EVALUATION OF POSTURE, MUSCLE ACTIVITY AND COMFORT DURING PORTABLE COMPUTER USE

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Abstract

With increased popularity of portable devices and their use outside of a traditional workstation becoming increasingly widespread, it is essential to expand on the limited research available concerning their ergonomic exposures. The goal of this study was to quantify how spine posture, muscle activation, and comfort varied depending on workstation layout, device type, and task.

Twenty university aged participants completed two tasks, reading-typing and swiping, for 15-minutes blocks in eight different combination of workstation layout and device. Mean angles, muscle activation, and discomfort ratings were measured. Participants showed an increased head, neck, upper thoracic, and lumbar flexion in the lap setting. When participants used the tablet, greater head flexion was observed. Additionally, participants elicited greater muscle activation in the trapezius during the reading-typing task.

Portable computer users should be conscious of the postures they adopt and consider the impact of workstation layout, device type, and task in fixed computing environments.

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Glossary

ASIS: Anterior superior iliac spine

CSA: Canadian Standards Association

EMG: Electromyography

EO: External oblique muscle (R/L refers to right or left)

FSU: Functional spine unit

GT: Greater trochanter

IC: Iliac crest

IO: Internal oblique muscle (R/L refers to right or left)

IVD: Intervertebral disc

LBP: Low back pain

LES: Lumbar erector spinae muscle (R/L refers to right or left)

LD: Latissimus dorsi muscle

LT: Lower-thoracic (relative angle between T_6 and T_{12} rigid bodies).

MF: Maximum trunk flexion

MMH: Manual materials handling

MVC: Maximum voluntary contraction; used to normalize EMG signals from experimental tasks, yielding %MVC

NIOSH: National Institute for Occupational Safety and Health

RA: Rectus abdominis muscle (R/L refers to right or left)

ROM: Range of motion

RT: Reading-typing

TES: Thoracic erector spinae muscle (R/L refers to right or left)

TR: Upper trapezius muscle (R/L refers to right or left)

UT: Upper-thoracic (relative angle between C_7 and T_9 rigid bodies)

1. Global Introduction

In recent decades, portable computer use of laptops and tablets have become the primary computing system for many workers due to their combination of portability and ease of use (Conte et al., 2014). Portable computers provide work and recreational computing experience that allows for various seated postures with an ergonomic disparity from traditional seated postures in an office workstation (Trudeau et al., 2013). With the continued increase in the use of portable computing devices (laptops and tablets) along with widely available free wireless internet networks, an increasing number of people are working in temporary computing environments (e.g. hotels, coffee shops, and restaurants) and working in communal spaces rather than traditional personal office workspaces. There are employees that work remotely and have the flexibility to work from home and in the office. When these employees work in the office, they often work in shared office arrangements or open communal spaces that tend to be fixed and not customized to each individual worker. As portable computer use has increased, this has been accompanied by longer periods of seated work with uninterrupted breaks (Lis et al., 2007).

Two-thirds of the population in the workforce is dominated by computer work and these jobs characterizied by extensive computer use often spend their workday seated (Toomingas et al., 2012). Prolonged sitting has been associated with health concerns such as low back pain (LBP). Sitting for extended periods displayed an increase in spinal loads, suggesting that prolonged sitting could be a risk factor for the development of LBP (Geldhof et al., 2007). It is estimated that 50-80% of individuals experience back pain at least once in their life time and approximately 15% of individuals with back pain take time off work (Waters, 2004; Wynne-Jones et al., 2014). Previous literature evaluating prolonged sitting has shown differences in postural and muscular responses between asymptomatic individuals and individuals with LBP.

