SEX-SPECIFIC ELECTROMYOGRAPHIC, PERFORMANCE, AND SYMPTOMATIC DIFFERENCES BETWEEN SITTING AND CYCLING COMPUTER WORKSTATIONS

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ABSTRACT

Previous studies have suggested that increased daily physical activity can reduce risk factors associated with the development of work-related musculoskeletal disorders (WMSDs). Active computer workstations have been proposed to reduce inactivity within the workplace and avoid WMSDs; however, the extent of our understanding of whether males and females may equally benefit from them is limited by a lack of mechanistic studies. Twenty-six computer users (n = 14 females) underwent two 60-minute typing tasks, either sitting on a sit-stand stool or cycling at their own pace within a pre-established target heart rate (25% of heart rate reserve). Muscle activation amplitude, eye, and musculoskeletal discomfort, as well as performance outcomes, were analyzed for main and interaction effects of Sex, Time, and Condition. Males' performance was negatively affected by cycling, with fewer words per minute, whereas females' performance was the same in both conditions. Cycling led to a smaller increase in neck/shoulder discomfort with time, especially in c . Moreover, with time, neck/shoulder muscle activation increased during sitting but conversely, decreased with time during cycling, especially in females. Lastly, low back muscle activity was higher and varied more with time during cycling, especially in females, even though there was no difference in seat discomfort between sitting and cycling. The results suggest that there exist sex-specific responses to cycling workstations during 60-minute computer work tasks, and that cycling workstations, although a promising alternative, should not necessarily be recommended to all males and all females.

RÉSUMÉ

Des publications scientifiques récentes ont suggéré qu'une activité physique quotidienne accrue peut réduire les facteurs de risque associés au développement de troubles musculo-squelettiques liés au travail (TMS). Des postes de travail informatiques actifs ont été proposés pour réduire l'inactivité sur le lieu de travail et éviter les TMS. Cependant, notre compréhension à savoir si les hommes et les femmes pourraient également en bénéficier est limitée par le manque d'études mécanistiques sur ce sujet. Vingt-six utilisateurs d'ordinateurs (n = 14 femmes) ont été soumis à deux tâches de frappes de 60 minutes, soit assis sur un tabouret assis-debout, soit en pédalant à leur propre rythme à l'intérieur des limites pré-établies de valeurs de fréquence cardiaque (25% de la réserve de fréquence cardiaque). L'amplitude de l'activation musculaire, l'inconfort oculaire et musculo-squelettique, ainsi que les résultats de performance, ont été analysés pour les effets principaux et l'interaction du sexe, du temps et de la condition. La performance des hommes a été affectée négativement par le pédalage, avec moins de mots par minute, tandis que celle des femmes était la même dans les deux conditions. Le pédalage a entraîné une augmentation moins importante de l'inconfort de la nuque et des épaules avec le temps, en particulier chez les femmes. De plus, avec le temps, l'activation des muscles du cou et des épaules a augmenté pendant la position assise, mais inversement, elle a diminué avec le temps pendant le pédalage, en particulier chez les femmes. Enfin, l'activité des muscles lombaires était plus élevée et variait davantage avec le temps pendant le pédalage, en particulier chez les femmes, même s'il n'y avait pas de différence dans l'inconfort du siège entre la position assise et le pédalage. Les résultats suggèrent qu'il existe des réponses sexospécifiques aux postes de travail à vélo lors de tâches informatiques de 60 minutes et que bien que les postes de travail à vélo constituent une alternative prometteuse, ils ne devraient pas nécessairement être recommandés à tous les hommes et toutes les femmes.

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CONTRIBUTION OF AUTHORS

Malak Selim, the candidate, oversaw the research project, setup, recruitment, data collection, analysis, writing, and any other steps necessary to complete the research study and submit the thesis as per McGill University requirements.

Julie N. Cote, Ph.D., Professor, Department of Kinesiology and Physical Education, McGill University, the candidate's supervisor, oversaw research design and writing, and was actively involved in every step and decision made regarding the research study and completion of thesis submission.

Erika Renda, Ph.D. student, assisted with the research design, data collection, and analysis.

Samuel Lamanuzzi, MSc., assisted with the research design and data collection.

Andrew (SangHoon) Yoon, Ph.D. student, assisted with the research design and analysis.

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are diverse and painful conditions affecting the bones, joints, muscles, and connective tissues and are caused by, or at least associated with, factors related to the work environment. WMSDs can result in acute and/or chronic pain, leading to impaired work performance as well as the loss of function and productivity (Government of Canada, 2022). These disorders are among the most disabling and costly conditions in North America (Yelin et al., 2016). The underlying mechanism of WMSDs are not well understood; however, awkward and/or sustained postures and prolonged sitting are potential contributing factors. These factors are commonly observed in predominantly seated work environments (i.e., offices, and schools) and are hypothesized to influence the onset, development, and severity of WMSDs. In addition to WMSDs, prolonged seated computer usage has been linked to symptoms of the visual system like blurry and itchy eyes, as well as other symptoms summarized as Computer Vision Syndrome (CVS), which is known to be more prevalent in women, although the specific mechanisms that link WMSDs to CVS are poorly understood (Ranasinghe et al., 2016).

Previous studies have shown that females are more susceptible to developing WMSDs (Côté, 2012;Hooftman et al., 2009). Although the exact etiology is unknown, differences between men’s and women’s WMSDs are thought to be due to sex (biological)-based, and/or gender (psychological and sociological)-based differences (Côté, 2012; Fedorowich et al., 2013; Scott & Marshall, 2014).

Active Office Workstations (AOWs), such as cycling workstations, have been proposed to help prevent WMSDs. Cycling workstations are a promising alternative as they address many of the musculoskeletal issues associated with seated workstations by activating larger muscle groups, decreasing sedentarism, and promoting blood flow (Baker et al., 2019; Frodsham et al., 2020). Furthermore, the majority of studies on AOWs have shown higher muscle activation amplitudes, especially in females when compared to males (Baker et al., 2019; Dupont et al., 2019; Frodsham et al., 2020; Yoon et al., 2019). Previous studies utilized cycle ergometers as opposed to ergonomically designed cycling workstations that utilize a system of under-desk floor pedals; further, muscle activity and visual outcomes have never been reported in this setup. We hypothesize that the cycling workstation when compared to the seated workstation, would elicit significantly higher electromyographic activity in all muscles of the upper limbs. No difference in typing performance was expected; however, we anticipated lower reported levels of physical discomfort and increased visual discomfort with time in the under-desk cycling condition compared to the sitting condition. Finally, we expected the above-described differences to vary between the sexes.

LITERATURE REVIEW

History of Computer Usage and the Rise of Sedentarism

The 1980s witnessed significant changes in computer technology, including the adoption of graphical user interfaces and networking technologies (Ambinder, 2005). These changes led to the widespread integration of computers in various domains of daily life, such as work, school, and business (Ambinder, 2005). By 1989, a considerable number of Canadian workers were using computers, and personal computer ownership had become more affordable, powerful, and compact (Fisher & Sim, 2007; Evans, 2016). The introduction of personal computers, local area networks, and the Internet revolutionized access to information, making computers an essential part of modern life (Evans, 2016).

Computer usage has become prolific, with a Canadian Community Health Survey conducted in 2012 revealing that 11.0% of Canadian adults spent over 20-24 hours per week using a computer (Anderson et al., 2016; Huffman & Szafron, 2017). Moreover, post-pandemic, computer usage has further increased, and it is now recognized as a high-risk sedentary activity (Family, 2020). This excessive computer usage has been associated with chronic sedentarism, which is linked to adverse health effects (Family, 2020; Park et al., 2020).

The adverse health effects of chronic sedentary behavior have been well-documented, including cardiovascular diseases, type II diabetes, depression, premature death, obesity, and certain forms of cancer (Garber et al., 2011). In addition, numerous studies have demonstrated a dose-response relationship between sitting time and health problems. Just two hours of constant sitting can lead to a 5% increase in the risk of obesity and a 7% increase in the risk of diabetes (Hu et al., 2003). Katzmarzyk et al. (2014) analyzed the 1981 Canadian fitness survey results and concluded that physically active individuals who engaged in prolonged sedentary behavior had a

1.4 times higher chance of death 12 years later compared to those who reported minimal sitting time. Furthermore, sedentary behavior, defined as any activity with lower energy expenditure than walking, has been identified as a stronger determinant of health than physical activity alone (Marshall & Ramirez, 2011; Tremblay et al., 2017). Finally, some studies have suggested that it might be insufficient to merely supplement physical activity outside of work; and that to gain sufficient levels of physical activity, it could also be incorporated within the work environment (Garber et al., 2011; Genin et al., 2018; van der Ploeg et al., 2012).

Excessive computer usage and prolonged sedentary behavior are associated with the development of musculoskeletal symptoms and disorders, including neck pain, back pain, shoulder pain, carpal tunnel syndrome, as well as eye discomfort such as dry eyes, red eyes, and blurred vision (Parihar et al., 2016). Developing effective ergonomic interventions is necessary to mitigate these contributing factors and promote better health and well-being.

Musculoskeletal Disorders and Work-related Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) are various painful disorders of the muscles, tendons, and nerves (CDC, 2020). Almost all MSDs are chronic and are the most common cause of long-term pain and disability (Government of Canada, 2019). The etiology of MSDs is not well known but has been related to a myriad of factors, such as repetitive movements, fatigue, muscular overuse, awkward and/or sustained postures, and prolonged sitting and standing (Pronk et al., 2012). MSDs result from cumulative exposure, and the causal factors are often not proximal to the injury, making it difficult to pinpoint the driving cause of each individual's condition (Oakman et al., 2016). MSDs affect 11 million Canadians annually, and due to the aging population, this number is expected to increase to 15 million in 2031 (Canada, 2010; Government of Canada, 2019).

Work-related musculoskeletal disorders (WMSDs) are conditions in which the work environment or the performance of work significantly contributes to the development or severity of the condition (CDC, 2020). WMSDs account for one-third of all workers' compensation costs, as well as for almost 400,000 injuries per year (U.S. Bureau of Labor Statistics, 2020). WMSDs are a major cause of morbidity among workers and influence work performance and productivity (Daneshmandi et al., 2017). Overall, WMSDs significantly impact workers and the workforce. Evidence-based occupational interventions are needed in order to support the workers optimally and address persisting issues within the typical work environments.

Visual symptoms and Computer Vision Syndrome

Computer vision syndrome (CVS) is a group of disorders of the eye and vision caused by activities that stress near vision and is oftentimes experienced in relation to computer usage (Rosenfield, 2011). The main symptoms reported are visual discomfort, eye strain, irritation, burning sensation, redness, blurred vision, and double vision (Bergqvist & Knave, 1994). The symptoms experienced tend to be acute; however, a minority of workers experience a recurrence or continuity of symptoms that worsen over time (Bergqvist & Knave, 1994; Loh & Redd, 2008).

CVS may also have a significant economic impact through its negative influence on performance and increases the prevalence of workplace absenteeism (Rosenfield, 2011). The symptoms of CVS increase the number of errors made during a computer task and the need for more frequent breaks (Rosenfield, 2011). Further, CVS has the potential to exacerbate MSDs and their symptoms (Blehm et al., 2005; Loh & Redd, 2008), although the mechanisms linking visual and musculoskeletal symptoms are poorly described. Overall, little is known about the specific features of computer work that influence the development and severity of visual discomfort.

Computer Work-Related Musculoskeletal Disorders

Prolonged usage of visual display terminals (VDTs), such as computers, has been linked with various MSDs (Pandey et al., 2020). Initial research on VDT was conducted in the 1980s, and since then the workforce has experienced an exponential increase in VDT usage. Early studies found that VDT users experience more discomfort than non-VDT users; it was further found that the frequency of their discomfort increased with the degree of VDT usage (Bendix et al 1985; Smith et al. 1981).

Sustained bouts of sedentary activity during computer work increase the individual's risk of upper-extremities MSDs (Tittiranonda et al., 1999). Disorders of the upper extremities are the leading cause of pain in many workplaces, particularly in offices (Blain, 1995; Katz et al., 2000). Several studies have demonstrated an association between computer usage and WMSDs, with the prevalence of computer related WMSDs being 55–69% for the neck, 31–54% for the lower back, and 15–52% for upper extremities (Janwantanakul et al., 2008; Klussmann et al., 2008;Sillanpää et al., 2003; Woods, 2005). Lower back, neck, and shoulders WMSDs are reportedly the most commonly developed among computer users (Janwantanakul et al., 2008; Klussmann et al., 2008; Sillanpää et al., 2003; Woods, 2005). A study by Blatter and Bongers (2002), analyzed the results of a nationwide survey of 11,308 office workers to determine the relationship between computer use duration and the development of musculoskeletal disorders of the neck and upper limbs, and found that about four hours of computer use per day contributed to musculoskeletal disorders of the neck or upper limb in women, and six hours or more of computer use caused these symptoms in men, suggesting sex-specificity for this disorder.

The underlying mechanisms of MSD development in relation to VDT usage are not well understood. Poor ergonomic computer setup is thought to be an important contributing factor to both musculoskeletal and visual problems (Borhany et al., 2018). Other contributing factors include the duration of computer use and the quantity of work (Borhany et al., 2018). It has been hypothesized that computer-related injuries result from cumulative trauma disorders or repetitive strain injuries (Ellahi et al., 2011). With regard to hand and wrist disorders, it was concluded in a review by Punnett and Bergqvist (1997), that the use of a keyboard was a direct causative agent. The same review also observed that neck/shoulder disorders were also associated with prolonged keyboard usage but less consistently than hand and wrist disorders (Punnett & Bergqvist, 1997).

