control, no prompts (n = 82). Age = 20 ~ 65 years.	Cluster Randomized Control Trial in two Field Settings, 4.5-month duration: 6-week baseline, 3-month intervention. Data collected for each workday, across 4.5 months.	Sit-stand Intervention. Sit-Stand ratio = 5:1. Computer-based posture-change prompts for Intervention; No prompts for control.	Sitting time, standing time, sit-stand transitions measured by software.	229% increase in sit-stand transitions for intervention compared to control 2.29 (95% CI: 1.79, 2.94, $p < 0.001$), 40% of participants adhere to sit-stand schedule for 3-months.

2.5. Evidence Synthesis

The initial database search returned a total of 2926 articles. Additional articles identified by manually checking the reference list of included articles from the database search yielded another 765 studies. After removing duplicates, the corpus of unique articles was 2865 articles. These articles were screened based on their title and abstract to satisfy inclusion criteria, leading to a collection of 44 relevant articles selected for a full-text review. Out of these 44 eligible articles for full text review, 14 were culled for reasons specified in Figure 2.1, resulting in 30 articles that fit the full inclusion criteria for the systematic review. Figure 2.1 shows a flow diagram of the study selection process.

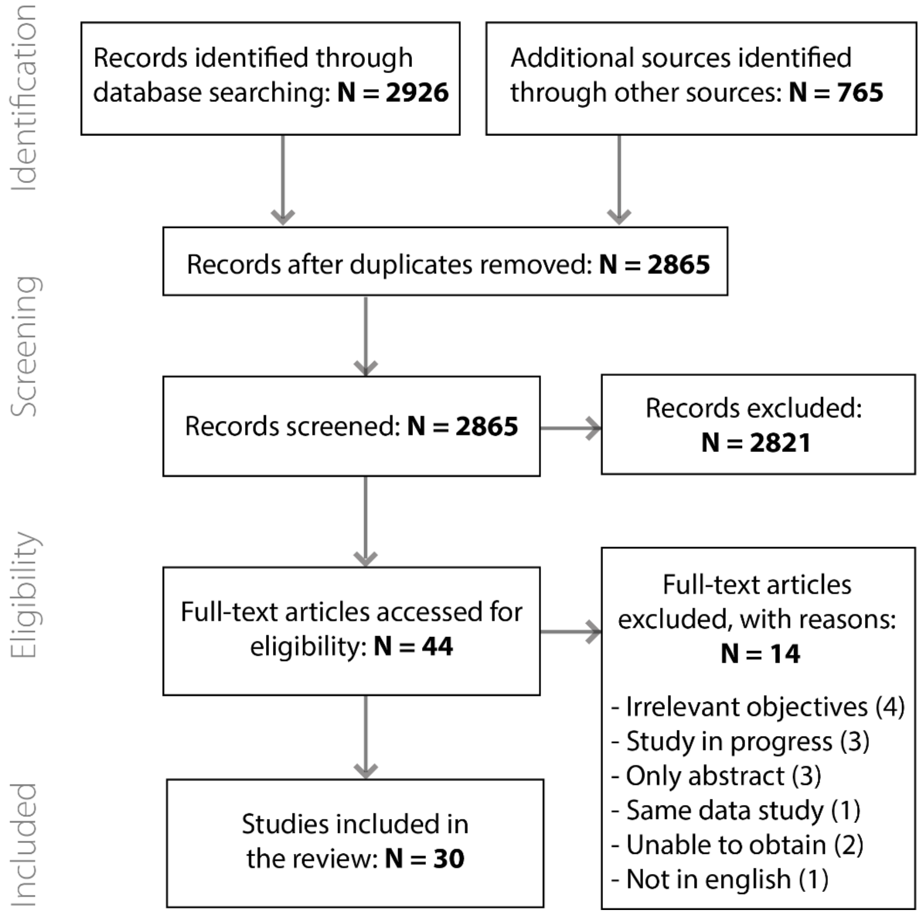

Figure 2.1. Flowchart of the article selection process based on inclusion/exclusion criteria

2.5.1. Study Characteristics

Studies were conducted before 30th June 2018; most were in the U.S. (n = 11) and Australia (n = 7); two each in Finland, Japan and Sweden; and one each in Brazil, Canada, Germany, the Netherlands, Portugal, and the U.K. Thirteen studies were cross-over designs, seven were randomized controlled trials (RCTs), four were cross-sectional, four were quasi-experimental, and three were prospective - one study combined data from a RCT and a cross-over design. There were 23 field studies and 7 laboratory studies. The number of participants in a study varied from 6 ~ 262; participants were predominantly female (62%) and aged between 18 ~ 69 years. Participants included bank tellers, call-center employees, office-workers, college students and older adults; all participants had prior experience working at sit-only desks.

2.5.2. Intervention Characteristics

Fourteen studies used an SSW-only intervention, while sixteen used an SSW as part of a multi-component intervention (e.g. ergonomics training and/or assessment, posture-change prompts, anti-fatigue mats, open office, half-standing posture). The duration of the SSW intervention varied in field settings from an 8-hour workday to 12-months, and in laboratory settings from 10-minutes to 120-minutes. In fourteen studies participants were not instructed on how much to sit vs. stand, while sixteen studies specified or suggested sit-stand ratios. Seven studies used a sit-stand ratio of 1:1; four studies used a ratio of 3:1; three studies used a ratio of 2:1; and two studies used a ratio of 5:1. The most frequently reported dependent measures were: musculoskeletal discomfort (n = 17), sitting time (n = 13), productivity (n = 12), physical activity (n = 10), and fatigue (n = 7).

2.5.3. SSWs and Musculoskeletal discomfort

Field Studies. Eleven field studies used self-report to measure perceived musculoskeletal discomfort or pain. Eight field studies reported reduction in musculoskeletal discomfort or pain (Ognibene et al., 2016; Gao et al., 2016; Davis & Kotowski, 2014; Pronk et al., 2012; Vink et al., 2009; Hedge & Ray, 2004; Roelofs & Straker, 2002; Nerhood & Thompson, 1994). Nerhood and Thompson (1994) reported a 62% reduction in musculoskeletal discomfort for office-workers who used SSWs for 9-months, while Hedge & Ray (2004) reported a 27.5% reduction in musculoskeletal discomfort for 54 office-workers who used SSWs for 4 ~ 6 weeks. Roelofs and Straker (2002) reported that alternating between seated and standing work for an 8-hour workday reduced musculoskeletal discomfort for 30 bank-tellers, while Gao et al. (2016) reported lower scores for back musculoskeletal discomfort ($p = 0.020$) for 24 office-workers who used SSWs for an 8-hour workday. Vink et al. (2009) reported significant reduction in back, neck and shoulder musculoskeletal discomfort for 10 office-workers who used SSWs for 2-weeks, while Pronk et al.

(2012) reported a 54% reduction in upper-back and neck pain for 24 office-workers who used SSWs for 4-weeks. Davis and Kotowski (2014) reported significant reductions in musculoskeletal discomfort for shoulders, upper and lower back for 37 call-center workers who used an SSW for 4-weeks, while Ognibene et al. (2016) conducted an RCT with 46 office-workers for 12-weeks to report significant reduction in lower back pain ($p = 0.020$). Three studies found no change in musculoskeletal discomfort or pain associated with SSW use (Graves et al., 2015; Neuhaus et al., 2014; Karlqvist, 1998). Karlqvist et al. (1998) reported no change in musculoskeletal discomfort for 10 office-workers who used SSWs for 1-week. Neuhaus et al. (2014) reported no change in musculoskeletal discomfort for 14 office-workers who used SSWs for 3-months, while Graves et al. (2015) conducted a study with 26 office-workers for 8-weeks to report no change in musculoskeletal discomfort.

Laboratory Studies. Six laboratory studies measured self-reported musculoskeletal discomfort (Karakolis et al., 2016; Thorp et al., 2014; Nevala & Choi, 2013; Husemann et al., 2009; Davis et al., 2009; Ebara et al., 2008). Four laboratory studies reported a reduction (Karakolis et al., 2016; Thorp et al., 2014; Husemann et al., 2009; Davis et al., 2009). In a study with 60 office-workers for 1-week, Husemann et al. (2009) reported reduction in musculoskeletal discomfort. Davis et al. (2009) conducted a study with 35 call-center workers for 2-weeks to report 20% reduction in musculoskeletal discomfort, while in a study with 23 office-workers for 1-week, Thorp et al. (2014) reported 32% reduction in lower back musculoskeletal discomfort. Karakolis et al. (2016) conducted a study with 24 participants performing data-entry for 1-hour to report lower musculoskeletal discomfort ($p = 0.006$). One study reported an increase; Ebara et al. (2008) conducted a study with 24 adults performing data-entry for 150-minutes, to report higher musculoskeletal discomfort. Nevala and Choi (2013) conducted a study with 12 participants performing computer tasks for 42-minutes to report mixed results - the SSW intervention resulted in lower musculoskeletal discomfort for upper limbs, but higher musculoskeletal discomfort for lower limbs.

Overall. Most studies reported a significant reduction in musculoskeletal discomfort (n = 12), some indicated no change in musculoskeletal discomfort (n = 4), and one study reported increase in musculoskeletal discomfort associated with use of SSWs. Results suggest that compared to a sit-only control, SSW interventions can reduce musculoskeletal discomfort for office-workers.

2.5.4. Sit-Stand Workstation and Sitting Time

Field Studies. Eight field studies used activity monitors (Chau et al., 2016; Carr et al., 2016; Tobin et al., 2016; Straker et al., 2013; Chau et al., 2014; Neuhaus et al., 2014; Dutta et al., 2014; Alkhajah et al., 2012), four studies used self-report (Gao et al., 2016; Graves et al., 2015; Pronk et al., 2012; Nerhood & Thompson, 1994), and one used video analysis (Davis & Kotowski, 2014) to measure sitting time. In a study with 32 office-workers for 3-months, Alkhajah et al. (2012) reported reduction in sitting time by more than 2-hours/workday ($p < 0.001$), while Straker et al. (2013) reported a reduction in sitting time by 5.3% ($p = 0.010$) for 131 call-center workers in a 6-hour work shift. Chau et al. (2014) reported a reduction in sitting time by 73-min/workday ($p = 0.004$) in a study with 42 office-workers for 4-weeks, while Dutta et al. (2014) reported a reduction in sitting time by 21% (95% CI. 18% to 25%, $p < 0.050$) in a study with 28 office-workers for 4-weeks. Neuhaus et al. (2014) reported reduction in sitting time by 89 minutes/workday (95% CI. -130, -47; $p < 0.001$) with 44 office-workers for 3-months, while Davis & Kotowski (2014) reported reduction in sitting time by 20% ($p < 0.001$) with 37 call-center workers for 1-month. Carr et al. (2016) reported reduction in sitting time by 66-minutes/workday ($p = 0.020$) with 69 office-workers for 6-months. In a study with 31 call-center workers for 19-weeks, Chau et al. (2016) reported reduction in sitting time by 100-minutes/workday (95% CI: −172, −29; $p = 0.009$), while Tobin et al. (2016) conducted a study with 37 office-workers for 5-weeks, to report reduction in sitting time by 100-minutes/workday ($p < 0.001$). Nerhood & Thompson (1994) reported that 12-months after the SSW intervention, office-workers on average spent 23% of the workday standing. Pronk et al. (2012) reported reduction in sitting time by 66-minutes/workday ($p = 0.030$) with 24 office-workers for 4-weeks. In a study with 47 office-workers for 8-weeks, Graves et al. (2015) found reduction in sitting time by 80 minutes/workday (95% CI = -129, -31.4; $p = 0.002$), while Gao et al. (2016) reported reduction in sitting time ($62.0 \pm 13.0\%$ vs. $83.6 \pm 12.0\%$, $p = 0.001$) with 24 participants for 3-months.

Overall. All 13 field studies indicate a reduction in sitting time with SSW use for office-workers. Results suggest that compared to a sit-only control, SSW interventions can reduce sitting time for office-workers.

2.5.6. SSWs and Productivity

Field Studies. Four field studies used self-report (Dutta et al., 2014; Alkhajah et al., 2012; Hedge & Ray, 2004; Nerhood & Thompson, 1994), while two used custom-software (Chau et al., 2016; Davis & Kotowski, 2014) to measure productivity. Four field studies reported no change in productivity (Chau et al., 2016; Dutta at al., 2014; Davis & Kotowski, 2014; Alkhajah et al., 2012). Alkhajah et al. (2012) found no change in productivity after 4-weeks for 32 office-workers, while Dutta et al. (2014) reported no change in productivity for 28 office-workers after 4-weeks. Davis and Kotowski (2014) reported no change in objectively measured productivity with 37 call-center workers after 4-weeks, while Chau et al. (2016) reported no change in objectively measured productivity at 1-week, 4-week and 19-week follow-ups with 31 call-center workers. Two studies suggested improved productivity associated with use of SSWs (Nerhood & Thompson, 1994; Hedge & Ray, 2004). Nerhood & Thompson (1994) reported increased productivity for office-workers during a 12-month SSW intervention, while Hedge & Ray (2004) reported increased productivity for 33 office-workers during a 4 ~ 6-week SSW intervention.

Laboratory Studies. Five laboratory studies used typing performance to measure productivity (Karakolis et al., 2016; Nevala & Choi., 2013; Husemann et al., 2009; Ebara et al., 2008; Hasegawa et al., 2001), and one study used self-report (Thorp et al., 2014). Three laboratory studies reported no change in productivity (Karakolis et al., 2016; Husemann et al., 2009; Ebara et al., 2008). Ebara et al. (2008) reported no change in productivity for 24 participants performing data-entry for 150-minutes. Husemann et al. (2009) had 60 participants perform data-entry for 45 minutes to report no change in productivity, while Karakolis et al. (2016) had 24 participants perform data-entry for 60-minutes to report no change in productivity. Three laboratory studies reported improved productivity with use of SSWs (Thorp et al., 2014; Nevala & Choi, 2013; Hasegawa et al., 2001). Hasegawa et al. (2001) reported higher productivity for the SSW intervention in a study with 16 participants who performed computer-based tasks for 60-minutes and 90-minutes. Nevala & Choi (2013) had 12 participants performing computer-based tasks for 42-minutes to report 10% increase in productivity for SSW intervention, while Thorp et al. (2014) had 23 office-workers performing office tasks for 1-week to report a trend towards improved productivity ($p = 0.053$) for the SSW intervention.

Overall. Most field and laboratory studies report no change in productivity with use of SSWs ($n = 7$), and some ($n = 5$) report increased productivity with SSW usage. No studies report reduction in productivity associated with use of SSWs. Results suggest that compared to a sit-only control, SSW interventions do not reduce productivity for office-workers, but also do not necessarily increase productivity.

2.5.7. SSWs and Physical Activity

Field Studies. Six field studies used activity monitors (Chau et al., 2016; Carr et al., 2016; Tobin et al., 2016; Chau et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014) while one study used self-report (Graves et al., 2015) to compare physical activity and/or energy expenditure between the SSW intervention and the sit-only control. One study reported increased physical activity (Dutta et al., 2014), while six studies found no change in physical activity between the SSW intervention and the sit-only control (Chau et al., 2016; Carr et al., 2016; Tobin et al., 2016; Graves et al., 2015; Chau et al., 2014; Neuhaus et al., 2014). Dutta et al. (2014) conducted a study with 28 office-workers for 4–weeks to report significantly higher activity-units/hour for the SSW intervention. In a study with 42 participants for 4-weeks Chau et al. (2014) reported no changes in stepping time at work, while Neuhaus et al. (2014) conducted a study with 44 office-workers for 3-months to report no significant changes in stepping time and physical activity. Chau et al. (2016) conducted a study with 31 call-center workers for 19-weeks to report no significant changes in walking time or doing physical tasks, while in a study with 69 office-workers for 6-months Carr et al. (2016) reported no significant change in walking time and steps taken. Tobin et al. (2016) conducted a study with 37 office-workers for 5-weeks to report no significant changes in stepping time. Graves et al. (2015) conducted a study with 47 office-workers for 8-weeks to report no differences in walking time at 4-week and 8-week follow-ups.

Laboratory Studies. Two laboratory studies using indirect calorimetry reported increase in energy expenditure for the SSW intervention compared to the sit-only control (Gibbs et al., 2017; Júdice et al., 2016). Júdice et al. (2016) conducted a cross-over study with 50 participants to report that sit-stand transitions performed once/minute for 10-minutes, resulted a 35% increase in Metabolic Energy Cost (MEC) compared to static sitting for the same duration. In a laboratory study with 18 adults for a 60-minute duration, Gibbs et al. (2017) reported a 7.8% increase in energy expenditure (5.5 $\pm$ 12.4 kcal/h, $p < 0.001$) and an increase in heart rate (7.5 ± 6.8 bpm) for the SSW intervention relative to the control.

Overall. Most studies report no change in physical activity with use of SSWs ($n = 7$), while three studies report increase in physical activity and/or energy expenditure with use of SSWs. None of the studies report any reduction in physical activity associated with use of SSWs. Results suggest that compared to a sit-only control, SSW interventions do not necessarily increase physical activity for office-workers.

2.5.8. Sit-Stand Workstation and Fatigue

Field Studies. Four field studies reported a reduction in self-reported fatigue or exertion for the SSW intervention compared to the control (Dutta et al., 2014; Pronk et al., 2012; Karlqvist, 1998; Paul, 1995). Paul (1995) conducted a cross-sectional study with 12 office-workers for 3-months to report workers feeling more energetic and less tired at end of the workday. Karlqvist (1998) conducted a prospective study with 10 office-workers for 1-week to report significantly lower perceived exertion ($p = 0.046$). Pronk et al. (2012) conducted a prospective study with 24 office-workers for 4-weeks to report significant reduction in fatigue ($p = 0.010$) while Dutta et al. (2014) conducted a cross-over study with 28 office-workers for 4-weeks to report workers feeling significantly more energetic and less tired.

Laboratory Studies. Three laboratory studies used self-report to compare fatigue between the SSW intervention and the sit-only control (Gibbs et al., 2017; Thorp et al., 2014; Hasegawa et al., 2001). Two studies reported reduced fatigue associated with SSWs (Hasegawa et al., 2001; Thorp et al., 2014) while one study (Gibbs et al., 2017) found no significant difference in fatigue between the SSW intervention and the sit-only control. Hasegawa et al. (2001) used short-duration data entry with 8 male participants to report that the SSW intervention reduced monotonous feelings of fatigue. In an RCT with 23 obese office-workers, Thorp et al. (2014) reported significantly lower fatigue for the SSW intervention (mean = 52.7, 95% CI: 43.8 to 61.5; $p < 0.001$) compared to the sit-only control (mean = 67.8, 95% CI: 58.8 to 76.7). Gibbs et al. (2017) conducted an RCT with 18 participants for 60-minutes to report no significant change in fatigue between the SSW intervention and the control.

Overall. Most studies report reductions in fatigue with use of SSWs (n = 6), while one study reported no change in fatigue with use of SSWs. Results suggest that compared to a sit-only control, SSW interventions can reduce fatigue for office-workers.

2.6. Discussion

This review summarizes the efficacy of the sit-stand paradigm of office work. Findings suggest that the adoption of SSWs for office-workers reduces musculoskeletal discomfort and fatigue, significantly lowers sitting time, and has no detrimental effect on productivity; however, physical activity is not higher compared to a sit-only control. The differences in assessment techniques, settings, participants, intervention durations, and measured dependents make it challenging to compare results and reduce the ability to generalize results. Therefore, this review did not include a meta-analysis or a quantitative analysis of the results; rather, a qualitative synthesis was undertaken. Findings pertaining to the specific dependent measures are discussed.

2.6.1. Musculoskeletal discomfort

There is strong evidence that adoption of SSWs can reduce musculoskeletal discomfort for office-workers. Most studies report reduced musculoskeletal discomfort (n =12), while a few report no changes in musculoskeletal discomfort (n = 4). One study found higher musculoskeletal discomfort associated with SSW use (Ebara et al. 2008) - the high proportion of older adults (50% of participants aged 60~69 years) and frequency of sit-stand transitions (16 transitions in 2-hours; 10-min seated, 5-min standing) could have been a factor for the increased musculoskeletal discomfort. Overall, the use of SSWs can reduce musculoskeletal discomfort for office-workers. However, there is need for objective measures for musculoskeletal discomfort, longitudinal data on musculoskeletal discomfort propagation and a fine-grained analysis of musculoskeletal discomfort at individual body-part level, to understand how SSW interventions impact musculoskeletal discomfort.

2.6.2. Sitting Time

There is strong evidence that the use of SSWs reduces sitting time for office-workers. All field studies (n = 13), a majority using activity monitors, reported an average reduction in sitting time by around 20%. The only exception was a study by Straker et al. (2013) that reported a 5.3% reduction in sitting time with 131 call-center workers assessed for 1-week. The modest change in sitting time may be attributed to the nature of the call-center task. While there is evidence for modest to significant reduction in sitting time associated with use of SSWs in experimental settings, there is need for longitudinal studies to see how these findings translate into real-world work environments. In some studies SSW intervention was part of a multi-component intervention strategy with ergonomics training, email reminders, and posture change prompts to reduce sedentary behaviors; these multi-component interventions may have collectively impacted sitting time. Overall, the use of SSWs reduces sitting time for office-workers.

2.6.3. Productivity

There is strong evidence that the use of SSWs does not reduce productivity for office-workers. Most studies report no change in productivity (n = 7), while some studies (n = 5) report higher productivity associated with SSWs. Of the five studies that reported increased productivity, two used a self-report measure (Hedge & Ray, 2004; Nerhood & Thompson, 1994), while two measured productivity in short-duration computer tasks (Nevala & Choi, 2013; Hasegawa et al., 2001). The only exception was a study by Thorp et al. (2014) with 23 office-workers for 1-week that reported a trend towards improved productivity, though this was not statistically significant (p = 0.053). Most studies used objectively measured productivity; however, tasks were limited to data entry and/or call-center work. In future, productivity should be measured objectively for a wider range of computer-based and other desk-based office tasks. Overall, the use of SSWs does not reduce productivity for office-workers.

2.6.4. Physical Activity

There is strong evidence to suggest that the use of SSWs does not increase physical activity for office-workers. Most studies report no change in physical activity (n = 7), while some (n = 3) report increase in physical activity and/or energy expenditure associated with SSWs. Of the three studies that reported an increase, two were in laboratory settings and used indirect calorimetry to measure energy expenditure (Gibbs et al., 2017; Júdice et al., 2016). The third used accelerometer data to compute activity-units/hour as a measure of physical activity (Dutta et al., 2014). Physical activity has been operationalized in different ways; stepping time, steps taken, walking time, activity-units, and energy expenditure have been used to report physical activity. In future, there is need for standardized measures to compare physical activity and/or energy expenditure in SSW interventions. Overall, the use of SSWs does not increase physical activity for office-workers.

2.6.5. Fatigue

There is evidence that use of SSWs reduces fatigue for office-workers. Most studies report reduction in fatigue (n = 6); the only exception was a study by Gibbs et al. (2017) that reported no change in fatigue associated with SSW use compared to a sit-only control. The short duration of the SSW intervention (60-minutes) may have been a reason for the lack of change in self-reported fatigue. In theory, the postural variability and muscle activity enabled by SSWs use may be the underlying reason for reductions in self-reported fatigue. In future, there is need for standardized, objective measures to compare fatigue in SSW interventions. Overall, the use of SSWs reduces fatigue for office-workers.

2.6.6. Multi-component Interventions

Sixteen studies featured multi-component interventions that combined the SSW intervention with additional interventions such as ergonomics training (n = 7), use of a high-chair for perching (n = 3), software-based posture change prompts (n = 4), email reminders for posture change (n = 2), ergonomic awareness interviews (n = 2), use of anti-fatigue mats when standing (n = 1) and shift to an open-plan office (n = 1). The reported change in dependent measures is a cumulative effect of the multi-component intervention; it is difficult to isolate and measure the change that can be attributed to the SSW intervention alone. Future studies should compare the efficacy of multi-component interventions to SSW-only interventions.

2.6.7. Sit-Stand Ratio

Sixteen studies in the review used specific sit-stand ratios - seven studies used a 1:1 ratio, three studies used a 2:1 ratio, four studies used a 3:1 ratio, and two studies used a 5:1 ratio. There is lack of consensus on what constitutes an optimal sit-stand ratio, and the efficacy of such a sit-stand ratio with respect to key dependent measures has not been experimentally verified. While interpreting the effect of SSW use on the dependent measures, one needs to be cognizant of the specific sit-stand ratio adopted in the study. Future research should investigate what constitutes an optimum sit-stand ratio for SSW use.

2.6.8. Participant Gender

Most studies (n = 25) had male and female participants; however only two studies reported on the interaction of gender and the SSW intervention on dependent measures (Karakolis et al., 2016; Straker et al., 2013). In a field-study with 131 call-center workers for 1-week, Straker et al. (2013) reported that compared to the male workers, the female workers stood for longer durations and reported lower fatigue in SSW use. In a laboratory study with 24 college students using SSWs for 1-hour, Karakolis et al. (2016) reported an interaction of gender and workstation type ($p = 0.004$) – male participants reported higher musculoskeletal discomfort with prolonged standing, while female participants reported higher musculoskeletal discomfort with prolonged sitting. Future studies of SSW interventions should evaluate the potential role of gender as a moderator.

2.6.9. Sit-Stand Compliance

Few studies have investigated long-term compliance of office workers to recommended use of the SSWs. This is important since a survey by Wilks et al. (2006) found that only about 18% of office-workers provided with SSWs for a year, reported use of the sit-stand function at least once-a-day. Another study with 24 office-workers for 7-weeks reported that removal of the SSW intervention largely negated all observed improvements, 2-weeks post-intervention (Pronk et al. 2012). Studies provide evidence for improved sit-stand compliance of office workers when they are provided with software-based posture change prompts (Garrett et al., 2018; Barbieri et al., 2017; Davis & Kotowski, 2014). Davis & Kotowski (2014) reported a 40% increase in sit-stand transitions associated with software-based posture change prompts, Barbieri et al. (2017) reported higher sit-stand transitions for semi-automated posture change prompts (0.65/hour vs.

0.29/hour; p = 0.001), and Garrett et al. (2018) reported a 229% increase in sit-stand transitions and 40% of participants adhering to the sit-stand schedule, 3-months post-intervention. Future studies need to consider strategies to improve long-term compliance of office workers to recommended use of the SSWs.

2.7. Limitations

There are several limitations of this systematic review. Given the differences in assessment techniques, settings, participants, study designs, duration of interventions and measured dependents, neither a meta-analysis, nor a quantitative analysis of the results was conducted; rather, a qualitative synthesis was undertaken. Therefore, any interpretation of the efficacy of the SSW interventions for office-workers should be interpreted within this context. Additionally, only published or in-press, peer-reviewed articles, written in the English language were included. As such, results may be subject to publication bias and are not generalizable for studies published in languages other than English. While an extensive search strategy was employed to identify all potentially relevant studies, there exists a possibility that some of the relevant studies may not have contained keywords used for the database searches, or the studies appeared in publications not indexed in the databases which were searched. Although every precaution was taken to code the data accurately and consistently, this was limited to the scope of the information provided in the original articles. Finally, included studies needed to have a sit-only control group; studies comparing different SSW interventions without a sit-only control group were excluded.

2.8. Conclusion

This review indicates that office workers experience reductions in sitting time, musculoskeletal discomfort and fatigue, without negative impacts on productivity in the use of SSWs. However, physical activity dose not increase significantly compared to seated work. There is lack of consensus on what constitutes an optimal sit-stand ratio, and the efficacy of such a sit-stand ratio with respect to key dependent measures. Further studies are needed to investigate strategies to increase physical activity and/or energy expenditure in sit-stand workstation use. Research on what office tasks are appropriate for seated vs. standing work is needed; so is the need for studies to understand how postural prompts can influence sit-stand compliance and increase postural variability. Additionally, this review highlights need for more consistent, objective measures to study the impact of SSWs on sedentary office workers.

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CHAPTER 3

A PILOT STUDY EXPLORING EFFECTS OF SEATED AND STANDING WORK ON SHORT-DURATION COMPUTER TASK PRODUCTIVITY AND MUSCULOSKELETAL DISCOMFORT

3.1. Abstract

This study evaluated effects of seated and standing work on objective short-duration computer transcription task productivity and perceived musculoskeletal discomfort. A repeated measures research design was used to evaluate task productivity and musculoskeletal discomfort for 12 participants on a 15-minute computer-based English language transcription task. Productivity was measured by number of characters typed per minute and number of errors calculated as a percentage. Musculoskeletal discomfort was evaluated using a modified version of the Nordic musculoskeletal discomfort questionnaire, measured for the whole body, as well as for the upper body and the lower body. Results suggest that for short-duration computer-based transcription tasks, standing work had fewer transcription errors, when compared to seated work. Also, there was no difference in impacting transcription speed between standing and seated work. Overall musculoskeletal discomfort for the whole body was similar for seated and standing work. However, there was an interaction of work condition and body region for musculoskeletal discomfort; upper body musculoskeletal discomfort was higher in seated work, while lower body musculoskeletal discomfort was higher in standing work. [1]

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3.2. Introduction

There is growing body of evidence to suggest that chair sitting for prolonged durations is a health hazard (Chau et al., 2010; Thorp et al., 2011). Sedentary behavior has been associated with increased risk of cardio-vascular disease (Warren et al., 2010), obesity (Proper et al., 2007; McGrady & Levine, 2009), weight gain (Brown et al., 2005), type-2 diabetes (Hu et al., 2003), depression (Teychenne et al., 2010), and pre-mature mortality (Katzmarzyk et al., 2012; Chau et al., 2013). From an evolutionary biology perspective, humans were not designed to sit all day (Grimsrud, 1990). Sitting in a chair is not bad in moderation, but in excess is addictive and harmful. According to Levine (2010), *'for every hour we sit, we lose two hours of our life.'*

In recent years, given the increased attention to chronic disease and pre-mature mortality associated with prolonged sitting (Patel et al., 2010), sit-stand workstations (SSWs) have become popular in the workspace (Karakolis & Callaghan, 2014). These SSWs feature variable-height work surfaces enabling users to alternate between seated and standing work. However, there are mixed results of the effectiveness of SSWs in reducing sitting time at work. While Alkhajah et al. (2012) reported a significant reduction in sedentary time with SSW use, Gibson et al. (2012) did not find significant change in sitting time with SSW use. Studies by Nerhood & Thompson (1994), Hedge & Ray (2004), and Vink et al. (2009) indicate that when provided with SSWs, office workers choose to stand for 20 ~ 30% of their workday. While the adoption of SSWs for office workers potentially improves energy expenditure at work, there is low compliance with use of SSWs in office work. Wilks et al. (2006) reported results from a survey of office workers using SSWs for a year to indicate low compliance with the sit-stand function - only 10% of office workers used the sit-stand function once-a-day.

A systematic review of SSW use reveals that alternating between seated and standing postures at work is likely to reduce musculoskeletal discomfort when compared to sit-only work (MacEwan et al., 2015). Although measuring musculoskeletal discomfort is subjective by nature, there have been significant correlations between objective measures (e.g. pressure distribution) and subjective musculoskeletal discomfort scores (De Looze et al., 2003). This correlation coupled with logistical limitations of objective measures in experimental conditions, has led to adoption of perceived musculoskeletal discomfort as a common dependent measure. Studies comparing SSW interventions with sit-only work as control report reduced musculoskeletal discomfort for the former. However, there is paucity of data comparing musculoskeletal discomfort between seated and standing work.

Worker productivity is another dependent measure used in assessing effectiveness of SSWs for office work. A literature review of productivity in SSW interventions reported mixed results (Karakolis & Callahan, 2014). Three studies reported increased productivity for the SSW intervention compared to a sit-only control (Ebara et al., 2008; Hedge and Ray, 2004; Dainoff, 2002). Four studies showed no change in productivity (Davis et al., 2009; Husemann et al., 2009 Hedge et al., 2005; Nerhood & Thompson, 1994), while one study by Hasegawa et al. (2001) had mixed results - higher volume of work was performed for the SSW intervention, but with more errors. There have been few studies, if any, comparing effects seated and standing work on short-duration computer transcription productivity.