Nelson-Wong & Callaghan (2010a) found differences in muscle activation between pain developers and non-pain developers during a 2-h standing protocol. Pain developers showed higher levels of co-contraction between gluteus medius, trunk flexors and extensors relative to individuals who did not develop pain. Dunk & Callaghan (2010) used tri-axial accelerometers to monitor lumbar spine angles and they discovered that individuals with LBP moved more than asymptomatic individuals during 90 minutes of seated computer work and they reported significant increase in LBP over time. In addition, sitting imposes a sustained flexed posture that is linked to increased intradiscal pressure (Wilke et al., 1999) and higher compression forces relative to standing (Callaghan & McGill, 2001). Therefore, movement permitting changes in sitting posture is encouraged to avoid risks associated with LBP (Callaghan & McGill, 2001).

There is no definitive indication that sitting duration in isolation is a significant risk factor in developing LBP (Lis et al., 2007). Whereas prolonged sitting combined with awkward postures during computer use has been established as an underlying mechanism linked to LBP (Stenlund et al., 2014). Previous literature has suggested that both upright and slump sitting postures can be an aggravating for patients with LBP, showing that ideal seated posture remains widely debated (O'Sullivan et al., 2006). A recommended seated spinal posture is one that allows variation and movement and maintains neutral spinal curves and avoids end range postures (O'Sullivan et al., 2012). People working at a desk tend to lean forward (Callaghan & McGill, 2001) and adopt a flexed spine posture or a slump posture (relaxation of the thoracic and lumbar spine with posterior pelvis rotation (O'Sullivan et al., 2006)). Position of the spine greatly influences trunk muscle activity, suggesting that slumped posture can be detrimental by increasing the risk of injury by inducing constant loading onto passive tissues (Dennerlein et al., 2014; Callaghan & Dunk, 2002). Although prolonged sitting has been well documented in literature, the affect of computer work on the spine is limited. Ergonomic studies have documented implications for upper extremity pain in the head and neck (Eltayeb et al., 2007; Seghers et al., 2003), shoulder, hand, and wrist (Wahlstrom, 2005), with very few studies focusing on the spinal regions. Caneiro et al. (2010) demonstrate a link between head/neck and thoraco-lumbar postures and motor activity while sitting. They found that slump sitting was associated with greater head/neck flexion and anterior translation of the head compared to thoracic and lumbo-pelvic sitting (Caneiro et al., 2010). Accordingly, this study showed how the human body is a system of interconnected rigid body links, and it highlights the importance of how thoraco-lumbar posture can affect head/neck posture.

Previous ergonomic studies have identified several factors such as input devices (Atkinson et al., 2004), chair design (Vergara & Page, 2000), work task (Moffet et al., 2002) and type of device (Sommerich et al., 2002) as significant risk factors in developing musculoskeletal disorders during computer use. Through previous findings, it is recommended that laptops and tablets are used at a standard desktop configuration with external peripherals (keyboard, mouse, and monitor) to avoid potentially detrimental postures (Asundi et al., 2010). However, these recommendations are challenging to administer in fixed computing environments and there are limited studies focusing on how posture is affected outside of a traditional office workstation (Asundi et al., 2010; Moffet et al., 2002; Sommerich et al., 2002). It is imperative to evaluate portable device use since the portable nature of laptop and tablet devices allows for a variety of postures outside of a conventional office environment, ranging from working with the laptop on the lap (Asundi et al., 2010), standing at a desk (Gallagher et al., 2014), to lying prone on a couch (Gold et al., 2012).

With the continued growth in portable computer use, it is essential to understand the impact of how fixed workstation layout, task and different portable devices can affect the movement patterns and muscle activation of the spine to potentially help minimize the risk of developing LBP.

1.1 Research Questions

The purpose of this thesis was to examine thoracic and lumbar postures, muscle activity and comfort between laptop and tablet use in varying workstation layouts and tasks.

In this study, workstation layout refers to a fixed chair with the participant working on a fixed desk height or on their lap. The devices used are a laptop or tablet, and the tasks are reading-typing (RT) or swiping task. Lastly, the configuration refers to participants completing two types of tasks (RT or swiping) in each different combination of workstation layout and device: desk-laptop (RT and swiping), lap-laptop (RT and swiping), desk-tablet (RT and swiping), and lap-tablet (RT and swiping) for a total of eight configurations.