Additionally, prolonged sitting in awkward postures, commonly observed in VDT users, increases the risk of developing computer WMSDs. Awkward postures increase tension on the ligaments and muscles in the lumbar region (Carter & Banister, 1994), thereby promoting isometric work and inactivity. This increase exacerbates the condition, and can in short and long-term health effects as well as reduced blood circulation that may affect alertness, performance, and contribute to fatigue buildup (Carter & Banister, 1994). Prolonged stationary seated work could also contribute to injury of the back/spine by increasing compressive and-or shear force on the intervertebral discs of the spine (Andersson, 1987; Punnett & Bergqvist, 1997; Sauter et al., 1991). A study by Baker et al. (2018), explored the short-term musculoskeletal and cognitive effects of prolonged sitting during office computer work. It was found that there were acute negative effects of 2 hours of prolonged sitting as well as clinically meaningful increases in discomfort in the low back. Furthermore, deterioration in cognitive function, specifically creative problem-solving, was also observed. Overall, Baker concluded that prolonged periods of seated work, commonly found in computer workers, may have negative consequences on musculoskeletal discomfort and cognitive function.

To conclude, the most commonly reported risk factors associated with computer use are prolonged awkward postures, computer work duration, workload, and desk ergonomics (Ellahi et al., 2011). Over time, it is believed that these factors contribute and ultimately culminate in injury and that the static nature of seated work encourages MSDs by preventing movement. Dynamic workstations could be beneficial in facilitating movement and could thereby promote healthy blood circulation, prevent overload of the same muscle fibers, and reduce overall sedentarism.

Alternatives to the Seated Workstation

To mitigate the negative effects associated to static sitting in office work, alternatives have been suggested, including the standing desk (Davis & Kotowski, 2015). Overall, the standing posture has advantages over the sitting posture, including increased upper body muscle activation variability, as well as the reduction of whole-back discomfort and trunk muscle activation, which could potentially help prevent MSDs (Karakolis et al., 2016; Park et al., 2020). A study by Fedorowich et al. (2018), explored the effects of standing computer work tasks on upper limb muscular and vascular characteristics of healthy young adult males and females. Authors found that upper limb discomfort occurred 27 minutes later in the standing condition compared to the seated one. Furthermore, participants demonstrated a higher performance (faster typing speed, and faster adjusted for errors typing speed), lower and more variable electromyographical amplitude, and lower indices of between-muscle connectivity, but an absence of change in blood flow. The lack of blood flow changes likely contributed to the observed increase in discomfort over time. Overall, these results suggest that there are benefits of standing computer work; however, there may also be some undesirable effects caused by its static characteristics that may contribute to WMSDs in the long run. Indeed, standing computer work has also been shown to be associated with some negative effects, such as increased muscle activation and blood pooling in the thigh and leg muscles when compared to seated computer work (Fedorowich & Côté, 2018; Gao, 2017). Therefore, it is not clear if shifting from static sitting to static standing can sufficiently alleviate the health risks associated with workplace sedentarism (Callaghan et al., 2015).

Sit-stand workstations, implemented either with height-adjustable desks or using a hybrid, sit-stand stool, has also been proposed as a way to address negative issues related to both static sitting and standing. Several studies have shown that alternating between seated and standing postures with the help of a sit-stand desk may reduce sedentary activity and whole back discomfort (Callaghan et al., 2015; Pronk et al., 2012). However, in a study by Park and Srinivasan (2021) it was found that the alternating sit-stand pattern, in comparison to seated and standing conditions, was associated with decreased back muscle activity and increased trunk stiffness. It has also been reported that the sit-standing posture results in similar back and upper limb outcomes to the standing posture for some types of low-load manual work (Antle et al., 2015). Overall, the alternating sit-stand workstation may be beneficial in mitigating low back pain, but it is not known if it can sufficiently reduce sedentarism and mitigate factors contributing to WMSDs within other regions of the body.

Therefore, more dynamic workstations may be preferable (Baker et al., 2019). Active Office Workstations (AOW) enable people to incorporate physical activity into sedentary tasks and may help reduce workplace inactivity (Frodsham et al., 2020). Such workstations include walking workstations, stepping workstations, elliptical, and cycling or under-desk pedaling workstations.

In a review by Torbeyns et al., (2014) it was found that AOWs had significant positive influences on health aspects such as energy expenditure, and overall health. However, studies have reported that walking and cycling workstations had either no effect or a detrimental effect on typing computer performance (Funk et al., 2012; Ohlinger et al., 2011; Straker & Mekhora, 2000). A study by Funk (2012) investigating the effect of treadmill/walking workstations, where participants walked at 1.6 km/hr while typing, found that performance was 18.2% worse under the walking condition than the seated condition. In another study by Koren et al. (2016) investigating the effects of cycling workstations on productivity (time and error) as well as a similar study by Torbeyns et al. (2017) exploring desk cycling and performance, reported that cycling had little to no detriment in typing performance. While another study by Yoon et al. (2019) studying the effects of typing while cycling with a Monark™ ergometer, showed improvement in typing performance at higher pedaling intensities, over time. Finally, a review by Oja et al. (2011) concluded that there was limited evidence to suggest that cycling workstations might decrease some aspects of performance; however, this could be due to a lack of familiarity with the workstations.

Nevertheless, cycling workstations still appear to be a promising alternative due to their more dynamic nature. According to a review paper by Dupont et al. (2019) cycling workstations result in greater cardiometabolic gains and maintain acceptable levels of productivity. Cycling workstations also provide more postural stability than walking ones, which may further help stabilize the upper limbs and visual platform, as opposed to the standing and walking computer work postures. Overall, there is limited and conflicting research regarding AOWs, especially cycling workstations on health and computer work. The studies that are available report conflicting results, especially regarding computer work performance (Frodsham et al., 2020; Ojo et al., 2018; Yoon et al., 2019). Indeed, more studies are needed on cycling workstations before conclusions can be drawn.

Sex/gender differences in mechanisms of computer work-related MSDs.

Biological sex differences (i.e., hormonal, anthropometric, etc.) as well as gender differences (i.e., behavioral, societal, etc.) could play a major role in the exposure to WMSD risk factors (Côté, 2012). The epidemiological differences in the incidence of WMSDs may be related to a myriad of biological sex-based factors such as hormonal, anthropometric, functional (e.g., strength), physiological (e.g., body composition), and fatigue adaptation mechanisms (Côté, 2012). These epidemiological differences may also be influenced by gender-based factors, such as gender differences in computer work assignments, and postural transition (Cairns & Gazerani, 2009; Côté, 2012; Yaginuma et al., 1990). Additionally, the sex/gender (s/g) difference in the incidence of WMSDs also appears to influence the region of the body that is affected, with women reporting more neck-shoulder symptoms, and men being more exposed to low back injuries (Côté, 2012; Hooftman et al., 2009). Furthermore, in a review by Cairns and Gazerani (2009), it was reported that there were significant sex differences in the occurrence of musculoskeletal pain. Women often report more severe, frequent, anatomically diffuse, and longer-lasting pain than men when suffering from the same pain condition (Cairns & Gazerani, 2009). Overall, nearly all epidemiological studies exploring s/g differences report a higher prevalence of MSD symptoms in women, particularly in MSDs of the upper limb (Côté, 2012; Larsson et al., 2007). However, more research exploring s/g differences in relation to the susceptibility and development of WMSDs and their symptoms is needed.

Several studies have compared the behavior of men and women in jobs focused on traditional computer work, but fewer have investigated how males and females respond to alternative computer workstations. Studies exploring sex differences in muscle activity during computer work have reported little to no difference in the muscular activity patterns of the upper trapezius (Blangsted et al., 2003; Nordander et al., 2000). However, they have found that females tend to exhibit a lower EMG gap time and higher static levels compared to males (Blangsted et al., 2003; Nordander et al., 2000). These finding are supported by a study by Le & Marras, (2016), where 30 young adults (20 male and 10 female) were instructed to perform a standardized typing task while using a: seated, standing, and perched workstation. This study found that females were more committed to sedentary behaviors and had fewer postural transitions when using any type of workstation (Le & Marras, 2016a). Overall, there is a general lack of studies exploring sex differences in muscle activity when using cycling computer workstations. Highlighting this is a study by Yoon et al. (2021), where 22 participants (12 males and 10 females) were recruited. Each group performed a typing task while cycling on a Monark cycle ergometer at low (25% HRR) or moderate (40% HRR) intensity on a separate day. This study found that there were sex differences in neuromuscular responses to cycling computer workstations. Specifically, these differences were time-based sex-specific responses in the cervical erector spinae, anterior deltoid, and middle trapezius. It was also found that pedaling intensity only affected the females' neck, shoulder, and forearm muscles (Yoon et al., 2021). Females demonstrated a decrease in the activation variability of the upper trapezius during the 25% HRR session. This is significant as low variability has been shown to be associated with high fatigability, particularly in females, and an elevated risk for MSDs (Fedorowich et al., 2018; Madeleine et al., 2011). This study shows that muscle activity in response to cycling workstations differs significantly between the sexes. However, this study did not use a cycling device fabricated specifically for computer work and did not include a seated condition to which the addition of cycling could be compared on a within-subject basis.

Summary and Knowledge Gaps

In summary, previous studies have shown that traditional seated workstations promote the development of WMSDs by encouraging major risk factors for WMSDs, such as prolonged static sitting, awkward postures, inactivity, etc. To our knowledge, no studies are available that compare the traditional seated workstation to the cycling workstation. Furthermore, no other study has been found that has identified the sex-specific impacts of cycling workstation on upper body and visual discomfort outcomes during computer work. It is also not well known how cycling workstations influence upper body muscle activity as well as productivity and performance.

Objectives and Hypotheses

The objectives of this study were to compare electromyographic (neck, upper limb, lower back muscles), typing performance, and discomfort of the: upper body, neck shoulder, visual, and seat comfort associated with 60 minutes of computer work between under-desk-cycling and sitting, and how these differ between males and females.

We hypothesized that cycling workstations when compared to the seated workstation, would significantly increase muscle activity amplitude in all muscles of the upper limbs. No change in typing performance was expected; however, we anticipated lower reported levels of physical discomfort with time in the under-desk cycling condition compared to the sitting condition. Finally, we expected the above-described differences to vary between the sexes.

RESEARCH ARTICLE

Sex-specific Electromyographic, Performance, and Symptomatic Differences between Sitting and Cycling Computer Workstations

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Abstract

Previous studies have shown some benefits of active workstations to reduce symptoms and improve overall health of computer workers. Cycling workstations are a promising workplace intervention, as they allow for greater energy expenditure, muscle activation, and increased blood flow. Cycling intensity has been shown to display sex-specific effects on upper muscle activity and typing performance in a computer typing task. However, whole-body effects of using commercial bike-and-type are poorly understood. Twenty-six computer users (n = 14 females) underwent two 60-minute typing tasks, either sitting on a sit-stand stool or cycling within a target heart rate of 25% of heart rate reserve. Surface electrodes were placed to collect from the upper limb and low back muscles. Typing speed, as well as visual, upper limb and seat discomfort were collected every 10-minutes. Results show that males' performance was negatively affected by cycling, with fewer words per minute, whereas females' performance was the same in both conditions (Sex × Time × Condition interaction effect, $p = 0.029$). Cycling led to a smaller increase in neck/shoulder discomfort with time, especially in females (Sex × Condition × Time interaction effect, $p = 0.006$). Moreover, with time, neck/shoulder muscle activation increased during sitting but conversely, decreased with time during cycling, especially in females. Lastly, low back muscle activity was higher and varied more with time during cycling, especially in females (Sex × Condition × Time interaction effect, $p=0.046$). Although there was no difference in seat discomfort between sitting and cycling. The results suggest that there exist sex-specific responses to cycling workstations during 60-minute computer work tasks, and that cycling workstations, although a promising alternative, should not necessarily be recommended to all males and all females.

Keywords: Electromyography, Musculoskeletal Discomfort, Cycling Workstation

1. Introduction

Workplace-related sedentarism, specifically prolonged static sitting, has been associated with higher incidences of cardiovascular disease, obesity, all-cause mortality, and the development of musculoskeletal disorders (MSDs) (Hu et al., 2003; Patel et al., 2010). Work-related MSDs (WMSDs) are disorders of the muscles, tendons, and ligaments caused by factors within the work environment (Government of Canada, 2022). Risk factors for WMSDs include poor posture, excessive static sitting, insufficient blood flow, lack of motor variability, repetitive movements, and sustained muscle contractions (Mörl & Bradl, 2013; Ranasinghe et al., 2016; Tittiranonda et al., 1999). Prolonged static seated computer work has been linked to both neck and upper limb WMSDs as well as increased low back discomfort and upper trapezius muscle activity (Fedorowich & Côté, 2018; Heinrich, 2004), which are well-known risk factors for developing MSDs at the back and neck/shoulders (Grondin et al., 2013).

Prolonged use of visual display terminals (VDTs), such as computers, has also been associated with Computer Vision Syndrome (CVS). CVS encompasses a group of eye and vision disorders caused by activities that strain near vision, particularly during computer usage (Rosenfield, 2011). Symptoms of CVS include eye discomfort, eye strain, irritation, burning sensation, redness, blurred vision, and double vision (Bergqvist & Knave, 1994). Symptoms of CVS tend to be acute, although some individuals experience recurring and worsening symptoms over time (Bergqvist & Knave, 1994; Loh & Redd, 2008). CVS symptoms can impair performance by increasing errors during computer tasks and necessitate more frequent breaks (Rosenfield, 2011). Moreover, CVS symptoms have the potential to exacerbate MSDs, although the mechanistic link between CVS and MSDs during computer work is poorly understood.

The existing literature consistently indicates that females have a higher susceptibility to developing both WMSDs and CVS (Juul-Kristensen, 2005; Treaster & Burr, 2004). The exact reasons for this disparity are not fully understood, but potential contributing factors can be related to either or both sex and gender, including variations in hormones, anthropometric and structural characteristics, sensorimotor strategies, and fatigue adaptation methods (Emery & Côté, 2012; Fedorowich et al., 2013; Srinivasan et al., 2016). The currently sub-optimal understanding of the mechanisms that underlie sex/gender differences in computer work-related symptoms makes it difficult to determine the extent to which adaptations to the traditional static seated computer work setup should be adapted to sex/gender.