3.3. Objectives

Given the deleterious health effects of sedentary behavior and the large number of people globally exposed to this pandemic, workstation alternatives that promote postural variability are being increasingly adopted (Tudor-Locke et al., 2014). The SSWs show promise in promoting postural variability at work (Davis & Kotowski, 2014). However, the paucity of data comparing productivity and musculoskeletal discomfort between seated and standing work limits our understanding the inter-relationships between work condition, musculoskeletal discomfort, and productivity in computer-based work. The aim of this study was to evaluate effects of seated and standing work on short-duration transcription task productivity and perceived musculoskeletal discomfort. It was hypothesized that there will be:

(H1) A main effect of work condition on task productivity.

(H2) A main effect of work condition on musculoskeletal discomfort.

(H3) An interaction of work condition and body-region with musculoskeletal discomfort.

3.4. Methods

3.4.1. Participants. Twelve male adults volunteered to participate in the study. They were recruited by email circulated among graduate students at Cornell University. Inclusion criteria were: at least 18 years old, a Body Mass Index between 18 ~ 30, experience with computer transcription tasks, involvement in physical activity and/or exercise (frequency: 1 ~ 5 sessions/week, duration: 30 ~ 90 minutes/session), and no musculoskeletal health complaints. Demographic data including computer experience, physical activity and musculoskeletal health were self-reported (Table 3.1). All participants (Ps) signed an informed consent form at the beginning of the study.

Criteria	**Mean**	**Std. Dev**
Age (years)	27.67	4.36
Weight (kg)	74.13	12.00
Height (cm)	177.00	4.00
Body Mass Index (kg/m^2)	23.46	3.15
Weekly Computer Work (hours/week)	49.67	22.53
Daily Occupational Sitting (hours/day)	6.17	2.11
Physical Exercise Frequency (# of times/week)	2.75	1.42
Physical Exercise Duration (minutes)	44.75	27.14

Table 3.1. Participant Demographics

3.4.2. Experimental Design. Using a repeated-measures design with randomized order of presentation, productivity and musculoskeletal discomfort on a 15-minute transcription task was assessed for two work conditions – seated (SIT) and standing (STA), in an office like laboratory environment. The transcription task was performed twice in each work condition; order of presentation of work conditions was randomized. Ps performed a total of four 15-minute transcription tasks, two in each work condition, for a total 60-minutes of transcription. The work condition was the independent variable; dependent variables were transcription task productivity and perceived musculoskeletal discomfort.

3.4.3. Apparatus. A 17-inch height-adjustable computer screen, wired keyboard and wired mouse (Dell, Round Rock, TX) were the computer peripherals used. For the SIT work condition, a fixed-height desk at 0.75 m from the floor level and a task chair (Mirra 2, Herman Miller, Zeeland, MI) were used. For STA work condition the fixed-height desk was supplemented by two raised surfaces at 1.00 m and 1.25 m from the floor level, to provide support to the keyboard and mouse, and to the monitor respectively. The heights for keyboard and mouse, computer screen and task chair were adjusted for each P, based on the standard reference conditions for seated and standing work in ANSI/HFES 100-2007.

3.4.4. Tasks and Assessments. The computer-based transcription task required Ps to transcribe text from a document window in left half of the screen to a document window in right half of the screen using a word-processing software (MS Word). Each mistyped word or punctuation was counted as an error. Task productivity was operationalized by two measures – (a) transcription speed (# of characters typed) and transcription error (# of mistyped words and punctuations). Musculoskeletal discomfort was operationalized using a 13-item Visual Analog Scale for Musculoskeletal discomfort (VAS-D) adapted from the standard Nordic questionnaire for musculoskeletal symptoms (Kuorinka et al., 1987). Each item corresponded to a region of the body as indicated on a body-part diagram divided into 13 regions of the body. Each item asked Ps to place an "X" representing how much musculoskeletal discomfort they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing "no musculoskeletal discomfort" to 100 mm representing "extreme musculoskeletal discomfort"). The 13-item VAS-D enabled classification of musculoskeletal discomfort by upper and lower body regions; a summation of these scores provided the whole-body musculoskeletal discomfort score.

3.4.5. Procedure. First, the researcher explained the experimental protocol and Ps signed the informed consent document. Next, a questionnaire administered to Ps documented their demographic characteristics (Table 3.1). Following this, Ps performed practice-transcription trials in both work conditions (SIT & STA) for 5 minutes each. Ps were then instructed to perform four transcription tasks, each of 15-minutes duration, based on a pre-determined randomized sequence. Ps received no productivity guidelines for the transcription task but were instructed to type in their normal speed. A 5-minute break was provided between transcription tasks; musculoskeletal discomfort ratings were recorded at 5 instances – at baseline (t = 0 minute), and at end of each transcription task (t = 15, 35, 55, 75 minutes). The complete protocol, including preparatory activities, transcription tasks, rest-breaks, and filling out questionnaires, took 100 minutes.

3.4.6. Data Analysis. Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 22.0. Paired T-tests (two-tailed) were used to compare short-duration transcription task productivity (speed and errors) and perceived musculoskeletal discomfort between seated work (SIT) and standing work (STA). Significance threshold was set at $p < 0.05$. Objective productivity and perceived musculoskeletal discomfort were plotted at 15-minute intervals (t = 15, 35, 55 and 75 minutes) to compare temporal trends for the SIT and STA work conditions.

3.5. Results

3.5.1. Productivity - Transcription Speed. Short-duration transcription speed was measured as number of characters including blank spaces typed in 15 minutes. A paired t-test (two-tailed) comparing mean values of transcription speeds in the SIT and STA work conditions revealed no main effect of work condition on short-duration transcription speed ($t = 1.5553$, $p = 0.1335$) (Figure 3.1).

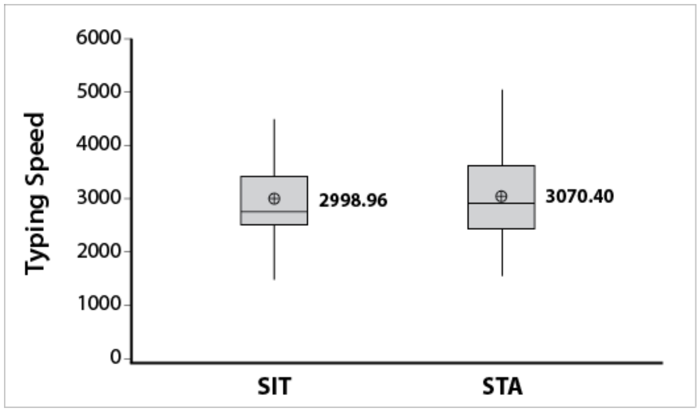

Figure 3.1. Mean transcription speed in SIT and STA conditions

There was evidence of a practice effect on transcription speed for both work conditions. On average, transcription speed for the SIT condition was higher in the second session (μ = 3069.25; σ = 801.96) compared to first (μ = 2889.25; σ = 730.84). Similarly, transcription speed for the STA condition was higher in second session (μ = 3135.50; σ = 887.72) compared to the first session (μ = 2988.58; σ = 882.22).

3.5.2. Productivity - Transcription Speed across Time. Mean transcription speed was plotted for all the four sessions. For the SIT condition, transcription speed increased in the first three sessions, but decreased in session four. For the STA condition, transcription speed decreased in session two, but increased in sessions three and four (Figure 3.2).

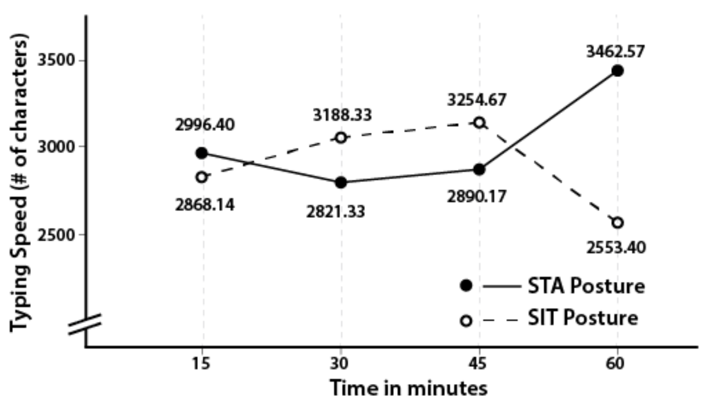

Figure 3.2. Transcription speed across time for SIT and STA conditions

3.5.3. Productivity - Transcription Error. A paired *t*-test (two-tailed) comparing mean values of transcription errors in SIT and STA conditions indicated a main effect of work condition on transcription errors (t = -3.1476, p = 0.0045). On average, transcription error in STA work (μ = 11.28; σ = 7.58) was significantly lower compared to SIT work (μ = 13.60; σ = 8.49)

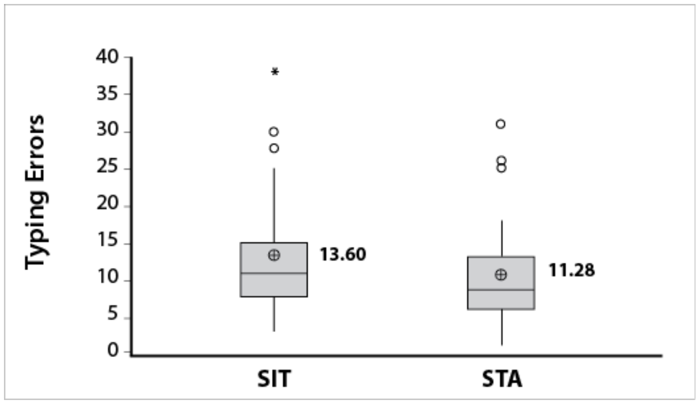

Figure 3.3. Mean transcription error in SIT and STA conditions

(Figure 3.3). There was evidence of a practice effect on transcription error in both conditions. For SIT work, transcription error in the second session (μ = 14.75; σ = 9.49) was higher compared to the first session (μ = 12.67; σ = 8.02). For STA work, transcription error in the second session (μ = 11.50; σ = 8.54) was higher compared to the first session (μ = 11.25; σ = 7.20).

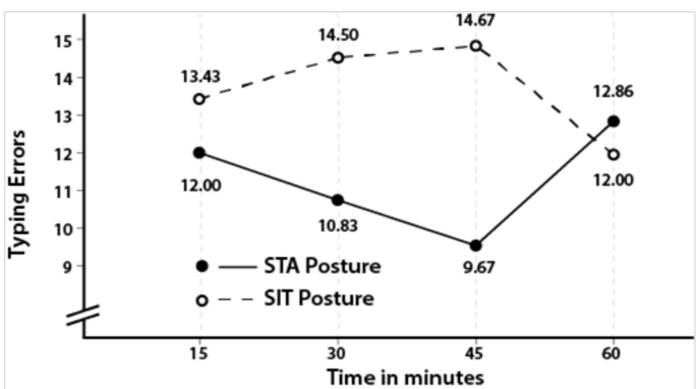

Figure 3.4. Transcription error across time for SIT and STA conditions

3.5.4. Productivity - Transcription Error across Time. Mean transcription error was plotted for all the four sessions. For the SIT condition transcription error increased in the first three sessions but decreased in session four. For the STA condition transcription error decreased in the first three sessions and increased in session four (Figure 3.4).

3.5.5. Musculoskeletal Discomfort. Overall musculoskeletal discomfort was calculated by averaging scores from the 13-item musculoskeletal discomfort measure. A paired t-test comparing mean values of perceived musculoskeletal discomfort in the SIT and STA conditions indicated no main effect of work condition on perceived musculoskeletal discomfort (t = 0.5190, p = 0.6204) (Figure 3.5).

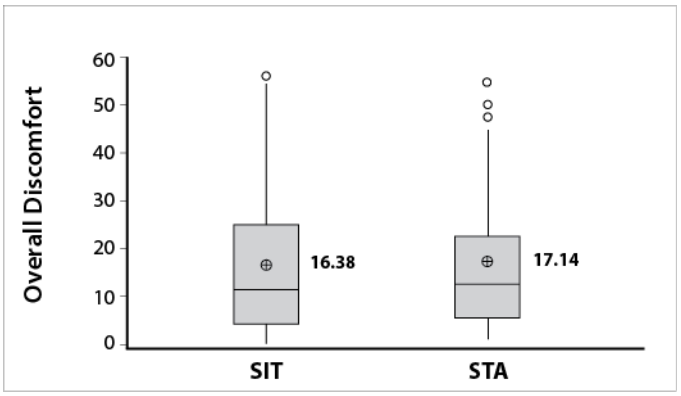

Figure 3.5. Mean musculoskeletal discomfort in SIT and STA conditions

3.5.6. Musculoskeletal Discomfort across Body Region. Musculoskeletal discomfort was analyzed with respect to upper body (head and neck, shoulder and arm, lower back, elbow and forearm, wrist and hands) and lower body (hip, thigh and knee, leg and foot). There was an interaction of body region (upper and lower) with work condition (SIT and STA), i.e. the effect of work condition on musculoskeletal discomfort varied with the body region. A paired *t*-test (two-tailed) comparing mean musculoskeletal discomfort for upper body in SIT and STA work conditions indicated a main effect of workstation condition on musculoskeletal discomfort (t = -2.1477, p = 0.0425). Similarly, a paired *t*-test (two-tailed) comparing mean musculoskeletal discomfort for the lower body in SIT and STA work conditions indicated a main effect of work condition on musculoskeletal discomfort (t = 2.1944, p = 0.0385) (Table 3.2).

Perceived Discomfort	SIT Posture	STA Posture
Upper Body	18.51	15.43
Lower Body	12.97	19.89
Overall Body	16.38	17.14

Table 3.2. Interaction of Body Region and Work Condition

3.5.7. Musculoskeletal discomfort across Time. Mean musculoskeletal discomfort was plotted for each of the four sessions. For the SIT condition there was a decrease in musculoskeletal discomfort in the second session, followed by an increase in musculoskeletal discomfort for session three and four. For the STA condition a decrease in musculoskeletal discomfort was observed across all four sessions (Figure 3.6).

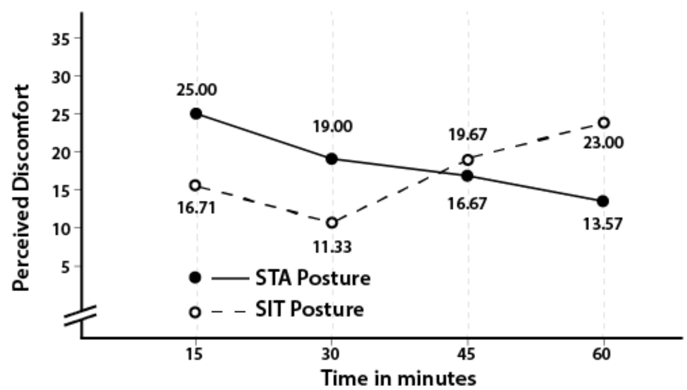

Figure 3.6. Musculoskeletal discomfort across time for SIT and STA condition

3.6. Discussion

The results of the study partially confirm the H1, i.e. there is a main effect of work condition on short-duration transcription task productivity. Mean transcription speed in STA and SIT work conditions are similar; the difference of means is not statistically significant. However, mean transcription errors for STA condition is significantly lower compared to SIT condition. While previous research suggests no significant changes in transcription task productivity between seated and standing conditions (Drury et al., 2008; Beers et al., 2008; Straker et al., 2009), analysis of transcription errors in the present study indicate that transcription accuracy in standing work is significantly higher compared to seated work. The increase in transcription accuracy may be because physiological arousal is reported to be higher in standing (Ebara et al., 2008).

The results do not confirm H2, i.e. there is no main effect of workstation condition on overall perceived musculoskeletal discomfort. While overall perceived musculoskeletal discomfort is higher in the STA condition compared to the SIT condition; the difference of means is not statistically significant. Previous studies have compared seated work with sit-stand work to suggest a significant reduction in perceived musculoskeletal discomfort for sit-stand work (Roelofs and Straker, 2002; Hedge and Ray, 2004; Husemann et al., 2009). This study is unique in comparing perceived musculoskeletal discomfort between the SIT and the STA conditions to report a non-significant difference in overall perceived musculoskeletal discomfort.

Results confirm H3, i.e. there is an interaction of work condition and body region with regard to perceived musculoskeletal discomfort. Findings suggest that for short-duration transcription tasks there is a tradeoff between perceived musculoskeletal discomfort and work condition. Across equivalent transcription tasks and durations, upper-body musculoskeletal discomfort is higher in SIT condition, while lower-body musculoskeletal discomfort is higher in STA condition. With respect to perceived musculoskeletal discomfort and body region, Roelofs and Straker (2002) found lower-limb musculoskeletal discomfort was greatest in the standing condition. Additional studies have shown a strong association between low-back pain with standing occupations (Andersen et al., 2007; Roelen et al., 2008), and with prolonged constrained standing work (Nelson-Wong & Callaghan, 2010). Consistent with previous research this study reports increase in mean musculoskeletal discomfort for lower body in the STA condition.

To provide adequate context of the results, the following strengths of this study need to be discussed. First, experiments were performed in a controlled, office-like laboratory environment with Ps performing short-duration transcription tasks. Second, while previous studies compared productivity and musculoskeletal discomfort between sit-only and sit-stand work, this is one of the first studies to independently compare productivity and musculoskeletal discomfort between SIT and STA work conditions. Third, productivity and musculoskeletal discomfort have been analyzed both in terms of both overall scores, as well as across 15-minute intervals. This enables for analysis of overall trends and a temporal perspective on how productivity and musculoskeletal discomfort are impacted by the work condition. Fourth, the method of analysis adopted enabled short-duration transcription productivity to be studied in terms of both speed and accuracy. Similarly, perceived musculoskeletal discomfort was analyzed both in terms of individual body region and whole-body scores. The fine-grained analyses suggest that accuracy in short-duration transcription tasks is impacted by work condition, and there is an interaction between work condition and body region for perceived musculoskeletal discomfort.

On the other hand, these strengths incorporate some limitations as well. First, the evaluations were based on short-duration transcription tasks performed for 15-minute durations. This short duration may not offer ecologically valid results for transcription task productivity generalizable across a workday. Second, the repeated measures design may have led to carry-over effects between treatments. Third, the choice of Ps and small sample size (n = 12) may reduce the external validity of results. Ps were male, relatively young (mean age 27.6), lean (mean BMI 23.4) and physically fit (reported on an average of 45-minute exercise / week). Generalizing these results to the office-worker population may be limited as productivity and musculoskeletal discomfort are affected by gender, age and fitness levels. Fourth, a majority of Ps were non-touch typists (n = 9), and the remaining were touch typists (n = 3); different typing styles may have impacted objective productivity and perceived musculoskeletal discomfort.

3.6. Conclusion

In conclusion, while seated work for extended periods of time is acknowledged to be a health hazard, alternatives to the sit-only paradigm of office work are not necessarily benign. Alternating between seated and standing work in the office is a viable and increasingly popular option, however there is scant data regarding the implications of these two work conditions on objective productivity and perceived musculoskeletal discomfort.

This research reports on a preliminary study comparing short-duration transcription task productivity and perceived musculoskeletal discomfort between seated and standing work. Results suggest that for short-duration computer transcription tasks, standing work provides for more accurate transcription without reduction in transcription speed. Additionally, while overall musculoskeletal discomfort is similar across the two work conditions, there is an interaction of work condition and body region for perceived musculoskeletal discomfort. Findings from this study should inform the next stage of empirical research investigating interrelationships between work condition, productivity and musculoskeletal discomfort.

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CHAPTER 4

THE IMPACT OF A SIT-STAND-WALK INTERVENTION ON MUSCULOSKELETAL DISCOMFORT, PHYSICAL & MENTAL FATIGUE, & PRODUCTIVITY FOR SHORT-DURATION, COMPUTER-BASED WORK.

4.1. Abstract

This study explored the potential of a sit-stand-walk intervention to reduce musculoskeletal discomfort, attenuate physical and mental fatigue, and increase physical activity without adversely affecting productivity in short-duration computer-based work. A between-subjects research design was used with 80 participants in Ahmedabad, India. Participants performed a two 30--minute typing transcription tasks after being randomly assigned to one of five work conditions: sit-stand, stand-sit, sitting, standing and sit–stand-walk. Variables measured included: musculoskeletal discomfort, physical and mental fatigue reported using visual analog scales; productivity operationalized by typing speed and tying error. The sit-stand-walk work condition was associated with significant reductions in: musculoskeletal discomfort compared to sitting and standing work, and physical fatigue compared to standing work. The sit-stand-walk intervention had no effect on mental fatigue and productivity. By combining postural variability with active breaks in short-duration computer-based work, the sit-stand-walk intervention demonstrates a beneficial alternative to sedentary computer-based work.

4.2. Introduction

Over the past 50 years, there has been a significant increase in the number of sedentary, desk-based occupations due to the advent of computer-based technologies in the workplace (Owen et al., 2010; Hedge & Ray, 2004). There is a growing body of evidence to suggest that increase in sedentary behaviors and physical inactivity is a public health risk (de Rezende et al., 2014; Dunstan et al., 2012). Sedentary behaviors have been associated with elevated risks for cardio-vascular disease, obesity, weight gain, type-2 diabetes, some forms of cancer, and premature mortality (Chau et al., 2013; Katzmarzyk et al., 2009). In addition to these deleterious health impacts, computer-based office work has long been linked to musculoskeletal disorders of the upper body (Rempel et al., 2006; Punnett & Bergqvist, 1997). From an employers' perspective, the increase in occupational sedentarism has been associated with absenteeism, presentism, reduced quality and quantity of work, short-term disability, work impairment and additional healthcare costs (Pronk & Kottke, 2009). The economic burden of sedentary behaviors and physical inactivity have recently been quantified; globally, direct costs were conservatively estimated to be $53.8 billion in 2013, with additional indirect costs estimated to be $13.7 billion (Ding et al., 2016).

Given that many working adults are engaged in occupations that require prolonged sitting, it is estimated that workplace sitting is the largest contributor to increase in sedentary behaviors. Time use data from Australia, the Netherlands, the U.S. and the U.K. indicate that working adults spend between 6.2 ~ 9.6 hours/day in sedentary behaviors, much of which involves sitting at work (Van Uffelen et al., 2010; Tudor-Locke et al., 2011; Clemes et al., 2014). Trends suggest that sedentary behaviors and physical inactivity will increase significantly in the next 20 years, not only in the developed countries such as the U.S. and the

U.K., but also in countries with large and growing working age populations, such as China and India (Ng & Popkin, 2012).

Given the prevalence of occupational sitting and deleterious health impacts associated with increased sedentary work, guidelines have been formulated to reduce sitting and increase physical activity in the workplace. These recommendations suggest that office workers break-up long durations of sitting-time with bouts of standing and light-intensity physical activity (Buckley et al., 2015; Haskell et al., 2007). Ergonomic research has focused on workplace interventions to reduce sitting and increase physical activity, with potential improvements in health, reduction in absenteeism and sick leave, and without negative impacts on productivity in computer-based work (Pronk & Kottke, 2009).

Recent studies have reported on the feasibility of reducing occupational sedentary behavior by adoption of workstation alternatives to the traditional sedentary, desk-based paradigm of office work (Tudor-Locke et al., 2014). The most prominent of these alternatives are the sit-stand workstations (SSWs) that feature variable-height work surfaces, enabling workers to alternate between sitting and standing work. Reviews of SSWs for office work indicate beneficial reductions in sitting time, musculoskeletal discomfort, fatigue, and low back pain, without negative effects on productivity (Agarwal et al., 2018; Karakolis & Callaghan, 2014). The use of SSWs combined with short bouts of standing have been associated with improved cardio-metabolic health markers (Healy et al., 2015). However, there is no consensus on what constitutes an optimal sit-to-stand ratio, physical activity is not significantly higher compared to sitting work, and the potential role of gender as a moderator between the sit-stand work condition and dependent variables has not been investigated.

In recent years there has been a trend towards the use of standing desks as an alternative to the sedentary, desk-based paradigm of office work. Standing-desk based office work has been associated with a small increase in energy expenditure, and potential improvements in cognitive performance (Isip, 2014; Grunseit et al. 2013). However, prolonged occupational standing has long been known to be associated with negative health dependents such as lower back and leg pain, cardio-vascular problems, physical fatigue and musculoskeletal discomfort (Baker et al., 2018; Waters & Dick, 2015). At present, there is a dearth of studies that compare musculoskeletal discomfort, fatigue, and productivity in office work between sitting, sit-stand, and standing work. In addition, researchers have not investigated the potential role of gender as a moderator between the work condition and dependent variables for standing-desk based office work.

Another approach to reduce the deleterious health impacts associated with occupational sitting involves changes in the temporal pattern of computer-based office work through the introduction of micro breaks. The use of micro breaks – usually short, rest breaks of 30 ~180 seconds duration, at 10 ~ 20 minutes intervals - can reduce musculoskeletal discomfort, attenuate fatigue, and improve productivity at work (McLean et al., 2001; Galinsky et al., 2000; Henning et al., 1994; Henning et al., 1989; Murrell, 1971). Similarly, use of the *Pomodoro Technique* – taking rest breaks every 25 minutes – suggest improvements in productivity (Cirillo, 2006). Recent research suggests that active breaks, i.e. micro breaks with light-intensity physical activity – can be particularly effective interventions to reduce musculoskeletal discomfort and pain, and improve cardio-metabolic health (Waongenngarm et al., 2018; Bailey & Locke, 2015). However, there has been an absence of controlled laboratory studies to examine how active breaks in combination with SSWs use impact musculoskeletal discomfort, fatigue and productivity in computer-based work.

Given the negative health consequences associated with sedentary, desk-based work, there is a critical need to investigate the efficacy of workstation alternatives that reduce occupational sitting time and increase physical activity. The use of SSWs in office work shows evidence of attenuating musculoskeletal discomfort and fatigue, without negatively impacting productivity. However, physical activity levels are not significantly higher compared to sitting work (Karakolis & Callaghan, 2014). The use of standing desks is associated with a moderate increase in physical activity and potential improvements in productivity. However, the negative health impacts of prolonged standing such as lower back and leg pain, cardio-vascular problems, musculoskeletal discomfort and fatigue are well established. The adoption of active breaks in data entry work has demonstrated reductions in musculoskeletal discomfort and fatigue, without negatively impacting productivity. However, there is an absence of studies combining postural variability enabled by SSWs along with light-intensity physical activity afforded by active breaks. Also, studies involving the use of SSWs, standing desks, or active breaks for computer-based office tasks have not considered the potential of gender as a moderator between the intervention and dependent variables.

Therefore, the aim of this study was to evaluate effects of two independent variables – work condition and participant gender, on four dependent variables – musculoskeletal discomfort, physical fatigue, mental fatigue, and productivity, for a short-duration computer-based task in a controlled laboratory environment. Participants (Ps) from the working age population were randomly assigned to one of five work conditions – Sit-Stand, Stand-Sit, Sitting, Standing, and Sit-Stand-Walk described in detail in the following section.

It was hypothesized that:

(H1) There would be an interaction of gender and work condition on dependent variables.

(H2) There would be a main effect of gender on dependent variables.

(H3) There would be a main effect of work condition on dependent variables.

4.3. Methods

4.3.1. Participants. The study was conducted with a convenience sample of 80 young adults (40 males and 40 females), recruited by email circulated among students in an educational institution in Ahmedabad, India. Inclusion criteria was: at least 18 years old, prior experience with computer typing in English, and no chronic musculoskeletal health complaints. Demographic data including computer usage, physical activity, and daily sitting duration were self-reported (Table 4.1). All participants (Ps) were right-handed, non-native English speakers, and none of them had prior experience of using a SSW at work. The study protocol was approved by the Cornell University Institutional Review Board for Human Subjects Research. Ps signed an informed consent document and were compensated for their participation (Appendix B).

Criteria	**Mean**	**(Std. Dev)**
Age (years)	26.04	(8.61)
Weight (kg)	63.05	(12.80)
Height (m)	1.67	(0.08)
Body Mass Index (kg/m^2)	22.53	(4.13)
Computer Use (years)	11.33	(4.70)
Weekly Computer Work (hours/week)	41.47	(16.50)
Daily Occupational Sitting (hours/day)	7.22	(2.49)
Physical Exercise Frequency (# times/week)	3.78	(2.28)
Physical Exercise Duration (minute)	44.75	(22.38)

Sample size (n = 80), Female = 40; Male = 40

Table 4.1. Participant Demographics

4.3.2. Experimental Design. The between-subjects experiment was conducted in a laboratory that simulated an office environment. Ps were randomly assigned to one of five work conditions: Sit-Stand, Stand-Sit, Sitting, Standing and Sit-Stand-Walk (Figure 4.1). Upon obtaining informed consent, Ps familiarized with the experimental protocol and practiced computer-based transcription tasks in sitting and standing work postures for a total of 10 minutes. Following this, each P performed two, 30-minute computer-based transcription tasks with a 5-minute break in between. Ps were seated during the 5-minute break. The work condition and gender were independent variables; dependent variables were musculoskeletal discomfort, physical fatigue, mental fatigue, and productivity operationalized by typing speed and typing errors. An equal number of Ps were allocated to each work condition (n = 16). To account for the time-of-day effects, Ps were assigned to one of the three time slots: 9 am ~ 11 am, 12 pm ~ 2 pm, and 3 pm ~ 5 pm. The study was conducted over a period of two months from June to July.

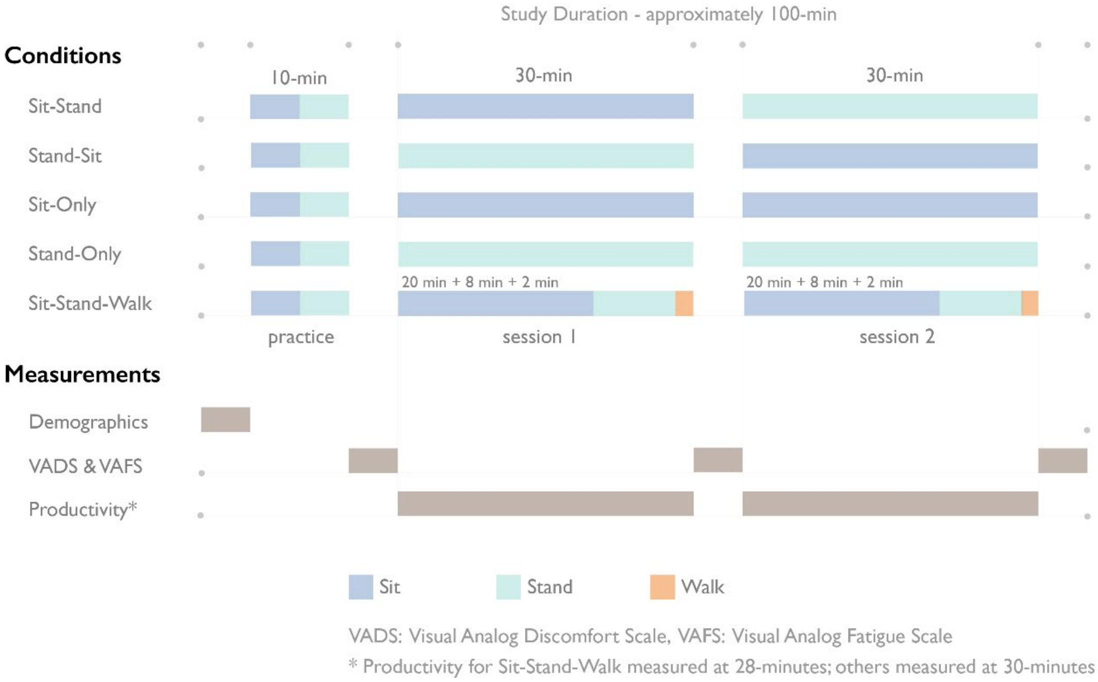

Figure 4.1. Experimental Protocol

Figure 4.2. Participant in Seated and Standing Work Postures

4.3.3. Apparatus. A 24-inch computer screen (Dell 2414 H) connected to a laptop (Lenovo ThinkPad T420), a wired keyboard (Dell Sk-8120 USB 104-key) and a wired mouse (Dell MS111 USB Scroll 3-button) were the computer peripherals used. A sit-stand workstation (Float, Humanscale, USA) capable of varying work-surface height from 70 ~ 120 cm, and a height-adjustable task chair with armrests removed (Toro 5001, HOF Furniture Systems, India) were used. The heights for the work surface, computer screen and chair were adjusted for each P, based on the standard reference postures for sitting and standing work in ANSI/HFES 100-2007 (HFES, 2007). The computer screen was placed on a 20-cm raised block, to account for the variability in eye-height between the sitting and standing work postures. Illumination levels were maintained at 450 lux measured at top of the keyboard in the sitting condition; ambient air temperature was between 30°C ~ 35°C, and relative humidity was between 55% ~ 65%. A pedestal fan (Supreme, Orient Electric, India) located 1.50 m to the right of the sit-stand workstation provided air cooling (Figure 4.2).