The following objectives were addressed in this thesis:

1. To understand which factors (workstation layout, device, task) contribute to back, abdominal, and shoulder muscle responses with the focus on thoracic and lumbar spine muscles.
2. To understand which factors (workstation layout, device, task) contribute to thoracic and lumbar spine motion characteristics
3. To understand which factors (workstation layout, device, task) affect the pain response in the back region

4. To understand the effect of workstation layout, device type, and task and/or the interactions between these factors on thoracic and lumbar spine

1.2 Hypotheses

This study was designed to investigate the movement patterns, muscle activity, and comfort of the thoracic and lumbar spine, with the focus on seated postures adopted outside of the traditional office workstation during the use of laptop and tablets. Additionally, the movement patterns of the head, neck, and pelvis were examined to evaluate how the thoracic and lumbar spine changes with respect to these segments. The segments listed above were measured through 3D motion analysis to investigate how these angles changed depending on the workstation layout, device, and task. Additionally, the muscle activity and perceived experience of discomfort will be examined.

The following hypotheses were tested:

1. As workstation layout changes to working on the lap, the lap layout will elicit:
    a. The greatest head, neck, thoracic and lumbar spine flexion than the desk setting.
    b. Lower muscle activity in the back musculature (TES, LES).
2. As device changes to working with the tablet, the tablet will elicit:
    a. The greatest head, neck, and thoracic flexion than the laptop.
    b. Lower muscle activity in the back musculature (TES)
    c. Reporting of higher discomfort ratings.
3. As task changes to the RT task, the RT task will elicit:
    a. No changes in flexion angles of the head, neck, thoracic, lumbar, and pelvis compared to the swiping task

b. Higher muscle activity in the shoulder muscle (TR)

c. Reporting of higher discomfort ratings.

2. Literature Review

2.1 Anatomy of the Spine

It is important to comprehend the anatomy of the spine to understand spine motion and muscle activation. The spine consists of seven cervical vertebrae, twelve thoracic vertebrae, five lumbar vertebrae, and five fused sacral vertebrae (White & Panjabi, 1990). The sacrum intersects with the hipbones to connect the spine to the pelvis (White & Panjabi, 1990). From a sagittal perspective, four normal anatomic curves in the spine can be observed; cervical lordosis, thoracic kyphosis, lumbar lordosis, and sacral kyphosis (White & Panjabi, 1990). The curves protect the vertebrae, assist with shock absorption, and increase strength of the vertebral column (Tortora, 2005). The spine regions are interrelated and the orientation of cervical, thoracic, lumbar, and sacral are influenced by one another (Lau et al., 2010). The functional spine units (FSU) consist of two vertebrae, surrounding soft tissues, intervertebral discs (IVD) and end plates. Spinal motion (flexion, extension, and lateral bending) occurs at the intervertebral discs (Ebraheim et al., 2004) and the IVD is comprised of three parts: the nucleus pulposus, the annulus fibrosus, and the cartilaginous end-plates. The nucleus pulposus is located in the center area and is bound superiorly and inferiorly by the endplates. The annulus fibrosus encircles the nucleus pulposus and surrounds it anteriorly, posteriorly, medially, and laterally (White & Panjabi, 1990). The nucleus pulposus is composed of translucent network of fibrous strands and is composed of up to 90% water that gradually decreases with age to about 70% water content (Ebaheim et al., 2004). The annulus fibrosus mainly consists of collagenous fibers that form the outer boundary of the disc (White & Panjabi, 1990). Lastly, the cartilaginous end plate is composed on hyaline cartilage that separates the nucleus pulposus and the annulus fibrosus from the vertebral body and functions to transfers nutrients from the vertebral body to the disc (Ebraheim et al., 2004).