Various alternative office work postures, such as standing, and sit-stand desks (Davis & Kotowski, 2015), have been proposed to mitigate the elevated occurrence of upper-body MSDs associated with extended periods of seated computer work. Although some benefits of these alternative workstations have been documented (Bastien et al., 2018; Frodsham et al., 2020), it is unclear whether they sufficiently alleviate the health risks associated with sedentarism (Callaghan et al., 2015). Consequently, more active office workstations (AOW), such as walking and cycling workstations, may be preferable (Baker et al., 2019). Cycling workstations are a promising alternative as they activate larger muscle groups, promote blood flow, and help prevent discomfort in the upper and lower limbs while providing a more stable seated support than during walking (Baker et al., 2019). Previous studies on both walking and cycling workstations have suggested some benefits (Fedorowich et al. 2018; Yoon et al., 2019). However, there is limited research particularly regarding cycling workstations: for instance, there have been no previous studies using commercial under-desk pedaling devices, and none has compared the visual symptoms or electromyographic (EMG) differences between sitting and cycling desk work.

The objectives of this study were to compare neck, upper limb, and lower back electromyography, performance, and discomfort across time and between males and females accomplishing a computer work task. We hypothesized that cycling workstations would result in earlier onset of visual discomfort. We expected no change in typing performance but anticipated decreased discomfort over time in the under-desk cycling condition compared to the sitting condition. Finally, we anticipated that the described differences would vary between the sexes.

2. Methods

2.1 Participants

To test our primary outcome, Upper Trapezius root mean square (RMS), it was determined that a sample size of 14 participants was required (G*Power software, Repeated Measures ANOVA within-between interaction: power = 0.80, alpha = 0.05, effect size = 0.56, number of groups = 2 [males and females], number of measurements = 24 [2 conditions with 12-time points], sphericity: 0.05). We used a power of 0.80 since it has been shown to be the ideal power of a study (Hintze, 2008). The effect size of 0.56 was used for the calculation; it was calculated using results for the main outcome of Upper Trapezius RMS from our previous study (Lamanuzzi et al., 2023), which assessed the sex-specific effects of alternating computer work postures in young adults. Four extra participants were recruited to account for the 20% dropout rate, and an additional eight were also recruited to increase the reliability of the results for the additional outcomes. Therefore, 26 young healthy adults (12 males, 14 females; age: male= age: 22.8 ± 2.3 female= age: 22.6 ± 2.1; height: male= height: 174.00 ± 6.33cm female= 160.42 ±

4.01cm; weight: male= 68.6 ± 12.6kg weight: female=65.3 ± 17.5kg; 19 right hand dominant, 6 left hand dominant, 1 ambidextrous) were recruited as a convenience sample from a university population (see Appendix A). Participants were included in the study if they met the following criteria: (1) were cleared by the Physical Activity Readiness Questionnaire for Everyone 2020 (CSEP Expert Advisory Committee, 2002), (2) were frequent computer users (≥ 6 hours/day or ≥ 40 hours/week) and (3) willingly provided informed written consent to participate in the study (see Appendix B). Participants were excluded from the study if they (1) had a medically diagnosed musculoskeletal or neurological pathology, (2) consumed alcohol or engaged in exercise ≤ 24 hr before the laboratory visit, (3) consumed caffeine ≤ 12 hours before the laboratory visit, (4) were unable to read or type in English for ≥ 60 minutes, (5) suffered from chronic headaches diagnosed by a doctor or requiring medical attention in the last 3 months, or (6) had a disorder of the upper or lower body in the last year. The study was approved by the McGill Research Ethics Board Office (Reference Number: 22-06-060).

2.2 Experimental Protocol

Participants sat on a Muvman™ sit-stand stool or Ergonomyx© Under Desk Bike while using a sit-stand table (Ergonomyx Technologies Canada 381 Inc., Victoria, Canada). The table was adjusted based on Canadian ergonomic guidelines and individualized based on anthropometric measures (Canadian Centre for Occupational Health and Safety, 2016; Occupational Health Clinics for Ontario Workers, 2008). Specifically, the desk height was set to provide an angle of 90° at the elbow joints when the hands were placed flat on the table (Winkel & Bendix, 1986). A laptop with a 15-inch monitor was placed on a laptop stand and connected to a standard wired keyboard. The monitor was placed at an arm’s length distance from the participant, with the top of the monitor being adjusted to be approximately 5cm below the participant's eye level. The keyboard and monitor were centered in line with the nose and belly buttons, and the keyboard was placed as close to the edge of the table as possible, to prevent the participant from supporting their forearms with the table. The participant was asked to relax their shoulders, keep their elbows close to their body, and to sit with their head and neck balanced and in line with their torso, and maintain this upper body posture during the entire recording protocol.

The participant completed two separate 60-minute computer tasks in a randomized presentation order on the same day. The task involved reading and typing solely using a keyboard, in either the seated or cycling posture. There was no mousing tasking involved in the set up. Fourteen participants started with the biking condition, while 12 started with the cycling condition.

Before beginning each condition, the participant engaged in a 10-minute familiarization task (5 minutes of cycling while typing, 5 minutes of sitting while typing) followed by a 5-minute break. The experimental task consisted of the participant performing six 10-minute trials of computer work where electromyography (EMG) of several muscles were recorded during the final 30s of each 10-minute trial. A 90-second break was provided at the end of each 10-minute trial, where performance (words per minute [WPM]), and WPM adjusted for the number of mistakes made during the bout i.e. adjusted words per minute [AWPM]) was measured by the Mavis Beacon Teaches Typing software (Crichton, 2001; Fedorowich & Côté, 2018), and the discomfort ratings of neck-shoulder, upper body, seat, and visual discomfort were collected using a 0-10 visual analog scale (VAS) from 0 = "no discomfort" (0mm) to 10 = "Discomfort as bad as it could possibly be" (100mm). When discomfort ratings were asked, the participant was instructed to pause the task (excluding pedaling, for the cycling condition) and they were then presented with four VAS scales, on different pieces of paper, to determine: neck-shoulder discomfort, upper body discomfort, visual discomfort, and seat discomfort. The participant was instructed to mark with a vertical line their current discomfort rating for the above-mentioned measures on during the 90-second break between each trial.

The participant was told at the beginning of each condition and trial to "type as accurately and as fast as possible" to ensure maximal computer performance. The participant was given 20 minutes to recover after the first bout of 60 minutes of computer work to reduce the possibility of residual fatigue affecting the data of the condition assigned in second (Le et al., 2016).

2.3 Muvman™ Sit-stand Stool

The Muvman™ sit-stand stool (Muvman®, aeris-Impulsmobel GmbH &Co.KG, Haar bei München, Germany) was utilized in this study to provide a static sitting condition as comparable as possible to that of the under-desk bike, while also still closely resembling sitting surfaces used in the office (Antle et al., 2015; Chester et al., 2002; Yang & Côté, 2021). Compared to the standard seated workstation, the Muvman™ sit-stand stool has a movable joint at the base, to allow some motion of the hips, trunk and upper body. The stool was selected to minimize the influence of seat discomfort on the other outcomes. To standardize the implementation of the sit-stool, it was briefly introduced to the participant. The participant was informed that the stool did allow some motion. The participant's stool height was adjusted to the midpoint of their greater trochanter and lateral epicondyles (Yang & Côté, 2021). The participant was then asked to find their most comfortable position on the sit-stand stool with their feet flat on the floor. Once they found their most comfortable position, they were not allowed to move their feet anymore (Appendix C).

2.4 Ergonomyx© Under Desk Bike

A standard positioning protocol described by Lopes et al. (2014) was used in combination with the Ergonomyx© Under Desk Bike. Feet were positioned such that the second metatarsal was over the pedal spindle. The participant was asked to adjust the bike to themself. The participant's ankle was in a neutral position (foot and tibia perpendicular) in the sagittal plane. The knee angle at maximum flexion and extension were also manually measured and recorded using a goniometer (Appendix D). During the task, the participant was instructed to bike at the same time as they were executing the computer task, and to stay within their target heart rate (see below). Resistance was monitored and adjusted throughout the bike-and-type condition to maintain the heart rate during the target zone (25% of Heart Rate Reserve, HRR).

2.5 Instrumentation-Heart rate Monitor

The heart rate monitor was placed upon arrival, and the Resting Heart Rate (RHR) was measured. Female participants were instructed to wear a sports bra, while male participants were asked to be shirtless. A digital heart rate monitor (Polar T61-coded) was aligned with the xiphoid process to monitor pedaling intensity (moderate 25%HRR; Yoon et al. 2019). The participant laid down on a massage table in a supine position with their eyes closed without falling asleep for five and a half minutes. The highest and lowest values were recorded during the last 30 s and were averaged to obtain the RHR. To calculate the appropriate %HRR (i.e., the target HR, TargetHR), the Karvonen formula (TargetHR = [MaxHR – RHR] x %intensity + RHR) was used, with an estimation for Maximum HR (MaxHR)= 220-age.

2.6 Experimental Task, Discomfort and Computer Performance

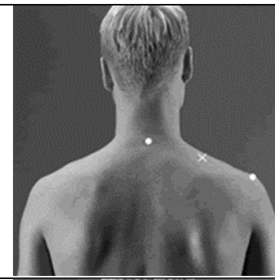
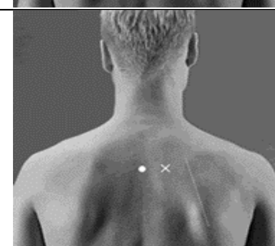
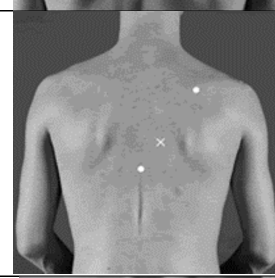
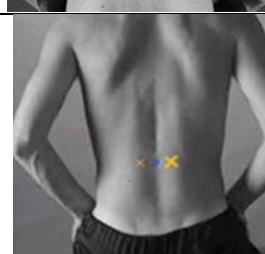
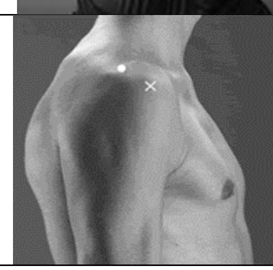
Twelve predetermined texts from the Grimm's Fairy Tales collection were randomly selected as the texts for the typing task in the Mavis Beacon Software (Kim et al., 2014; Yoon et al., 2021). The randomly selected texts had similar Flesch-Kincaid grade levels to the texts mentioned in a study by Kim et al. (2014) that investigated typing performance on a virtual and conventional keyboard. The texts chosen had a Flesch-Kincaid grade level of 5.1–5.7, indicating that the texts could be easily understood by the average 12-year-old.

3.0 Muscle activity

Surface EMG Electrodes (Delsys© Trigno™, USA) were placed on seven neck and shoulder muscles: upper trapezius, middle trapezius, lower trapezius, anterior deltoid and lumbar erector spinae (bilaterally) with alignment of the electrode parallel to the muscle fibers. The muscle sites were shaved and abraded with alcohol before placing the electrodes to prevent hair or dead skin cells from interfering with the conductivity. Muscle activity was continuously recorded using an A/D converter and a multichannel data acquisition software to sample the EMG data at 2000 Hz.

Electrodes were placed as described in Table 1 (Hermens et al., 2000).

Table 1. EMG electrode position for each muscle

Muscle	**EMG Placement**	
Upper trapezius	Electrode placed halfway between the acromion and C7 vertebrae	
Middle trapezius	Electrodes placed, horizontally, halfway between the medial border of the scapula and the spine, at the level of T3 vertebrae.	
Lower trapezius	Electrode placed, at an angle, 2/3 of the way from the trigonum spinae to the T8 vertebrae	
Lumbar erector spinae	Electrode placed two finger widths from the spine at the midpoint between T12 and S1, along lumbar spine over transverse process	
Anterior deltoid	Electrode placed two-finger width distal and anterior to the acromion.	

3.1 Submaximal Voluntary Isometric Contractions (sMVICs)

sMVICs were recorded after placing the electrodes and before performing the experimental tasks, from all the following muscles: middle trapezius, lower trapezius, lumbar erector spinae, anterior deltoid and upper trapezius. sMVICs were performed against gravity in the postures and with held positions as described in Table 2.

Table 2. sMVICs position and action for each muscle

Muscle	**sMVICs position**	**sMVICs held position**
Middle trapezius	Prone lying, shoulder horizontally abducted and externally rotated (palm facing the floor)	Shoulder horizontal abduction held at 90°
Lower trapezius	Prone lying, shoulder horizontally abducted with external rotation, and with the arm raised overhead in line with the lower trapezius muscle fibre	Shoulder flexion held at 180° (i.e., parallel to the floor)
Lumbar erector spinae	Prone lying, upper body off the physio table, lower body secured	Lumbar extension held at 0°
Anterior deltoid	Seated with their legs flexed at 90 degrees	Shoulder flexion held at 90° with the wrist in neutral position
Upper trapezius		Shoulder abduction held at 90°, with palm facing down

sMVICs were recorded only once, before the first of the two sessions (since both sessions were scheduled on the same day, and electrodes were kept on the participants in between both sessions). For sMVICs, two ramp-up, hold, ramp-down, five-second trials were performed for each muscle. Guidance and feedback were provided to ensure the participant reached the target posture. One minute of rest was given between each sMVICs trial. The mean of the two trials was used to define the sMVICs for data analysis.

4.0 Data Analysis

The collected EMG data was band-pass filtered (Butterworth 2nd order, 10–450 Hz), full-wave rectified, and normalized. All EMG data was then visually screened for heartbeat contamination, and spikes. All heartbeats and spikes were removed.

RMS values that were best reflective of the sMVICs trials were visually selected and used to normalize the EMG data collected during the typing trials. The average RMS value of each 30 second typing trial per muscle was calculated and represented the EMG RMS for each muscle and for each condition.

4.1 Statistical Analysis

The mean and standard deviation for age, weight, and height for males and females were determined and compared using Independent-Samples T-Test. A p-value of < 0.05 was indicative of significant sex differences for variables of equal variance.