4.3.4. Tasks and Assessments. The computer-based transcription task required Ps to copy text from a window in left-half of the screen to the right-half of the screen using MS Word. The transcription texts were based on news articles in English that were at least five years old, with Flesch Kincaid Grade Level of 9.6 ± 0.50, and average syllables per word of 1.56 ± 0.06. The sequence of the texts was randomized to compensate for any order effects. To measure typing error, the Spell-Check and Auto-Correct features in MS Word were disabled; Ps received no productivity guidelines but they were instructed to type at their normal speed.

Musculoskeletal discomfort was operationalized using a 15-item Visual Analog Musculoskeletal Discomfort Scale adapted from the Standard Nordic questionnaire for musculoskeletal symptoms (Kuorinka et al., 1987). Each item corresponded to a region of the body indicated on a body-part diagram divided into 15 regions (neck, upper back, lower back, left and right sides of shoulder, forearm, wrist, thigh, knee, lower leg). Each item asked Ps to place an “X” representing how much musculoskeletal discomfort they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing “no musculoskeletal discomfort” to 100 mm representing “extreme musculoskeletal discomfort”). Physical and mental fatigue were each operationalized using a single item Visual Analog Fatigue Scale. Each item asked Ps to place an “X” representing how much fatigue they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing “no fatigue” to 100 mm representing “extreme fatigue”) (Appendix D). Typing task productivity was operationalized by typing speed (in characters/minute), and typing errors (as a percentage) calculated by comparing the original and transcribed documents for removals and additions, post-experiment.

4.3.5. Procedure. Prior to starting the experiment, Ps signed an informed consent document and filled a paper-based survey to document their demographic characteristics including computer usage, physical activity, and daily sitting duration (Appendix C). Following this, Ps familiarized with the experimental protocol and practiced computer-based English language transcription tasks for 10-minutes; 5-minutes in the sitting work condition, followed by 5-minutes in the standing work condition. Next, a paper-based survey was administered to document their baseline scores for musculoskeletal discomfort, physical fatigue and mental fatigue. Ps were then instructed to perform two English language transcription tasks of 30-minutes duration each, after being randomly assigned to one of five work conditions.

These five work conditions were – 1. Sit-Stand: sitting for 30-minutes followed by standing for 30-minutes; 2. Stand-Sit: standing for 30-minutes followed by sitting for 30-minutes; 3. Sitting: sitting for two successive sessions of 30-minutes each; 4. Standing: standing for two successive sessions of 30-minutes each; and 5. Sit-Stand-Walk: two 30-

minute sessions each that comprised of sitting for 20-minutes, standing for 8-minutes, followed by a 2-minute walk.

Ps were instructed to walk in a corridor 20 m in length, adjacent to the workstation and were timed using a stopwatch. In the Sit-Stand-Walk work condition total time for transcription was 28-minutes instead of 30-minutes for the other four conditions. Ps received no productivity guidelines for the transcription task but were instructed to type in their normal speed. A 5-minute break was provided in between the two 30-minute transcription tasks; participants were seated during the break. Musculoskeletal discomfort, physical fatigue and mental fatigue scores were recorded using paper-based surveys at 2 instances – at the baseline ($t = 0$ min), and at the end of experiment ($t = 65$ min). Typing speed and typing errors were calculated by the researcher, post-experiment. For each P, the complete experimental protocol, including preparatory activities, practice sessions, transcription tasks, rest-breaks, and filling out the surveys, took approximately 100-minutes.

4.3.6. Data Analysis. The raw data was tabulated in MS Excel and statistical analyses performed using Statistical Package for Social Sciences (SPSS) version 25.0. Typing speed was calculated in characters/minute, and typing error calculated as a percentage of total characters typed; for musculoskeletal discomfort, physical fatigue and mental fatigue, difference of scores between baseline ($t = 0$ min) and at end of the experiment ($t = 65$ min) was calculated. To analyze results from this between-subjects study, a two-way MANOVA was run with two independent variables – gender and work condition, and five dependent variables – musculoskeletal discomfort, physical fatigue, mental fatigue, typing speed and typing error. Following up on the significant main effect on dependent variables, a two-way univariate ANOVA was conducted. To further investigate main effects on individual dependent variables a post-hoc analysis with Bonferonni correction was conducted. For all statistical tests, significance was set at $p < 0.05$.

4.4. Results

4.4.1. MANOVA. To analyze the results of this between-subjects factorial study, the researcher conducted a two-way MANOVA. Because the assumption of homogeneity of covariance matrices was violated, as assessed by Box's M test ($p = 0.007$), results of the MANOVA are reported using Pillai's trace (Table 4.2). The interaction effect between gender and work condition on the combined dependent variables was not statistically significant, F (20, 276) = 0.599, $p = 0.912$, Pillai's Trace = 0.166, partial η2 = 0.042. Results do not indicate that gender moderates the relationship between work condition and dependent variables.

Effect	Pillai's Trace	F - value	Hypothesis df	Error df	Significance	Partial Eta.Sq
Intercept	0.985	888.439[b]	5.000	66.000	0.000	0.985
Work Condition	**0.475**	**1.858**	**20.000**	**276.000**	**0.015**	**0.119**
Gender	0.101	1.480[b]	5.000	66.000	0.208	0.101
Work Condition * Gender	0.166	0.599	20.000	276.000	0.912	0.042

a. Design: Intercept + Work Condition + Gender + Work Condition * Gender
b. Exact statistic

Table 4.2: Results of the MANOVA

The main effect of gender on combined dependent variables was not statistically significant, F (5, 66) = 1.480, $p = 0.208$, Pillai's Trace = 0.101, partial η2 = 0.101. Results do not indicate that Ps' gender had an impact on the combined dependent variables. There was a statistically significant main effect of work condition on the combined dependent variables, F (20, 276) = 1.858, $p = 0.015$, Pillai's Trace = 0.475, partial η2 = 0.119. Results indicate that Ps' work condition had an impact on the combined dependent variables.

Source	Type III Sum of Sq.	df	Mean Sq.	F-value	Significance	Partial Eta.Sq
Discomfort	**2663.838**	**4**	**655.959**	**5.645**	**0.001**	**0.244**
Physical Fatigue	**12348.135**	**4**	**3087.034**	**5.222**	**0.001**	**0.230**
Mental Fatigue	4403.538	4	1100.885	1.881	0.123	0..097
Typing Speed	5269.545	4	1317.386	1.256	0.296	0.067
Typing Error	2.600	4	0.650	0.441	0.778	0.025

Table 4.3: Results of the 2-Way ANOVA

Dependent Variable			Mean Diff.	Std. Error	Sig. [b]	95% C.I. for Difference [b]	
						Lower	Upper
Discomfort	Sit-Stand-Walk	Sit-Stand	-130.729	48.000	0.078	-268.868	7.409
		Stand-Sit	-105.396	48.000	0.307	-243.534	32.743
		Sitting	-114.915	47.635	0.179	-252.003	22.172
		Standing	**-149.249 ***	**47.635**	**0.023**	**-28.6.337**	**-12.161**
Physical Fatigue	Sit-Stand-Walk	**Sit-Stand**	**-22.271***	**5.655**	**0.002**	**-38.545**	**-5.997**
		Stand-Sit	**-17.375***	**5.655**	**0.028**	**-33.649**	**-1.101**
		Sitting	**-20.663***	**5.612**	**0.004**	**-36.813**	**-4.513**
		Standing	**-18.335***	**5.612**	**0.012**	**-34.985**	**-2.684**
Mental Fatigue	Sit-Stand-Walk	Sit-Stand	-14.938	6.227	0.185	-32.858	2.983
		Stand-Sit	**-19.396***	**6.227**	**0.025**	**-37.316**	**-1.476**
		Sitting	**-25.774***	**6.179**	**0.001**	**-43.558**	**-7.990**
		Standing	-13.158	6.179	0.360	-30.942	4.626
Typing Speed	Sit-Stand-Walk	Sit-Stand	18.968	21.619	1.000	-43.249	81.185
		Stand-Sit	-4.395	21.619	1.000	-66.613	57.822
		Sitting	-16.596	21.455	1.000	-78.340	45.148
		Standing	-5.591	21.455	1.000	-67.335	56.154
Typing Error	Sit-Stand-Walk	Sit-Stand	0.313	0.453	1.000	-0.990	1.617
		Stand-Sit	0.451	0.453	1.000	-0.853	1.755
		Sitting	0.585	0.450	1.000	-0.709	1.878
		Standing	0.455	0.450	1.000	-0.838	1.749

Based on estimated marginal means
*. The mean difference is significant at the **p = 0.05** level.
b. Adjustment for multiple comparisons: Bonferroni.

Table 4.4: Results of the Pairwise Comparisons

Following up on the significant main effect of work condition on the combined dependent variables, a two-way univariate ANOVA was conducted (Table 4.3). There was a statistically significant main effect of the work condition on musculoskeletal discomfort, F (4, 70) = 5.645, $p = 0.001$, partial η2 = 0.244, and on physical fatigue, F (4, 70) = 5.222, $p = 0.001$, partial η2 = 0.230. However, there was no significant main effect of work condition on mental fatigue, F (4, 70) = 1.881, $p = 0.123$, partial η2 = 0.097; on typing speed, F (4, 70) = 1.256, $p = 0.296$, partial η2 = 0.067; and on typing error, F (4, 70) = 0.441, $p = 0.778$, partial η2 = 0.025. To further investigate the main effects of the specific work condition, the researcher ran a post-hoc analysis with Bonferonni correction (Table 4.4).

4.4.2. Musculoskeletal discomfort. When compared to the baseline, Ps in the Sit-Stand-Walk work condition reported a reduction in mean musculoskeletal discomfort of -2.59 ± 2.71 (95% CI, -8.00 to 2.82). In contrast, Ps in the Sit-Stand,

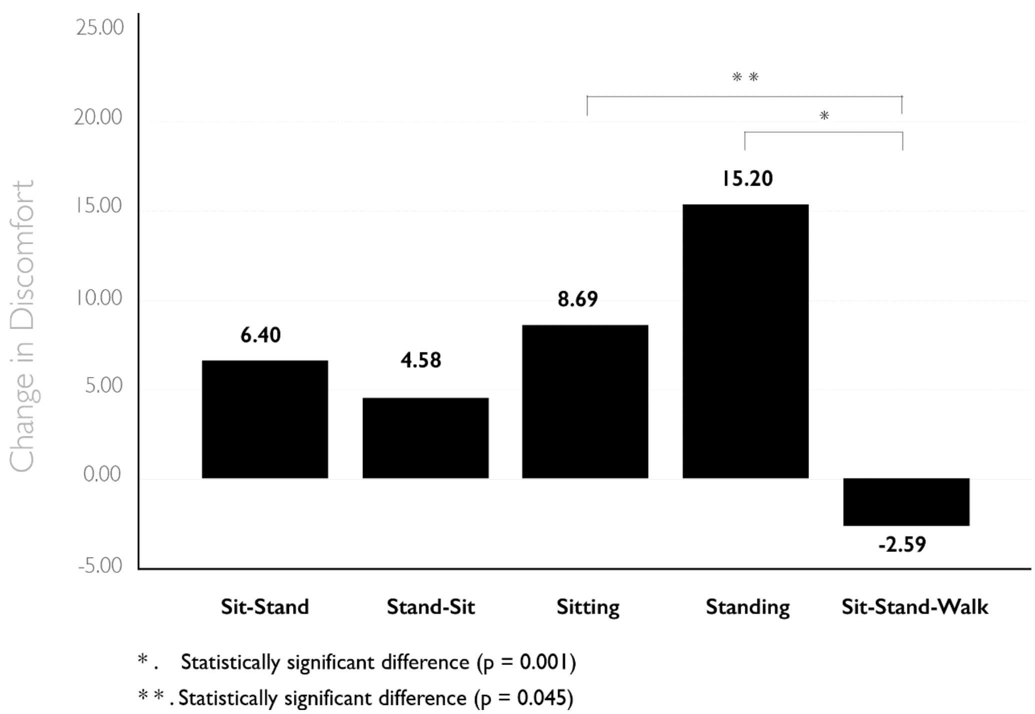

Figure 4.3. Change in Musculoskeletal Discomfort

Stand-Sit, Sitting, and Standing work conditions reported increases in mean musculoskeletal discomfort compared to the baseline. Pairwise comparisons revealed that mean musculoskeletal discomfort for the Sit-Stand-Walk work condition was significantly lower compared to the Sitting work condition, a statistically significant mean difference of -11.28 ± 3.84 (95% CI, -22.41 to -0.15), $p = 0.045$. Similarly, mean musculoskeletal discomfort for the Sit-Stand-Walk work condition was significantly lower compared to the Standing work condition, a statistically significant difference of -17.78 ± 3.84 (95% CI, -28.92 to -6.66), $p > 0.001$. Results suggest that the Sit-Stand-Walk work condition is associated with significantly lower mean musculoskeletal discomfort when compared to the Sitting and Standing work conditions, respectively (Figure 4.3).

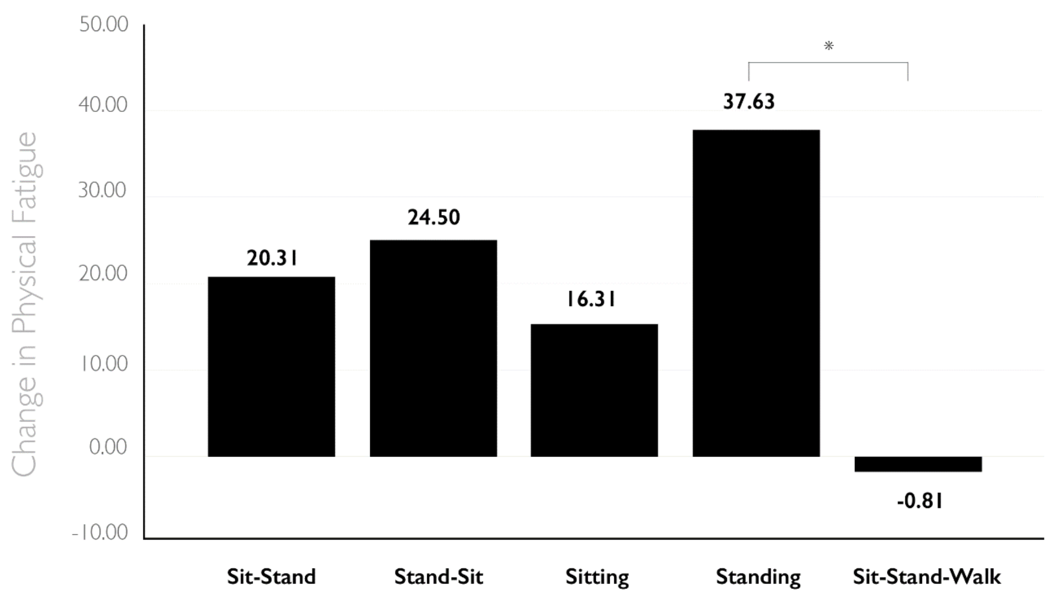

Figure 4.4. Change in Physical Fatigue

4.4.3. Physical Fatigue. When compared to baseline, Ps in the Sit-Stand-Walk work condition reported reduction in mean physical fatigue of -0.81 ± 6.07 (95% CI, -

12.94 to 11.31). In contrast, Ps in the other four work conditions reported increase in mean physical fatigue, when compared to baseline (Table 4.5). Pairwise comparisons revealed that mean physical fatigue for the Sit-Stand-Walk work condition was significantly lower compared to the Standing work condition, a statistically significant mean difference of -38.44 ± 8.59 (95% CI, -63.35 to –13.52), $p > 0.001$. Results suggest that the Sit-Stand-Walk work condition is associated with significantly lower mean physical fatigue when compared to the Standing work condition (Figure 4.4).

4.4.4. Mental Fatigue. When compared to baseline, Ps in the Sit-Stand-Walk work condition reported mean increase in mental fatigue of 5.25 ± 6.04 (95% CI, -6.81 to 17.31). In contrast, Ps in the other four work conditions reported increases of a larger magnitude in mean mental fatigue, when compared to baseline scores (Table 4.5). Pairwise comparisons revealed no significant difference in mean mental fatigue for the Sit-Stand-Walk work condition compared to the other four work conditions. Results suggest that mental fatigue is not impacted by the work condition (Figure 4.5).

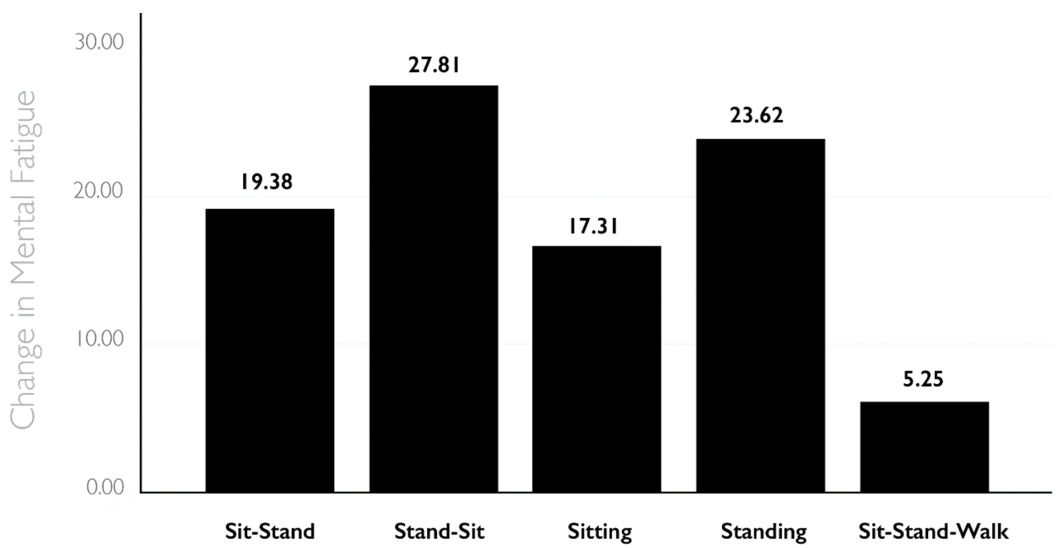

Figure 4.5. Change in Mental Fatigue

Dependent Variable		Mean	Std. Error	95% Confidence interval	
				Lower	Upper
Musculoskeletal Discomfort	Sit-Stand	6.396	2.715	0.980	11.812
	Stand-Sit	4.590	2.804	-1.003	10.183
	Sitting	8.688	2.715	3.272	14.103
	Standing	15.196	2.715	9.780	20.612
	Sit-Stand-Walk	-2.592	2.715	-8.007	2.824
Physical Fatigue	Sit-Stand	20.313	6.078	8.189	32.436
	Stand-Sit	24.100	6.278	11.579	36.621
	Sitting	16.313	6.078	4.189	28.436
	Standing	37.625	6.078	25.502	49.748
	Sit-Stand-Walk	-0.812	6.078	-12.936	11.311
Mental Fatigue	Sit-Stand	19.375	6.048	7.313	31.437
	Stand-Sit	27.217	6.246	14.760	39.674
	Sitting	17.313	6.048	5.251	29.374
	Standing	23.625	6.048	11.563	35.687
	Sit-Stand-Walk	5.250	6.048	-6.812	17.312
Typing Speed	Sit-Stand	121.329	8.097	105.180	137.478
	Stand-Sit	129.567	8.363	112.888	146.246
	Sitting	130.572	8.097	114.423	146.721
	Standing	112.459	8.097	96.310	128.609
	Sit-Stand-Walk	111.207	8.097	95.058	127.356
Typing Error	Sit-Stand	4.247	0.303	3.641	4.852
	Stand-Sit	4.236	0.313	3.611	4.861
	Sitting	4.434	0.303	3.828	5.039
	Standing	4.693	0.303	4.088	5.298
	Sit-Stand-Walk	4.588	0.303	3.983	5.194

Table 4.5. Marginal Means for Dependent Variables

4.4.5. Productivity. Transcription task productivity was operationalized by typing speed measured in characters/minute, and typing error measured as a percentage. Ps in the Sit-Stand-Walk work condition had a mean typing speed of

111.27 ± 8.09 (95% CI, 95.06 to 127.36). Pairwise comparisons revealed no statistically significant difference in mean typing speeds for the Sit-Stand-Walk work condition compared to the other four work conditions.

Results suggest that typing speed is not impacted by work condition. Ps in the Sit-Stand-Walk work had a mean typing error of 4.58 ± 0.03 (95% CI, 3.98 to 5.19). Pairwise comparisons revealed no statistically significant difference in typing error for the Sit-Stand-Walk work condition compared to the other four work conditions. Results suggest that typing error is not impacted by work condition. Results of typing speed and typing error, considered in totality indicate that task productivity was not impacted by the work condition.

4.5. Discussion

4.5.1 Hypothesis 1. The results of the study do not confirm H1, i.e. there was no interaction between gender and work condition on the combined dependent variables. Results indicate that gender did not moderate the relationship between the work condition and combined dependent variables. Only one previous SSW intervention by Karakolis et al. (2016) reported an interaction of gender with workstation type - females experienced higher musculoskeletal discomfort during prolonged sitting, while males experienced higher musculoskeletal discomfort during prolonged standing. The present study used a between-subjects research design with a 1:1 sit-to-stand ratio for the SSW intervention, while Karakolis and colleagues (2016) used a repeated-measures research design with a 3:1 sit-to-stand ratio for the SSW intervention. The differences in sit-stand ratios and the research designs prevent a clear conclusion to be drawn. It may be possible that longer task durations could provide evidence for the moderating influence of gender.

4.5.2. Hypothesis 2. The results of the study do not confirm H2, i.e. there was no main effect of gender on the combined dependent variables. Ps' gender did not impact their scores for musculoskeletal discomfort, physical fatigue, mental fatigue, and task productivity. Previous studies on computer work suggest that female workers are at higher risk of musculoskeletal disorders, with reports of higher neck and upper extremity symptoms when compared to male workers (Wahlstörm, 2005; Ekman et al., 2000). In the present study, with 40 male and 40 female Ps randomly assigned to one of the five work conditions, there was no evidence for a main effect of gender on the combined dependent variables. It may be possible that the short-duration transcription task was not sensitive enough to provide evidence for the potential main effect of gender on the dependent variables.

4.5.3. Hypothesis 3. The results of the study do confirm H3, i.e. there was a main effect of work condition on the combined dependent variables. Ps' work condition significantly impacted their musculoskeletal discomfort ($p = 0.023$). Pairwise comparisons revealed that mean musculoskeletal discomfort for the Sit-Stand-Walk work condition was significantly lower compared to the Sitting ($p = 0.045$), and the Standing ($p > 0.001$) work conditions, respectively. Previous research suggest that use of SSWs is associated with reductions in musculoskeletal discomfort and low back pain (Davis & Kotowski, 2014; Karakolis & Callaghan, 2014; Karol & Robertson, 2015; Agarwal et al., 2018), while active breaks have also been associated with reductions in musculoskeletal discomfort and pain (Waongenngarm et al., 2018). In accordance with previous research, results from this study suggest that the adoption of a sit-stand-walk intervention – combining sit-stand work with active breaks – can significantly reduce musculoskeletal discomfort.

Ps' work condition significantly impacted their physical fatigue ($p = 0.001$). Pairwise comparisons revealed that mean physical fatigue for the Sit-Stand-Walk work condition was significantly lower compared to the Standing work condition ($p < 0.001$). Previous studies of sit-stand office work have indicated reduced fatigue for the SSW intervention (Thorp et al., 2014; Hasegawa et al., 2001; Paul, 1995), while the adoption of micro breaks for data entry work have also been associated with reduction of fatigue (McLean et al., 2001; Henning et al., 1989). In accordance with previous research, results of this study suggest that adoption of a sit-stand-walk intervention – combining sit-stand work with active breaks – can significantly reduce physical fatigue.

Ps' work condition did not impact their mental fatigue ($p = 0.123$). On average, mental fatigue for the Sit-Stand-Walk work condition was not significantly different in comparison to the Sit-Stand, Stand-Sit, Sitting and Standing work conditions, respectively. As there are no previous studies of sit-stand work reporting on mental fatigue, findings from the current study have to be considered independently.

Ps' work condition did not impact their typing speed ($p = 0.296$) and typing error ($p = 0.778$). On average, typing speed and typing error for the Sit-Stand-Walk work condition was not significantly different in comparison to the Sit-Stand, Stand-Sit, Sitting and Standing work conditions, respectively. Reviews of sit-stand office work indicate no adverse impact of productivity in the use of SSWs (Karol & Robertson, 2015; Karakolis & Callaghan, 2014), and active breaks do not reduce productivity in office work (Waongenngarm et al., 2018). In accordance with previous research, results of this study suggest that adoption of a sit-stand-walk intervention – combining sit-stand work with active breaks – does not impair productivity.

4.5.4. Strengths. To provide adequate context of the results, the following strengths of this study need to be discussed. First, experiments were conducted in a controlled laboratory that simulated an office work environment. Second, this is one of the few studies that compared musculoskeletal discomfort, physical and mental fatigue, and productivity between sit-stand, sitting and standing work conditions. Third, the study investigated whether the order of the postural change: Sit-Stand or Stand-Sit, impacted the dependent variables. Fourth, the study investigated the possibility of gender as a moderator between the work condition and dependent variables. Fifth, as far as the author is aware, this is potentially the first study to investigate and demonstrate benefits of combining a sit-stand intervention with active breaks for computer-based work. Sixth, the 20:8:2 sit-stand-walk intervention demonstrates a potentially optimal sit-stand ratio for computer-based office work. Seventh, the study was conducted with a robust sample size (n = 80), with an equal number of Ps (n = 16) randomly assigned to one of five work conditions. Finally, this is possibly the first study reporting on use of SSWs with a participant sample from the Indian population - prior studies have been limited to participants from North America, Western Europe, Australia and Japan.

4.5.5 Limitations. On the other hand, these strengths incorporate some limitations as well. First, Ps two, 30-minute sessions with a 5-minute break in the middle. The short-duration transcription task may not offer ecologically valid results for computer-based office tasks generalizable across an 8-hour workday. Second, the short-duration may not be sensitive to provide evidence for gender differences, if any, that may impact the dependent variables. Third, the study used a between-subjects design, with Ps randomly assigned to one of five working conditions. While a between-subjects design avoids carry-over effects associated with within-subjects designs, there may be limitations due to individual variability and assignment bias. Fourth, Ps were a convenience sample of college students who were mostly young, not obese, and exercised frequently. Generalizing results to the office working population may be limited as the dependent variables may be affected by age, obesity and exercise habits. Fifth, Ps had no prior experience in use of SSWs and were provided 10-minutes for familiarization. A longer time frame for Ps to familiarize with the work condition and task may have impacted the dependent variables. Sixth, musculoskeletal discomfort, physical and mental fatigue were self-reported - use of objective measures in combination with self-report could make the research claims more robust. Finally, while the fifth work condition involved a 2-minute active break with a plausible increase in physical activity – there was no objective measure of physical activity to validate this claim.

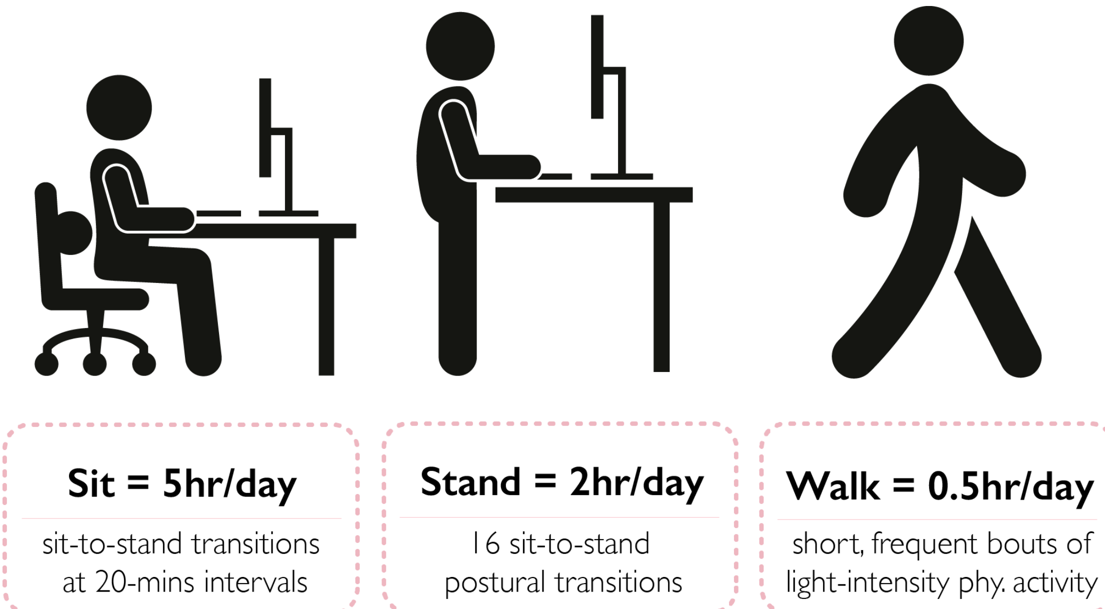

Figure 4.6. Extrapolating the Sit-Stand-Walk Intervention to a Workday

4.5.6. Sit-Stand-Walk Protocol. This study provides evidence for benefits of a sit-stand-walk intervention using a 20:8:2 ratio, for a 60-minute computer transcription task. The 20-minute seated duration is based on public health recommendations to break-up sitting at 20 ~ 30-minute intervals. The 20:8 sit-to-stand ratio is based on prior research that indicates beneficial scores of musculoskeletal discomfort and fatigue for sit-stand ratios between 2:1 and 3:1 (Bao & Lin, 2018; Karakolis & Callaghan, 2014). The 2-minute walk builds on evidence which indicates that active breaks improve cardio-metabolic dependents, and reduce low back pain, fatigue and musculoskeletal discomfort (Waongenngarm et al., 2018; Bailey & Locke, 2015). While findings from this study are limited to a 60-minute task duration, extrapolating the intervention over a 7 ½ hour workday translates to 5 hours of sitting, 2 hours of standing, 30 minutes of walking, and 16 sit-to-stand transitions as gravitational stimuli

(Vernikos & Schneider, 2010) (Figure 4.6). This sit-stand-walk intervention conforms to occupational health recommendation for working adults to break-up long periods of sitting with short bouts of standing, engage in moderate physical activity for 30-minutes/day, and accumulate at least standing for 2 hour/day (Buckley et al., 2015; Haskell et al., 2007). While further research is needed, the sit-stand-walk intervention may provide an optimal approach to realize the dual goals of reduced sitting time and increased physical activity in the workplace.