Along with the intervertebral disc, facets, ligaments, and muscles have been shown to influence movement of the spine (Watkins et al., 2005). Facet joint (zygapophyseal or synovial joint) consist of adjacent inferior and superior articular processes and the articular capsule (Ebraheim et al., 2004). At the thoracic level, orientation of the thoracic facet joints permits increased lateral bending and rotation to occur. At the lumbar level, facet orientation limits axial twist but grants flexion/extension movement (Tortora, 2005). With regards to ligaments, there are respective ligaments that play a critical role in stabilization and movement of the spine. The anterior longitudinal ligament limits the extension of the spinal column and the posterior longitudinal ligament helps to stabilize the spinal column during flexion (Ebraheim et al., 2004).

The spine and the intervertebral disc are exposed to direct trauma, single exertion (overexertion), or as a result of collective exertions from flexion of the spine or complex movements of combined flexion, lateral bending, and twisting (Pope et al., 1991; White & Panjabi, 1990). As a result, the National Institute for Occupational Safety and Health (NIOSH) developed an equation to evaluate lifting demands in the sagittal plane (Waters et al., 1993). They propose a weight limit for healthy workers to safely execute a task over a substantial period of time without an increased risk of developing LBP (Waters et al., 1993). The NIOSH weight restriction is 3.4 kN of compression and exceeding this limit increases the risk of lumbosacral stress and lifting related low back injury. Therefore, it is of utmost importance for the lumbar spine to maintain a position of elastic equilibrium. Elaestic equilibrium is a position where the passive tissues are balanced to have an angle of minimal joint load (Scannell & McGill, 2003). Elastic strain that is applied for a sustained duration can exceed the strain tolerance of the tissue, leading to pain or tissue failure (Scannell & McGill, 2003).

Another essential factor that contributes to spine movement, muscles provide stability and motions of the spine (White & Panjambi, 1990). The main extensors of the back are the erector spinae muscles (iliocostalis, longissismus, and spinalis). One movement of the spine that is extensively reviewed is flexion, involving both the spine and pelvis to bend forward in a two-part movement (White & Panjabi, 1990). The initial 60° of movement is due to the lumbar, followed by movement at the hip joint of around 25°. During flexion, the weight of the trunk increases activity of the erector spinae muscles and superficial muscles of the back (White & Panjabi, 1990). When a person reaches full flexion, the back muscles are in complete relaxation and the ligaments and passive extension of the muscles are in control of the bending movement.

2.2 Low Back Pain

LBP occurrence has been widely documented in different industries and work situations (Anderson, 1981) and is responsible for the increasing health care costs in North America (Nelson-Wong et al., 2008). It accounts for a significant portion of work place injuries and disability in persons under 45 years old (Anderson, 1981). The prevalence of LBP in the general population is up to 80% (Griffin et al., 2008) and accounts for one-fifth of all workplace injuries (Marras et al., 1995). It was the leading cause for injured workers to claim workers' compensation benefits in Ontario (Steenstra et al., 2016). In Canada, compensation costs was estimated to cost between $11 to $23 billion CAD (Dagenais et al., 2008). To address this growing public health problem, there have been many research studies focused on understanding the mechanisms and prevention of LBP (Hoy et al., 2010).

The risk of LBP is highly associated with the type of work involved in an occupation (Marras et al., 1995). Some occupational risk factors associated with LBP include static work postures (Williams et al., 1991), force (McGill & Norman, 1986), vibration (De Carvalho et al., 2010), and repetition. These are often encountered in manual materials handling (MMH) activities such as lifting, pushing, or pulling (Marras et al., 1993). Marras et al. (1995) determined that lifting frequency, load moment, trunk velocity, and trunk sagittal angle were factors that raise the risk of occupational-related low back disorders.