Generalized estimating equations (GEE) were used to assess effects on EMG, performance, and discomfort measures. Sex (Males, Females) was modeled as a between-subject factor, while Condition (seated vs. cycling) and Time (6 x 10 min trials) were modeled as within-subject factors. The GEE approach was applied as it is able to obtain a higher power with a smaller sample size in comparison to the repeated measures analyses of variance (RM-ANOVA), it also employs less restrictive assumptions than RM-ANOVA and helps to estimate the overall average effects per group (Ma et al., 2012; Naseri et al., 2016). If statistically significant effects were observed using pairwise comparisons (Wald X^2), sequential Bonferroni corrections were performed. The significance level was $p < 0.05$. Statistics were conducted in SPSS (SPSS Statistics v24, IBM Corp., US).

3. Results

Participant characteristics are presented in Table 1. Males were significantly ($p<0.001$) taller than females. They did not differ significantly in terms of weight and age.

Table 1. Mean and standard deviation (SD) of male and female participants. Independent-Samples T-Tests were performed with equal variances for age, height, and weight. A p-value of < 0.05 indicates a significant sex difference.

Characteristic	Males	Females	p-value
Age (years)	23.00 (2.26)	22.64(2.06)	=0.68
Height (m)	174.59(6.37)	160.42(4.01)	**<0.001**
Weight (kg)	69.30(12.22)	65.27(17.52)	=0.51

3.1 Computer Performance

For computer performance (Words per minute, WPM), a significant interaction effect of Sex × Condition ($X^2 = 4.89$, $p = 0.029$) was found. A significantly lower performance was observed in males in the cycling condition compared to the seated condition (Fig.1). Female computer performance was similar in both conditions (Fig.1).

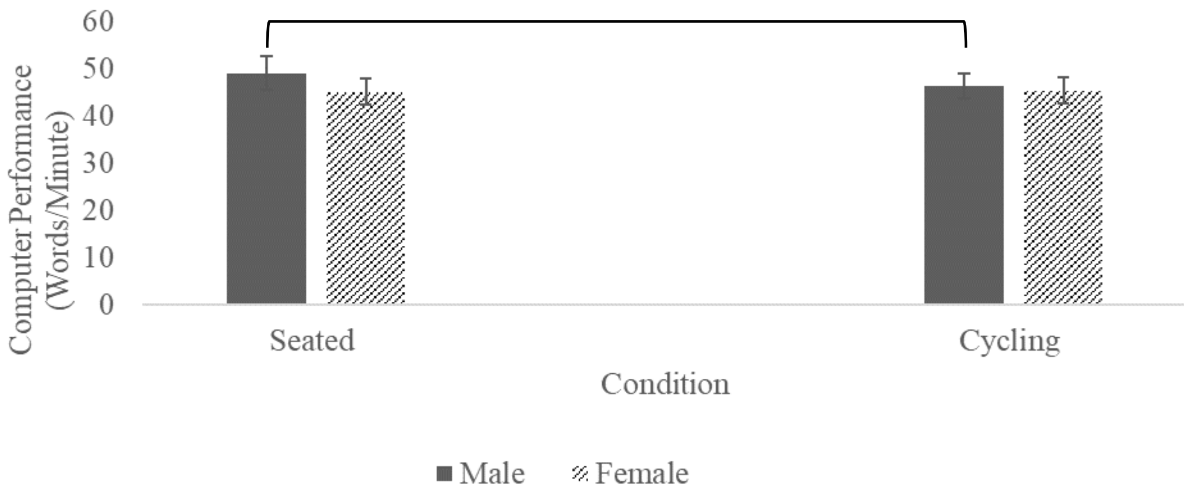


Figure 1. Computer performance measures (words per minute) as a function of condition and time. There was a significant interaction effect of Sex × Condition for computer performance (p =0.029). Error bars indicate standard error.

A significant interaction effect of Sex × Time ($X^2 = 54.69$, p=0.027) was also determined. Males' performance decreased from 20 minutes to 40 minutes, from 48 words/min to 45 words/min (Fig.2). Females' performance also decreased from 30 minutes to 50 minutes, from 46 words/min to 44 words/min (Fig.2).

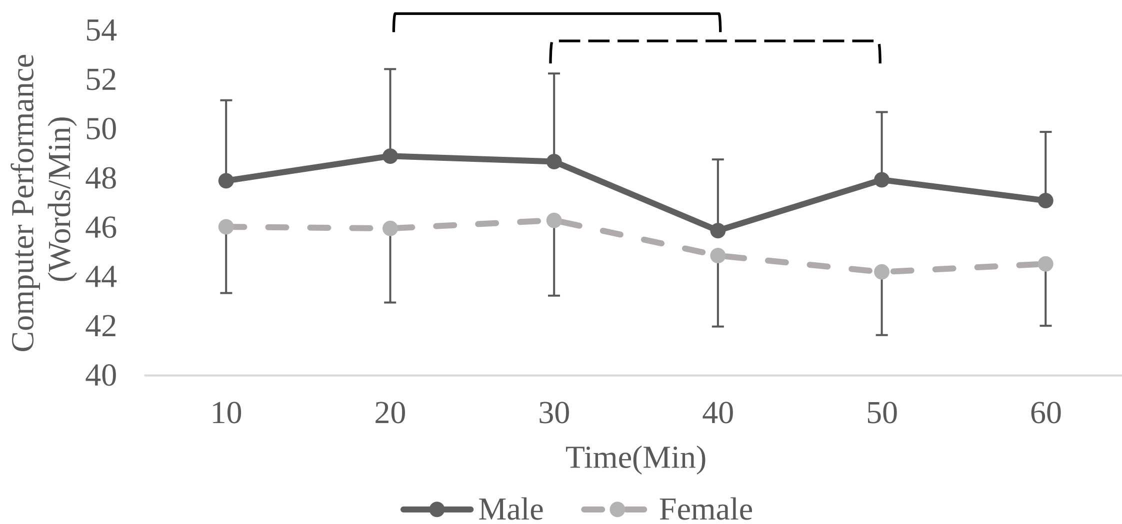


Figure 2. Computer performance measures (words per minute) as a function of condition, time, and sex. There was a significant interaction effect of Sex × Time for computer performance (p =0.027). Error bars indicate standard error.

A significant main effect of Time was also determined (p<0.001) for WPM. Computer performance remained relatively consistent; however, there was a significant drop at the very end in comparison to the beginning, from 46 words/min to 45 words/min. There were no other main or interaction effects on WPM.

A significant interaction effect of Sex × Condition ($X^2 = 12.08$, p=0.003) was determined for adjusted computer performance (AWPM). Males' computer performance, adjusted for their typing mistakes, was lower in the cycling condition compared to the seated, whereas there was no difference between the conditions for females (Fig.3).

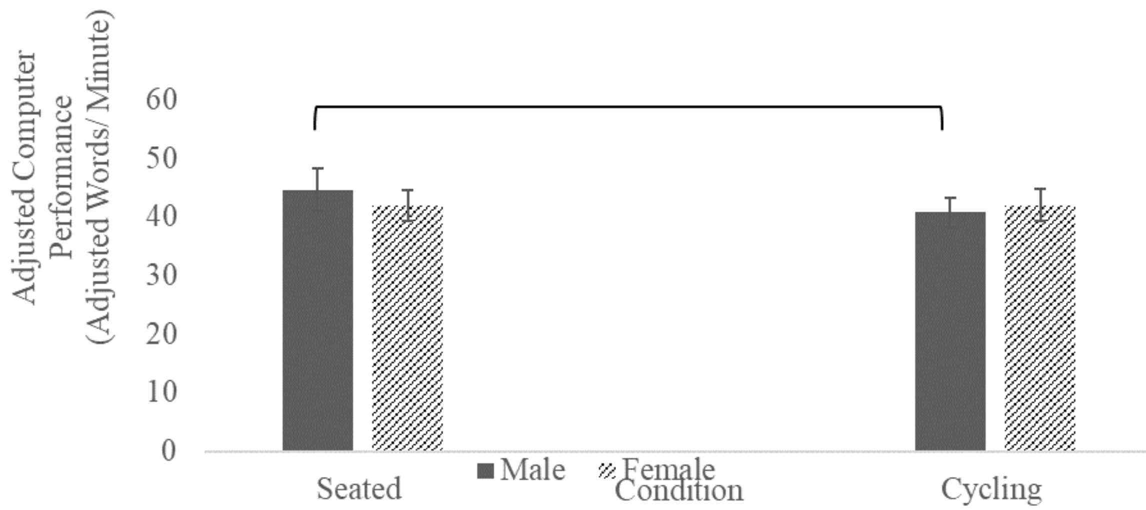


Figure 3. Adjusted computer performance measures (adjusted words per minute) as a function of condition and sex. There was a significant interaction effect of Sex × Condition for computer performance ($p = 0.003$). Error bars indicate standard error.

A main effect of Condition ($p=0.003$) was also determined on AWPM. A higher adjusted computer performance was observed during the seated condition in comparison to the cycling condition. Finally, a significant main effect of Time ($X^2 = 10.84$, $p=0.031$) was also found for adjusted computer performance. Adjusted computer performance decreased during the first 40 minutes, from 42 words/min to 41 words/min and continued to decrease for another 10 minutes (Fig.4). There were no other interactions or main effects on AWPM.

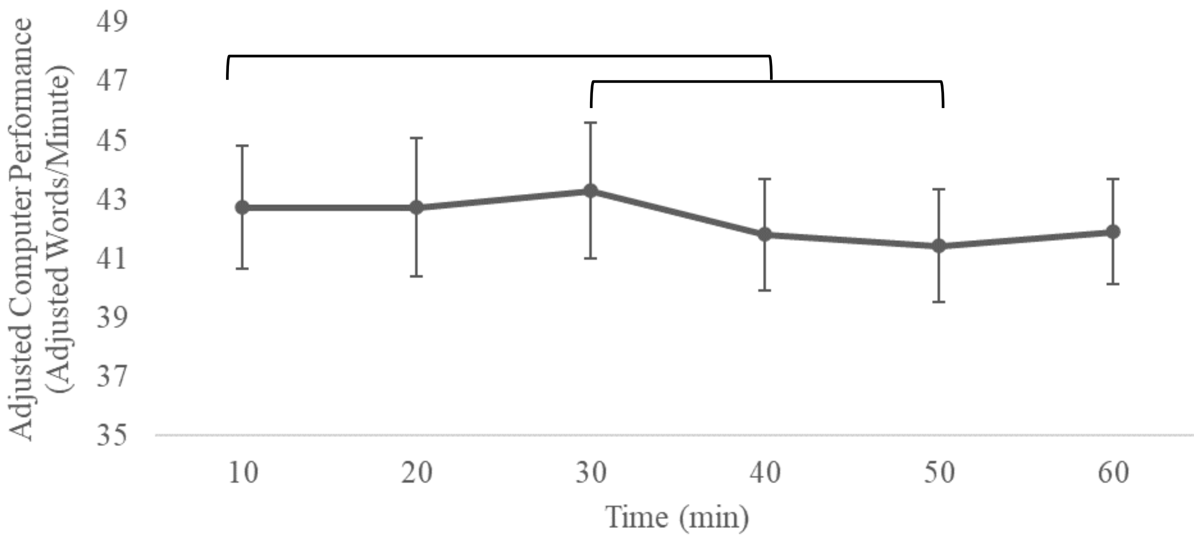


Figure 4. Adjusted typing performance measures (adjusted words per minute). There was a significant main effect of Time for adjusted typing computer performance (p =0.031). Error bars indicate standard error.

3.2 Discomfort

Regarding visual discomfort, a significant main effect of Time ($X^2 = 37.19$, $p < 0.001$) was found. Visual discomfort appeared to increase steadily over time, with a plateau during the last 10 minutes (Fig. 5).

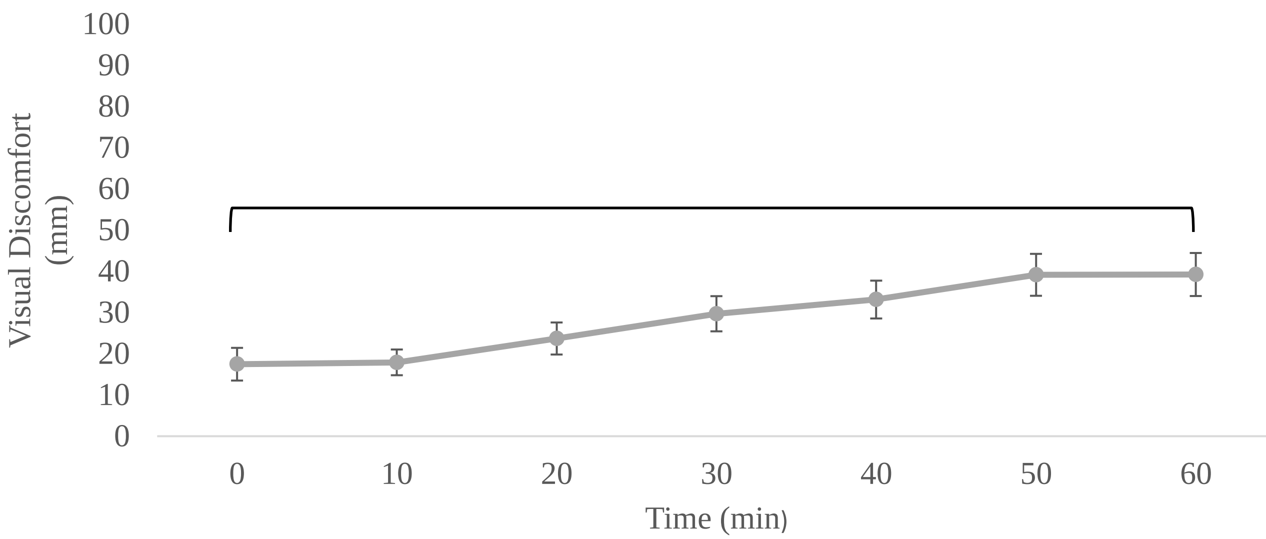


Figure 5. Visual discomfort (measured on a 0-100 mm visual analog scale) was reported during the computer task. Baseline measures were taken before the trial began (baseline=0 minutes). A significant main effect of Time ($p < 0.001$) was found. Error bars indicate standard error.