4.6. Conclusion

This study experimentally validates the benefits of combining sit-stand posture transitions with regularly scheduled active work breaks for computer-based work. Results suggest that the SSWI was associated with significant reductions in - musculoskeletal discomfort compared to sitting and standing work, and physical fatigue compared to the standing work. In addition, this study demonstrates that implementation of the SSWI has no detrimental effect on productivity. Also, the study suggests that participant gender does not moderate the relationship between the work condition and dependent variables. Finally, this work provides evidence for a 20:8:2 sit-stand-walk ratio that combines postural transitions in sit-stand work with short bouts of light-intensity physical activity in active breaks, thereby demonstrating a beneficial and practically viable alternative to the sedentary paradigm of office work. Future work will involve expanding the duration of the experiment to simulate a 7 ½ hour workday. Physical activity will be quantified using objective measures. The study will be replicated in field settings with office workers to investigate if the results from simulated office work translate to the real-world office work environment. Findings from this study will inform the next stage of empirical research investigating the potential of combining postural variability with active breaks to address the challenges of health, well-being and productivity in sedentary office work.

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CHAPTER 5

EFFECTS OF A SIT-STAND-WALK INTERVENTION ON MUSCULOSKELETAL DISCOMFORT, PHYSICAL & MENTAL FATIGUE, & PRODUCTIVITY FOR SHORT-DURATION COMPUTER-BASED WORK

5.1. Abstract

This study explored the potential of a sit-stand-walk intervention to reduce musculoskeletal discomfort, physical and mental fatigue, and increase physical activity without adversely affecting productivity in computer-based work. A between-subjects research design was used with 100 participants in Ithaca, United States. Participants performed two 30-minute typing transcription tasks after being randomly assigned to one of five work conditions: sit-stand, stand-sit, sitting, standing and sit–stand-walk. Variables measured included: musculoskeletal discomfort, physical and mental fatigue reported using visual analog scales; and productivity operationalized by typing speed and typing error. The sit-stand-walk work condition was associated with significant reductions in: musculoskeletal discomfort compared to standing work; physical fatigue compared to all other work; and mental fatigue compared to stand-sit and sitting work. Sit-stand-walk had no effect on productivity. By combining postural variability with active breaks in short-duration computer-based task, sit-stand-walk demonstrates a beneficial alternative to the sedentary paradigm of work.

5.2. Introduction

Over the past 50 years, the advent of computer-based technologies in the workplace has resulted in a significant increase in the number of sedentary, desk-based occupations (Levine, 201; Hedge & Ray, 2004). There is a growing body of evidence to suggest that increase in sedentary behaviors and physical inactivity is a public health hazard (Dunstan et al., 2012; Owen et al., 2010; Hamilton et al., 2008). Sedentary behaviors and physical inactivity have been associated with elevated risks for cardio-vascular disease, obesity, weight gain, type-2 diabetes, some forms of cancer, and premature mortality (de Rezende et al., 2014; Chau et al., 2013; Thorp et al., 2011; Katzmarzyk et al., 2009). In addition to these adverse health impacts, computer-based office work has long been linked to musculoskeletal disorders of the upper body (Rempel et al., 2006; Norman et al., 2004; Luttmann et al., 2003).

From a business perspective, the increase in occupational sedentarism has been associated with absenteeism, presenteeism, reduced quality and quantity of work, short-term disability, work impairment and additional healthcare costs (Pronk & Kottke, 2009). The economic burden of sedentary behaviors and physical inactivity have recently been quantified - globally, the direct costs were conservatively estimated to be $53.8 billion in 2013, with additional indirect costs estimated to be $13.7 billion (Ding et al., 2016).

It is estimated that workplace sitting is the largest contributor to the increase in sedentary behaviors, given that working adults are engaged in a wide range of occupations that require prolonged sitting (Bennie et al., 2015). Time use data from Australia, the Netherlands, the U.S. and the U.K. indicate that working adults spend between 6.2 ~ 9.6 hours/day in sedentary behaviors, much of which involves sitting at work (Clemes et al., 2014; Tudor-Locke et al., 2011; Van Uffelen et al., 2010). Estimates suggest that by 2030, sedentary behaviors in the U.K. and the U.S. will increase to 51 and 42 hours/week, respectively (Ng & Popkin, 2012). Given the prevalence of occupational sitting and negative health impacts associated with increased sedentary work, there have been public health guidelines to reduce occupational sitting and increase physical activity in the workplace. These recommendations suggest that office workers break-up long durations of sitting time with bouts of standing and increase physical movement (Buckley et al., 2015; Haskell et al., 2007). Ergonomics research has focused on workplace interventions that reduce sitting and increase physical activity, with potential improvements in health, reduction in absenteeism and sick leave, without adverse impacts on productivity (Pronk & Kottke, 2009).

Recent studies have reported on the feasibility of reducing the frequency and duration of occupational sitting by the adoption of workstation alternatives to the sedentary, desk-based paradigm of office work (Tudor-Locke et al., 2014). The most prominent of these workstation alternatives are sit-stand workstations (SSWs) that feature variable-height work surfaces, enabling workers to alternate between sitting and standing at work (Davis & Kotowski, 2014). Reviews indicate that the use of SSWs in office work is associated with beneficial reductions in sitting time, musculoskeletal discomfort, fatigue, and low back pain, without negative effects on productivity (Agarwal et al., 2018; Karol & Robertson, 2015; Karakolis & Callaghan, 2014). The use of SSWs with short bouts of standing have been associated with improved cardio-metabolic health markers (Healy et al., 2015). However, there is no consensus on what an optimal sit-to-stand ratio is, physical activity is not significantly higher compared to sitting work, and the potential role of gender as a moderator between the sit-stand work condition and dependent variables has not been investigated.

In recent years there has been a trend towards the use of standing desks as an alternative to the sedentary, desk-based paradigm of office work. Standing-desk based office work has been associated with a small increase in energy expenditure, and potential improvements in cognitive performance (Grunseit et al. 2013). However, prolonged occupational standing has long been known to be associated with deleterious health dependents including lower back and leg pain, cardio-vascular problems, physical fatigue and musculoskeletal discomfort (Baker et al., 2018; Waters & Dick, 2015; Bahk et al., 2012; Krause et al., 2000). At present, there is a dearth of studies that compare musculoskeletal discomfort, fatigue, and productivity in office work between sitting, sit-stand, and standing work conditions. In addition, researchers have not investigated the potential role of gender as a moderator between the work condition and the dependent variables for standing-desk based office work.

Another approach to reduce the negative health impacts associated with occupational sitting involves changes in temporal pattern of computer-based work through introduction of micro breaks. The use of micro breaks – *which are short, rest breaks of 30 ~180 seconds duration, at 10 ~ 20 minutes intervals* - can reduce musculoskeletal discomfort, attenuate fatigue, and improve productivity at work (McLean et al., 2001; Galinsky et al., 2000; Henning et al., 1994; Henning et al., 1989; Murrell, 1971). Similarly, use of the *Pomodoro Technique* – taking rest breaks every 25 minutes – suggest improvements in productivity (Cirillo, 2006). Recent research suggests that active breaks, i.e. micro breaks with low-intensity physical activity such as walking can be particularly effective in reducing musculoskeletal discomfort and pain, increasing cerebral blood flow, and improving cardio metabolic health (Waongenngarm et al., 2018; Carter et al., 2018; Bailey & Locke, 2015). However, there is an absence of controlled laboratory studies to examine how active breaks in combination with SSW use can impact musculoskeletal discomfort, physical fatigue, mental fatigue, and productivity in computer-based work.

Given the negative health consequences associated with sedentary, desk-based work, there is a critical need to investigate efficacy of alternative approaches to reduce occupational sitting time and increase physical activity. The use of SSWs in computer-based work shows evidence of attenuating musculoskeletal discomfort and fatigue, without negatively impacting productivity. However, physical activity levels are not significantly higher compared to sitting work. The use of standing desks is associated with a moderate increase in physical activity and potential improvements in productivity. However, prolonged standing is linked to deleterious health impacts such as lower back and leg pain, cardio-vascular problems, musculoskeletal discomfort and fatigue. The adoption of active breaks in computer-based work has demonstrated reductions in musculoskeletal discomfort and fatigue, without negatively impacting productivity. However, there is an absence of studies combining postural variability enabled by SSWs along with light-intensity physical activity afforded by active breaks. Also, studies involving the use of SSWs, standing desks, or active breaks for computer-based office tasks have not investigated the potential role of gender as a moderator between the intervention and the dependent variables.

Therefore, the aim of this study was to evaluate effects of two independent variables – work condition and participant gender, on four dependent variables – musculoskeletal discomfort, physical fatigue, mental fatigue, and productivity, for a short-duration computer-based office task in a controlled laboratory environment. Participants (Ps) were randomly assigned to one of five work conditions – Sit-Stand, Stand-Sit, Sitting, Standing, and Sit-Stand-Walk described in detail in the following section. It was hypothesized that:

(H1) There would be an interaction of gender and work condition on dependent variables.

(H2) There would be a main effect of participant gender on the dependent variables.

(H3) There would be a main effect of the work condition on the dependent variables.

5.3. Methods

5.3.1. Participants. The study was conducted with a convenience sample of 100 young adults (42 males and 58 females), recruited by email circulated among students in a research university in the northeastern United States. Inclusion criteria was: at least 18 years old, a Body Mass Index (BMI) between 18 ~ 30 kg/m^2, prior experience with computer typing, and no chronic musculoskeletal health complaints. Demographic data including computer usage, physical activity, and daily sitting duration were self-reported (Appendix C) (Table 5.1). The study protocol was approved by the Cornell University Institutional Review Board for Human Subjects Research (Appendix B). Participants (Ps) reviewed and signed an informed consent document in the beginning of the study and were compensated $20 for participation. Majority of Ps were right handed (n = 98), though not by design; none had prior experience of SSWs.

Criteria	**Mean**	**(Std. Dev)**
Age (years)	24.46	(5.19)
Weight (kg)	63.97	(11.31)
Height (m)	1.69	(0.10)
Body Mass Index (kg/m^2)	22.25	(2.75)
Computer Use (years)	13.81	(3.94)
Weekly Computer Work (hours/week)	42.32	(18.62)
Daily Occupational Sitting (hours/day)	6.68	(2.85)
Physical Exercise Frequency (# times/week)	3.61	(1.80)
Physical Exercise Duration (minute)	53.26	(28.38)

Sample size (n = 100), Female = 58; Male = 42

Table 5.1. Participant Demographics

5.3.2. Experimental Design. The between-subjects experiment was conducted in a simulated office environment. Ps were randomly assigned to one of five work conditions: Sit-Stand, Stand-Sit, Sitting, Standing and Sit-Stand-Walk (Figure 5.1). Upon obtaining informed consent, Ps familiarized with the experimental protocol and practiced computer-based transcription tasks in sitting and standing work postures for a total of 10 minutes. Following this, each P performed two, 30-minute computer-based transcription tasks with a 5-minute seated break in between. The work condition and participant gender were the independent variables; dependent variables were musculoskeletal discomfort, physical fatigue, mental fatigue, typing speed and typing errors. The number of Ps allocated to each condition was equal (n = 20). To account for the time-of-day effects, Ps were assigned to one of the three time slots: 9 am ~ 11 am, 12 pm ~ 2 pm, and 3 pm ~ 5 pm. The study was conducted over a period of three months from August to October.

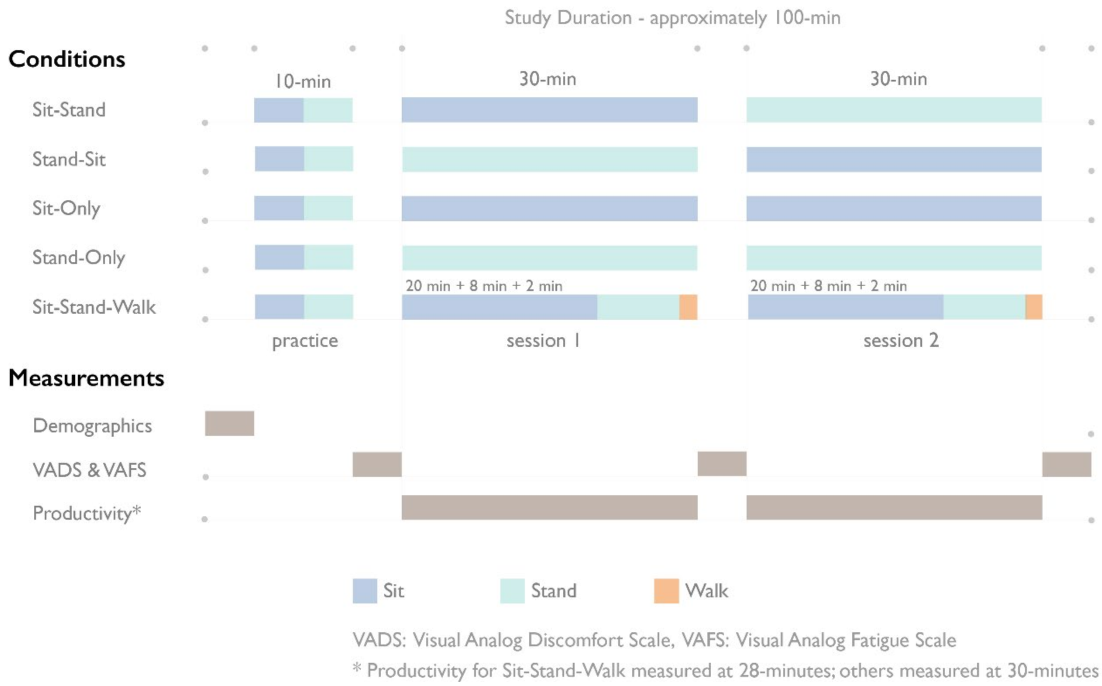

Figure 5.1. Experimental Protocol

5.3.3. Apparatus. A 24-inch computer screen (Dell 2414 H) connected to a laptop (Lenovo ThinkPad T420), a wired keyboard (Dell Sk-8120 USB 104-key) and a wired mouse (Dell MS111 USB Scroll 3-button) were the computer peripherals used. A sit-stand workstation (Float, Humanscale, USA) capable of varying work-surface height from 70 ~ 120 cm and a height-adjustable task chair with arm-rests at the lowest position (Freedom Chair, Humanscale, USA) were used (Figure 5.2). The heights for the work surface, monitor and chair were adjusted for each P, based on the standard reference postures for sitting and standing work in ANSI/HFES 100-2007 (HFES, 2007). The computer screen was placed on a

20-cm raised block, to account for the variability in eye-height between the sitting and standing work postures. Illumination level was maintained at 500 lux measured at the top of the keyboard in the sitting condition, ambient temperature was maintained between 23°C ~ 27°C, and relative humidity was maintained between 45% ~ 50%.

Figure 5.2. Participant in Seated and Standing Work Postures

5.3.4. Tasks and Assessments. The computer-based transcription task required Ps to copy text from a window in left-half of the screen to the right-half of the screen using MS Word. The transcription texts were based on English language news articles that were at least five years old with following readability statistics: Flesch Kincaid Grade Level of 9.6 ± 0.50, and average syllables per word of 1.56 ± 0.06. The sequence of the texts was randomized to compensate for any order effects. To measure typing error, Spell-Check and Auto-Correct features in MS Word were disabled.

Musculoskeletal discomfort was operationalized using a 15-item Visual Analog Musculoskeletal discomfort Scale adapted from the standard Nordic questionnaire for musculoskeletal symptoms (Kuorinka et al., 1987). Each item corresponded to a region of the body indicated on a body-part diagram divided into 15 regions (neck, upper back, lower back, left and right sides of shoulder, forearm, wrist, thigh, knee, lower leg). Each item asked Ps to place an “X” representing how much musculoskeletal discomfort they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing “no musculoskeletal discomfort” to 100 mm representing “extreme musculoskeletal discomfort”).

Physical and mental fatigue were each operationalized using a single item Visual Analog Fatigue Scale. Each item asked Ps to place an “X” representing how much fatigue they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing “no fatigue” to 100 mm representing “extreme fatigue”) (Appendix D). Computer task productivity was operationalized by typing speed (in characters/minute) and typing errors (as a percentage) calculated by comparing the original and transcribed documents for removals and additions, post-experiment.

5.3.5. Procedure. Prior to starting the experiment, Ps signed an informed consent document and filled a paper-based demographic survey. Following this, Ps familiarized with the experimental protocol and practiced computer-based English language transcription tasks for 10-minutes; 5-minutes in the sitting work condition, followed by 5-minutes in the standing work condition. Next, a paper-based survey documented their baseline scores for musculoskeletal discomfort, physical fatigue and mental fatigue. Ps were then instructed to perform two English language transcription tasks of 30-minutes duration each after being randomly assigned to one of five work conditions. These five work conditions were – 1. Sit-Stand: sitting for 30-minutes followed by standing for 30-minutes; 2. Stand-Sit: standing for 30-minutes followed by sitting for 30-minutes; 3. Sitting: sitting for two successive sessions of 30-minutes each; 4. Standing: standing for two successive sessions of 30-minutes each; 5. Sit-Stand-Walk: two successive 30-minute sessions that comprised of sitting for 20-minutes, standing for 8-minutes, followed by a 2-minute walk. Ps were instructed to walk in a designated path adjacent to the workstation and were timed using a stopwatch. In the Sit-Stand-Walk condition total time for transcription was 28-minutes instead of 30-minutes for the other four conditions. Ps received no productivity guidelines for the transcription task but were instructed to type in their normal speed. A 5-minute seated break was provided in between two 30-minute transcription tasks. Musculoskeletal discomfort, physical fatigue and mental fatigue scores were recorded using paper-based surveys at 2 instances – at the baseline (t = 0 min), and at end of the experiment (t = 65 min). For each P, the complete experiment, including preparatory activities, practice sessions, transcription tasks, rest-breaks, and filling out surveys, took approximately 100-minutes.

5.3.6. Data Analysis. The raw data was tabulated in MS Excel and statistical analyses were performed using Statistical Package for Social Sciences (SPSS) version 25.0. Typing speed was calculated as number of characters/minute and typing error was calculated as a percentage of total characters typed; for musculoskeletal discomfort, physical fatigue and mental fatigue, the difference of scores between baseline (t = 0 min) and at end of the experiment (t = 65 min) was calculated. To analyze results from this between-subjects factorial study, a two-way MANOVA was run with two independent variables – gender and work condition, and five dependent variables – change in musculoskeletal discomfort, change in physical fatigue, change in mental fatigue, typing speed and typing errors. Following up on the significant main effect on dependent variables, a two-way univariate ANOVA was conducted. To further investigate main effects on individual dependent variables a Bonferonni post-hoc analysis was conducted. For all statistical tests, significance was set at $p < 0.05$.

5.4. Results

5.4.1. MANOVA. To analyze the results of this between-participants factorial study, the researcher conducted a two-way MANOVA. Because the assumption of homogeneity of covariance matrices was violated, as assessed by Box's M test (*p = 0.007*) results of the MANOVA are reported using Pillai's trace (Table 5.2). The interaction effect between gender and work condition on the combined dependent variables was not statistically significant, F (20, 356) = 1.199, *p* = 0.252, Pillai's Trace = 0.252, partial η2 = 0.063. Results do not indicate that gender moderates the relationship between work condition and dependent variables.

Effect	Pillai's Trace	F - value	Hypothesis df	Error df	Significance	Partial Eta.Sq
Intercept	0.973	623.309[b]	5.000	86.000	0.000	0.973
Work Condition	**0.377**	**1.852**	**20.000**	**356.000**	**0.015**	**0.094**
Gender	0.115	2.241[b]	5.000	86.000	0.057	0.115
Work Condition * Gender	0.252	1.119	20.000	356.000	0.252	0.063

a. Design: Intercept + Work Condition + Gender + Work Condition * Gender
b. Exact statistic

Table 5.2. Results of the MANOVA

The main effect of gender on the combined dependent variables was not statistically significant, F (5, 86) = 2.241, *p = 0.057*, Pillai's Trace = 0.115, partial η2 = 0.115. Results do not indicate that Ps gender had an effect on the combined dependent variables. There was a statistically significant effect of work condition on the combined dependent variables, F (20, 356) = 1.852*, p = .015*, Pillai's Trace = 0.377, partial η2 = 0.094. Results indicate that Ps work condition had an impact on the combined dependent variables.

Source	Type III Sum of Sq.	df	Mean Sq.	F-value	Significance	Partial Eta.Sq
Musculoskeletal Discomfort	**263097.820**	**4**	**65774.455**	**2.974**	**0.023**	**0.117**
Physical Fatigue	**6294.631**	**4**	**1573.658**	**5.126**	**0.001**	**0.186**
Mental Fatigue	**7048.601**	**4**	**1762.150**	**4.734**	**0.002**	**0.174**
Typing Speed	13089.307	4	3272.327	0.729	0.574	0.031
Typing Error	3.866	4	0.967	0.491	0.743	0.021

Table 5.3. Results of the 2-way ANOVA

Dependent Variable			Mean Diff.	Std. Error	Sig. [b]	95% C.I. for Difference [b]	
						Lower	Upper
Discomfort	Sit-Stand-Walk	Sit-Stand	-130.729	48.000	0.078	-268.868	7.409
		Stand-Sit	-105.396	48.000	0.307	-243.534	32.743
		Sitting	-114.915	47.635	0.179	-252.003	22.172
		Standing	**-149.249 ***	**47.635**	**0.023**	**-28.6.337**	**-12.161**
Physical Fatigue	Sit-Stand-Walk	**Sit-Stand**	**-22.271***	**5.655**	**0.002**	**-38.545**	**-5.997**
		Stand-Sit	**-17.375***	**5.655**	**0.028**	**-33.649**	**-1.101**
		Sitting	**-20.663***	**5.612**	**0.004**	**-36.813**	**-4.513**
		Standing	**-18.335***	**5.612**	**0.012**	**-34.985**	**-2.684**
Mental Fatigue	Sit-Stand-Walk	Sit-Stand	-14.938	6.227	0.185	-32.858	2.983
		Stand-Sit	**-19.396***	**6.227**	**0.025**	**-37.316**	**-1.476**
		Sitting	**-25.774***	**6.179**	**0.001**	**-43.558**	**-7.990**
		Standing	-13.158	6.179	0.360	-30.942	4.626
Typing Speed	Sit-Stand-Walk	Sit-Stand	18.968	21.619	1.000	-43.249	81.185
		Stand-Sit	-4.395	21.619	1.000	-66.613	57.822
		Sitting	-16.596	21.455	1.000	-78.340	45.148
		Standing	-5.591	21.455	1.000	-67.335	56.154
Typing Error	Sit-Stand-Walk	Sit-Stand	0.313	0.453	1.000	-0.990	1.617
		Stand-Sit	0.451	0.453	1.000	-0.853	1.755
		Sitting	0.585	0.450	1.000	-0.709	1.878
		Standing	0.455	0.450	1.000	-0.838	1.749

Based on estimated marginal means
*. The mean difference is significant at the **p = 0.05** level.
b. Adjustment for multiple comparisons: Bonferroni.

Table 5.4. Results of the Pairwise Comparisons

Following up on the significant main effect of work condition on dependent variables, a two-way univariate ANOVA was conducted (Table 5.3). There was a statistically significant main effect of work condition on musculoskeletal discomfort, F (4, 90) = 2.974, $p = 0.023$, partial η2 = 0.117; physical fatigue, F (4, 90) = 5.126, $p = 0.001$, partial η2 = 0.186; and mental fatigue, F (4, 90) = 4.734, $p = 0.002$, partial η2 = 0.174. However, there was no main effect of work condition on typing speed, F (4, 90) = 0.729, $p = 0.574$, partial η2 = 0.031; and on typing error, F (4, 90) = 0.491, $p = 0.743$, partial η2 = 0.021. To further investigate the main effects of work condition on the individual dependent variables, the researcher ran a post-hoc analysis with Bonferonni correction (Table 5.4).

5.4.2. Musculoskeletal discomfort. When compared to the baseline, Ps in the Sit-Stand-Walk work condition reported a reduction in mean musculoskeletal discomfort of -49.87 ± 33.94 (95% CI, -117.30 to 17.55). In contrast, Ps in the Sit-Stand, Stand-Sit, Sitting, and Standing work conditions reported increases in mean musculoskeletal discomfort compared to the baseline (Table 5.4). Pairwise comparisons revealed that mean musculoskeletal discomfort for the Sit-Stand-Walk work condition was significantly lower compared to the Standing work condition, a statistically significant mean difference of -149.24 ± 47.63 (95% CI, -286.34 to -12.16), $p = 0.023$. Results suggest that the Sit-Stand-Walk work condition is associated with significantly lower mean musculoskeletal discomfort when compared to the Standing work condition (Figure 5.3).

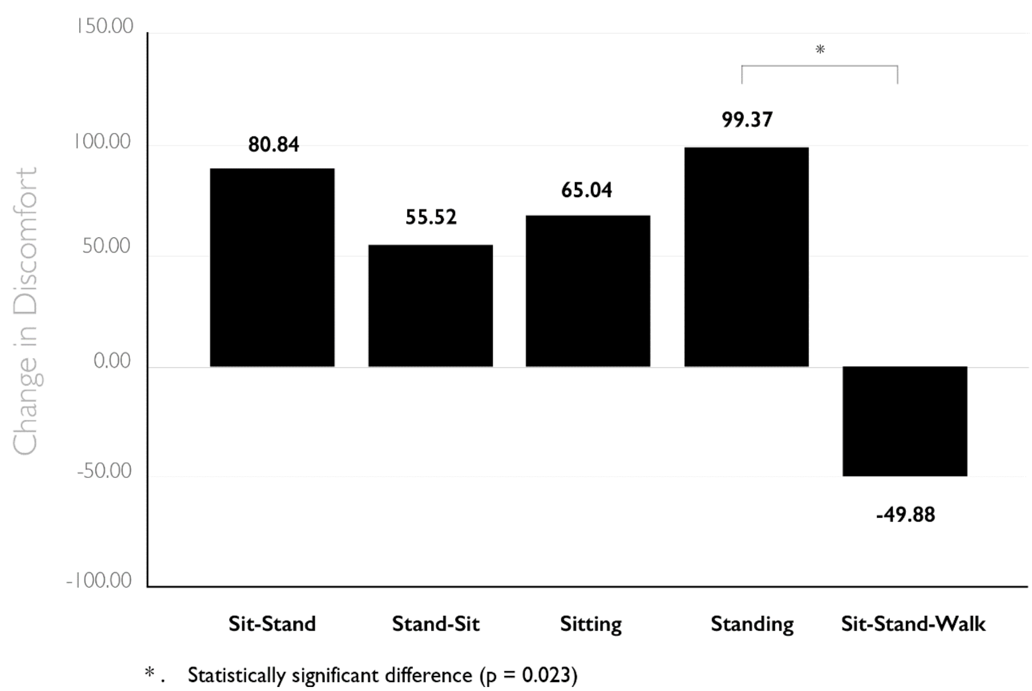

Figure 5.3. Change in Musculoskeletal discomfort

5.4.3. Physical Fatigue. When compared to the baseline, Ps in the Sit-Stand-Walk work condition reported a reduction in mean physical fatigue of -4.70 ± 3.99 (95% CI, -12.65 to 3.23). In contrast, Ps in other four work conditions reported increases in mean physical fatigue compared to baseline (Table 5.5). Pairwise comparisons revealed that mean physical fatigue for Sit-Stand-Walk work condition was significantly lower compared to: Sit-Stand work condition with a statistically significant mean difference of -22.27 ± 5.65 (95% CI, -38.54 to -5.99), $p = 0.002$; Stand-Sit work condition with a statistically significant mean difference of -17.37 ± 5.65 (95% CI, -33.64 to -1.10), $p = 0.028$; Sitting work condition with a statistically significant mean difference of -20.66 ± 5.61 (95% CI, -36.81 to -4.51), $p = 0.004$; and the Standing work condition, a statistically significant mean difference of -18.83 ± 5.61 (95% CI, -34.98 to -2.68), $p = 0.012$. Results suggest that Sit-Stand-Walk work condition is associated with significantly lower mean physical fatigue when compared to the Sit-Stand, Stand-Sit, Sitting and Standing work conditions, respectively (Figure 5.4).

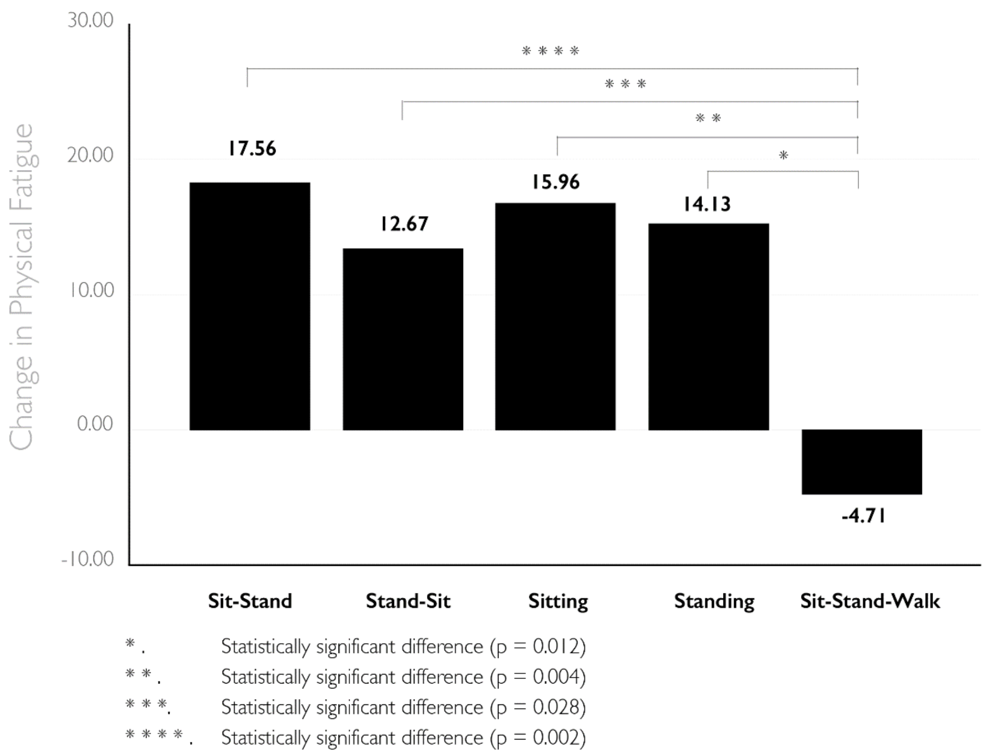

Figure 5.4. Change in Physical Fatigue

5.4.4. Mental Fatigue. When compared to baseline scores, Ps in the Sit-Stand-Walk work condition reported a mean reduction in mental fatigue of -1.04 ± 4.40 (95% CI, -9.78 to 7.70). Ps in the other four work conditions reported increases in mean mental fatigue compared to baseline scores (Table 5.5). Pairwise comparisons revealed that mean mental fatigue for the Sit-Stand-Walk work condition was significantly lower compared to: the Stand-Sit work condition with a statistically significant mean difference -19.39 ± 6.22 (95% CI, -37.31 to -1.47), $p = 0.025$; and the Sitting work condition with a statistically significant mean difference of -25.77 ± 6.17 (95% CI, -43.55 to -7.99), $p = 0.001$. Results suggest that the Sit-Stand-Walk work condition is associated with significantly lower mean mental fatigue when compared to the Stand-Sit and Sitting work conditions, respectively (Figure 5.5).