2.3 Sitting as a Risk Factor of LBP

The focus for research on health and physical activity centers around sedentary behaviors (Owens et al., 2010). Time spent in sedentary behaviors has been associated with negative health outcomes such as increased risk of cardiovascular disease and premature mortality (Healy et al., 2011). Sedentary behaviors include low level energy expenditure activities, such as sitting during commuting and sitting in the workplace (Taylor et al., 2013). Prolonged sitting has also been associated with adverse health consequences including LBP, and is frequently reported in work environments as various occupations involve a high percentage of siting throughout the workday (Taylor et al., 2013; Waters et al., 1993). The prolonged mechanical load imposed by seated posture has been attributed to LBP (Van Dieen et al., 2001). Sitting causes posterior rotation of the pelvis and this increases strain on the posterior passive elements of the spine (De Carvalho et al., 2010). De Carvalho et al. (2010) radiographed eight male participants standing and sitting in automobile seats measuring lumbar, IVD and lumbosacral angles, as well as sacral tilt. Authors of this study found significant differences in sagittal radiographic measures of lumbar spine and pelvis angles between sitting and standing (De Carvalho et al., 2010). They identified the importance of returning motion segments to a less flexed posture may play a role in preventing injury and LBP (De Carvalho et al., 2010). Seated postures play a significant role in most occupational environments involving a computer workstation (Callaghan & McGill, 2001). Callaghan & McGill (2001) examined lumbar spine kinematics, trunk muscle activation patterns and spinal joint loads while participants sat at a computer workstation while performing uncontrolled tasks (computer work, reading, homework, etc.) for a period of 2 hours. The authors found that the upper and lower ES groups shifted to higher levels of activation and individuals adopted a flexed posture of the lumbar spine during prolonged seated work at a computer workstation (Callaghan & McGill, 2001). Flexed posture is defined as a relaxed sitting posture where the neutral spine position is lost and has been suggested as a potential mechanical risk factor for LBP as a result of sustained spinal loading and ineffective load sharing (Callaghan & McGill, 2001; O'Sullivan et al., 2002). A study by McGill & Brown (1992) measured creep response of the lumbar spine using a non-invasive electromagnetic source by monitoring participants in full flexion for 20 minutes. This study showed that individuals who spend an extended period sitting or in a slumped posture may be at an increased risk of injury to the disc and ligaments of the spine (McGill & Brown, 1992). Prolonged periods of flexed posture can also cause viscoelastic creep on the posterior passive elements of the spine, resulting in increased muscle spasm and laxity (De Carvalho & Callaghan, 2011). Additional literature suggests that static flexion results in a reduced moment arm for the extensor muscles and a decreased tolerance to compressive loads (McGill et al., 2000). Also, static flexion transfers the load from muscle to passive tissue causing a rise in the risk of injury (McGill et al., 2000). Since static postures are defined by slow rates of change or minimal variation within a task or a given period of time (Briggs et al., 2007), it is important that the human body engages in movement to nourish structures like the nucleus pulposus and the intervertebral disc and shift the loading to prevent LBP (Harrison et al., 1999; Van Dieen et al., 2001; Callaghan & McGill, 2001).

Movement of the spine is also encouraged to allow rest of muscular and passive tissue loads to mitigate the health concerns associated with prolonged sitting.

There has been extensive research focusing on sitting and LBP during driving (De Carvalho et al., 2010), chair adjustability (Van Dieen et al., 2001; Vergara & Page, 2002), the task performed (Moffet et al., 2002), stability ball as an alternative use of an office chair (Gregory et al., 2006), and seated breaks (Gallagher et al., 2014). However, there is a lack of consensus on the ideal sitting posture (O'Sullivan et al., 2012). O'Sullivan et al. (2002) examined a difference in muscle activation of specific lumbopelvic muscles in neutral upright sitting compared to slumped sitting. Neutral upright was defined as a neutral pelvic tilt, neutral lumbar lordosis, and neutral thoracic kyphosis. These authors found that activation of the superficial lumbar multifidus, internal oblique, and thoracic erector spinae muscles decreased during slump sitting compared to upright sitting (O'Sullivan et al., 2002). The results in this study suggest that these muscle groups act as stabilizers during upright sitting, as opposed to passive posture of slumped sitting (O'Sullivan et al., 2002). These relaxed postures rely on passive lumbopelvic structures to maintain and upright position against gravity (O'Sullivan et al., 2002). Additionally, Scannell & McGill (2003) evaluated lumbar spine posture of 18 participants during sitting, standing and walking after a 12-week exercise program. They found that maintaining the lumbar lordosis in different postures can be a protective mechanism on the spine (Scannell & McGill, 2003).