A significant main effect of Condition ($X^2 = 4.13$, $p=0.047$) was also found on visual discomfort. Compared to the seated condition, the cycling condition demonstrated significantly lower levels of visual discomfort. There were no other main or interaction effects on visual discomfort (Fig. 6).

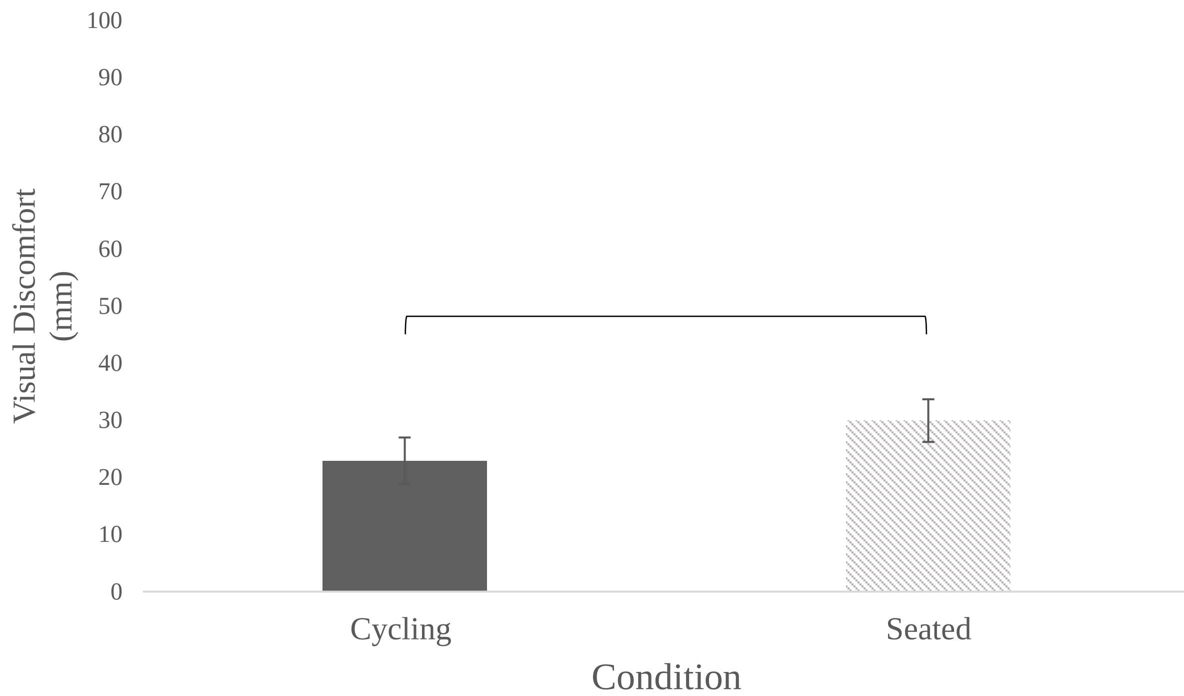


Figure 6. Visual discomfort (measured on a 0-100 mm visual analog scale) was reported during the computer task. Baseline measures were taken before the trial began (baseline=0 minutes). A significant main effect of Condition (p= 0.047) was found. Error bars indicate standard error.

For neck/shoulder discomfort, a significant interaction effect of Sex × Condition × Time ($X^2 = 18.29$, $p = 0.006$) was determined. Throughout time, the cycling condition demonstrated the lowest levels of neck/shoulder discomfort, and less of an increase with time, for both sexes, compared to the seated condition. Females also demonstrated lower levels of neck/shoulder discomfort than males in both conditions; however, this sex difference varied over time (Fig. 7). These findings were also reflected with significant Time x Condition ($X^2 = 25.30$, $p < 0.001$), and Time x Sex ($X^2 = 22.85$, $p <0.001$) interaction effects, as well as a main Time effect ($X^2 = 103.49$, $p < 0.001$). There were no other interactions or main effects on neck/shoulder discomfort (Fig.7).

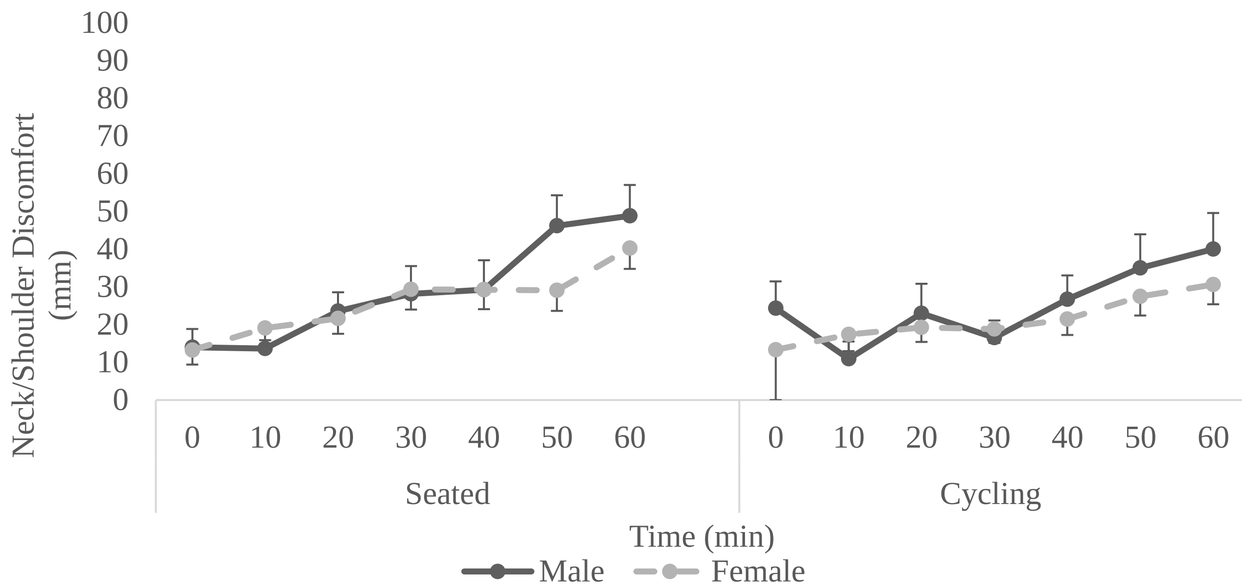


Figure 7. Neck/shoulder discomfort (measured on a 0-100 mm visual analog scale) was reported during the computer task. Baseline measures were taken before the trial began (baseline=0 minutes). A significant interaction effect of Sex × Condition × Time for neck/shoulder discomfort (p =0.006) was found. Error bars indicate standard error.

For upper body discomfort, only a significant effect of Time ($X^2 = 72.98$, $p < 0.001$) was found. Upper body discomfort increased steadily from approximately 14 to 44mm, from beginning to end (Fig.8).

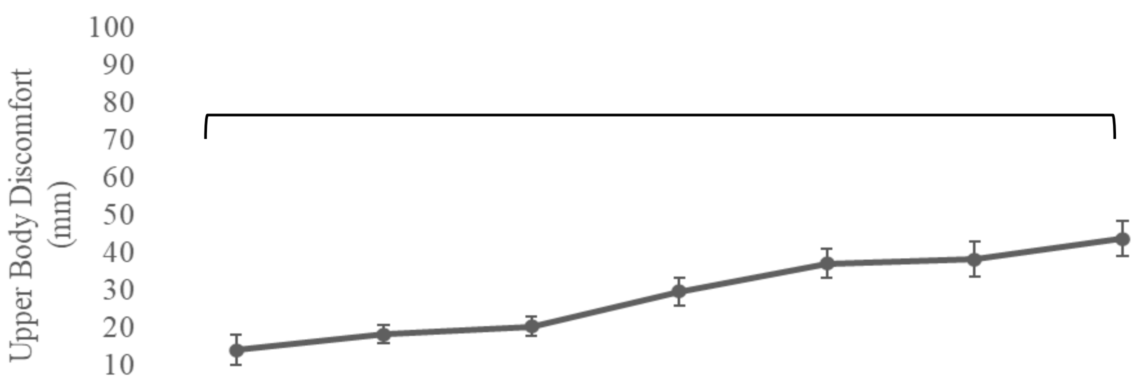


Figure 8. Upper Body discomfort (measured on a 0-100 mm visual analog scale) was reported during the computer task. Baseline measures were taken before the trial began (baseline=0 minutes). A significant effect of Time for upper body discomfort ($p < 0.001$) was found. Error bars indicate standard error.

Similarly, for seat discomfort, only a significant effect of Time ($X^2 = 182.84$, $p < 0.001$) was found. Seat discomfort increased steadily from beginning to end (Fig.9).

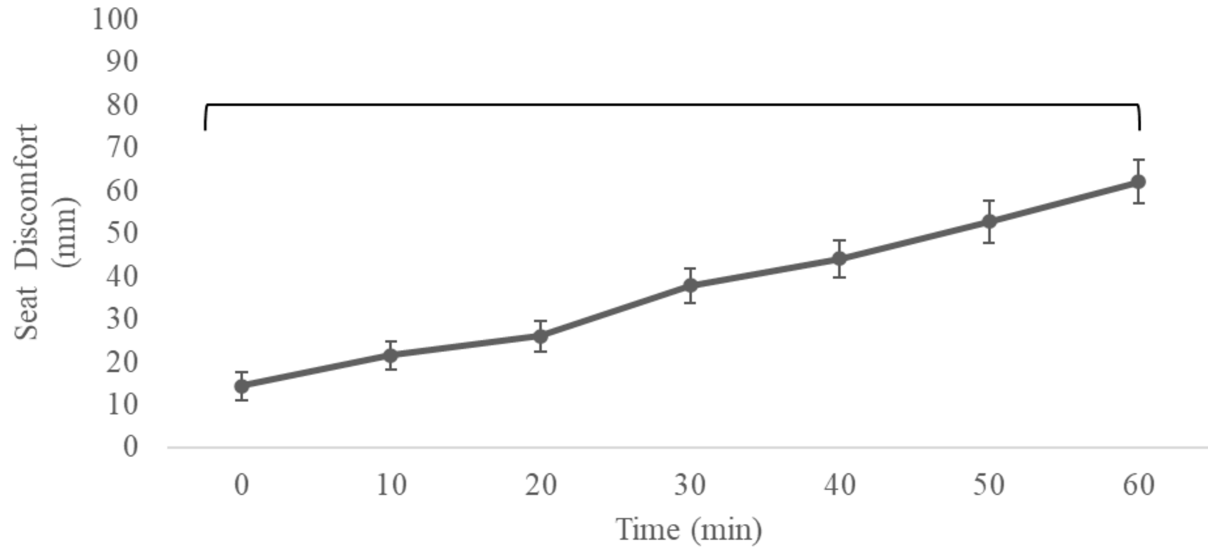


Figure 9. Seat discomfort (measured on a 0-100 mm visual analog scale) was reported during the computer task. Baseline measures were taken before the trial began (baseline=0 minutes). A significant effect of Time for seat discomfort ($p < 0.001$) was found. Error bars indicate standard error.

3.3 Muscle Activation Amplitude (RMS)

Significant and non-significant p-values are presented in Table 2, for the activity amplitude of the six muscles tested. A significant interaction effect of Sex × Condition × Time was determined for the upper trapezius ($X^2 = 25.39$, $p<0.001$), the left lumbar erector spinae ($X^2 = 14.78$, $p=0.011$), and right lumbar erector spinae muscles ($X^2 = 11.30$, $p=0.046$).

Table 2. Test of model effects (main and interaction), Wald Chi-Square, and p-values for muscle activation amplitude of six tested muscles using generalized estimated equations. A p-value of < 0.05 indicates a significant effect.

Muscle	Test of Model Effects	Wald Chi-Squared	p-value
Upper Trapezius	Sex × Condition × Time	25.39	**<0.001**
	Sex × Condition	2.04	0.15
	Sex × Time	17.40	**0.004**
	Condition × Time	29.12	**<0.001**
	Sex	0.038	0.85
	Condition	0.49	0.48
	Time	147.44	**0.014**
Middle Trapezius	Sex × Condition × Time	2.29	0.81
	Sex × Condition	0.43	0.51
	Sex × Time	5.88	0.32
	Condition × Time	10.46	0.063
	Sex	5.06	**0.025**
	Condition	1.81	0.18
	Time	12.70	**0.026**
Lower Trapezius	Sex × Condition × Time	5.27	0.38
	Sex × Condition	3.63	0.057
	Sex × Time	11.73	**0.039**
	Condition × Time	3.31	0.65
	Sex	0.42	0.52
	Condition	1.54	0.22
	Time	4.13	0.53
Anterior Deltoid	Sex × Condition × Time	3.12	0.68
	Sex × Condition	0.62	0.43
	Sex × Time	7.49	0.19
	Condition × Time	60.07	**<0.001**
	Sex	1.97	0.16
	Condition	10.43	**<0.001**
	Time	4.86	0.43
Lumbar Erector Spinae Left	Sex × Condition × Time	14.78	**0.011**
	Sex × Condition	2.48	0.12
	Sex × Time	9.19	0.1
	Condition × Time	10.88	0.05
	Sex	6.87	**0.009**
	Condition	162.79	**<0.001**
	Time	7.31	0.19
Lumbar Erector Spinae Right	Sex × Condition × Time	11.30	**0.046**
	Sex × Condition	0.38	0.54
	Sex × Time	7.82	0.17
	Condition × Time	5.49	0.36
	Sex	0.49	0.48
	Condition	47.51	**<0.001**
	Time	14.74	**0.012**

Regarding the upper trapezius muscle, activation amplitude mainly rose with time in the seated condition but displayed the opposite trend in the cycling condition (Fig.10). Moreover, females' activation was higher than males' in the cycling condition, but the opposite was found in the seated condition.