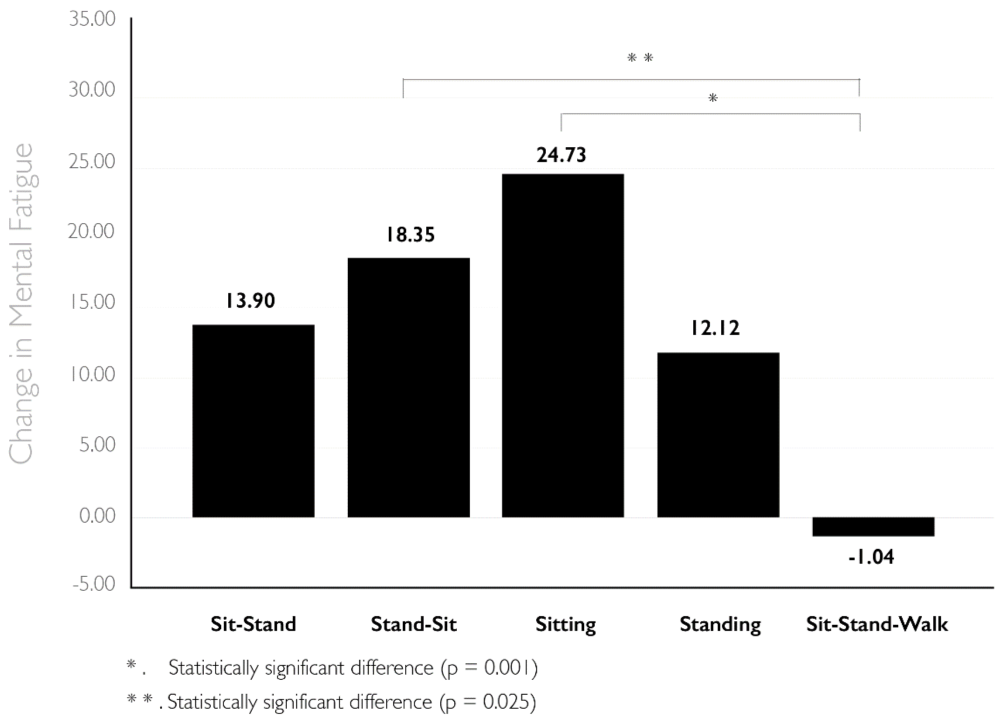

Figure 5.5. Change in Mental Fatigue

Dependent Variable		Mean	Std. Error	95% Confidence interval	
				Lower	Upper
Musculoskeletal Discomfort	Sit-Stand	80.854	33.941	13.424	148.284
	Stand-Sit	55.521	33.941	-11.909	122.951
	Sitting	65.040	33.423	-1.360	131.441
	Standing	99.374	33.423	32.973	165.774
	Sit-Stand-Walk	- 49.875	33.941	-117.305	17.555
Physical Fatigue	Sit-Stand	17.563	3.999	9.619	25.506
	Stand-Sit	12.667	3.999	4.723	20.611
	Sitting	15.955	3.938	8.132	23.777
	Standing	14.126	3.938	6.304	21.949
	Sit-Stand-Walk	- 4.708	3.999	-12.652	3.236
Mental Fatigue	Sit-Stand	13.896	4.403	5.148	22.643
	Stand-Sit	18.354	4.403	9.607	27.102
	Sitting	24.732	4.336	16.118	33.346
	Standing	12.116	4.336	3.502	20.730
	Sit-Stand-Walk	- 1.042	4.403	**-9.789**	7.706
Typing Speed	Sit-Stand	175.092	15.287	144.722	205.462
	Stand-Sit	198.455	15.287	168.085	228.826
	Sitting	210.656	15.054	180.749	240.583
	Standing	199.650	15.054	169.744	229.557
	Sit-Stand-Walk	194.060	15.287	163.689	224.430
Typing Error	Sit-Stand	3.329	0.320	2.682	3.965
	Stand-Sit	3.191	0.320	2.555	3.827
	Sitting	3.057	0.315	2.431	3.684
	Standing	3.187	0.315	2.560	3.813
	Sit-Stand-Walk	3.642	0.320	3.006	4.278

Table 5.5. Marginal Means for Dependent Variables

5.4.5. Task Productivity. Transcription task productivity was operationalized by typing speed measured in characters/minute, and typing error measured as a percentage. Ps in the Sit-Stand-Walk work condition had a mean typing speed of 194.06 ± 15.28 (95% CI, 163.68 to 224.43). Pairwise comparisons revealed no statistically significant difference in mean typing speeds for the Sit-Stand-Walk work condition compared to the other four work conditions. Results suggest that typing speed is not impacted by work condition. Ps in the Sit-Stand-Walk work had a mean typing error of 3.64 ± 0.32 (95% CI, 3.01 to 4.27). Pairwise comparisons revealed no statistically significant difference in typing error for the Sit-Stand-Walk work condition compared to the other four work conditions. Results suggest that typing error is not impacted by work condition. Therefore, these results taken together suggest that task productivity was not impacted by the work condition.

5.5. Discussion

5.5.1. Hypothesis 1. The results of the study do not confirm H1, i.e. there was no interaction between gender and work condition on the combined dependent variables. Results indicate that gender did not moderate the relationship between the work condition and combined dependent variables. Previously, a study by Karakolis et al. (2016), reported an interaction of gender with workstation type - females experienced higher musculoskeletal discomfort during prolonged sitting, while males experienced higher musculoskeletal discomfort during prolonged standing. The present study used a between-subjects research design with a 1:1 sit-to-stand ratio for the SSW intervention, while Karakolis et al. (2016) used a repeated-measures research design with a 3:1 sit-to-stand ratio for the SSW intervention. Differences in sit-stand ratios and research designs prevent meaningful comparisons to be made. Longer task durations could potentially account for the moderating influence of gender, if any.

5.5.2 Hypothesis 2. The results of the study do not confirm H2, i.e. there was no main effect of gender on the combined dependent variables. Ps' gender did not impact their scores for musculoskeletal discomfort, physical fatigue, mental fatigue, and productivity. Previous research on computer work suggests that female workers are at a higher risk of musculoskeletal disorders, with reports of higher neck and upper extremity symptoms when compared to male workers (Wahlstörm, 2005; Coury et al., 2002; Ekman et al., 2000). In the present study, with 42 male and 58 female Ps randomly assigned to one of the five work conditions, there was no evidence for a main effect of gender on the combined dependent variables. It may be possible that the short-duration of the transcription task was not sensitive enough to provide evidence for the potential main effect of gender on the dependent variables.

5.5.3 Hypothesis 3. The results of the study do confirm H3, i.e. there was a main effect of work condition on the combined dependent variables. Ps' work condition significantly impacted their musculoskeletal discomfort. Pairwise comparisons revealed that mean musculoskeletal discomfort for the Sit-Stand-Walk work condition was significantly lower compared to the Standing work condition ($p = 0.023$). Previous research suggest reductions in musculoskeletal discomfort associated with the adoption of SSWs or active breaks in office work (Waongenngarm et al., 2018; Karakolis & Callaghan, 2014). In contrast, the use of standing desks have been associated with increased musculoskeletal discomfort, particularly in the back and lower limbs (Le & Marras, 2016; Gallagher & Callaghan 2015). In accordance with prior research, results from this study suggest that adoption of a SSWI – combining sit-stand posture transitions with active breaks – can significantly reduce musculoskeletal discomfort in short-duration computer-based work.

Ps' work condition significantly impacted their physical fatigue ($p = 0.001$). Pairwise comparisons revealed that mean physical fatigue for the Sit-Stand-Walk work condition was significantly lower compared to Sit-Stand ($p = 0.002$), Stand-Sit ($p = 0.028$), Sitting ($p = 0.004$) and Standing ($p = 0.012$) work conditions, respectively. Previous research suggest reductions in fatigue associated with adoption of SSWs or micro breaks in office work (Thorp et al., 2014; McLean et al., 2001; Hasegawa et al., 2001; Paul, 1995; Henning et al., 1989). In accordance with prior research, results from this study suggest that the adoption of a SSWI – combining sit-stand posture transitions with active breaks – can significantly reduce physical fatigue in short-duration computer-based work.

Ps' work condition significantly impacted their mental fatigue ($p = 0.002$). Pairwise comparisons revealed that mean mental fatigue for Sit-Stand-Walk work condition was significantly lower compared to Stand-Sit ($p = 0.025$) and Sitting work conditions ($p = 0.023$), respectively. Previous research indicates that sit-stand office work is associated with higher arousal level compared to sitting work (Ebara et al., 2008), and that active breaks are associated with increased cerebral blood flow (Carter et al., 2018). In accordance with prior research, results from this study suggest that the adoption of a SSWI – combining sit-stand posture transitions with active breaks – can significantly reduce mental fatigue in short-duration computer-based work.

Ps' work condition did not impact their typing speed ($p = 0.574$) and typing error ($p = 0.743$). On average, typing speed and typing error for the Sit-Stand-Walk work condition was not significantly different in comparison to the Sit-Stand, Stand-Sit, Sitting and Standing work conditions, respectively. Previous reviews suggest no reduction in productivity associated with use of SSWs or active breaks in office work (Waongenngarm et al., 2018; Karakolis & Callaghan, 2015; Karol & Robertson, 2015). In accordance with prior research, results of this study suggest that adoption of a SSWI – combining sit-stand posture transitions with active breaks – does not impair productivity in short-duration computer-based work.

5.5.4 Strengths. To provide adequate context of the results, the following strengths of this study need to be discussed. First, experiments were conducted in a controlled laboratory that simulated an office work environment. Second, this is one of the few studies to compare musculoskeletal discomfort, physical fatigue, mental fatigue, and productivity between sit-stand, sitting and standing work conditions. Third, the study investigated whether order of the postural change: Sit-Stand or Stand-Sit impacted the dependent variables. Fourth, the study investigated the possibility of gender being a moderator between the work condition and dependent variables. Fifth, this is probably the first study to investigate and demonstrate benefits of combining sit-stand work with active breaks for computer-based work. Sixth, the 20:8:2 sit-stand-walk intervention shows evidence for a potentially optimal sit-to-stand ratio for computer-based work. Finally, the study was conducted with a robust sample size (n = 100), having randomly allocated 20 Ps to each of the five work conditions.

5.5.5 Limitations. On the other hand, these strengths incorporate some limitations as well. First, Ps performed two, 30-minute transcription tasks with a 5-minute break in the middle. The short-duration transcription task may not offer ecologically valid results for computer-based work generalizable across a workday. Second, the short-duration may not be sensitive to account for gender differences, if any, which may impact the dependent variables. Third, the study used a between-participants design, with Ps randomly assigned to one of five working conditions. While a between-participants design avoids carry-over effects associated with within-subjects designs, there may be limitations due to individual variability and assignment bias. Fourth, Ps were a convenience sample of college students who were mostly young, not obese, and exercised frequently. Generalizing results to the office working population may be limited as the dependent variables may be affected by age, obesity and exercise habits. Fifth, Ps had no prior experience in use of SSWs and were provided 10-minutes for familiarization. A longer time frame for Ps to familiarize with the work condition and task may have impacted the dependent variables. Sixth, musculoskeletal discomfort, physical fatigue, and mental fatigue were self-reported; use of objective measures in combination with self-report could enhance the robustness of the research claims. Finally, while the fifth work condition involved a 2-minute active break with a plausible increase in physical activity – there was no objective measure of physical activity to validate this claim.

5.5.6 Sit-Stand-Walk Protocol. This study provides preliminary evidence for benefits of a sit-stand-walk intervention using a 20:8:2 ratio, for a 60-minute computer transcription task. The 2.5:1.0 sit-stand ratio is based on prior studies which have indicated beneficial responses to musculoskeletal discomfort and fatigue for sit-stand ratios between 2:1 and 3:1

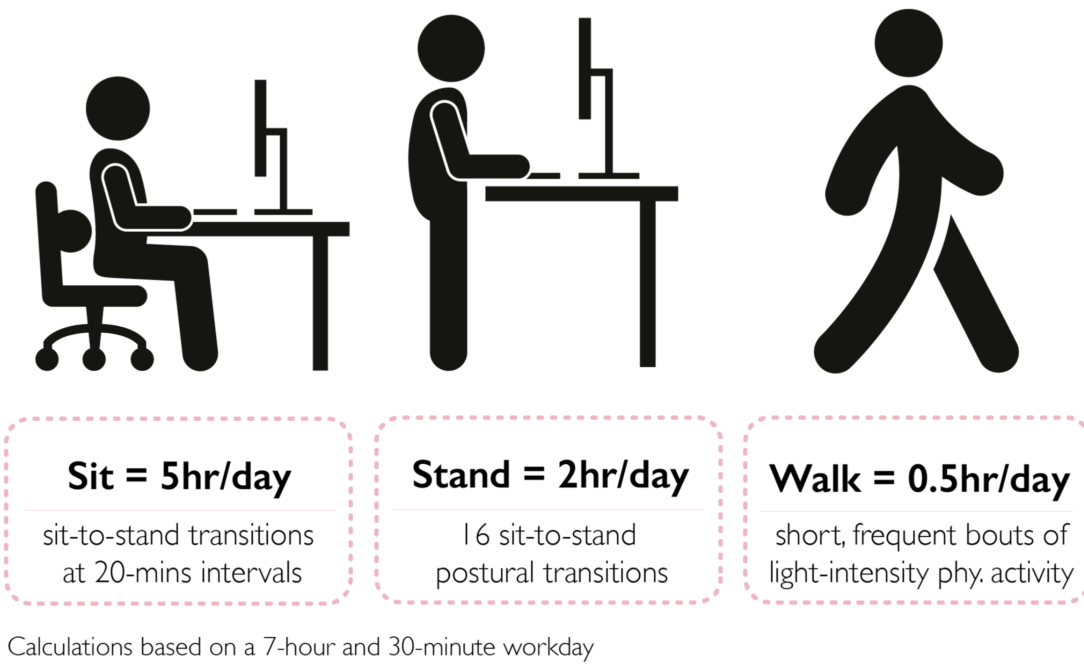

Figure 5.6. Extrapolating the Sit-Stand-Walk Intervention to a Workday

(Bao & Lin, 2018; Karakolis & Callaghan, 2014). The 2-minute walk builds on prior research to indicate that active breaks improve cardio-metabolic outcomes, enhance cerebral blood flow; reduce low back pain, and attenuate fatigue and musculoskeletal discomfort when compared to seated work (Carter et al., 2018; Waongenngarm et al., 2018; Bailey & Locke, 2015).

While findings from this study are limited to a 60-minute task duration, extrapolating the intervention over a 7 ½ hour workday translates to 5 hours of sitting, 2 hours of standing, 30 minutes of walking, and 16 sit-to-stand transitions as gravitational stimuli (Vernikos &

Schneider, 2010) (Figure 5.6). The sit-stand-walk schedule conforms to the WHO guidelines on physical activity for health which recommend that working adults to break up long periods of sitting with short bouts of standing, engage in moderate intensity physical activity for 30-minutes/day, and accumulate at least standing for 2 hour/day (Buckley et al., 2015). While further research is needed to replicate findings, initial evidence suggest that the sit-stand-walk intervention maybe an optimal approach to realize the dual goals of reduced sitting time and increased physical activity in the workplace.

5.6. Conclusion

In conclusion, findings from this study suggest that the SSWI was associated with significant reductions in: musculoskeletal discomfort compared to standing work; physical fatigue compared to all the other work; and mental fatigue compared to stand-sit and sitting work. In addition, the sit-stand-walk intervention has no detrimental effect on productivity. The study suggests that gender does not moderate the relationship between work condition and dependent variables. Finally, this work provides evidence for a sit-stand-walk ratio that combines postural transitions enabled by sit-stand workstations with short bouts of light-intensity physical activity through active breaks, thereby demonstrating a beneficial and practically viable alternative to sedentary paradigm of computer-based work.

Future work will involve expanding the experimental duration to simulate a complete workday. Physical activity levels will be quantified objectively. The study will be replicated in field settings with office workers, to investigate if results from laboratory settings translate to real-world office work environments. Study findings should inform the next stage of empirical research investigating the potential of combining postural variability with active breaks to address the challenges of health, well-being and productivity in sedentary work.

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CHAPTER 6

EFFECT OF WORKSTATION CONFIGURATION ON MUSCULOSKELETAL DISCOMFORT, FATIGUE, PRODUCTIVITY & POSTURAL RISKS IN A SIT-STAND-WALK INTERVENTION FOR COMPUTER-BASED WORK

6.1. Abstract

Objective: Compare musculoskeletal discomfort, fatigue, productivity, and postural risks in short-duration computer-based work between two SSW configurations: one, custom designed and configured for workers according to ergonomic guidelines (Ergo-Fit); another, commercially available and self-adjusted by workers according to their preference (Self-Adjusted). *Participants:* Using a sit-stand-walk intervention (SSWI), 36 participants completed two 30-minute typing transcription tasks at the two workstations. *Methods*: A repeated measures design with a counterbalanced order was used. Musculoskeletal discomfort and fatigue were reported through visual analog scales, productivity was operationalized by typing speed and typing error, postural risks were assessed by RULA for seated work and REBA for standing work. *Results:* Musculoskeletal discomfort and fatigue were similar between the two workstation configurations. Typing error was significantly higher, and typing speed significantly lower for Ergo-Fit configuration when compared to Self-Adjusted configuration. Postural risks, as assessed by RULA and REBA, were significantly lower for the Ergo-Fit configuration. *Conclusion:* Use of the Ergo-Fit workstation configuration facilitates sit-stand transitions and enables workers to adopt safe, neutral postures for seated and standing work; however, there is a trade-off with productivity. This study provides evidence for benefits of using an ergonomically-fit SSW that enables workers using a SSWI, to optimize postural variability and increase physical activity in computer-based work.

6.2. Introduction

The advent of computer-based technologies and automation in the workplace has led to a significant increase in sedentary, desk-based occupations (Levine, 2014; Hedge & Ray, 2004). Time use data from Australia, the Netherlands, the U.S. and the U.K. indicate that working adults spend between 6.2 ~ 9.6 hours/day in sedentary behaviors, much of which involves occupational sitting (Tudor-Locke et al., 2011; Van Uffelen et al., 2010). It is estimated that by the year 2030, sedentary behaviors in the U.K. and the U.S. will increase to 51 hours/week and 42 hours/week, respectively (Ng & Popkin, 2012). This is a cause for concern, because increased sedentary behaviors and reduced physical activity are associated with elevated risks for cardio-vascular disease, obesity, type-2 diabetes, some cancers, and pre-mature mortality (Chau et al., 2013; Dunstan et al., 2012; Thorp et al., 2011; Katzmarzyk et al., 2009). In addition, computer-based office work has long been linked to musculoskeletal disorders of the upper limbs (Rempel et al., 2006; Norman et al., 2004; Luttmann et al., 2003).

Given the deleterious health impacts of occupational sedentarism, studies have investigated the feasibility of reducing occupational sitting time by adopting workstation alternatives to the sedentary, desk-based paradigm of office work (Tudor-Locke et al., 2014). The most prominent of these workstation alternatives are the sit-stand workstations (SSWs) which feature variable-height work surfaces, enabling office workers to alternate between seated and standing work. Reviews of SSWs indicate beneficial reductions in sitting time, musculoskeletal discomfort, fatigue, and low back pain, without negative effects on productivity in computer-based work (Agarwal et al., 2018; Karol & Robertson, 2015; Karakolis & Callaghan, 2014). Recent studies have provided evidence for benefits in adopting a sit-stand-walk intervention that combines postural variability with active breaks, thereby addressing the dual needs for reduced sitting time and increased physical activity (Kar & Hedge, 2018). In controlled laboratory settings, the sit-stand-walk intervention has demonstrated significant reductions in musculoskeletal discomfort and fatigue compared to seated and standing work, without negative impacts on productivity.

The introduction of SSWs in the office have not necessarily increased the desired levels of sit-stand postural transitions. Wilks et al. (2006) reported results from a survey of office workers in Sweden who used SSWs for a year, to indicate low compliance with the sit-stand function - only 20% of the office workers used the sit-stand function at least once a day. Nooijen et al. (2018) conducted a survey among office workers using SSWs to report that the common perceived barriers to effective sit-stand usage include: sitting as a habit (67%); standing being uncomfortable (29%) and tiring (24%); and the lack of motivation to stand up from sitting (19%). Studies have reported that office workers provided with SSWs often select workstation set ups that do not conform to recommended guidelines for seated and standing work (Asundi et al., 2011), and work surface heights are often lower than what the guidelines for standing work suggest (Lin et al., 2016). When untrained users self-adjust workstation set ups, keyboard heights maybe positioned sub-optimally, resulting in non-neutral wrist postures, greater wrist extension, and risks of occupational injuries (Hedge et al., 2005). Positioning the keyboard above the elbow has been linked to increased musculoskeletal risks for the neck, shoulder and upper arm (Marcus et al., 2002; Sauter et al., 1991).

A persistent concern in the introduction of SSWs to the workplace is that their correct usage calls for knowledge and interest in the user (Wilks et al., 2006). Green and Briggs (1989) observed that providing office workers with adjustable workstations had a meagre effect on musculoskeletal symptoms, and concluded that negative results could be attributed to lack of information and training on how workstation equipment should be adjusted. Demure et al. (2000) reported results from a study in which workers who were provided with fully-adjustable workstations reported increased risks of musculoskeletal discomfort for the neck/shoulder and the arm/wrist compared to workers in partially-adjustable workstations. In contrast, workers provided with an adjustable work environment coupled with an ergonomics training program, reported significant reductions in musculoskeletal symptoms (Robertson et al., 2008; Nerhood & Thompson, 1994). Additionally, enabling office workers to have control over work environment through workstation adjustability and ergonomics knowledge may enhance productivity, health and well-being (Robertson & Huang, 2006; O'Neill, 1994).

The adoption of a sit-stand-walk intervention shows promise in reduction of musculoskeletal discomfort and physical fatigue, without negative impacts on productivity in computer-based work. In addition, the 2-minute walking break provides an opportunity for intermittent bouts of light-intensity physical activity recommended by public health experts (Buckley et al., 2015). However, no comprehensive ergonomic guidelines on the proper usage of SSWs are in existence (Lin et al. 2016); there are common perceived barriers to effective use of SSWs (Nooijen et al., 2018); compliance with recommended use of SSWs is low (Wilks et al., 2006); and self-adjusted workstation set ups can increase overuse injuries of the neck, shoulder and upper-limbs (Green & Briggs, 1989).

6.3. Objectives

In this context, the author wanted to: (1) test the feasibility of using a novel SSW configuration, custom-fit to the worker in accordance with ergonomic guidelines for seated and standing work (Ergo-Fit configuration), and (2) compare the Ergo-Fit configuration to a standard, commercially available SSW configuration, self-adjusted by the worker according to their preference (Self-Adjusted configuration). The sit-stand-walk intervention, experimentally verified in prior research (Kar & Hedge, 2018) was the work protocol for both workstation configurations. The aim of this study was to evaluate effects of the workstation configuration on four dependent variables – (1) self-reported musculoskeletal discomfort; (2) self-reported fatigue; (3) productivity operationalized by typing speed and typing error; (4) postural risks operationalized by RULA for seated work, and REBA for standing work.

Using a repeated-measures study design, participants (Ps) from the working age population performed two 30-minute computer-based transcription tasks in two workstation configurations – (1) Ergo-Fit (E-F) and (2) Self-Adjusted (S-A), described in detail in the following section.

It was hypothesized that –

(H1): Change in self-reported musculoskeletal discomfort will be higher in the E-F configuration, i.e. there will be a main effect of workstation configuration on self-reported musculoskeletal discomfort.

(H2): Change in self-reported fatigue will be higher in the E-F configuration, i.e. there will be a main effect of workstation configuration on self-reported fatigue.

(H3): Typing speed will be higher in the E-F configuration, i.e. there will be a main effect of workstation configuration on typing speed.

(H4): Typing error will be lower in the E-F configuration, i.e. there will be a main effect of workstation configuration on typing error.

(H5): RULA scores in seated work will be lower in the E-F configuration, i.e. there will be a main effect of workstation configuration on RULA scores.

(H6): REBA scores in standing work will be lower in the E-F configuration, i.e. there will be a main effect of workstation configuration on REBA scores.

6.4. Methods

6.4.1. Participants. The repeated-measures laboratory study was conducted with a convenience sample of 36 young adults (18 males and 18 females), recruited by email circulated among students at Cornell University. Inclusion criteria was: at least 18 years old, prior experience with computer typing, and no chronic musculoskeletal health complaints. Demographic data including age, weight, height, years of computer use, weekly computer usage, and daily sitting duration were self-reported (Table 6.1). All participants (Ps) were right-handed; none had prior experience of using an SSWI at work. All protocols and informed consent forms were approved by the Cornell University Institutional Review Board (Appendix E); Ps signed an informed consent document and were compensated $40 for participation. Of the 36 Ps who volunteered, 32 Ps agreed to be video recorded for posture analysis.

Criteria	**Mean**	**(Std. Dev)**
Age (years)	25.78	(4.50)
Weight (kg)	62.61	(11.18)
Height (m)	1.69	(0.09)
Body Mass Index (kg/m^2)	21.83	(2.78)
Computer Use (years)	14.19	(3.47)
Weekly Computer Work (hours/week)	42.22	(22.30)
Daily Occupational Sitting (hours/day)	6.58	(2.21)

Sample size (n = 36), Female = 18; Male = 18

Table 6.1. Participant Demographics

6.4.2. Experimental Design. The study protocol consisted of two transcription task sessions of 60-minutes - one each in the E-F and S-A configurations, using a counterbalanced order of presentation. The 60-minute duration was chosen so that each session would be long enough for Ps to potentially develop early signs of musculoskeletal discomfort or fatigue. Ps performed computer-based transcription tasks using a SSWI that had been experimentally verified to reduce musculoskeletal discomfort and fatigue, without negatively impacting productivity in computer-based work (Kar & Hedge, 2018). The workstation configuration was the independent variable; the dependent variables were musculoskeletal discomfort and fatigue reported through surveys, productivity operationalized by typing speed and typing error, and postural risks assessed using the Rapid Upper Limb Assessment (RULA) for seated work and the Rapid Entire Body Assessment (REBA) for standing work (Figure 6.1).

Figure 6.1. Experimental Protocol

6.4.3. Apparatus. The repeated-measures experiment was conducted in a laboratory that simulated an office environment. For the E-F configuration, a 24-inch computer monitor (U2414H Monitor, Dell, Round Rock, Texas, USA) mounted on a monitor arm (LX Dual Stacking Arm, Ergotron, Minnesota, USA) and connected to a laptop (ThinkPad T420, Lenovo USA, Morrisville, North Carolina, USA), a wireless mini-keyboard and mouse (Periduo-720, Perixx Computer GmbH, Dusseldorf, Germany) were the computer peripherals used. A sit-stand workstation (Float, Humanscale, New York, USA) capable of varying work surface height from 70 ~ 120 cm was used. For seated work, a height-adjustable task chair with armrests removed (Mesh Drafting Chair, Office Factor, San Antonio, Texas, USA), connected to an adjustable seated footrest (Anchorite Work System, ErgoRX.com, Arlington, Virginia, USA) were used. A lap-supported keyboard tray (Ankorite Work System, ErgoRX.com, Arlington, Virginia, USA), was provided to place the keyboard and mouse during seated work. The keyboard and mouse were placed on the sit-stand workstation during standing work. A height-adjustable standing footrest (Ankorite Work System, ErgoRX.com, Arlington, Virginia, USA) was provided for use during standing work (Figure 6.2).

For the S-A configuration, a 24-inch computer screen (U2414H, Dell, Round Rock, Texas, USA) connected to a computer (Optiplex 7800, Dell, Round Rock, Texas, USA), a wireless mini-keyboard and mouse combination (Periduo-720, Perixx Computer GmbH, Dusseldorf, Germany) were the computer peripherals used. A sit-stand workstation (Quickstand, Humanscale, New York, USA) capable of varying work-surface height from 70 ~ 120 cm was attached to a fixed-height table, and a height-adjustable task chair with armrests at the lowest position (Freedom Chair, Humanscale, New York, USA) were used. A 10-cm high seated footrest was provided to Ps, if needed (Figure 6.2). For both workstation configurations, illumination levels were maintained at 450 lux measured at top of the keyboard while seated at work, ambient air temperature was maintained between 23°C ~ 27°C, and relative humidity was maintained between 45% ~ 50%. A video camera (Vixia HF R800, Canon USA, Melville, New York, USA) placed to the right, 2.0 m away from the participant and 1.1 m above the floor level, recorded Ps' postures for analysis.

Figure 6.2. Apparatus (1) E-F Seated, (2) E-F Standing, (3) S-A Seated, (4) S-A Standing

6.4.4. Fitting protocol. In the E-F configuration, Ps were 'fitted' to the workstation using the following protocol. For standing work - First, the work surface height was adjusted to Ps standing height with elbows bent to 90 degrees and wrist in neutral posture. Second, the standing footrest was adjusted with hip positioned at 45 degrees of flexion. Third, the keyboard was centered to align with body midline. Fourth, the standing monitor was adjusted for height, depth and pitch to ensure that neck and pelvis were in neutral posture. In standing work, Ps were advised to oscillate their feet by alternately positioning the left and right leg on the standing footrest.

For seated work – First, while keeping the work surface height unchanged from standing work, the seat height was positioned 15 cm above the knee when standing. Second, Ps were seated on the task chair with hips positioned as far back as possible. Third, the seated footrest was adjusted with knee at about 120 degree of flexion. In seated work, Ps were advised to oscillate their feet by rotating the inclined surface of the seated footrest. Fourth, the monitor was adjusted to be about one arm's length away with the top of the monitor level with the eyebrows. Fifth, the keyboard tray was positioned on the lap with neck, shoulders, elbows and wrists in neutral posture. In the E-F configuration, once the workstation was *fitted* to the participant, they were advised not to rearrange the workstation setup during the transcription task. In the S-A configuration, Ps were not provided with instructions on how to setup the workstation; they were free to rearrange their workstation setup at any point in time during the transcription task.

6.4.5. Tasks and Assessments. Musculoskeletal discomfort was operationalized using a 15-item Visual Analog Scale for Musculoskeletal Discomfort (VAS-D) adapted from the Nordic questionnaire for musculoskeletal symptoms (Appendix F) (Kuorinka et al., 1987). Each item corresponded to a region of the body indicated on a body-part diagram divided into 15 regions (neck, upper back, lower back, left and right sides of shoulder, forearm, wrist, thigh, knee, lower leg). Each item asked Ps to place an "X" representing how much musculoskeletal discomfort they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0 mm representing "no musculoskeletal discomfort" to 100 mm representing “extreme musculoskeletal discomfort”). Fatigue was operationalized using a 17-item Visual Analog Scale for Fatigue (VAS-F) adapted from Lee et al. (1991). Each item asked Ps to place an “X” representing how much fatigue (or a synonymous descriptor of fatigue) they currently felt, along a 100-mm horizontal line that extended between two extremes (from 0-mm representing “not at all” to 100-mm representing “extremely high”) (Appendix G).

The computer-based transcription task required Ps to copy text from a document window in left-half of the screen to a document window in the right-half of the screen using a word processing software (MS Word). The sequence of texts was randomized to compensate for any order effects. To measure typing error, the Spell-Check and Auto-Correct features in the word processing software (MS Word) were disabled. Ps did not receive any productivity guidelines but were instructed to type at their normal speed. Transcription task productivity was operationalized by typing speed (measured in characters per minute), and typing errors (measured as a percentage by comparing original and transcribed documents for removals and additions). The analysis of task productivity was conducted on a sample of Ps ($n = 35$), since typing data for one P could not be retrieved.

Postural risks were assessed using the RULA (McAtamney & Corlett, 1993) for seated work, and REBA (Hignett & McAtamney, 2004) for standing work. Ps were video recorded in each workstation configuration for a duration of 28-minutes during the second transcription session. A sagittal-perpendicular view of the P was kept for consequent postural analysis (NIOSH, 2014). Video frames were sampled at 2-minute intervals resulting in 11 samples (starting at $t = 0$ min, and ending at $t = 20$ min) for 20-minutes of seated work, and 5 samples (starting at $t = 0$ min, and ending at $t = 8$ min) for 8-minutes of standing work. The 2-minute walk was not video recorded. Since all Ps were right-handed, RULA and REBA scores were calculated for the right-side only. Each sample was assessed considering a force load score of zero for RULA and REBA, and a coupling score of zero for REBA. The analysis of postural risks was conducted on a sample of participants (n = 32), as four of the Ps declined to be video recorded.