Previous literature has also identified biomechanical differences in postural and muscular responses between asymptomatic individuals and individuals with LBP during prolonged sitting. Dunk & Callaghan (2010) evaluated 16 participants with LBP and 16 asymptomatic participants during 90 minutes of seated computer work using a tri-axial accelerometer to measure lumbar spine postures. These authors found individuals with a history of LBP reported increased pain over time, used up to 80% of their lumbar spine range of motion (ROM) and demonstrated large, frequent movements in lumbar spine posture during the 90 minutes of seated work. Whereas asymptomatic individuals reported little no to pain and used only 30% of their lumbar spine ROM with smaller movements around a mean lumbar spine posture (Dunk & Callaghan, 2010).

Standing resulted in different lumbar spine posture compared to sitting, which could administer relief for the passive and active structures of the low back (Callaghan & McGill, 2001). In addition, fast walking would produce cyclic muscular activation that is potentially a beneficial rest activity from prolonged sitting (Callaghan & McGill, 2001). However, previous authors have reported that supervised exercise programs involving muscle strengthening are the most effective intervention for LBP (Nelson-Wong & Callaghan, 2010b). Nelson-Wong & Callaghan (2010) investigated the response of muscle activation and LBP to a prescribed exercise program. These authors found positive changes in muscle activation factors predisposing for LBP during standing with a selected exercise intervention.

Prolonged static postures can lead to detrimental effects on the different structures of the spine (Dunk & Callaghan, 2010). There are various studies that highlight the importance of evaluating seated postures on LBP (Callaghan & McGill, 2001; O'Sullivan et al., 2002; Schinkel-Ivy et al., 2013b). Therefore, it is necessary to investigate short duration sitting studies to identify and evaluate snapshots of various sitting postures.

2.4 Reviewing Computer Ergonomics and Portable Computer Research

The majority of previous work on portable computers has been conducted with a spotlight on upper extremities. There is deficient research on the spine during portable computer use, although it is well documented in relation to sitting and LBP. In recent decades, there has been a growing increase of laptop and tablet sales. In 2012, there were 201 million laptop computers and 145 million tablets sold in Canada (Statista, 2016). Due to the common nature of fixed computing and availability of wireless Internet, the popularity of laptop and tablets have dominated the traditional desktops (Asundi et al., 2010). Over 100,000 university students from 14 countries ranked laptops as the most important device for academic purposes (Kay & Lauricella, 2016) and several countries (New Zealand, Singapore, and Britain) have begun to integrate tablets into school programs (Wang et al., 2016). Laptops and tablets are increasingly popular because they are portable, compact, and self-sufficient (battery provided) (Young et al., 2012). As a result, they are widely used by professionals and students who commute and work in dynamic settings with a computer system (Moffet et al., 2002) and in computing environments that do not provide an adjustable workstation. Users develop a risk for musculoskeletal injuries when working in awkward positions for an extended period of time. Therefore, it is important to follow guidelines set by the Canadian Standards Association (CSA) Guideline on Office Ergonomics (CSA-Z412-00) to minimize posture fatigue and discomfort. According to CSA guidelines, a typical workstation layout should have the external monitor set at a height so that the user's neck will be straight, elbow joints at 90° and thighs roughly parallel to the floor with feet flat on the floor (A Guideline to Office Ergonomics, 2000). It is also important to have a height-adjustable chair (42 to 51 cm) and a seat pan that is large enough to provide support for thighs and bottoms with a tilt of 3° forward and 4° back. In addition, the backrest should have lumbar support adjustable to 15 to 25 cm and armrests that do not impede computer work and are height adjustable to 19 to 24 cm (A Guideline to Office Ergonomics, 2000). Improper monitor height and viewing distances may lead to visual fatigue and fatiguing head positions. Use of a backrest allows body weight to be transferred to the backrest and increases lumbar lordosis and reduce disc deformation (De Carvalho et al., 2010). In addition, arm rests offer support that unloads the spine. In a workstation set up, it is recommended that computer users work on desks that can be adjusted. Work surfaces that are too low, users are required to lean forward placing stress on the arms and back. Work surfaces that are too high will force users to raise their arms and shoulders, requiring muscular effort that may be fatiguing. With regards to portable devices, laptop computers often have the keyboard and screen attached, making it difficult to position the computer in a comfortable posture. According to the CSA, it is recommended that the laptop be placed on a flat surface with the screen tilted back to 110 to 150°. The laptop should be placed at a comfortable viewing distance in the range of 40 to 74 cm in a place that minimizes glare from lights and windows. However, many portable computer users regularly operate their laptops and tablets in a mobile environment where it is difficult to implement these recommended guidelines. In this case, it is recommended that computers used in a moving vehicle should be positioned directly in front of user on a flat object to allow a level typing surface and the seat should be moved as far back as possible (A Guideline to Office Ergonomics, 2000).