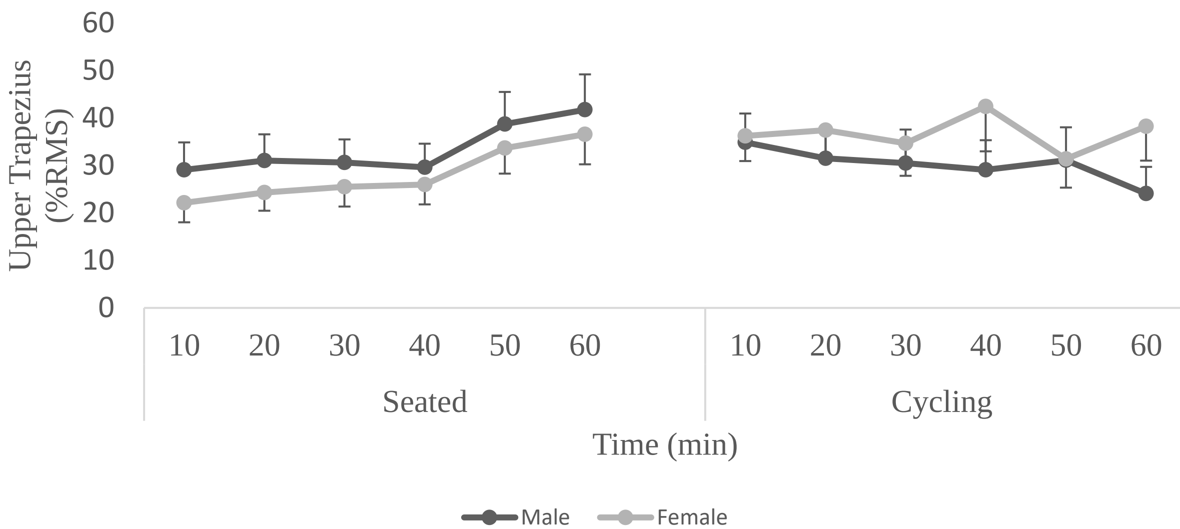


Figure 10. Muscle activation amplitude of the upper trapezius (group average values, error bars indicate a standard error) recorded during the last 30s of each 10-minute typing task. A significant interaction effect of Sex × Condition × Time for upper trapezius activation amplitude ($p < 0.001$) was found.

As for the left lumbar erector spinae (Fig. 11), the three-way interaction effect reflects higher activation amplitude during cycling, with increasingly higher amplitude with time in males. Conversely, for the right lumbar erector spinae (Fig. 12), females showed higher activation amplitude in the cycling condition compared to males.

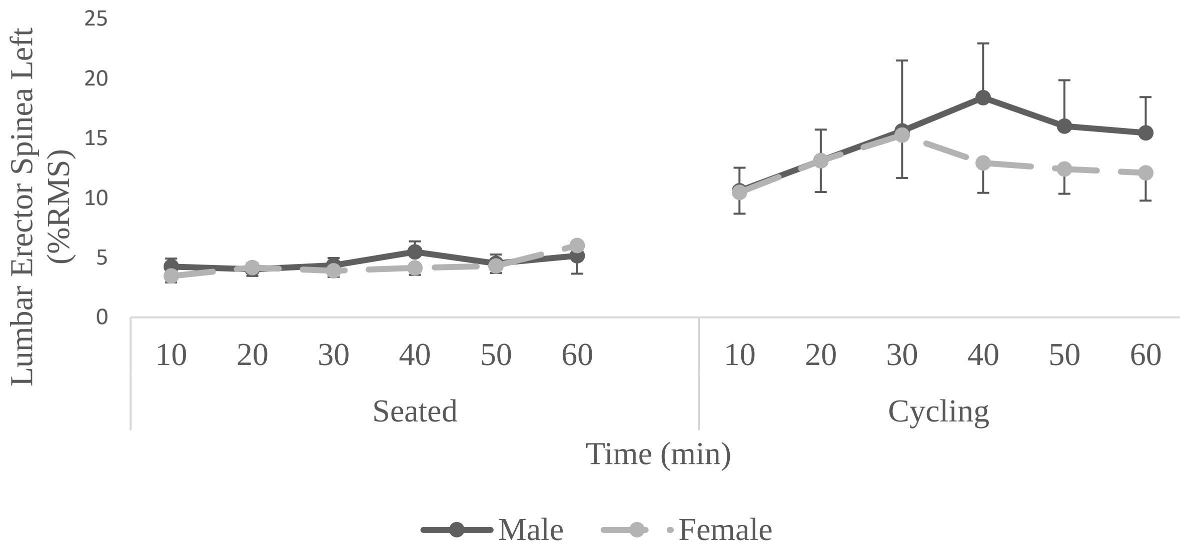


Figure 11. Muscle activation amplitude of the lumbar erector spinae left (group average values, error bars indicate a standard error) recorded during the last 30s of each 10-minute typing task. A significant interaction effect of Sex × Condition × Time for lumbar erector spinae left activation amplitude (p =0.011) was found.

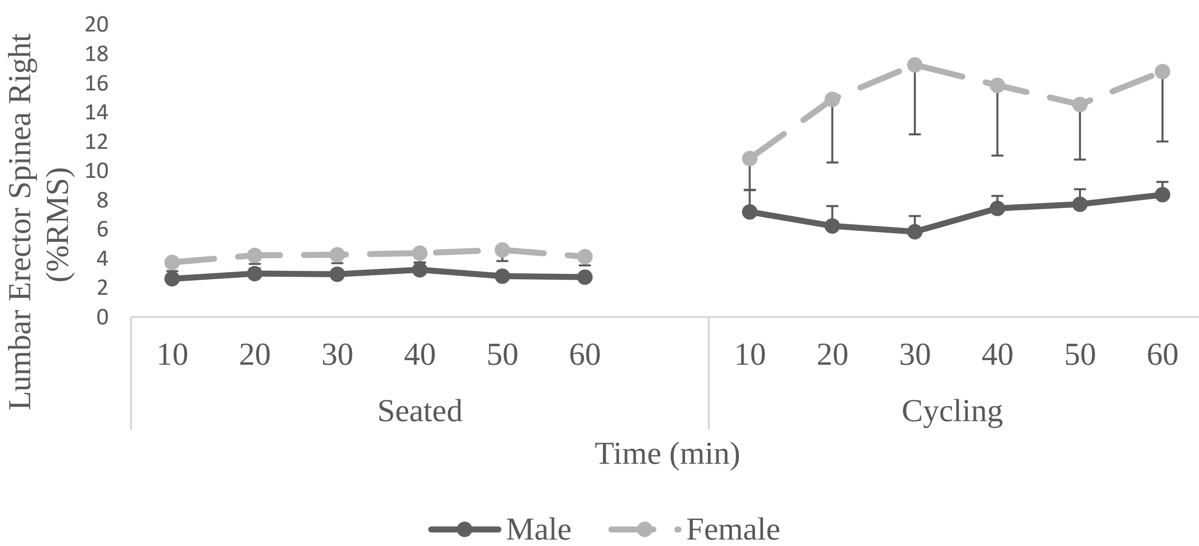


Figure 12. Muscle activation amplitude of the lumbar erector spinae right (group average values, error bars indicate a standard error) recorded during the last 30s of each 10-minute typing task. A significant interaction effect of Sex × Condition × Time for lumbar erector spinae right activation amplitude (p = 0.046) was found.

A significant interaction effect of Condition × Time was determined for the anterior deltoid (X^2 =26.88, $p < 0.001$). After 10 minutes, muscle activation amplitude of the anterior deltoid decreased and continued to decrease in the seated condition and started to decrease later in the cycling condition (Fig.13). There were no other significant interaction effects, but there was a main Condition effect, on this muscle, with higher activity during cycling.

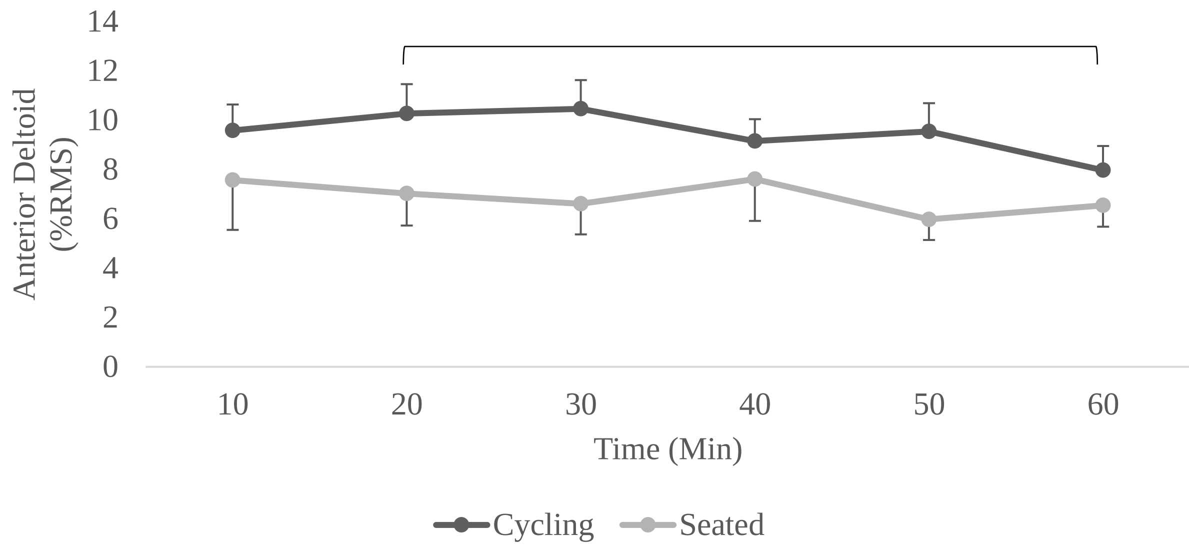


Figure 13. Muscle activation amplitude of the anterior deltoid (group average values, error bars indicate a standard error) recorded during the last 30s of each 10-minute typing task. A significant interaction effect of Condition × Time for anterior deltoid activation amplitude ($p < 0.001$) was found.

A significant interaction effect of Sex × Time was also determined for the lower trapezius (X^2 =21.16, p= 0.039). Lower trapezius muscle activation amplitude after 30 minutes showed an increasing trend in both males and females until the end of the condition (Fig. 14), and overall, there was a trend towards an increase with time in females only. There were no other significant main or interaction effects for this muscle.

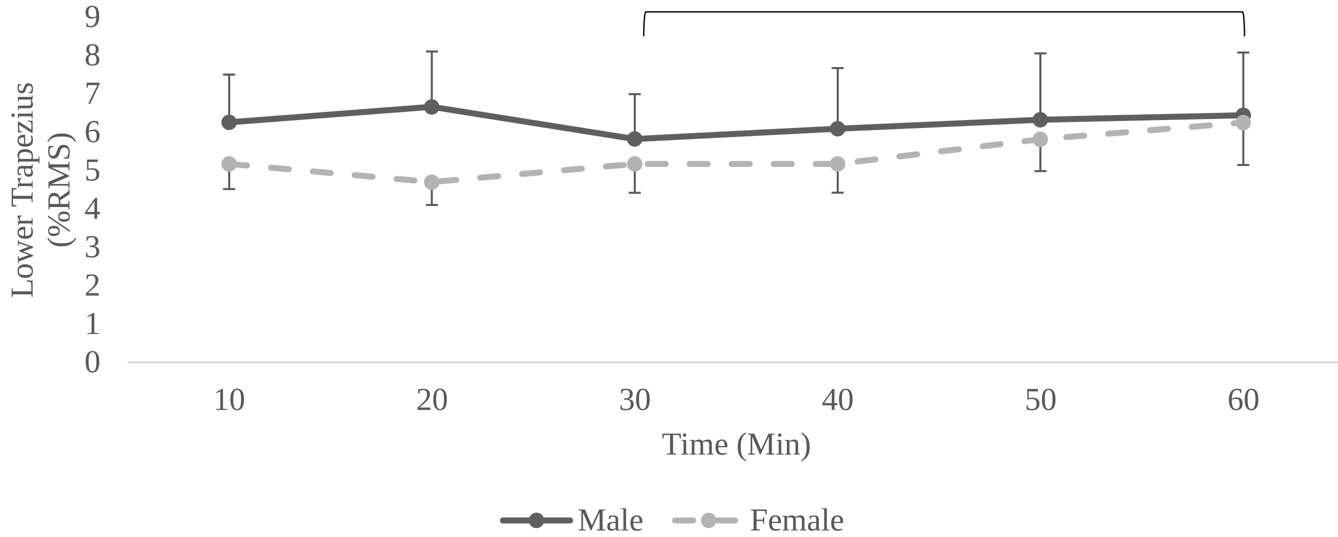


Figure 14. Muscle activation amplitude of the lower trapezius (group average values, error bars indicate a standard error) recorded during the last 30s of each 10-minute typing task. A significant interaction effect of Sex × Time for lower trapezius activation amplitude (p = 0.039) was found.

A significant main effect of Time was determined for the middle trapezius (X^2 =6.87, p= 0.026). Middle trapezius muscle activation amplitude displayed a slight decrease with time (Fig. 15). There was also a main Sex effect on this muscle, with higher activity amplitude in females (X^2=3.24, p= 0.072) (Fig. 16).