6.4.6. Procedure. Prior to starting the experiment, Ps signed an informed consent document and filled a paper-based survey to document their demographic characteristics. Following this, Ps practiced computer-based transcription tasks for 10-minutes in their first workstation configuration: 5-minutes for seated work, followed by 5-minutes for standing work. Next, a survey was administered to document pre-trial (t = 0 min) scores for musculoskeletal discomfort and fatigue in the first workstation configuration. Ps were then instructed to perform two transcription tasks of 30-minutes duration each, using a sit-stand-walk protocol that comprised of sitting and typing for 20-minutes, standing and typing for 8-minutes, followed by a 2-minute break in which Ps were instructed to walk at their normal pace (Kar & Hedge, 2018). Ps received no productivity guidelines for the computer-based transcription task but were instructed to type in their normal speed. At the end of the first 60-minute session, Ps were provided a 5-minute seated break and a paper-based survey was administered to document post-trial (t = 60 minute) scores for musculoskeletal discomfort and fatigue in the first workstation configuration. After the break, Ps repeated the same experimental schedule for the second workstation configuration. For each P, the complete protocol, including preparatory activities, practice sessions, transcription tasks, rest-breaks, and filling out the surveys, took approximately 2-hours and 45-minutes.

Musculoskeletal discomfort and fatigue scores were recorded using paper-based surveys at 4 instances; two times each at the pre-trial (t = 0 minute), and post-trial (t = 60 minute) periods for the two workstation configurations. Typing speed and typing errors for the typing transcription tasks were calculated by the researcher, post-experiment. Video recording for postural analysis was done for the second 30-minute transcription session.

6.4.7. Data Analysis. The raw data was tabulated in a spreadsheet (MS Excel) and statistical analyses performed using Statistical Package for Social Sciences (version 25.0, IBM Corporation, Armonk, NY). Change in musculoskeletal discomfort and fatigue were calculated as the difference of scores between pre-trial (t = 0 min) and post-trial (t = 60 min), typing speed was calculated in characters per minute, and typing error calculated as a percentage of total characters typed. Video frames for postural analysis were sampled at 2-minute intervals for the second 30-minute session of the 60-minute typing transcription task; postural risk scores for RULA and REBA were used in the analysis. Results from the study were analyzed using Wilcoxon signed-ranked test for dependent variables that were not normally distributed; paired-samples t-test was used for dependent variables that were normally distributed. Significance criteria was set at $p = 0.05$.

6.5. *Results*

6.5.1. Musculoskeletal discomfort. A Wilcoxon signed-rank test was conducted to determine the effect of workstation configuration on self-reported musculoskeletal discomfort. The difference in self-reported musculoskeletal discomfort scores between the two workstation configurations was approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. Of the 36 Ps recruited for the study, 20 Ps reported higher reduction in musculoskeletal discomfort for the E-F configuration compared to the S-A configuration, and 16 Ps reported lower reduction in musculoskeletal discomfort. Data are medians unless otherwise stated. There was no statistically significant median increase in self-reported musculoskeletal discomfort (0.400) when Ps used the E-F configuration (0.667) compared to the S-A configuration (0.300), $z = 0.479$, $p = 0.632$.

6.5.2. Fatigue. A Wilcoxon signed-rank test was conducted to determine the effect of workstation configuration on self-reported fatigue scores. The difference in self-reported fatigue scores between the two workstation configurations was approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. Of the 36 Ps recruited for the study, 23 Ps reported a higher reduction in fatigue for the E-F configuration compared to the S-A configuration, and 13 Ps reported a lower reduction in fatigue. Data are medians unless otherwise stated. There was no statistically significant median increase in self-reported fatigue (4.382) when Ps used the E-F configuration (2.588) compared to the S-A configuration (0.529), $z = 1.555$, $p = 0.120$.

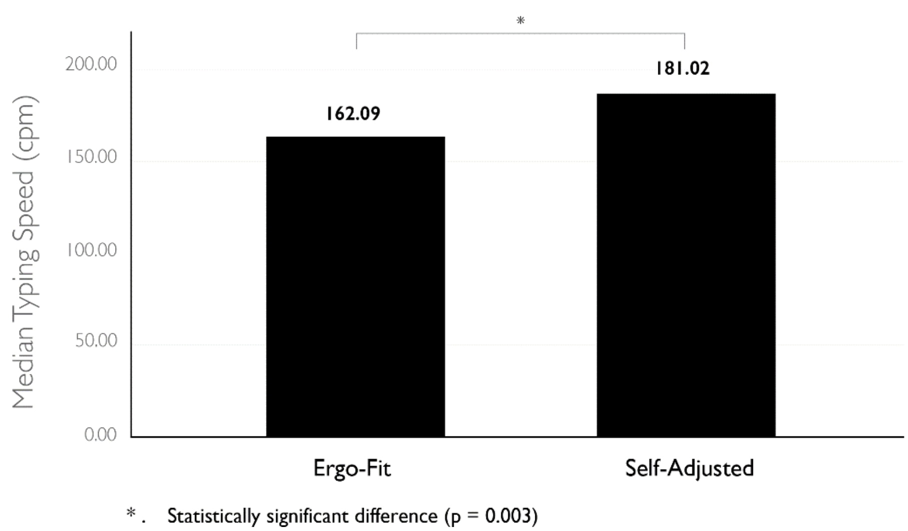

Figure 6.3. Median Typing Speed for E-F and S-A Configurations

6.5.3. Typing Speed. A Wilcoxon signed-rank test was conducted to determine the effect of workstation configuration on typing speed. The difference in typing speed between the two workstation configurations was approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. Of the 35 Ps whose typing speed was tabulated, 25 Ps had higher typing speed in the S-A configuration compared to the E-F configuration, and 10 Ps had a lower typing speed. Data are medians unless otherwise stated.

There was a statistically significant median increase in typing speed (6.012 characters/minute) for Ps in the S-A configuration (181.025 characters/minute) compared to the E-F configuration (162.093), z = 2.997, p = 0.003 (Figure 6.3).

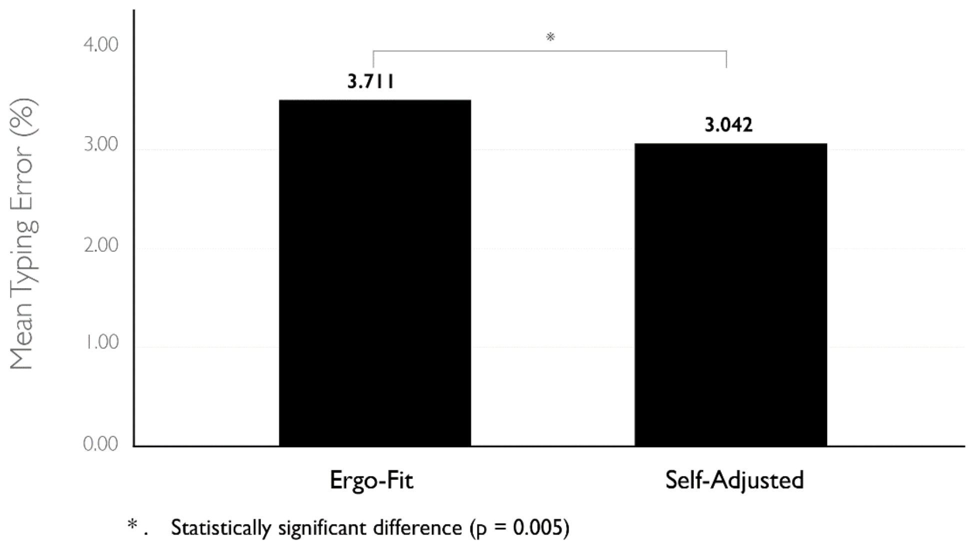

Figure 6.4. Mean Typing Error for E-F and S-A Configurations

6.5.4. Typing Error. A paired-samples t-test was conducted to determine the effect of workstation configuration on typing error. The difference in typing error between the two workstation configurations was normally distributed, as assessed by Shapiro-Wilk's test (p = 0.127). One outlier was detected that was more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of the value did not reveal it to be extreme, and the outlier was kept in the analysis. Data are mean ± standard deviation, unless otherwise stated. Ps made fewer errors in the S-A configuration (3.04 ± 1.04%) as compared to the E-F configuration (3.71 ± 1.31%), a statistically significant mean difference of -0.67% (95% CI, -0.80 to -0.44), t (34) = -5.94, p < 0.0005 (Figure 6.4).

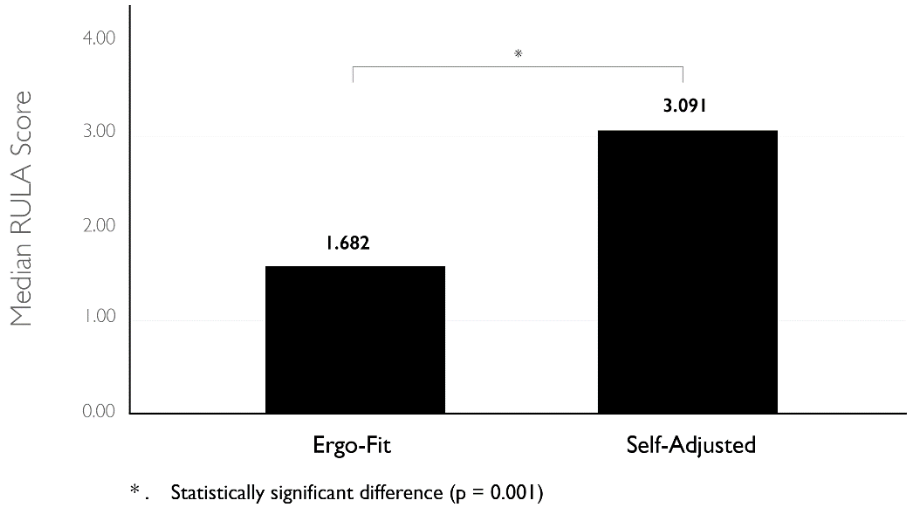

Figure 6.5. Median RULA Scores for E-F and S-A Configurations

6.5.6. RULA. A Wilcoxon signed-rank test was conducted to determine effect of workstation configuration on postural risks in seated work, as measured by RULA scores. The difference in RULA scores between the workstation configurations was approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. All 32 Ps had higher RULA scores in the S-A configuration, compared to the E-F configuration.

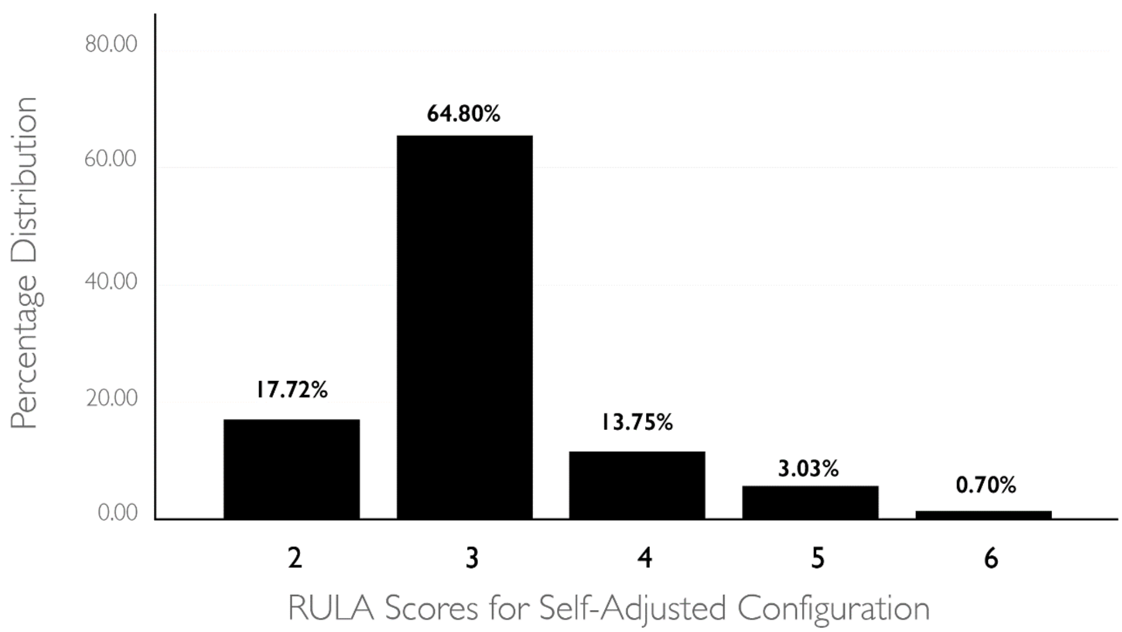

Figure 6.6. Percentage Distribution of RULA Scores in S-A Configuration

There was a statistically significant median increase in RULA scores (1.54) in seated work for the S-A configuration (3.09) compared to the E-F configuration (1.68), $z = 4.942$, $p < 0.0005$ (Figure 6.5). In case of the E-F configuration, 98.37% of the RULA scores were between 1 ~ 2, with the remaining 1.63% between 3 ~ 4. For the S-A configuration, 17.72% of the RULA scores were between 1 ~ 2, 78.55% between 3 ~ 4, and the remaining 3.73% between 5 ~ 6 (Figure 6.6).

Results suggest that RULA scores for the E-F configuration are associated with negligible risks and acceptable work posture, while those for the S-A configuration have higher risks with need for change in work posture. Higher RULA scores for the S-A configuration maybe attributed to non-neutral seated work postures including extension of the forearm, bending of the wrist, forward leaning of the trunk, rotation of the neck, and legs crossed-over at the ankles or at the knee (Figure 6.7).

Figure 6.7. Examples of Non-neutral Seated Postures in S-A Configuration

6.5.7. REBA. A Wilcoxon signed-rank test was conducted to determine the effect of workstation configuration on postural risks in standing work, as measured by REBA scores. The difference in REBA scores between the two workstation configurations was approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve. Of the 32 Ps, 16 Ps were subject to higher REBA scores in the S-A configuration compared to the E-F configuration, 12 Ps were subject to no change in REBA scores, and 4 Ps were subject to lower REBA scores. Data are medians unless otherwise stated. There was a statistically significant median increase in REBA scores (0.20) in standing work for S-A (1.60) compared to E-F configurations (1.10), $z = 3.038$, $p < 0.002$ (Figure 6.8).

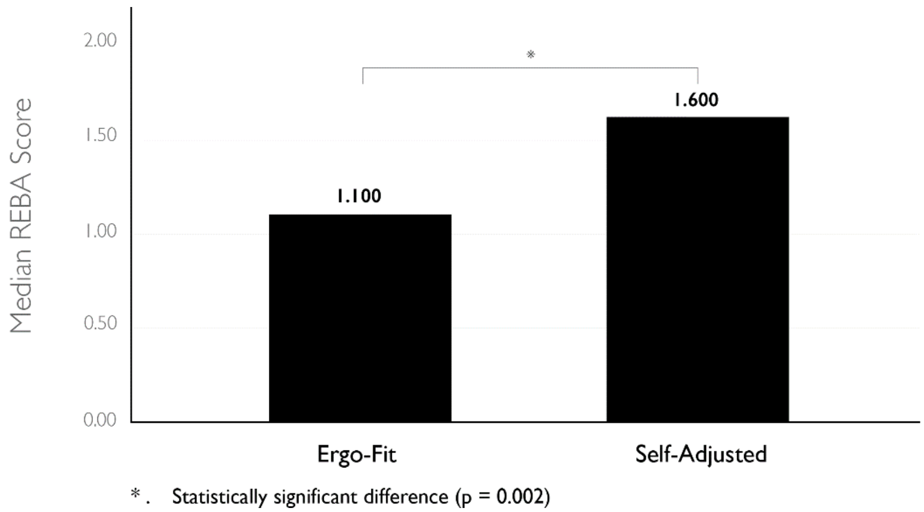

Figure 6.8. Median REBA Scores for E-F and S-A Configurations

In case of the E-F configuration, 99.44% of the REBA scores were between 1 ~ 2, and the remaining 0.56% between 3 ~ 4. For the S-A configuration, 90.27% of the REBA scores were between 1 ~ 2, and the remaining 9.73% between 3 ~ 4 (Figure 6.9).

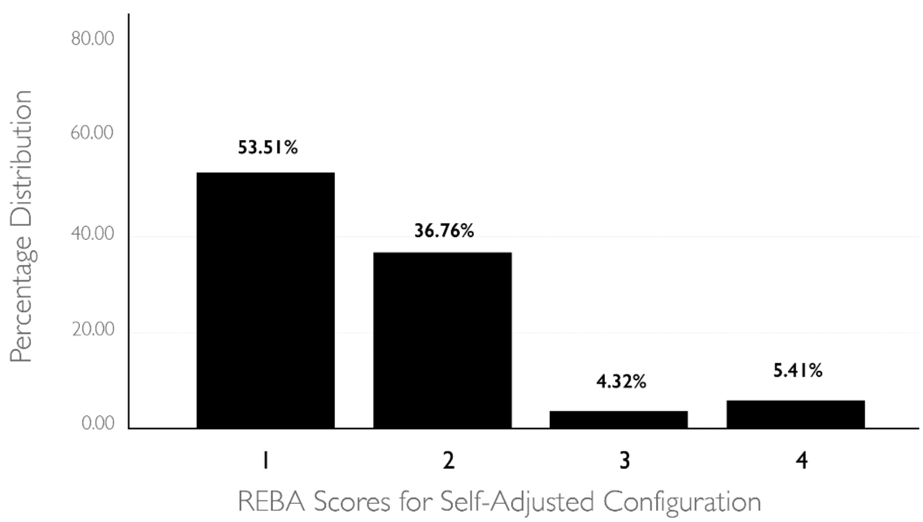

Figure 6.9. Percentage Distribution of REBA Scores for S-A Configuration

Results suggest that REBA scores for both work configurations have acceptable work posture associated with negligible risks, although the median value for the S-A configuration is higher. The higher REBA scores for the S-A configuration can be attributed to non-neutral standing work postures including forward leaning of the trunk, bending of the neck, and unstable standing postures with legs crossed over at the ankles (Figure 6.10).

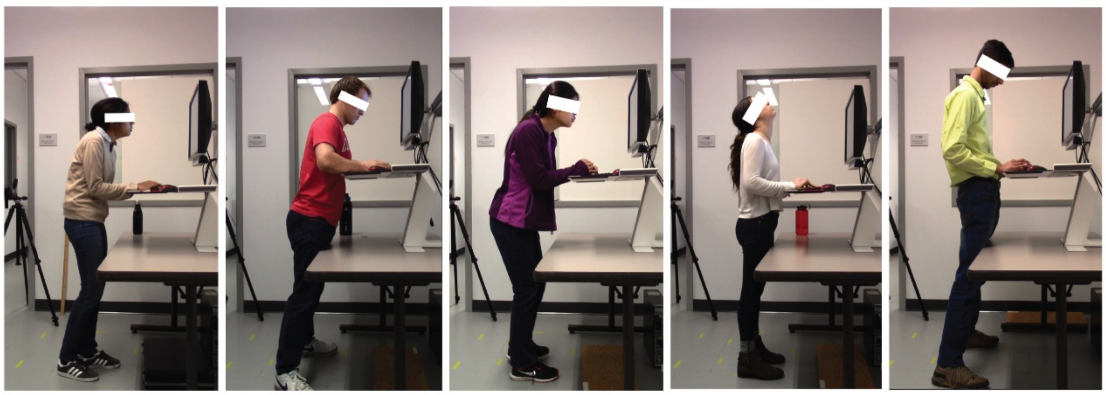

Figure 6.10. Examples of Non-neutral Standing Postures in the S-A Configuration

6.6. Discussion

6.6.1. Musculoskeletal discomfort. The results of the study do not confirm H1, i.e. there was no main effect of workstation configuration on change in self-reported musculoskeletal discomfort. Change in musculoskeletal discomfort was not higher in the E-F configuration compared to the S-A configuration. Prior research suggests beneficial reductions in musculoskeletal discomfort for the sit-stand-walk intervention as compared to sitting and standing work (Kar & Hedge, 2018). Results from this study indicate that for short-duration computer-based tasks using a sit-stand-walk intervention, workstation configuration does not impact musculoskeletal discomfort.

6.6.2. Fatigue. The results of the study do not confirm H2, i.e. there was no main effect of workstation configuration on change in self-reported fatigue. Change in fatigue was not higher in the E-F configuration compared to the S-A configuration. Prior research suggests reduced physical fatigue in the sit-stand-walk intervention as compared to sitting, standing and sit-stand work (Kar & Hedge, 2018). Results from this study indicate that for short-duration computer-based tasks using a sit-stand-walk intervention, workstation configuration does not impact fatigue.

6.6.3. Typing Speed. The results of the study confirm H3, i.e. there was a main effect of workstation configuration on typing speed. Typing speed for the E-F configuration was significantly lower compared to the S-A workstation condition. Specifically, the median difference in typing speed between workstation configurations was 6.012 characters/minute which translates to a difference of 3.36%. However, the magnitude of difference may not have practical implications for real-world computer-based office tasks. Previous research suggests no decrease in typing speed for short-duration computer-based office tasks when using a sit-stand-walk intervention as compared to sitting, standing and sit-stand work (Kar & Hedge, 2018). Results from this study indicate that for short-duration computer-based tasks using a sit-stand-walk intervention there is a main effect of workstation configuration on typing speed, i.e. typing speed is significantly lower for the E-F configuration. The difference in typing speeds may attributed to Ps being unfamiliar with the use of a lap-supported keyboard tray in the E-F configuration.

6.6.4. Typing Error. The results of the study confirm H4, i.e. there was a main effect of workstation configuration on typing error. Typing error for the S-A configuration was significantly lower compared to the E-F workstation condition. Specifically, the mean difference in typing error between workstation configurations was 0.669% (95% CI, -0.889 to -0.440). However, this magnitude of difference may not have practical implications for real-world computer-based office tasks. Previous research suggests no decrease in typing error for short-duration computer-based office tasks when using a sit-stand-walk intervention compared to sitting, standing and sit-stand work (Kar & Hedge, 2018). Results from this study indicate that for short-duration computer-based tasks using a sit-stand-walk intervention there is a main effect of workstation configuration on typing error, i.e. typing error is higher in the E-F configuration. The difference in typing errors may attributed to Ps being unfamiliar with the use of a lap-supported keyboard tray in the E-F configuration.

6.6.5. RULA Scores. The results of the study confirm H5, i.e. there was a main effect of workstation configuration on postural risks in seated work, as assessed by RULA scores. Ps in E-F configuration had significantly lower RULA scores compared to S-A configuration. Specifically, the median difference in RULA scores between the workstation configurations was 1.545. Results indicate that seated work in the S-A configuration was associated with greater postural risks, as indicated by a median RULA score of 3.090. Non-neutral work postures including extension of the forearm, bending of the wrist, forward leaning of the trunk, rotation of the neck, and legs crossed-over at the ankles or knee were frequently observed.

In contrast, seated work in E-F configuration had negligible postural risks, as indicated by a median RULA score of 1.545. There were few instances of non-neutral work postures; all Ps used the back rest while seated, legs were well supported and rarely crossed over. This finding is significant, since observational research on a sample of 1004 sedentary office workers revealed that when seated at work, fewer than 40% of workers used the back rest, and 47% of them leaned forward (Hedge, 2016). Also, the significantly higher RULA scores for S-A configuration are a cause for concern, since seated work constitutes 2/3rd of the sit-stand-walk duration and translates to a cumulative sitting for at least 5 hours/workday.

6.6.6. REBA Scores. The results of the study confirm H6, i.e. there was a main effect of workstation configuration on postural risks in standing work as assessed by REBA scores. Ps in E-F configuration had significantly lower REBA scores compared to S-A configuration. Specifically, the median difference in REBA scores between the workstation configurations was 0.200. Results indicate that standing work in the S-A configuration was associated with greater postural risks, as indicated by a median REBA score of 1.600. Non-neutral work postures including extension of the forearm, bending of the wrist, forward leaning of the trunk, forward leaning and flexion of the neck, and legs not adequately supported.

In contrast, standing work in the E-F configuration had lower postural risks, as indicated by a median REBA score of 1.100. There were very few instances of non-neutral work postures; all Ps used the recommended work surface height for standing work, legs were well supported and rarely crossed over. The higher RULA scores as compared to REBA scores are consistent with prior studies that indicate RULA to have greater sensitivity to detect prompt and critical action levels in comparison to REBA (Chowdhury et al., 2017; Kee & Karwowski, 2007).

6.6.7. Strengths. To provide adequate context of the results, the following strengths of the study need to be discussed. First, the study was conducted in a controlled laboratory that simulated an office work environment. Second, as far as the author is aware, this is probably the first study to use a sit-stand-walk intervention comparing two workstation configurations – an E-F configuration and an S-A configuration – with respect to musculoskeletal discomfort, fatigue, task productivity, and postural risks. Third, the repeated measures study was conducted with a robust sample size (n = 36); Ps were assigned to the two workstation configurations in a counterbalanced order. Finally, the adoption of a sit-stand-walk protocol using an E-F workstation demonstrates a potentially optimal solution combining postural variability and physical activity with ergonomic fit to offer a safe and healthy alternative to sedentary, desk-based office work.

6.6.8. Limitations. On the other hand, these strengths incorporate some limitations as well. First, Ps performed a two 30-minute transcription tasks. The short-duration transcription task may not offer ecologically valid results for computer-based office tasks generalizable across a workday. Second, Ps were a convenience sample of college students who were relatively young, and not obese. Generalizing results to the office working population may be limited as the dependent variables may be affected by worker demographics such as age and obesity. Third, Ps had no prior experience using SSWs, and were provided with 10-minutes to familiarize with each workstation configuration. A longer familiarization time may impact the dependent variables. Fourth, musculoskeletal discomfort and fatigue were self-reported; use of objective measures in combination with self-report could increase the robustness of the research claims. And finally, Ps were not provided knowledge and/or training in ergonomics prior to the study; especially for the S-A configuration, Ps had to setup their workspace without any guidance from the researcher.

6.7. Conclusion

The major contribution of this study is the determination of the beneficial effect in using a customized workstation with ergonomic fit for a sit-stand-walk intervention in short-duration computer-based work. Results suggest that compared to S-A configuration, E-F configuration was associated with significant reduction in postural risks for both seated and standing work. In addition, the E-F configuration had no detrimental effect on self-reported musculoskeletal discomfort and fatigue. While, transcription task productivity was significantly lower in E-F configuration, the magnitude of the difference may not impact real-world productivity for computer-based tasks. Finally, this study provides evidence for benefits in adoption of an ergonomically-fit, custom-designed SSW that enables workers using a SSWI to optimize postural variability and increase physical activity in computer-based office work.

Future work should involve expanding the duration of the experiment to simulate a complete workday. Musculoskeletal discomfort and fatigue should be quantified using objective measures. The study should be replicated in field settings with office workers, to investigate if the results from the controlled laboratory settings translate to real-world office work environments. Findings from this study should inform the next stage of empirical research investigating the potential benefits in adopting a sit-stand-walk intervention to address the challenges of health, well-being and productivity in sedentary office work.

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CHAPTER 7

DISCUSSION

The focus of this dissertation was in designing, testing and validating a SSWI that combined sit-stand postural transitions with frequent, short bouts of light intensity physical activity. The series of studies of the SSWI were able to demonstrate reductions in musculoskeletal discomfort and fatigue, without negatively impacting task productivity in computer-based office work. In this concluding chapter, findings from the previous studies are consolidated, their collective strengths and limitations discussed, and future directions for research envisioned. In addition, the design implications for transforming the static, unhealthy, sedentary office into an active, healthy, movement-oriented workplace is outlined.

7.1. Musculoskeletal Discomfort

Self-reported musculoskeletal discomfort was measured using a modified version of the Nordic musculoskeletal questionnaire (Kuorinka et al., 1987) administered at baseline ($t = 0$ min), at the middle point ($t = 30$ min) and at the end of the experiment ($t = 65$ min). The present analysis has considered change in musculoskeletal discomfort scores between end of experiment ($t = 65$ min) and baseline ($t = 0$ min); future work should look at the progression of musculoskeletal discomfort across the three temporal reference points.

Results from the Ahmedabad and Ithaca cohort studies indicate that participants in the sit-stand-walk intervention reported reductions in mean musculoskeletal discomfort by 4.9% and 3.0% respectively, when compared to baseline values. In contrast, participants in the seated work condition reported increased mean musculoskeletal discomfort by 8.6% and 6.5% respectively, when compared to baseline values. A similar trend was observed for participants in the standing work condition who reported increased mean musculoskeletal discomfort by 15.20% and 9.93% respectively, when compared to baseline values.

Consistent with previous scientific literature, findings from the Ahmedabad and Ithaca cohort studies suggest that prolonged seated and standing work resulted in increased musculoskeletal discomfort (Baker et al., 2018; Le & Marras, 2016; Gallagher & Callaghan, 2015; Nelson-Wong et al., 2008; Rempel et al., 2006; Gerr et al., 2002). Prior studies report beneficial reductions in musculoskeletal discomfort associated independently with SSW use (Karakolis & Callaghan, 2014; Nevala & Choi, 2013) and with use of active work breaks (Waongenngarm et al., 2018). Building on evidence from prior research, the Ahmedabad and Ithaca cohort studies demonstrate that adoption of a sit-stand-walk intervention – combining sit-stand postural transitions with frequent, short bouts of light-intensity physical activity – can lead to beneficial reductions in musculoskeletal discomfort for short-duration computer-based work.

7.2. Physical Fatigue

Physical fatigue was measured using a visual analog fatigue scale administered at baseline (t = 0 min), at the middle point (t = 30 min) and at end of the experiment (t = 65 min). The present analysis has considered change in physical fatigue scores between the end of experiment (t = 65 min) and the baseline (t = 0 min); future work should look at progression of physical fatigue across the three temporal reference points. Results from the Ahmedabad and Ithaca cohort studies indicate that participants in the sit-stand-walk intervention reported reduction in mean physical fatigue by 0.81% and 4.71% respectively, when compared to baseline values. In contrast, participants in the seated work condition reported increase in mean physical fatigue by 16.31% and 15.96% respectively, when compared to baseline values. A similar trend was observed for participants in the standing work condition who reported an increase in mean physical fatigue by 37.63% and 14.13% respectively, when compared to baseline values.

Consistent with previous scientific literature, the Ahmedabad and Ithaca cohort studies demonstrate that prolonged seated and standing work result in increased levels of physical fatigue (Garcia et al. 2015; Halim et al., 2012; Hansen et al., 1998, Straker et al., 1997). Prior studies have indicated beneficial reductions in physical fatigue associated independently with SSW use (Thorp et al., 2014; Nevala & Choi, 2013; Hedge et al., 2004; Hasegawa et al., 2001) and with use of active work breaks (Tucker, 2003; Kopardekar & Mital, 1994). Building on the evidence from prior research, findings from the Ahmedabad and Ithaca cohort studies suggest that the adoption of a sit-stand-walk intervention – combining sit-stand transitions with frequent, short bouts of light-intensity physical activity – can lead to beneficial reductions in physical fatigue for short-duration computer-based work.

7.3. Mental Fatigue

Mental fatigue was measured using a visual analog fatigue scale administered at baseline (t = 0 min), at the middle point (t = 30 min) and at the end of the experiment (t = 65 min). The present analysis has considered change in mental fatigue scores between end of experiment (t = 65 min) and baseline (t = 0 min); future work should look at progression of mental fatigue across the three temporal reference points. Results indicate that participants in the sit-stand-walk intervention reported an increase in mean mental fatigue by 5.25% for the Ahmedabad Cohort and a reduction in mean mental fatigue by 1.04% for the Ithaca cohort, when compared to baseline values. In contrast, participants in the seated work condition for Ahmedabad and Ithaca cohorts reported increase in mean mental fatigue by 17.31% and 24.73% respectively, when compared to baseline values. A similar trend was observed for participants in the standing work condition who reported increase in mean mental fatigue by 23.62% and 12.12% respectively, when compared to baseline values.

Prior studies have indicated beneficial reductions in mental fatigue associated independently with SSW use (Wennberg et al., 2016) and with adoption of active work breaks (Engelmann et al., 2011). Building on evidence from prior research, findings from the Ahmedabad and the Ithaca cohort studies suggest that the adoption of a sit-stand-walk intervention – combining sit-stand postural transitions with frequent, short bouts of light-intensity physical activity – can reduce mental fatigue in short-duration computer-based work.