A recent study by Werth & Babski-Reeves (2014) evaluates the muscle activity, posture, and performance differences across 3 portable computing devices (laptop, netbook, and slate computer) and two work settings (desk and computer) during data entry tasks in nontraditional settings. The authors conclude that injury is increased when working on smaller, portable computers in nontraditional work settings (Werth & Babski-Reeves, 2014). However, this study only focuses on the neck and wrist postures. Regardless, these nontraditional work settings lack adjustability and routinely require users to work with the computer on their lap, lowering the screen and keyboard height (Young et al., 2012). Extensive research has been conducted to look at the most suitable postures for using computers (Straker et al., 1995; Dennerlein & Johnson, 2006). Sommerich et al. (2002) evaluated effects of use in laptops on posture, postural fixity, muscle activity, productivity and discomfort. They found that laptop use without external peripherals resulted in significantly more postural fixity in several joints and induced more non-neutral postures than using a laptop with an external mouse or external keyboard (Sommerich et al., 2002). Therefore, these authors recommend using external peripherals to hinder poor posture and back discomfort during laptop use. In addition, a study by Young et al. (2012) used 15 experienced tablet users to complete a set of simulated tasks with two types of tablets in four typical user configurations to determine how head and neck postures varied. These authors reported greater head and neck flexion angles during tablet use in comparison to angles reported in previous literature on laptop and desktop computer. The authors also recommend using the tablet on a table rather than on the lap and use the tablet in a case to improve viewing angles by avoiding low gaze angles (Young et al., 2012).

However, this is not achievable in many portable computing environments where a desk is not available or the desk and chair are fixed. Moffet et al. (2002) evaluated laptop use under practical conditions. These authors compared neck and upper limb postures, muscle activity and productivity in two typical work situations: on desk and on lap with two different laptop designs. They found large differences in posture when comparing two situations (desk or lap). Greater physical muscular constrains were imposed to the shoulder region in the desk situation whereas the head-neck and wrist segments were more stressed in the lap situation, displaying the influence of workstation layout on posture (Moffet et al., 2002). It is relevant to assess portable computer use and user settings since work postures adopted by an individual are a byproduct of the interaction between an individual's anthropometry and physical arrangement of workstation (Li & Haslegrove, 1999).