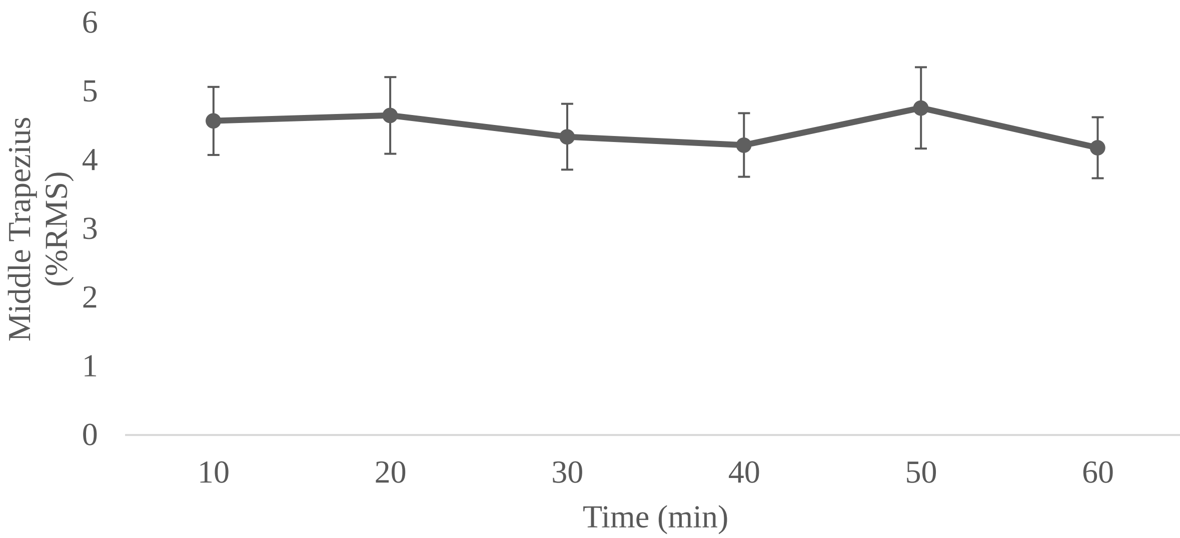


Figure 15. Muscle activation amplitude of the middle trapezius (group average values, error bars indicate a standard error) recorded during the last 30s of each 10-minute typing task. A significant main effect of Time for middle trapezius activation amplitude (p = 0.026) was found.

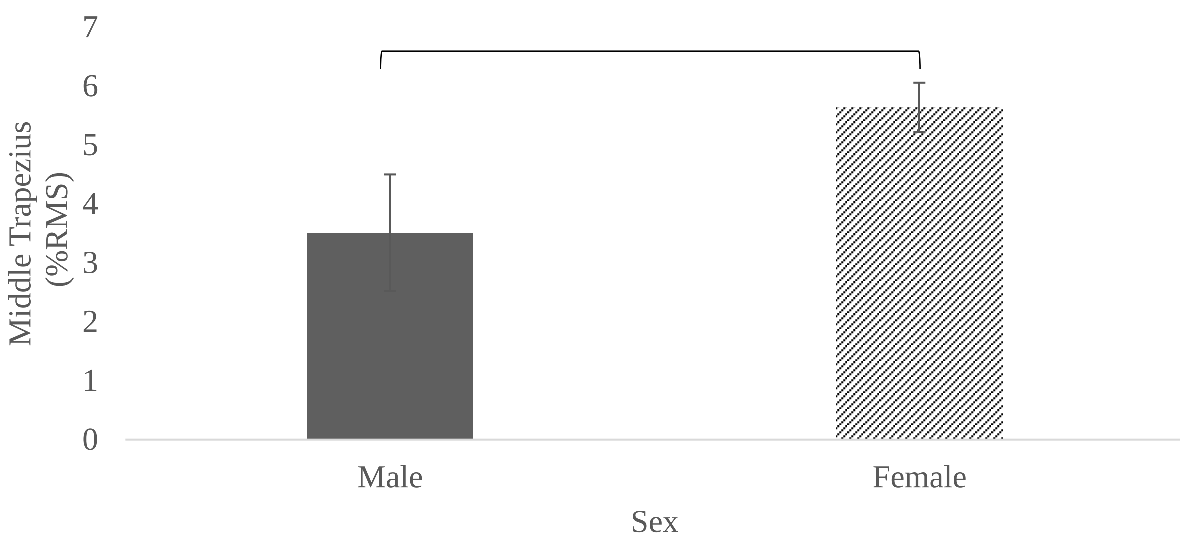


Figure 16. Muscle activation amplitude of the middle trapezius (group average values, error bars indicate a standard error) recorded during the last 30s of each 10-minute typing task. A significant main effect of Sex for middle trapezius activation amplitude (p = 0.072) was found

4. Discussion

The current study examined the sex-specific electromyographic, performance, and symptomatic differences between experimental seated and cycling computer workstations. The hypotheses of this study were that the cycling workstation when compared to the seated workstation, would elicit significantly higher electromyographic activity in all muscles of the upper limbs. No difference in typing performance was expected; however, we anticipated lower reported levels of physical discomfort with time in the under-desk cycling condition compared to the sitting condition. Finally, we expected the above-described differences to vary between the sexes. The main findings of this study were: 1) Males' performance was negatively affected by cycling, with fewer words per minute, whereas females' performance was the same in both conditions; 2) Cycling led to a smaller increase in neck/shoulder discomfort with time, especially in females; 3) With time, neck/shoulder muscle activation increased during sitting but conversely, decreased with time during cycling; 4) Low back muscle activity was higher and varied more with time during cycling, even though there was no difference in seat discomfort between the seated and cycling conditions.

4.1. Computer performance

Regarding computer performance measures (words per minute, WPM, and adjusted words per minute, AWPM), male typing performance was poorer in the cycling condition compared to the seated condition, for both WPM and AWPM. However, female computer performance was similar in both conditions. We elected to analyze both AWPM and WPM in case a comparison across conditions and sexes yielded different results for each variable. Additionally, both variables have been studied in previous literature (Fedorowich & Côté, 2018; Yoon et al., 2019). The negative impact of cycling on male performance aligns with existing literature, which commonly reports small decrements in typing performance when using an active workstation (Funk et al., 2012; John et al., 2009; Straker et al., 2009). The decrease in performance may be attributed to attentional constraints caused by dividing attention between typing and cycling. On the other hand, the female performance results are consistent with a recent study where females showed less change in performance over time at higher pedaling intensities (Yoon et al., 2019). The sex difference in typing performance in the cycling condition may also be due to sex differences in the physical constraint of having to maintain typing performance while moving the legs, which are typically heavier in males. In a study by Mansour et al. (2021) it was found that age-matched females weighed 15.7% less, and exhibited a significantly higher percentage of fat mass (17.2 ± 1.8%) compared to males. According to this study, variances in body composition, particularly body fat, accounted for 30 to 70% of the observed differences between male and females' lower limb performances and power outcomes measured during jump tests (Mansour et al., 2021). Thus, the same pedaling rate in males and females could create more postural imbalance in males, which could affect more strongly the control of their neck and upper limb as well as their vision, which could combine to negatively affect their typing performance. On a more general level, dual tasking has previously been shown to represent more of a challenge in males. In a study by Stoet and colleagues (2013) it was found that males and females exhibit differences in their ability to perform dual tasks such as tasks that combined requirements of verbal processing, and language comprehension. Overall, our results demonstrate sex differences in typing performance when implementing cycling workstations. These differences may reflect varying levels of compensation for additional task complexity, and they could also be attributed to differences in the interpretation of the same instructions.

4.2. Discomfort

The findings of the current study indicate that visual discomfort increased over time in both conditions. However, visual discomfort was lower in the cycling condition compared to the seated condition and was not influenced by sex. As for upper body and seat discomfort, only an effect of time was observed, with both discomfort levels steadily increasing throughout the study. Additionally, the cycling condition exhibited the lowest levels of neck/shoulder discomfort for both sexes compared to the seated condition. However, there were sex differences in neck/shoulder discomfort that varied over time, with females reporting lower discomfort levels than males in both conditions.

Neck/shoulder discomfort is a common complaint among office workers and may be caused by metabolic disturbances resulting from prolonged static muscle activity during sitting (Larsson et al., 2007). Females typically report higher levels of neck/shoulder discomfort, which could be attributed to biological sex differences in muscle fiber type characteristics. Indeed, even though females are known to have more type 1, fatigue-resistant muscle fibers especially in the neck/shoulder region, previous studies have also shown a predominance of the most vulnerable type 1 (Cinderella) fibers in women who develop repetitive strain injuries. These fibers exhibit poor capillarization and impaired local microcirculation in the trapezius muscles (Côté, 2012; Kupa et al., 1995; Nordander et al., 2000; Simoneau & Bouchard, 1989). In the long run, during prolonged bouts of sustained neck postures and repetitive upper limb efforts, female neck/shoulder muscles may thus increasingly rely on anaerobic metabolism, leading to the peripheral buildup of metabolites that cause pain and discomfort, and they especially may benefit from alternative ways to engage their neck/shoulder muscles than static seated computer work.

The potential benefits of cycling computer workstations on upper limb muscles can be explained in the following way. The higher physical activity associated with the cycling workstation may enhance blood flow to the upper limbs, improving muscle oxygenation and reducing reliance on anaerobic metabolism. This decrease in metabolic buildup could slow the development of symptoms of pain and discomfort. Furthermore, the lower reported neck/shoulder discomfort associated with the cycling workstation could also be attributed to increased postural variability that is likely to occur with the movements of the legs during cycling (Babski et al., 2016; Sangachin et al., 2016). Postural variability helps distribute the load and stress on the neck and shoulder muscles and joints more evenly, reducing strain and promoting better load distribution (Cid et al., 2020; Fedorowich & Côté, 2018; Yang et al., 2019)

Moreover, the lower levels of neck/shoulder discomfort during cycling may have influenced the development of visual discomfort, which may explain why visual discomfort was lower during cycling. Although these symptoms are often studied separately, there is evidence of physiological relationships and mutual influence between neck/shoulder muscular and visual systems (Blehm et al., 2005; Robertson et al., 2013; Woods, 2005). Indeed, some intervention studies have shown that implementing appropriate visual ergonomics can reduce both eye and musculoskeletal discomfort (Hemphälä & Eklund, 2012). Thus, it is important to consider both visual and neck/shoulder symptoms when implementing active workstations in the workplace.

In summary, our findings suggest that integrating physical activity into computer-based tasks can decrease symptoms of discomfort and lower the likelihood of developing WMSDs, especially among females. Our findings further highlight the need to consider sex-specificity, and the potential mutual relationship between visual and neck/shoulder discomfort when implementing workplace interventions.

4.3. Muscle Activation Amplitude (RMS)

In line with our hypothesis, there were some significant effects of the cycling condition on muscle activity amplitude, including some that varied according to time and sex, although the majority of these cycling effects were of generally small magnitude. We found that the muscle activation amplitude of the Upper Trapezius increased over time in sitting, but conversely, decreased over time in the cycling condition. This increase with time in sitting may be a consequence of individuals adopting an increasingly less neutral shoulder posture with prolonged sitting (Lin et al., 2017) in which the legs are maintained statically in a position anterior to the trunk, creating a constant spine flexion moment. In comparison, the repeated forward and backward movement of the legs during cycling may promote a better balance of sagittal plane moments, which may result in reduced load on the posterior spine muscles, including the Upper Trapezius. Regardless of the specific mechanisms, a time-based decrease in activity amplitude of the Upper Trapezius is likely beneficial as a way to prevent the development of Trapezius myalgia. However, our results also suggest that males seem to benefit more from a reduction in Upper Trapezius activity amplitude with cycling than females, who show a slightly higher Upper Trapezius activity amplitude when cycling as compared to males. Thus, our results do not help support cycling as an intervention to reduce the risk of Trapezius myalgia in females, the sex most at risk of developing this type of injury (Cid et al., 2020; Cui et al., 2020; Ekman et al., 2000; Côté, 2012; Fedorowich et al., 2013).

Generally speaking, the Anterior Deltoid and Lumbar Erector Spinae muscles were the only ones that displayed a higher activation amplitude during cycling as compared to sitting, regardless of sex. Regarding the Anterior Deltoid, it is unlikely that a 2% higher activation during an 8% effort amplitude (Fig. 12) is clinically meaningful. As for the Lumbar Erector spinae, as expected, its activity amplitude was clearly higher, as well as more variable across the 60-minute task, when cycling. Although this may seem to represent a negative impact of cycling, there is no evidence that higher Lumbar muscle activation amplitude, especially at such low levels as measured during the computer task, represents any increase in risk of low back pain during computer work. In fact, stiffness of passive tissues is a better-known mechanism for prolonged sitting-related low back pain, and several interventions to reduce low back pain have rather tried to further engage the activation of the trunk musculature to prevent symptoms related to prolonged sitting, such as through the use of sit-stand stools (Antle et al., 2015; Alameri et al., 2019; Yang et al., 2019; Yang & Côté, 2021). Combined with our findings of no negative impact of cycling on seat comfort, added to the likely benefit of cycling to increase blood circulation and muscle regeneration, our Lumbar Erector Spinae results do not likely reflect a negative impact of cycling while typing on the low back.

Finally, our results also show some effects of sex and time that were independent of the cycling condition. The Lower Trapezius showed a constant activation level in males but a slight time-based increase in females. These findings align with the findings of Yoon et al. (2021), who reported higher activation amplitudes in the Middle and Lower trapezius, as well as the Lumbar Erector Spinae among cycling females compared to males. In addition, these findings support several previous studies showing that females tend to operate at muscle activation intensities that are closer to their maximum during occupational tasks. This elevated level of intensity, maintained over extended periods of work, could potentially explain why females are more susceptible to developing injuries of the upper (Nordander et al., 2008; Wahlström et al., 2000).

Interventions in addition to, or instead of, cycling, are necessary in order to address the higher vulnerability of females to computer work-related musculoskeletal disorders.

4.4. Limitations

It is important to interpret the results of the current study while considering the sample population, which consisted of young and healthy adults who were mainly University students. Future studies should aim to include older and more diverse populations to enhance generalizability. Additionally, the typing program as well as the Muvman™ sit-stand stool that was used may not fully reflect real office work as well as true office conditions. However, the computer typing program used has been utilized in other laboratory-based studies. Furthermore, the Muvman™ sit-stand stool did allow for a 4-degrees of tilt in all directions, was higher than a regular chair and did not include a backrest. Both experimental conditions were performed on the same day, but residual fatigue was minimized by allowing for a 20-minute recovery period between conditions (Le & Marras, 2016a). To further reflect ecological validity, measurements should be taken in more ecological conditions, including taking measurements over a longer period of time to assess the longer-term potential effects of the cycling condition. Lastly, our sample size was smaller than hoped and could explain the few findings of sex specificity in our results. At the same time, it is also possible that there exists a truly high inter-individual difference in activation patterns, especially in females. Future studies of sex-specific effects of alternative computer workstations should test a higher sample size in order to address this issue with higher statistical power.