7.4. Productivity

Productivity for the typing transcription task was measured in terms of typing speed (characters/minute) and typing error (%). Results indicate that productivity for participants in the sit-stand-walk intervention did not differ significantly, when compared to participants in the seated and standing work conditions. Consistent with previous scientific literature, findings from the Ahmedabad and the Ithaca cohort studies demonstrate that productivity in short-duration computer-based work does not differ significantly between seated and standing work postures (Schwartz et al., 2018; Russel et al., 2016). Prior research indicates no effect of productivity associated independently with SSW use (Karakolis & Callaghan, 2014) and with the use of active work breaks (Waongenngarm et al., 2018). Building on evidence from prior research, findings from the Ahmedabad and the Ithaca cohort studies suggest that the adoption of a sit-stand-walk intervention – combining sit-stand postural transitions with frequent, short bouts of light-intensity physical activity – does not reduce productivity in short-duration computer-based work.

7.5. Sitting Time

In all three laboratory-based, controlled studies, the use of a 20-8-2 sit-stand-walk protocol resulted in 1/3rd of the occupational sitting time being replaced by light-intensity physical activity in the form of standing and walking. While studies were limited to a 60-minute experimental duration, extrapolating the sit-stand-walk intervention over a 7 ½ hour workday translates to 5 hours of seated work, 2 hours of standing work, and 30 minutes of walking (Figure 7.1). In theory, seated work is reduced by 150 minutes, which equates to a 33.34% reduction in sitting time. This compares favorably with field-based studies of sit-stand workstation use which have reported reductions in sitting time by 20 ~ 30% (Dutta et al., 2014; Davis & Kotowski, 2014; Alkhajah et al., 2012). The sit-stand-walk intervention ensured that not only was total sitting time reduced by one-third, but also that uninterrupted sitting durations were limited to a 20-minutes. This is a significant finding, since recent studies have shown evidence for improved cognitive performance, reduced risks for cardio-metabolic diseases, improved cardio-vascular health associated with short, frequent breaks from sitting at work (Carter et al., 2018; Fuezeki et al., 2017; Mailey et al., 2016; Bailey & Locke, 2015).

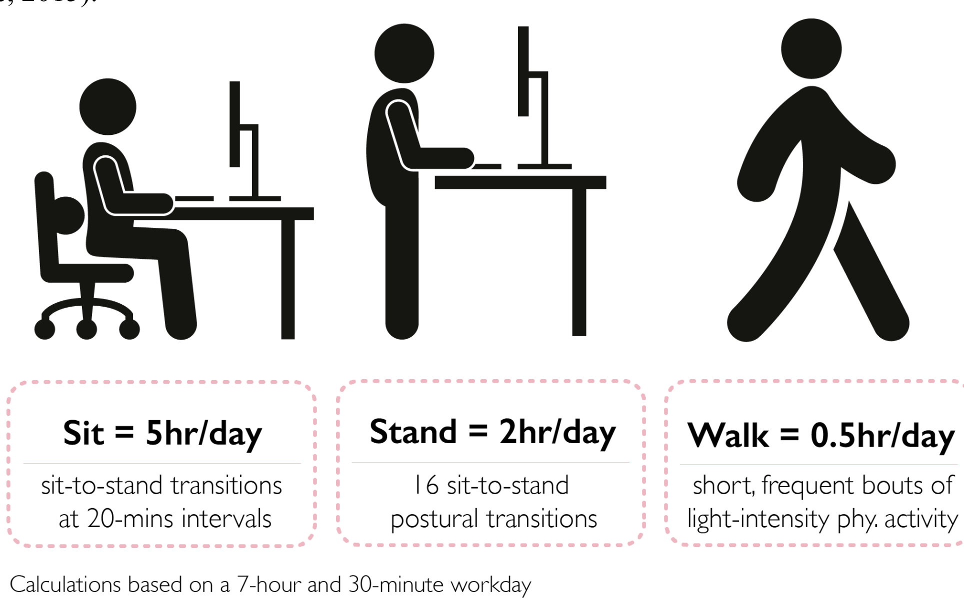

Figure 7.1. Extrapolating the Sit-Stand-Walk Intervention to a Workday

7.6. Physical Activity

Physical activity was not measured objectively, but was inferred from the duration of light-intensity physical activity attributed to 8-minutes of standing and 2-minutes of walking as part of the sit-stand-walk intervention. Prior studies have reported a moderate increase in energy expenditure associated with standing, when compared to sitting (Saeidifard et al., 2018). Also, walking is classified a light-intensity physical activity by the *American College of Sports Medicine* (Ainsworth et al., 2000). In all the three laboratory-based studies, two of which were conducted in Ithaca, NY and one in Ahmedabad, India, participants in the sit-stand-walk intervention were engaged in light-intensity physical activity for 1/3rd of their experimental duration; they were seated for the remainder of the experiment.

While the experimental duration was limited to 60-minutes, extrapolating the sit-stand-walk intervention over a 7 ½ hour workday translates to 2-hours and 30-minutes of light-intensity physical activity. In theory, the increase in physical activity attributed to the sit-stand-walk intervention is in tune with recommendations to accumulate at least 2-hr/day of standing and light walking during a workday (Buckley et al., 2015). The sit-stand-walk intervention involves 16 instances of sit-stand postural transitions and 32-minutes of walking over a workday; thereby increasing the gravity stimulus (Vernikos, 1996), and elevating energy expenditure to counteract positive energy balances associated with sedentary office work (Tudor-Locke et al., 2014).

While prior studies indicate no increase in physical activity for the SSW intervention, when compared to the sitting work condition (Karakolis & Callaghan, 2014), preliminary evidence from this research suggests that the use of a sit-stand-walk intervention may increase light-intensity physical activity in computer-based office work. This is an important finding, since recent studies have shown that short, frequent bouts of light-intensity physical activity at 30-minute intervals across the workday are associated with significant health and performance benefits. These benefits include: increased cerebral blood flow (Carter et al., 2018; Greene et al., 2017), improved lipoprotein lipase (LPL) regulation (Hamilton et el., 2007), reduced glycemic variability (Wheeler et al., 2017; Bailey & Locke, 2015; Duvivier et al., 2013), improvements in cardio-metabolic and cardio-vascular health (Fuezeki et al., 2017; Mailey et al., 2016; Bailey & Locke, 2015; Thosar et al., 2015; Larsen et al., 2014), enhanced cognitive performance and creativity (Wheeler et al., 2017; Oppezzo & Schwartz, 2014; Ratey & Loehr, 2011), and a reduction mortality risk (Hagger-Johnson, et al., 2016; Pulsford et al., 2015).

7.7. Participant Gender

These three studies investigated the potential role of gender as a moderator between the work condition and the dependent variables. A prior study by Karakolis and colleagues (2016) used SSWs with a 3:1 sit-stand ratio for a 60-minute duration to report an interaction of gender with work condition – females reported higher musculoskeletal discomfort during seated work, while males reported higher musculoskeletal discomfort during standing work. The authors conjectured that the difference in musculoskeletal discomfort scores could be because males adopted a much more extended lumbar posture in standing, compared to a more neutral posture in the case of females. In contrast, these three studies using the sit-stand-walk intervention for a 60-minute duration did not report an interaction of gender and work condition. The differences in experimental design, study settings, sit-stand ratios, participant demographics, and intervention characteristics makes it difficult to effectively compare the research findings and generalize results.

7.8. Anthropometric Fit

The third study, investigating the effect of workstation configuration on the dependent variables demonstrated that the use of custom-designed, ergonomically-fit, SSWs enabled participants to adopt a safe and neutral work posture, optimized sit-stand transitions, and increased physical activity and movement in computer-based office work. Prior studies report that office workers provided with SSWs often select workstation setups that do not conform to the recommended ergonomic guidelines (Lin et al., 2016; Asundi et al., 2011), thereby resulting in non-neutral work postures (Hedge et al., 2005), and increased risks for musculoskeletal disorders (Marcus et al., 2002; Demure et al., 2000; Sauter et al., 1991). Studies have also indicated that when office workers are provided with an adjustable work environment that is coupled with an ergonomics training program, they report significant reductions in musculoskeletal symptoms (Robertson et al., 2008; Robertson & O'Neill, 1999; Nerhood & Thompson, 1994). Additionally, by enabling office workers to have control over the work environment through workstation adjustability and knowledge of ergonomics may enhance worker productivity, health and well-being (Robertson & Huang, 2006; O'Neill, 1994). Consistent with previous scientific literature, findings from the workstation configuration study demonstrate that a custom-fit workstation configuration is associated with significantly lower postural risks, compared to a user-adjusted workstation configuration.

7.9. Cross-cultural Ergonomics

The Ahmedabad and Ithaca cohort studies replicated the same experiment in two different locations to investigate if cross-cultural and geographical differences in participant demographics would impact the dependent variables. Findings from both studies consistently indicate significant reductions in musculoskeletal discomfort, physical fatigue and mental fatigue for the sit-stand-walk intervention, when compared to the seated and the standing work conditions, respectively. However, typing speed was significantly higher and typing error significantly lower for the Ithaca cohort, compared to the Ahmedabad cohort. The difference in typing productivity could be attributed to the fact that English is not the first language for participants in the Ahmedabad, India cohort. The sit-stand-walk intervention studies were replicated in two culturally and geographically distinct locations to investigate if differences in participants demographics such as: anthropometry, physiology, language, culture and bodily practices would impact dependent variables.

Most ergonomic studies in the past have been limited to chair-sitting populations in

North America and Western Europe (Chapanis, 1974) even though alternatives to chair-sitting are prevalent in North Africa, the Middle East, India, South-East Asia and parts of Korea, Japan and Polynesia (Bridger, 1991). In fact, anthropological studies indicate that humans are capable of more than a thousand body positions (Hewes, 1957), and floor sitting postures such as squatting, kneeling and sitting cross-legged are prevalent even today in many non-western cultures, particularly in India (Cranz, 1998; Gurr et al., 1998; Chakrabarti, 1997; Sethi, 1989; Singh & Wason, 1988; Sen, 1984; Daftuar, 1974).

These floor sitting postures shaped by the interaction of the body, culture and behavior (Cranz 1998; Hewes, 1967), impact the physiology of seated work (Sen, 1984) and necessitate different range of motion requirements (Mulholland & Wyss, 2001). In addition, the global increase in sedentary behavior and physical inactivity, especially in countries such as China, Brazil and India (Ding et al., 2017) necessitate research on non-chair based sedentary behaviors. Future studies should investigate non-chair sedentary work postures prevalent in many non-western cultures.

7.10. Collective Strengths

To provide adequate context, following strengths of these studies are discussed. First, experiments were conducted in controlled laboratory conditions that simulated an office work environment. The first study was conducted in the Ergonomics Laboratory at the National Institute of Design, Ahmedabad, India where the illumination level was maintained at 450 lux, the ambient air temperature was kept between 30°C ~ 35°C, and relative humidity was maintained between 55% ~ 65%. The room was naturally ventilated with a pedestal fan providing forced-air cooling. The second and third studies were conducted in the Human Performance & Ergonomics Laboratory at Cornell University, Ithaca, United States where illumination level was maintained at 500 lux, the ambient air temperature was kept between

23°C ~ 27°C, and relative humidity was maintained between 45% ~ 50%.

Second, all three studies had a robust sample size with participants from the working age population performing computer-based transcription tasks for 1-hr in one work condition. For the first and second studies, a between-participants research design was used with 80 and 100 participants in the Ahmedabad and Ithaca cohorts, respectively. For the third study, a within-participants research design was used; 36 participants performed typing transcription tasks for 1-hr each in both of the workstation configurations. For all three studies participants were at least 18 years old, had prior experience with computer typing in English, were not obese, reported no history of chronic musculoskeletal health complaints, and exercised frequently.

Third, the Ahmedabad and Ithaca cohort studies compared five workstation conditions: sit-stand, stand-sit, sitting, standing and sit-stand-walk across four dependent variables – musculoskeletal discomfort, physical fatigue, mental fatigue and task productivity. While prior studies have compared sit-stand work to seated and standing work; this research may be the first to compare a sit-stand-walk intervention with seated, standing and sit-stand work, with respect to dependent variables such as musculoskeletal discomfort, physical fatigue, mental fatigue, and productivity.

Fourth, the Ahmedabad and Ithaca cohort studies investigated the potential role of participant gender as a moderator between the work conditions and the dependent variables. Findings from both the Ahmedabad and the Ithaca cohort studies indicate: neither an interaction between gender and work condition on dependent variables; nor a main effect of gender on dependent variables. These findings should be seen in context of the fact that the experimental duration was limited to a 60-minute typing transcription task; the use of longer experimental durations may offer insights into the potential role of gender as a moderator.

Fifth, the sit-stand-walk intervention was tested in two workstation configurations – a self-adjusted setup (Self-Adjusted) and a custom-designed, ergonomically-fit setup (Ergo-Fit). Results from the workstation configuration study suggest that compared to the Self-Adjusted configuration, the Ergo-Fit configuration was associated with a significant reduction in postural risks for both seated and standing work. In addition, the Ergo-Fit configuration had no detrimental effect on self-reported musculoskeletal discomfort and fatigue. However, the Self-Adjusted configuration had significantly higher productivity compared to the Ergo-Fit configuration.

Sixth, the 20-8-2 sit-stand-walk intervention was able to demonstrate the benefits of combining sit-stand postural transitions with short, frequent active breaks to reduce sitting time and increase light-intensity physical activity. Compared to seated and standing work, participants in the sit-stand-walk intervention reported significantly lower musculoskeletal discomfort, physical fatigue, and mental fatigue, without any effect on task productivity. The Ahmedabad and Ithaca cohort studies could be the first to demonstrate the feasibility of combining SSWs with active breaks for short-duration computer-based work.

Seventh, the 20-8-2 sit-stand-walk intervention maybe an optimal ratio for SSW use, enabling sedentary office workers to engage in at least 2-hr of standing and light-intensity physical activity over a workday. This is an important finding, because there are no accepted optimal sit-stand usage ratios which balance the need for health and productivity in computer-based work. The 20-8-2 sit-stand-walk ratio builds on prior evidence for the benefits of sit-stand postural transitions (Davis & Kotowski, 2014; Karakolis & Callaghan, 2014) and combines it with the advantage of taking short, frequent active breaks (Waongenngarm et al., 2018) to demonstrate a practically viable and beneficial alternative to sedentary work.

Eight, the studies investigated whether the sequence of the postural change: Sit-to-Stand or Stand-to-Sit, impacted the dependent variables. Results suggest that the Sit-to-Stand sequence reported marginally greater musculoskeletal discomfort and physical fatigue compared to the Stand-to-Sit sequence, though the magnitude of the difference was not statistically significant. The Stand-to-Sit sequence reported marginally higher mental fatigue compared to the Sit-to-Stand sequence. Since these two work sequences used the same 1:1 sit-stand ratio, preliminary results suggest that the sequential order of postural change does impact the dependent variables. However, results suggest that the propagation and magnitude of musculoskeletal discomfort, physical fatigue, and mental fatigue may vary as a function of the sequence of the work postures adopted. These findings have implications for designing optimal sit-stand ratios – both in terms of the durations for each work posture and the temporal sequence in which seated and standing work are arranged.

And finally, the study was replicated in two locations – Ahmedabad, India and Ithaca, United States, to investigate if cross-cultural differences in participant demographics and geography impacted the dependent variables. The cross-cultural study was necessary since an overwhelming majority of prior research on workplace ergonomics have been based on populations in North America and Western Europe, while a majority of the global working population in the near future is projected to be predominantly from countries such as India, China, Nigeria (UN, 2017). Comparing results from the Ahmedabad and the Ithaca cohorts reveal consistent trends such as reports for significantly lower musculoskeletal discomfort, physical fatigue and mental fatigue for the sit-stand-walk intervention compared to seated and standing work. Task productivity as operationalized by typing speed and typing error was not impacted by the work condition. However, in case of the workstation configuration study transcription task productivity was lower for the Ahmedabad cohort compared to the Ithaca cohort, potentially due to the fact that English is not the first language for participants in India.

7.11. Collective Limitations

On the other hand, these studies incorporate some limitations as well

First, in all three studies, participants performed two 30-minute, typing transcription tasks. These results from the short-duration typing transcription task may not be generalizable for computer-based tasks across an eight-hour workday.

Second, the Ahmedabad and the Ithaca cohort studies used a between-participants designs with participants randomly assigned to one of five work conditions. While a between-participants design avoids the carry-over effects which are associated with a within-participants design, there can be limitations due to individual variability and assignment bias.

Third, participants were a convenience sample of college students who were mostly young, not obese, and exercised frequently. Generalizing research findings to represent the office working population may be limited, since results may be affected by age, obesity and exercise habits of the participant sample.

Fourth, participants had no prior experience in use of SSWs and were provided with only 10-minutes to familiarize themselves with seated and standing work. A longer time-frame for participants to familiarize with the work conditions could have impacted the dependent variables of the study.

Fifth, dependent measures such as musculoskeletal discomfort, physical fatigue, and mental fatigue were self-reported; use of objective measures could increase the robustness of the research design.

Sixth, while the sit-stand-walk work condition involved a 2-minute walk with a plausible increase in light-intensity physical activity, there was no objective measure of physical activity to validate this claim.

Seventh, all three studies used a typing transcription task which is an accepted, reliable and valid measure of task productivity. However, the use of a typing transcription task is not representative of the range of computer-based work performed by a worker across a workday.

Eight, participants in the three laboratory-based studies followed the work condition protocols as instructed by the researcher. Therefore, the research findings do not necessarily translate to real-world field-settings since participants' compliance with the sit-stand-walk intervention is impacted by factors such as training, attitudes, motivation, and incentives, as

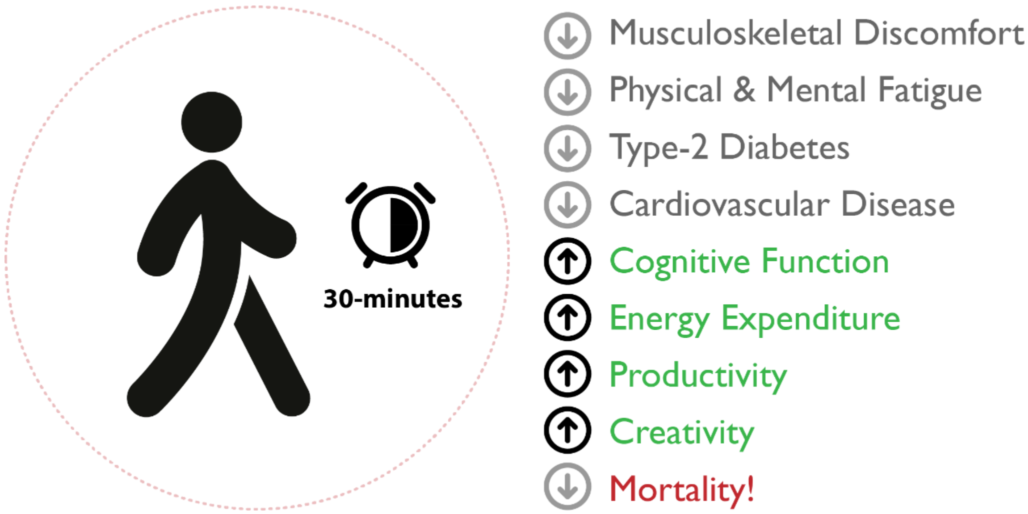

Figure 7.2. Benefits of short, frequent bouts of walking, every 30-minutes

well as the nature of leadership and the organizational culture of the workplace. And finally, the short-duration of the transcription task may not have been sensitive enough to account for the potential role of gender as a moderator. A longer duration of the experiment should help to uncover gender differences, if any, and their impact on the dependent variables.

7.12. Sit-Stand-Walk – Implications for Productivity

The logic of the sit-stand-walk intervention builds on an array of recent epidemiological studies that indicate improved health outcomes associated with regularly scheduled, short, intermittent bouts of light-intensity physical activity (LIPA) distributed across the workday. Studies have demonstrated that breaking-up sitting with frequent, short bouts of LIPA (such as standing up and walking), can reduce musculoskeletal discomfort and fatigue (Thorp et al., 2014), lower sedentary time (Mailey et al., 2016), marginally increase energy expenditure (Saeidifard et al., 2018; Hagger-Johnson et al., 2016), improve cardio-vascular health (Thosar et al., 2015; Restiano et al., 2015; Larsen et al., 2014), improve cardio-metabolic health (Wheeler et al., 2017; Bailey & Locke, 2015; Hamilton et al., 2007), improve brain function (Siddarth et al., 2018; Carter et al., 2018; Greene et al., 2017), protect against cognitive decline in older adults (Wheeler et al., 2017; Falck et al., 2017; Ratey & Loehr, 2011) and reduce risk of mortality associated with uninterrupted sedentary behaviors (Fuezeki et al., 2017; Hagger-Johnson et al., 2016). In addition, there is evidence that intermittent movement improves cognitive function and enhances creativity (Ratey & Loehr, 2011; Oppezzo & Schwartz, 2014) (Figure 7.2).

From the perspective of evolutionary biology, breaking up seated work with regularly scheduled, short, intermittent bouts of LIPA can enable office workers to synchronize their bodies and minds with temporal cycles of work and rest, the origins of which can be traced back to hunter-gatherer lifestyles in early humans (Levine, 2014). The specific contribution of this dissertation is to demonstrate the feasibility of breaking up seated work with intermittent LIPA, without negatively impacting computer-based task productivity. Thus, the sit-stand-walk intervention translates findings from public health research into a viable, and potentially optimal, 20-8-2 sit-stand-walk ratio, which has been experimentally proven to reduce sitting time and improve health outcomes, without negatively impacting productivity in computer-based work.

7.13. Sit-Stand-Walk – Implications for Workplace Design.

These research findings can work as a catalyst in enabling office workers to transition from a static, un-healthy sedentary office towards an active, healthy, movement-friendly workplace. This involves changes - both in terms of the design of the physical environment, as well as in addressing need for engaging in behavior change. Specific implications for workplace design are elucidated below:

7.13.1. Design of Workstations. The adoption of a healthy, active, movement-friendly workspace necessitates substantial changes to the hardware of the office which includes office furniture, computing technologies and accessories. Fixed height desks need to be replaced with SSWs – these may be variable-height workstations (as in the Ahmedabad and Ithaca cohort studies), or may be fixed-height workstations with an elevated task chair for seated work (as in the workstation configurations study). While there is no consensus on which of these two options is more viable and facilitates ease of postural transitions, there is need to custom-fit the workstation to the workers' anthropometrics. In addition, the adjustability of the task chair needs to consider the workers' anthropometrics, and workers need to be trained to ensure a neutral posture during seated work (ANSI/HFES 2007). The use *active seating* and *active standing* equipment should be considered, given that preliminary studies indicate that these promote concurrent physical activity without negatively impacting task productivity (Kar et al., 2017; Koren et al., 2016; Torbeyns et al., 2014). The use of floor mats may reduce musculoskeletal discomfort in the lower limbs during standing work and maybe used with SSWs (Dutta et al., 2014).

Currently, computer equipment and accessories for the office are designed to be used primarily in the seated work posture. There is need to redesign office equipment by considering the anthropometric variability between seated and standing work postures. As a case in point, the design of the existing computer monitor used for the experiments allowed for a range of 115 mm for height adjustment. This range of adjustability was insufficient for standing work; therefore, an additional 150 mm in height had to been provided. The keyboard tray and the mouse pad were positioned on the work surface or on the keyboard tray (for the workstation configuration study); however prior research indicates that the use of a negative-tilt keyboard may be beneficial for computer-based office work in seated and standing postures (Hedge et al., 2005).

7.13.2. Temporality in the Design of Work. The adoption of a sit-stand-walk intervention for computer-based office work builds on previous research that optimized work-rest cycles for workers engaged in manually intensive occupations (Christensen et al., 2000; Wood et al., 1997; Janaro & Bechtold, 1985; Ray, 1961). The unique contribution of this research is in demonstrating the feasibility of an optimum work-rest-activity cycle for computer-based work. However, the successful adoption of the sit-stand-walk intervention is contingent upon redesigning tasks based on recognizing the temporal need to interrupt seated-based work at ~ 20-minute intervals. Practical barriers to the adoption of active work breaks in the office exist due to prevailing attitudes and norms towards productivity, and the need to be *'seen'* to be doing work.

There is need to communicate the benefits of short, frequent, intermittent work breaks both to the employees and to the management. Computer-based tasks have to be re-aligned by including cycles of intermittent standing and movement in the sedentary office. This would necessitate compartmentalizing work into "activity chunks" of about 30-minute durations, and in parallel working on incorporating standing and movement through activities such as stand-biased meetings, walking discussions and other forms of active engagements (Buckley et al., 2015; Tudor-Locke et al., 2014). Future research should consider ways to motivate workers to engage in intermittent standing and movement in the office. The critical challenge is to create movement friendly workplaces which incorporate successful environmental and behavioral innovations to enhance and preserve worker health.

7.13.3. Design for Behavior Change. The adoption of SSWs for office work has had mixed results – while over 90% of offices in Scandinavia have implemented SSWs, barely

10% of users report to have used the sit-stand function at least once a day (Wilks et al., 2006). Installation of the physical hardware of SSWs is just one part of the puzzle to reduce sedentary behaviors in the office; training and motivating workers to shift to an activity-oriented, movement-friendly culture of work is equally important. There is need to investigate frameworks such as the *Behavior Model for Persuasive Design* (Fogg, 2009) that can enable workers to: (a) be sufficiently motivated to interrupt seated work with intermittent light-intensity physical activity, (b) have the ability to perform the desired behavior, and (c) be triggered to perform the behavior.

Models of behavior change investigated in fields such as behavioral economics, communication design, and organizational psychology should be considered in light of the 'wicked' problem of nudging workers to be more active. Besides investigating frameworks for behavior change, there is need for research to investigate how environmental cues, affordances and prompts can 'nudge' office workers to adopt postural variability and movement in the sedentary office. Recent studies have demonstrated the benefits of using software-based prompts to induce postural variability and reduce sitting time (Barbieri et al., 2017, De Cocker et al., 2015; Donath et al., 2015; Swartz et al., 2014). In future, there is need for studies on behavioral perceptions and long-term compliance to office work that includes regular bouts of standing and light-intensity physical activity.

7.13.4. Design Standards and Guidelines. While research findings on SSW interventions for office work have been reported over the past three decades, currently there are no ergonomic guidelines for the safe, effective and optimal use of SSWs. At present, SSW interventions are based off existing standards for computer-based office work (ANSI/HFES 2007) and standing-based industrial work (ILO, 2011; NIOSH, 1997). There is need for a dedicated ergonomic standard for SSW use that integrates the requirements for anthropometric fit, postural variability, physical activity and task productivity.

In addition, the introduction of SSWs in the workplace necessitates the updating of standards for ambient lighting, and for calculating the Heating, Ventilation and Air Conditioning (HVAC) requirements for the movement-friendly office. This is because ambient lighting levels are calculated based on the work surface height - currently set to the seated work height (usually 750 mm above finished floor level). Ambient lighting calculations need to be revised by considering the variability in work surface heights introduced due to seated and standing work.

HVAC calculations for office environments are based on metabolic heat produced while in a seated work posture. However, the adoption of a sit-stand-walk intervention is assumed to increase metabolism levels and correspondingly increase the heat produced. Laboratory based tests reveal that energy expenditure as measured by METs is the least in sitting (1.29 ± 0.19 kcal/kg/hr), marginally higher in standing (1.41 ± 0.22 kcal/kg/hr), and significantly higher in sitting interrupted by movement (1.91 ± 0.24 kcal/kg/hr) (Fountaine et al., 2016). The additional heat produced by standing and movement needs to be factored in the revised HVAC calculations for an activity-oriented, movement-friendly workplace. Also, as more research findings on active workstations emerge, occupational health and workplace safety guidelines need to be updated to incorporate optimal work-rest-activity cycles that offer health, well-being and productivity.

7.13.5. Architectural & Interior Design. The design of movement-friendly workplaces necessitates rethinking the spatial layout and circulation patterns in office environments. The aim of the redesign should be to enable intermittent bouts of purposeful and non-purposeful movements throughout the workday. These include movements induced by (a) computer-based prompts, (b) personal motion-assessment devices, (c) placement of staircases, toilets, kitchens and meeting places on different floors, (d) stair-use promotions, (e) standing meetings, and (f) messages delivered in person (Levine, 2014). The adoption of SSWs for the sedentary office necessitates increase in the floor-space-per-person due to two main considerations: (a) increase in spatial requirements to account for both seated and standing work, and (b) increase in use-able ambulatory space to enable light-intensity physical activity and movement. In addition, furniture, equipment, and interior design should creatively build in environmental affordances and behavioral nudges to induce movement and light-intensity physical activity at work.

7.13.6. Ergonomics Training. As evidenced from findings of the third study, ensuring an anthropometric fit between the office worker and the SSW is crucial for a successful sit-stand-walk intervention. Prior studies have reported that when office workers were provided with an adjustable work environment coupled with an ergonomics training program, significant reductions in musculoskeletal symptoms was observed (Robertson et al., 2008; Robertson & O'Neill, 1999; Nerhood & Thompson, 1994). Additionally, by enabling office workers to have control over the work environment through workstation adjustability and ergonomics knowledge may enhance worker productivity, health and well-being (Robertson & Huang, 2006; O'Neill, 1994). Introducing SSWs for office work should include a comprehensive ergonomics training program for the office workers, and ensure anthropometric fit to enable office workers to perform work in correct, neutral work postures.

7.13.7. Organizational Culture. The transition from a static, seated-chair-and-desk-based workplace to an active, movement-friendly, sit-stand-walk paradigm involves changes in tangible workplace hardware including the introduction of SSWs and creation of movement-friendly spaces for work. However, an equally important and perhaps neglected aspect of this transition involves changes made to the intangible software of the workplace such as the organizational culture, leadership style, workers' attitudes, motivation levels, and their readiness to embrace change. Introducing a culture of movement and physical activity in the workplace involves developing goal setting strategies, using motivational aids for positive reinforcement, and designing nudges to effect behavior change. There is need for research to investigate the role of the organizational culture in enabling office workers to reduce sitting time, and increase physical activity without negatively impacting productivity at work.

7.13.8. The Economics of Ergonomics. Given that musculoskeletal disorders in the workplace are associated with high costs to the employers such as absenteeism, lost productivity, and increased health care, disability, and worker's compensation costs (CDC, 2001), the adoption of a sit-stand-walk paradigm should reduce risks for musculoskeletal disorders and associated costs. However, there are no studies that focus on the business case for introducing SSWs in the workplace. There is need for research to calculate reductions in direct and indirect costs associated with the adoption of a sit-stand-walk paradigm for office work. Parameters to consider would include comparing worker's compensation claims, medical payments, legal expenses, as well as costs for absenteeism and presenteeism for workers in the pre-and-post intervention conditions. If the economic rationale for movement-friendly workplaces is quantified, this could create the economic logic that can convince employers to introduce the sit-stand-walk work paradigm. However, such business decisions would need to factor in the ROI for such investments in the tangible and intangible hardware of the workplace.

7.14. Sit-Stand-Walk – Implications for Future Research.

This dissertation demonstrated the benefits of a sit-stand-walk intervention in reducing musculoskeletal discomfort and fatigue, without negatively impacting productivity in computer-based office work. However, there in need for further research to investigate the benefits of combining sit-stand postural transitions with frequent, short bouts of light-intensity physical activity. The implications for future research are outlined below.

7.14.1. Methodological Improvements. This section discusses how to build on the current research direction and make methodological improvements to increase the validity, reliability and generalizability of the research findings.

First, existing research protocol is limited to computer-based transcription for a 1-hour duration. In future, research protocols should consider expanding the study to 4-hour and 8-hour durations. It is important to consider the cumulative effects of the sit-stand-walk intervention across an entire workday.