5. Conclusion

Findings from the current study suggest sex-specific responses to cycling workstations during 60-minute computer work tasks. The cycling computer workstation should be recommended based on the computer worker's signs and symptoms; importantly, the observed sex differences reinforce the notion that the same recommendations should not necessarily be made for all males and all females. Future studies should measure other exposure measurements and test the upper and lower body simultaneously in diverse populations to verify the benefits of cycling computer workstations.

CONCLUSION

Although several studies have examined discomfort and EMG outcomes during cycling computer work, there is a lack of research regarding the sex-specific effects of cycling workstations on upper body discomfort and visual outcomes during computer work when compared to a seated control. This thesis aimed to fill this gap in knowledge. The results indicate that cycling workstations may have a positive impact on mitigating visual discomfort. However, our findings also revealed that cycling negatively affected males' performance, resulting in a lower number of words per minute. In contrast, females' performance was unaffected by cycling compared to the seated condition (WPM and AWPM). Furthermore, cycling conditions led to smaller increases in neck/shoulder discomfort over time, particularly among females. We observed several interaction effects on EMG RMS during the cycling condition, with a less pronounced increase compared to the seated condition, except for the neck/shoulder muscles. Interestingly, low back muscle activity was higher and exhibited more variability over time during cycling, especially in females, despite no difference in seat discomfort between the seated and cycling conditions. Conversely, EMG outcomes for neck/shoulder muscle activation increased during sitting but decreased with time during cycling, particularly in females. Our findings suggest that females, especially, could benefit from utilizing active computer workstations, from a whole-body perspective. Moreover, to mitigate the risk factors associated with WMSDs, such as eye discomfort, neck/shoulder discomfort, and muscle activation amplitude in females over time, it is advisable to avoid prolonged periods of seated computer work.

However, it is crucial to acknowledge the limitations of our study, including: 1) participants were sampled from a young and healthy sample population, 2) conducting both sessions on the same day with a 20-minute recovery period between tasks, 3) the typing task not fully reflecting actual computer work. Future studies should address these limitations by analyzing data from a more diverse population and incorporating representative tasks for computer work, thus further examining the benefits of cycling workstations. By addressing these limitations, we can help prevent and reduce the potential development of WMSDs in the workplace for both male and female computer users.

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APPENDICES

Appendix A

Version Date: 16 - 08 - 2022 REB File #: 22-06-060

Are you interested in getting involved in research related to Kinesiology and biomechanics? Do you want to contribute to the science of computer work ergonomics?

If so, then this is your chance to take part in a study that could help prevent muscle injuries in chronic computer users, just like yourself!

WE NEED YOU!

Criteria:

- You should be between 18 and 30 years of age and in general good health, with no known musculoskeletal or neurological conditions of the upper or lower body in the past year
- You do not suffer from chronic headaches or dry eyes

Objectives:

- To determine the influence of under-desk cycling computer workstations on typing performance, posture, symptoms of discomfort, and visual fatigue.
- To evaluate if under-desk cycling affects male and female young adult computer users differently.

Duration:

- 1 session 4-5 hours

Location:

- Currie Gym, McGill University, 475 Pine Avenue West, Montreal, QC.

For more information, please contact:

- Malak Selim (malak.selim@mail.mcgill.ca)
- Supervisor: Dr. Julie Côté (julie.cote2@mcgill.ca)

Appendix B

Version Date: 16 - 08 - 2022 REB File #: 22-06-060

Participant Informed Consent form

Researcher

Malak Selim, M.Sc. Candidate, Department of Kinesiology and Physical Education, McGill University, (514) 398-4455 ext. 0583 or 0783

Supervisor

Julie Côté, Ph.D., Associate Professor, Department of Kinesiology and Physical Education, McGill University, (514) 398-4184 ext. 0539, (450) 688-9550, ext. 4813

Title of project

Sex-specific Electromyographic, Kinematic, Performance, and Symptomatic Differences between Sitting and Cycling Computer Workstations

Sponsor

Equipment and supplies for this project are funded by Canadian Natural Sciences and Engineering Research Council (NSERC, RGPIN-2022-04757) and Canada Foundation for Innovation (CFI #36715) research grants. The student in charge of this project is funded by a Canada Graduate Scholarship – Master's level (CGS-M) by the NSERC.

Preamble/Introduction

You are invited to participate in a study exploring the sex-specific effects of under desk cycling on physical, physiological, and biomechanical outcomes during computer work in young adults. Before participating in this study, please consider the following information.

Within this consent form, the aims of this study, the procedures, advantages, risks, and drawbacks, as well as the necessary persons to contact will be divulged.

Please feel free to ask any questions or disclose any information you believe will benefit the researchers and other members of the staff assigned to the study or for your own clarity.

Project description, objectives, and planned dissemination

The objective of this study is to compare differences in the head posture and movements, upper limb muscle activity, typing performance, and discomfort characteristics between under desk cycling workstations and seated workstations as well as to uncover the sex-specific effects of under desk cycling during computer work in the above-mentioned outcomes.

The long-term objective of this project is to further the understanding of the effects of under-desk-cycling on computer users. This research will ultimately serve to improve sex- specific evidence-based ergonomic interventions of computer users. Results from this project will be disseminated in the forms of a M.Sc. Thesis, conference presentations, and peer-reviewed manuscripts.

Nature and duration of your participation

The study will take place at McGill University, Currie Gymnasium (Room 326) in Montreal.

You are asked to participate in one experimental session that will last around 4-5 hours.

The session will consist of three phases: Phase 1: familiarization/preparation (30-40 minutes), Phase 2- computer typing task under two conditions (randomized): Condition 1- seated typing procedure (60 minutes), and Condition (2) under desk typing procedure (60 minutes), Phase 3: recovery (10 minutes).

During Phase 1, The study will be explained to you, and you may clarify any questions/concerns. You will also be asked to fill out the Par-Q fitness questionnaire that evaluates your current overall fitness level, in order to determine if you can safely participate in this study.

We will then measure and calculate the following: resting heart rate, heart rate reserve, height, weight, baseline neck-shoulder discomfort, upper body discomfort, and visual discomfort. You will then be instrumented with non-invasive muscle electrodes, kinematic markers, and a digital heart rate monitor. Following, you will be asked to perform a series of low-intensity tasks with the neck, shoulder, and trunk muscles.

Lastly, you will be asked to practice cycling while typing for 5 minutes, followed by 5 minutes of seated typing work, followed by a 5-minute recovery.

During Phase 2, You will be asked to complete a typing task under two conditions: a seated typing condition and an under-desk cycling condition. The order of these conditions will be randomized. Each protocol is approximately 70 minutes long. You will be asked to mark your perceived level of neck-shoulder discomfort, upper body discomfort, and eye fatigue on a visual analog scale every 10 minutes. There will be 20-minute rest period between the end of the first condition and the start of the second condition.

During Phase 3, You will relax and recover from the typing procedure. You will be asked about your perceived level of the neck-should discomfort, upper body discomfort, and eye fatigue. You may walk around or sit to relieve any tension or discomfort you may feel.

Voluntary participation

Participation in this research study is voluntary. You are under no obligation to participate. You may withdraw at any time. You have the right to decline to answer any questions. If you choose to withdraw, all documents of your participation will be destroyed. You may also withdraw after participation until such time as your data remains identifiable. Once data has been published, it can't be withdrawn. We can only remove it from further analysis and publication.

Potential benefits associated with your participation.

There are no benefits from participating in this study. However, you will contribute to the advancement of knowledge on human movement and musculoskeletal injury.

Potential risks associated with your participation.

None of the techniques used are invasive. Your participation in this project does not put you at any medical risk.

Personal inconvenience

Some small regions (6, 3 x 3 cm each) of the skin over your neck, shoulder, and back muscles will be shaven before placing the electrodes. This may cause some redness and very light- mild irritation. Further, although it is hypo-allergenic, the adhesive tape used to fix the electrodes on your skin may also occasionally produce some slight skin irritation. Should this happen, a calming lotion will be applied to your skin to relieve skin irritation. Also, you may experience some fatigue towards the end of the typing protocol, which may cause some soreness, stiffness, and/or pain in your upper body.

Monetary compensation

There is no monetary compensation for participating in this study.

Confidentiality

All collected data will be securely stored in password-protected files on a password-protected computer. Your identifiable information will be kept separate in a locked filing cabinet in the Supervisor's office or lab. Only authorized individuals who are involved in the project will have access to this information. Your identification will be protected even if the results of this research project are presented or published. After a five-year period, identifiable data will be destroyed. The de-identifiable data will be kept for a total of seven years following publication, according to University Policy.

The researchers may wish to photograph you during the study with a digital camera. All photographs are de-identified and may be used in presentations and publications.

Consenting to camera photography is optional for this study.

Yes: ____ *No:* _____ You consent to camera photography. Images will not contain any of your facial features.

Funding agencies and publishers often ask researchers to make their data accessible upon completion of their study. Making research data available to others allows qualified researchers to reproduce scientific findings and stimulates exploration of existing data sets. To ensure confidentiality and anonymity, any shared data would be stripped of any information that could potentially identify a participant

Yes: ____ *No:* _____ You consent for your de-identified data to be used for future, unspecified uses.

Questions concerning the study

You can ask questions at any time. The researchers present during the testing should answer your questions in a satisfactory manner.

Contact persons

If you need to ask questions about the project, signal an adverse effect and/or an incident, you may contact Julie Côté, Ph.D., or Malak Selim, M.Sc., at the numbers indicated on the 1st page.

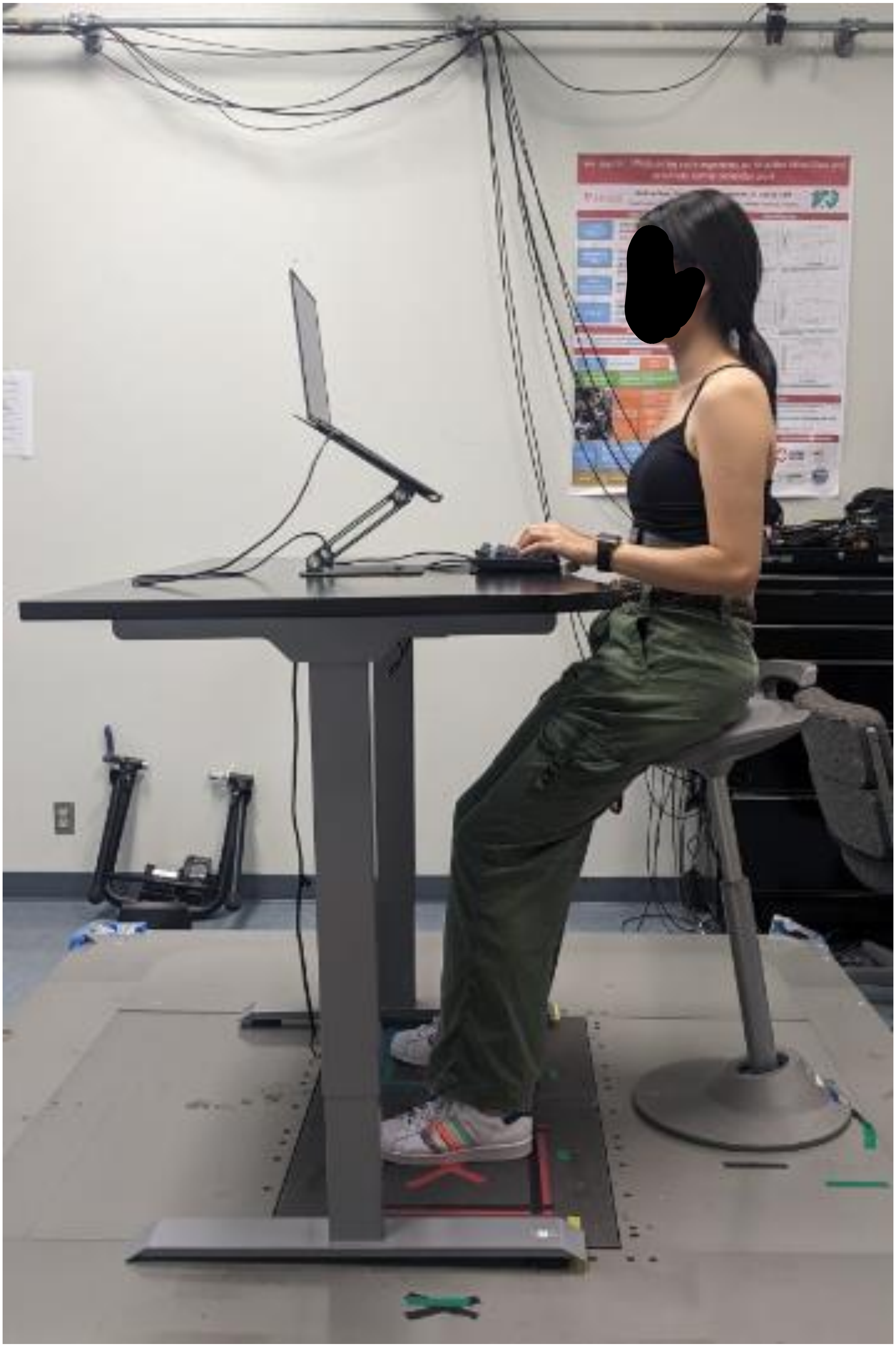
If you have any questions or concerns regarding your rights or welfare as a participant in this research study, you can contact the McGill Ethics Officer at 514-398-6831 or email lynda.mcneil@mcgill.ca.

Please sign below if you have read the above information and consent to participate in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. A copy of this consent form will be given to you and the researcher will keep a copy.

Participant's Name: (please print) ____

Participant's Signature: ________________________________ Date: ___________

Appendix C



Appendix D