Second, the sit-stand-walk intervention with a 20:8:2 ratio is one of many possible permutations and combinations to interrupt seated-based with light-intensity physical activity. There is need to test alternative interventions that reduce sitting time with light-intensity physical activity. In particular, a future study should compare conventional seated work with (a) sit-stand-walk and (b) sit-walk interventions.

Third, studies need to consider a range of computer-based office tasks beyond the standardized transcription task used in the current series of experiments. Future work should compare productivity in tasks such as computer-aided design work, creativity tests and cognitive performance tests.

Fourth, the dependent variables such as musculoskeletal discomfort, physical and mental fatigue were self-reported; future research should consider adding objective measures such as muscle activity (EMG), and brainwave signals (EEG) to quantify the physiological and psychological dependent variables.

Fifth, the sit-stand-walk intervention involves increase in light-intensity physical activity (LIPA) due to the 8-minutes of standing-based work followed by the 2-minute walk. However, the plausible increase in LIPA was not objectively measured; future work should consider use of physical activity sensors to measure the increase in LIPA.

Sixth, studies were limited to a convenience sample of university students who were relatively young, not-obese, and exercised frequently. Future research should consider involving participants from a range of age groups – children, young adults, adults and older adults, and with varying health and fitness levels.

Seventh, two of the three studies used a between-participants research design due to the logistical limitations of conducting the studies. However, a within-participants study design comparing the same participants across multiple work conditions would increase the robustness of the research design and the validity of the findings.

And finally, there is need for longitudinal studies in a real-world field setting, potentially for 6-months or longer duration, to investigate if results from these three laboratory-based studies translate to the real-world office environments.

7.14.2. Incremental Advancements.

This section outlines broader questions that emerge from the dissertation research.

First, studies were conducted in a controlled laboratory environment with the sit-stand-walk protocol enforced by the researcher. Future research needs to investigate how worker attitudes, personality types, motivation, organizational culture and leadership styles influence the behavioral transition from a static, seated-chair-and-desk-based paradigm of work towards an active, movement-friendly workplace.

Second, future studies need to consider need for imparting ergonomics training to increase worker motivation and improve compliance with the sit-stand-walk protocol. Research on the role of worker training in optimizing SSW use has been neglected, so far with consequences such as low compliance to sit-stand transitions and risks of occupational injuries due to inadequate anthropometric fit.

Third, there is a need for longitudinal studies of *active work* interventions to investigate the long-term health, well-being and productivity impacts of such interventions in the workplace. Current studies are mostly limited to laboratory based experiments which do not consider long term compliance to active work interventions in the workplace.

Fourth, there is need to investigate role of potential moderators such as gender, obesity and age in impacting the relationship between work condition and dependent variables. While current studies using a convenience sample of participants for a one-hour duration did not find any moderators, longer experimental durations with a representative sample of office workers may offer evidence for potential moderators, if any.

Fifth, benefits of the sit-stand-walk protocol have been considered primarily from the perspective of office workers. However, there is evidence to indicate that "other" populations such as primary school children and older adults benefit from breaking-up sitting time with intermittent bouts of light-intensity physical activity. Recent studies indicate that stand-biased desks improve cognitive performance in school children (Mehta et al., 2015), and that walking prevents cognitive decline in older adults (Wheeler et al., 2017). Future studies should investigate the holistic role of physical activity and movement on human behavior and health.

Sixth, while these three studies have considered the scenario of computer-based office work with designated workspaces for each worker, there is a growing trend towards alternative models for the workspace such as co-working spaces and work-from-home. The need for postural variability and movement at work is universal and independent of the workplace model. Therefore, future research should focus on how to reduce sedentary behavior and increase physical activity in alternative workplace scenarios such as co-working spaces and work-from-home contexts.

Seventh, there is need for cross-cultural comparisons by replicating the sit-stand-walk intervention in different countries with variations in population characteristics. The pandemic of physical inactivity is a global phenomenon; potential solutions such as the sit-stand-walk intervention need to be tested across diverse demographics and countries to investigate if the findings from this research are replicated and thereby, generalizable.

And finally, findings from this study contribute to develop a research framework that investigates how the intersection of human behavior and design create a new paradigm for public health research. Future research on sedentary behavior should integrate perspectives from workplace ergonomics, organizational psychology, behavioral economics and public health to create a holistic model to investigate how people work.

7.14.3. Meta-level Questions.

The broader implications of this research in the context of ergonomics theory, public health policy and design practice are elucidated below. First, while there is sufficient evidence from research on the benefits of short, intermittent bouts of light-intensity physical activity in the workplace, there exist a number of barriers to successfully translating these occupational health guidelines into active work habits and behaviors.

A fundamental question that needs to be addressed is to know what *'active work'* means to people. Researchers need to investigate the meanings and motivations for people to embrace the concept of active work and put it into practice. Future research should consider applying human-centered design principles to design effective workplace strategies that enable office workers to successfully transition into the active work paradigm.

Second, there is need to consider the role of environmental psychology in aiding this behavioral transition. In particular, future research should consider the role of the physical environment in shaping activity-oriented behaviors – especially the elements and qualities of the physical environment that influence and motivate office workers to engage in physical activity and movement in the workplace. Findings from this research would translate to guidelines for environmental design that support active work behaviors.

Third, it is imperative to recognize that people are not rational agents, and that their decisions and behaviors are often shaped by emotion or innate bias. Therefore, public health strategies to influence and 'nudge' people to embrace physical activity and movement at work should consider incorporating ideas from behavioral economics - the science of using psychological insights to influence human behavior (Thaler & Sunstein, 2009). Future research should consider the role of behavioral nudges in influencing workers to adopt physical activity and movement at work.

Fourth, the current state of science on sedentary behavior and health advocates for breaking up sitting with short, intermittent bouts of light-intensity physical activity. However, a broader question relates to how physical activity and movement in the workplace impact workers' physiology, psychology and cognition. Future research should consider the role of postural variability and movement in shaping physiological, psychological, and cognitive dependents. Findings from the research would help inform design of work-rest-activity cycles that optimize health, well-being and productivity in office work.

Fifth, a crucial feature of the sit-stand-walk protocol is the frequency of postural transitions across a workday (16 transitions in 8-hours). It has been hypothesized that the frequency of these postural transitions translates to improved health dependents because of the frequency and magnitude of change in the gravity stimulus. Prior evidence from head-down bed-rest (HDBR) studies with astronauts returning from low-earth orbits indicate that short, frequent bouts of moderate-intensity physical activity distributed across a workday is more effective in physiological recovery, when compared to one high-intensity bout of physical activity once in the workday (Vernikos & Schneider, 2010; Pavy-Le Traon et al., 2007). The parallels between findings from the active breaks research and the HDBR studies suggest that the magnitude and frequency of change in the gravity stimulus maybe a crucial factor common to both contexts. Future research should investigate the importance of gravity stimulus in physiological and psychological health.

Sixth, health benefits of postural transitions and active breaks from chair-seated work postures suggest that this research approach should also extend to alternative, non-chair-based, seated work postures such as kneeling, squatting and cross-legged sitting. The current paradigm of research on sedentary behavior and health is biased towards the chair-sitting paradigm; future studies should investigate the impacts of floor-sitting work postures on worker health, well-being and productivity.

And finally, the traditional office workstation design with its chair-and-desk paradigm is shaped by the demands of contemporary computer software and hardware. In today's workplace, the arrangement of the computer monitor, keyboard, mouse and other accessories determines the layout of the workstation and constrains the office worker to the seated-chair-and-desk paradigm of work. As computing technologies evolve and the hardware merges into the intelligent environment, there is an opportunity to redesign the workplace of the future from first principles, i.e. workplaces could be designed based on the fundamental human need for flexibility, physical activity and movement.

7.15. Conclusion

The adoption of a sit-stand-walk intervention maybe an optimal approach to realize the dual needs for reduced sitting time and increased physical activity at work. Combining postural transitions enabled by sit-stand workstations, with light-intensity physical activity through regularly scheduled active breaks demonstrates beneficial reductions in musculoskeletal discomfort and fatigue, without negatively impacting productivity in short-duration simulated office tasks. In addition, the use of a custom-designed, ergonomically-fit, sit-stand workstation enables office workers using a sit-stand-walk intervention to maintain neutral posture and reduce risks for occupational injuries in computer-based office work. Future work may focus on extending the current research to study more office tasks for longer durations in field settings. *In a nutshell, it's time for workers to stand up and make a move!*

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APPENDIX

Appendix A. Keyword Search Syntax for Systematic Literature Review

1. PubMed/MEDLINE

sitting* work*[tw] OR standing* work*[tw] OR sitting* desk*[tw] OR standing* desk*[tw] OR sit-stand desk*[tw] OR sit-stand work*[tw] OR sitting* standing* desk*[tw] OR sitting* standing* work*[tw] OR sit-stand[tw] OR sit/stand[tw] OR sit-stand work*[tw] OR sit-stand desk*[tw] OR variable-height desk*[tw] OR variable-height work*[tw] OR height-adjust* work*[tw] OR height-adjust* desk*[tw] OR active desk*[tw] OR active workstation*[tw] OR workstation alternative*[tw] OR stand-biased[tw] OR activity permissive[tw] OR hot desk[tw] OR fixed height work*[tw] OR fixed height desk*[tw] OR chair sit*[tw] OR vertical work*[tw]

2. CINAHL

sitting* work* OR standing* work* OR sitting* desk* OR standing* desk* OR sit-stand desk* OR sit-stand work* OR sitting* standing* desk* OR sitting* standing* work* OR sit-stand OR sit/stand OR sit-stand work* OR sit-stand desk* OR variable-height desk* OR variable-height work* OR height-adjust* work* OR height-adjust* desk* OR active desk* OR active workstation* OR workstation alternative* OR stand-biased OR activity permissive OR hot desk OR fixed height work* OR fixed height desk* OR chair sit* OR vertical work*

3. Ergonomic Abstracts

sitting* work* OR standing* work* OR sitting* desk* OR standing* desk* OR sit-stand desk* OR sit-stand work* OR sitting* standing* desk* OR sitting* standing* work* OR sit-stand OR sit/stand OR sit-stand work* OR sit-stand desk* OR variable-height desk* OR variable-height work* OR height-adjust* work* OR height-adjust* desk* OR active desk* OR active workstation* OR workstation alternative* OR stand-biased OR activity permissive OR hot desk OR fixed height work* OR fixed height desk* OR chair sit* OR vertical work*

4. PsychINFO

sitting* work* OR standing* work* OR sitting* desk* OR standing* desk* OR sit-stand desk* OR sit-stand work* OR sitting* standing* desk* OR sitting* standing* work* OR sit-stand OR sit/stand OR sit-stand work* OR sit-stand desk* OR variable-height desk* OR variable-height work* OR height-adjust* work* OR height-adjust* desk* OR active desk* OR active workstation* OR workstation alternative* OR stand-biased OR activity permissive OR hot desk OR fixed height work* OR fixed height desk* OR chair sit* OR vertical work*

5. Web of Science
“sitting* work*” OR “standing* work*” OR “sitting* desk*” OR “standing* desk*” OR “sit-stand desk*” OR “sit-stand work*” OR “sitting* standing* desk*” OR “sitting* standing* work*” OR “sit-stand” OR “sit/stand” OR “sit-stand work*” OR “sit-stand desk*” OR “variable-height desk*” OR “variable-height work*” OR “height-adjust* work*” OR “height-adjust* desk*” OR “active desk*” OR “active workstation*” OR “workstation alternative*” OR “stand-biased” OR “activity permissive” OR “hot desk” OR “fixed height work*” OR “fixed height desk*” OR “chair sit*” OR “vertical work*”

6. Science Direct
"sit stand" OR "height adjustable" OR "variable height" OR "workstation alternatives" OR "stand biased" OR "activity permissive" OR " active desks" OR "hot desks" OR “active workstations” OR “standing desk” OR “fixed height workstation” OR “vertical work” OR “chair sitting” OR “fixed height desk”

7. Google Scholar
allintitle: "sit stand" OR "height adjustable" OR "variable height" OR "workstation alternatives" OR "stand biased" OR "activity permissive" OR "active desks" OR "hot desks" OR "active workstations" OR "standing desks" OR "fixed height workstations"

8. BioMed Central
"sit stand" OR "height adjustable" OR "variable height" OR "workstation alternatives" OR "stand biased" OR "activity permissive" OR "active desks" OR "hot desks" OR "active workstations" OR "standing desks" OR "fixed height workstations"

Appendix B. Informed Consent Document for Ahmedabad and Ithaca Cohort Studies

Informed Consent Form

We are asking you to participate in a research study titled "*Comparative Study of Short-term Computer Typing Tasks in Varying Work Postures.*" We will describe this study to you and answer any of your questions. Please read this form carefully and ask any questions you may have before agreeing to take part in the study.

Who are conducting the research: The principal investigator for this study is Gourab Kar, a doctoral candidate in Department of Design and Environmental Analysis, Cornell University. The Faculty Advisor for this study is Prof. Alan Hedge, Director, Human Factors and Ergonomics Laboratory, Cornell University.

What the study is about: The purpose of this research is to understand how different postures at work impact short-term computer typing performance and physical musculoskeletal discomfort. You will be asked to perform a series of computer typing tasks while in a sitting or standing work posture. Before and after completing the typing tasks, you will be requested to provide feedback through a survey.

What we will ask you to do: Should you agree to volunteer for the study, we will ask you to complete the following procedures outlined below.

- First, you will be asked to read and sign the consent form. (5 minutes)
- Second, you will be asked to complete a questionnaire about your physical activity levels and familiarity with use of computers. (5 minutes)
- Third, you will have time to familiarize with the computer-typing task in both sitting and standing work postures. (10 minutes)
- You will then fill-out a survey to indicate your <u>level of physical musculoskeletal discomfort</u>. (5 minutes)
- You will be asked to perform a computer typing task for <u>15-minutes</u>. The task requires you to read text from a MS Word document in the left half of the screen and type this text on to a blank MS Word document in the right half of the screen.
  - *Please type in your usual speed <u>without</u> worrying about spelling and punctuation.*
  - *The Spellcheck feature in MS Word is <u>disabled</u> for the study.*
- In total there will be four typing sessions of 15 minutes each. (30 x 2 = 60 minutes)
- You will have a 5-minute break at end of each typing session. (5 minutes)
- During the 5-minute break you will fill-out a survey to indicate your <u>level of physical musculoskeletal discomfort</u>.
- You will be in either a sitting or standing posture for each of the two, 30-minute typing sessions. The order of the typing sessions is randomly assigned.
- The entire experiment should take you about <u>1 hour and 40 minutes</u> to complete.

Risks and Musculoskeletal discomforts: We do not anticipate any risks to you participating in this study other than those encountered in day-to-day life.

Benefits: There are no direct benefits for you for participating in this research. We hope to learn more about the interrelationship between task performance and physical musculoskeletal discomfort in short-term computer typing tasks. Findings from the study will help determine

an optimal sit-to-stand ratio in computing work.
Compensation: You may earn extra credit if you are taking a class that offers credit for research studies. The class instructor will assign credit according to class policy. If you wish, you may earn $20.00 instead of extra credit.

Your answers will be confidential: The records of this study will be kept private. In any sort of report we make public we will not include any information that will make it possible to identify you. Research records will be kept in a locked file; only the only the principal investigator and faculty advisor will have access to the records.

Participation is Voluntary: Your participation in this study is completely voluntary. You may refuse to participate before the study begins, discontinue at any time, and skip any questions/procedures that make you feel uncomfortable. Your level of participation has no effect on the compensation earned before withdrawing, or your academic standing, record or relationship with the university.

Follow up studies: We may contact you again to request your participation in a follow up study. As always, your participation will be voluntary and we will ask for your explicit consent to participate in any of the follow up studies.

May we contact you again to request your participation in a follow up study? Yes / No

If you are injured by this research: In the event that any research-related activities result in an injury, treatment will be made available including first aid, emergency treatment, and follow-up care as needed. Cost for such care will be billed in the ordinary manner to you or your insurance company. No reimbursement, compensation, or free medical care is offered by Cornell University. If you think that you have suffered a research-related injury, contact **Gourab Kar** right away.

If you have questions: The main researcher conducting this study is Gourab Kar, a doctoral student at Cornell University. Please ask any questions you have now. If you have questions later, you may contact **Gourab Kar**. If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) for Human Participants at 607-255-6182 or access their website at http://www.irb.cornell.edu. You may also report your concerns or complaints anonymously through Ethicspoint online at www.hotline.cornell.edu or by calling toll free at 1-866-293-3077. Ethicspoint is an independent organization that serves as a liaison between the University and the person bringing the complaint so that anonymity can be ensured.

Statement of Consent: I have read the above information, and have received answers to any questions I asked. I consent to take part in the study.

Your Signature …………………………………………………………..Date ………………..

Your Name (printed) ………………………………………………………………………………

Signature of person obtaining consent ....Date…………………

Printed name of person obtaining consent ………………………………………………………...

Appendix C. Demographic Questionnaire for Ahmedabad and Ithaca Cohort Studies

Demographic Questionnaire

Please let us know more about you by answering the following questions.

<u>Circle your chosen option(s), or write-in your response</u>

1. Do you have any <u>chronic musculoskeletal pain</u> in any part of your body: YES / NO
2. Please indicate your **handedness**: right-handed / left-handed
3. Please indicate your **gender**: female / male
4. Please indicate your **age in years**: ________
5. Please indicate your **weight in lb.** OR **kg**: ________
6. Please indicate your **height in feet-inches** OR **cm**: ________
7. Please indicate if <u>English</u> is your **first language**: YES / NO
8. How many <u>years</u> have you been using a computer (either desktop OR laptop): ……….
9. How many <u>hours per week</u> do you use a computer (either desktop OR laptop): ………
10. How often do you <u>engage in physical exercise in a week</u>: 0 / 1 / 2 / 3 / 4 / 5 / 6 (times) *Exercise includes brisk-walking, running, swimming, aerobics, yoga, cycling, gym exercises, and sports*; *if anything else <u>please mention</u>:* ………………………………..
11. How long do you exercise in one session: 30 / 60 / 90 / 120 / 150 / 180 (minutes)
12. Do you <u>use a sitting workstation</u> at work: YES / NO

    If you answered YES, how many hours/day do you sit at work? ……………...
13. Do you <u>use a standing workstation</u> at work: YES / NO

    If you answered YES, how many hours/day do you stand at work? …………..
14. *A sit-stand workstation enables you to raise the work surface to from sitting to standing work posture or vice-versa.* Do you <u>use a sit-stand workstation</u> at: YES / NO

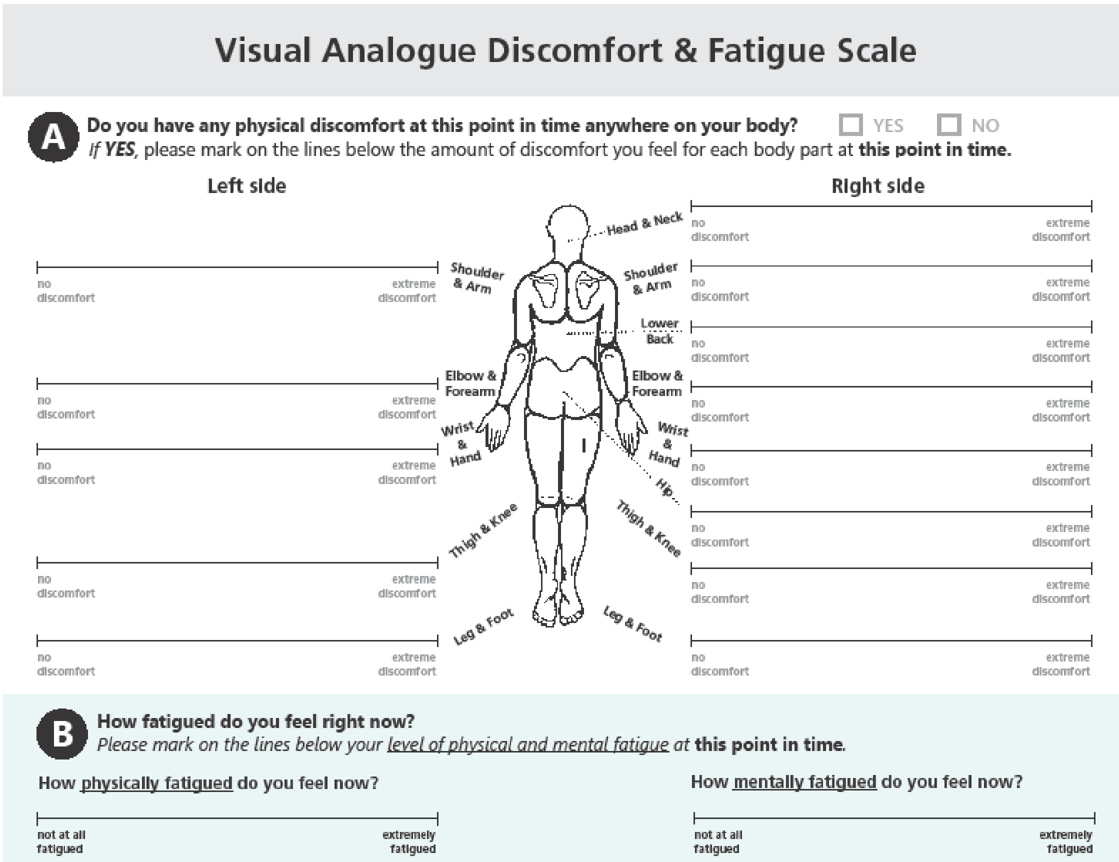
    If you answered YES, how many hours/day do you sit at work?

    ____

    If you answered YES, how many hours/day do you stand at work?

    ____
15. Do you consider yourself to be: (*Choose one of the three options*)
    a) Touch-typist = YOU <u>DO NOT</u> look at the keyboard while typing
    b) Non touch-typist = YOU <u>DO</u> look at the keyboard <u>*sometimes*</u> while typing

Appendix D. Musculoskeletal Discomfort & Fatigue Scale for Ahmedabad and Ithaca Cohort Studies



Visual Analogue Discomfort & Fatigue Scale

A **Do you have any physical discomfort at this point in time anywhere on your body?** ☐ YES ☐ NO
*If **YES***, please mark on the lines below the amount of discomfort you feel for each body part at **this point in time.**

Left side

Shoulder & Arm: no discomfort — extreme discomfort
Elbow & Forearm: no discomfort — extreme discomfort
Wrist & Hand: no discomfort — extreme discomfort
Thigh & Knee: no discomfort — extreme discomfort
Leg & Foot: no discomfort — extreme discomfort

Right side

Head & Neck: no discomfort — extreme discomfort
Shoulder & Arm: no discomfort — extreme discomfort
Lower Back: no discomfort — extreme discomfort
Elbow & Forearm: no discomfort — extreme discomfort
Wrist & Hand: no discomfort — extreme discomfort
Hip: no discomfort — extreme discomfort
Thigh & Knee: no discomfort — extreme discomfort
Leg & Foot: no discomfort — extreme discomfort

B **How fatigued do you feel right now?**
Please mark on the lines below your level of physical and mental fatigue at **this point in time.**

How physically fatigued do you feel now?
not at all fatigued — extremely fatigued

How mentally fatigued do you feel now?
not at all fatigued — extremely fatigued

Appendix E. Informed Consent Document for Workstation Configuration Study

Informed Consent Form

We are asking you to participate in a research study titled "*Comparative Study of Short-term Computer Typing Tasks in Varying Work Postures.*" We will describe this study to you and answer questions. Please read this form carefully and ask us any questions you may have before agreeing to take part in the study.

Who are conducting the research: The principal investigator for this study is Gourab Kar, a doctoral candidate in Dept. of Design and Environmental Analysis at Cornell University. The Faculty Advisor for is Prof. Alan Hedge, Director, Human Factors and Ergonomics Laboratory at Cornell University.

What the study is about: The purpose of this research is to understand how different work protocols impact short-term computer typing performance, musculoskeletal discomfort and fatigue. You will be asked to perform a series of computer typing tasks while in a sitting or standing posture. Before starting and after completing the typing tasks, you will be requested to provide feedback through a questionnaire.

What we will ask you to do: Should you agree to participate, we will ask you to complete the following procedures outlined below.

- First, you will be asked to read and sign the consent form. **(5 min)**
- Second, you will be asked to complete a demographic questionnaire. **(5 min)**
- Third, we will help you wear an arm-band to measure your heart rate.
- Fourth, you will fill-out a paper-based musculoskeletal discomfort and fatigue questionnaire. **(5 min)**
- Next, you will be assigned experimental condition A or B.
    - You will complete both the experimental conditions in the study.
    - The order of the experimental conditions will be A→ B or B→A.
    - Each experimental condition should take 60 minutes to complete.
- You will have time to familiarize with the computer-based typing task. **(10 min)**
    - *In condition A, we will arrange the workspace to fit your task needs.*
    - *In condition B, you will arrange the workspace to fit your task needs.*
- You will be performing a computer-based typing task using this protocol: **(60 min)** Sitting 20 min → Standing 8 min + Walking 2 min (*no typing*) → Sitting 20 min → Standing 8 min + Walking 2 min (*no typing*).
- You will fill-out a paper-based musculoskeletal discomfort and fatigue survey. **(5 min)**
- You will have time to familiarize with the short-duration typing task. **(10 min)**
    - *In condition A, we will arrange the workspace to fit your task needs.*
    - *In condition B, you will arrange the workspace to fit your task needs.*
- You will be performing a computer-based typing task using this protocol: **(60 min)** Sitting 20 min → Standing 8 min + Walking 2 min (*no typing*) → Sitting 20 min → Standing 8 min + Walking 2 min (*no typing*).
- You will fill-out a paper-based musculoskeletal discomfort & fatigue survey. **(5 min)**

- Finally, we will help you remove the arm-band worn.
- In each experimental condition (A or B), you will be asked to perform a computer-based typing task. The task requires you to read text from a MS Word document in the left half of screen and type this text on to a blank MS Word document in the right half of screen.
  - *Please type in your usual speed without worrying about spelling and punctuation.*
  - *The spellcheck feature in MS Word is disabled for the study.*
- The entire study should take you about **2 hour and 45 minutes** to complete.

Risks and Musculoskeletal discomforts: We do not anticipate any risks to you participating in this study other than those encountered in day-to-day life.

Benefits: There are no direct benefits for you for participating in this research.

Video Recording: We may be video recording the experiments to analyze your body posture at work. Video data will be stored on a secure hard drive; only the principal investigator and the faculty advisor will have access to the data. The video files will be erased 6-months after the completion of the study.

Please sign below if you are willing to have this interview video recorded. You may still participate in this study if you are not willing to have the interview recorded.

☐ I do not want to have this interview recorded.

☐ I am willing to have this interview recorded.

Signed: ____Date: ___________________

Compensation: You may earn extra credit if you are taking a class that offers credit for research studies. The class instructor will assign credit according to class policy. If you wish, you may earn $40.00 instead of extra credit.

Your answers will be confidential: The records of this study will be kept private. In any sort of report we make public we will not include any information that will make it possible to identify you. Research data will be kept in a locked file; only the principal investigator and faculty advisor will have access to the records.

Participation is Voluntary: Your participation in this study is completely voluntary. You may refuse to participate before the study begins, discontinue at any time, and skip any questions/procedures that make you feel uncomfortable. Your level of participation has no effect on the compensation earned before withdrawing, or your academic standing, record or relationship with the university.

If you are injured by this research: In the event that any research-related activities result in an injury, treatment will be made available including first aid, emergency treatment, and follow-up care as needed. Cost for such care will be billed in the ordinary manner to you or your insurance company. No reimbursement, compensation, or free medical care is offered by Cornell University. If you think that you have suffered a research-related injury, contact **Gourab Kar** right away.

If you have questions: The main researcher conducting this study is Gourab Kar, a doctoral student at Cornell University. Please ask any questions you have now. If you have questions later, you may contact **Gourab Kar**.

If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) for Human Participants at 607-255-6182 or access their website at http://www.irb.cornell.edu. You may also report your concerns or complaints anonymously through Ethicspoint online at www.hotline.cornell.edu or by calling toll free at 1-866-293-3077. Ethicspoint is an independent organization that serves as a liaison between the University and the person bringing the complaint so that anonymity can be ensured.

Statement of Consent: I have read the above information, and have received answers to any questions I asked. I consent to take part in the study.

Your Signature______________________________________**Date**_______________

Your Name (printed)____

Signature of person obtaining consent_____________________Date_______________

Printed name of person obtaining consent_____________________________________

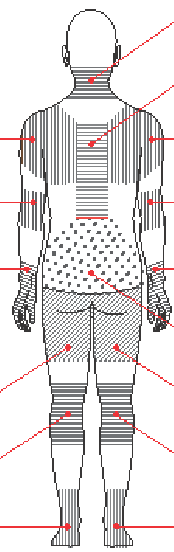
Appendix F. Musculoskeletal Discomfort Questionnaire for Workstation Configuration Study

Discomfort Questionnaire

I am trying to find out how much **discomfort your feel in your body right now**. There are 15 items I would like you to respond to. This should only take about two minutes of your time. **Thank You.**

DIRECTIONS: You are asked to place an "X" through these lines to indicate how much discomfort you are feeling RIGHT NOW. Please answer every question, even if you experience no discomfort in any part of your body. The picture shows how the body has been divided. You should choose for yourself which part (if any) is, or has been affected.

NOW PLEASE COMPLETE THE FOLLOWING ITEMS.



neck
no discomfort — extreme discomfort

upper back
no discomfort — extreme discomfort

left shoulder
no discomfort — extreme discomfort

right shoulder
no discomfort — extreme discomfort

left forearm
no discomfort — extreme discomfort

right forearm
no discomfort — extreme discomfort

left wrist / hand
no discomfort — extreme discomfort

right wrist / hand
no discomfort — extreme discomfort

lower back
no discomfort — extreme discomfort

left hip / thigh
no discomfort — extreme discomfort

right hip / thigh
no discomfort — extreme discomfort

left knee
no discomfort — extreme discomfort

right knee
no discomfort — extreme discomfort

left lower leg
no discomfort — extreme discomfort

right lower leg
no discomfort — extreme discomfort

Time: ________ a.m. ________ p.m. Participant ID: ____________ Sequence: 0 / 1 / 2 / 3 / 4 Date: ____________

Appendix G. Fatigue Questionnaire for Workstation Configuration

Fatigue Questionnaire

Time: ______ a.m. _______ p.m. Participant ID: __________ Sequence: 0 / 1 / 2 / 3 / 4 Date: __________

I am trying to find out about your level of energy right now. There are 17 items I would like you to respond to. This should only take about two minutes of your time. **Thank You.**

DIRECTIONS: You are asked to place an "X" through these lines to indicate how you are feeling RIGHT NOW. For example, suppose you have not eaten since yesterday. Where would you put the "X" on the line below?

not hungry at all |————————————————| extremely hungry

You would probably put the "X" closer to the "extremely hungry" end of the line.
This is where I put it.

not hungry at all |——————————X———| extremely hungry

NOW PLEASE COMPLETE THE FOLLOWING ITEMS.

not at all tired	|————————————————|	extremely tired
not at all sleepy	|————————————————|	extremely sleepy
not at all drowsy	|————————————————|	extremely drowsy
not at all fatigued	|————————————————|	extremely fatigued
not at all worn out	|————————————————|	extremely worn out
not at all energetic	|————————————————|	extremely energetic
not at all active	|————————————————|	extremely active
not at all vigorous	|————————————————|	extremely vigorous
not at all efficient	|————————————————|	extremely efficient
not at all lively	|————————————————|	extremely lively
not at all exhausted	|————————————————|	extremely exhausted
keeping my eyes open is no effort at all	|————————————————|	keeping my eyes open is a tremendous chore
moving my body is no effort at all	|————————————————|	moving my body is a tremendous chore
concentrating is no effort at all	|————————————————|	concentrating is a tremendous chore
carrying on a conversation is no effort at all	|————————————————|	carrying on a conversation is a tremendous chore
I have absolutely no desire to close my eyes	|————————————————|	I have a tremendous desire to close my eyes
I have absolutely no desire to lie down	|————————————————|	I have a tremendous desire to lie down