Concerns regarding computer use and the development of musculoskeletal disorders have propelled the focal point of research and related guidelines on traditional desktop computers, with deficient research on laptops and tablets (Straker et al., 2008). With telecommuting (working outside the office through the use of a personal computer) is becoming increasingly popular, published guidelines on the use of portable computers may not be adequately applied. Furthermore, research on tablet use is limited because tablet devices are a newer development in mobile computing. A difference between laptop and tablet computers is that laptop screens are fixed to the keyboard with a hinge that allows for the angle viewing to be adjusted. Whereas tablets integrate the display and keyboard via a touch-screen, the reduction in size could impose different constraints on the user compared to the laptop design (Young et al., 2012). Straker et al. (2008) compared posture and muscle activity loads between a tablet computer, traditional desktop computer, and pencil and paper. The authors found that tablet computer use exhibited less neutral spinal posture with greater activation in the upper trapezius and cervical erector spinae muscles and elevated scapular posture. They concluded that tablet use results in different musculoskeletal stresses than desktop computer use; therefore, it is essential to evaluate how tablet use influences spine posture and muscle activity (Straker et al., 2008).

Another area that is also a subject of investigation involves postures and movement with respect to different tasks. Devices change in platform size (small keys and monitor), integrated monitor/keyboard, and differences in data entry methods (keyboards, swiping/gesturing). Dennerlein & Johnson (2006) found that tasks involving keyboard were associated with greater posture variability, whereas mouse-intensive tasks were associated with more constrained postures. This illustrates a difference in risk factors across distinctive computer tasks that require varying amounts of mouse and keyboard use. In another study by Li & Haslegrove (1999), it was reported that manual and visual demands as well as task difficulty had an effect on posture. The authors identified a change in head/neck, lower trunk and arm posture varied with task height. It was also reported that head and trunk postures were adjusted to the visual demands of the task, to the extent of adopting uncomfortable postures (Li & Haslegrove, 1999). Therefore, poor work postures can be caused by the visual and manual demands of the task as well as by inadequate workstation layout. The adopted posture of the head, neck and lower trunk differs with the type of task being performed (visual, manual or combined) along with the difficulty of the task (Li & Haslegrove, 1999).

Working on computer workstations includes many of the risks related to developing LBP (repetition, prolonged sitting, awkward posture). The CSA guideline should be followed to minimize the development of pain by ensuring proper workstation set up to avoid biomechanical risks in the wrist, hand, shoulder, neck and trunk. However, it is important to remember that seated computer work is a sedentary activity associated with many health concerns and maintaining a seated posture over a long duration can be detrimental, regardless of proper set up. Taking breaks to encourage postural change from computer work can help prevent microdamage to the ligaments, maintain tissue tolerance and allow rest to muscles is the most effective strategy in reducing discomfort in occupations involving prolonged seated work (Callaghan & McGill, 2001; Le & Marras, 2016). Many studies encourage movement by adopting multiple postures and postural variation, with standing becoming a popular approach to introduce movement from sitting (Callaghan & McGill, 2001; Gallagher et al., 2014; Le & Marras, 2016). Although there are no guidelines regarding time spent between sitting and standing, a suggested recommendation for an 8 hour workday is to have 4 hours of seated work and 4 hours of nonsedentary time (walking, standing, or other activities) (Callaghan et al., 2015).

3. Introduction

Ergonomic risks are increased when using compact, portable computers in nontraditional settings (working with a laptop on the lap) (Moffet et al., 2002; Asundi et al., 2010; Werth & Babski-Reeves, 2014). Musculoskeletal discomfort have been well documented in angles of the head and neck (Young et al., 2012), shoulder flexion/abduction (Gerr et al., 2000) and wrist extension and ulnar deviation (Asundi et al., 2010). However, there are gaps in the literature regarding the postural characteristics of the spine during portable computer use (Gold et al., 2012). Static, prolonged sitting postures adopted during computer use are risk factors for developing LBP (Tessendorf et al., 2009). The office ergonomics guidelines and standards are well documented for the traditional setting, where users are provided with height adjustable desk, chair and external peripherals (external monitor, mouse, keyboard, tray). With the increasing in workers telecommuting and an increase of portable computer use at work and recreationally, the computer ergonomics standards and guidelines need to be updated for commuting environments. Therefore, evaluating the postural variations during portable computer in nontraditional settings can provide further knowledge on the development of LBP. The purpose of this thesis was to focus on spinal posture, muscle activation, and discomfort during laptop and tablet use.

4. Methodology

4.1 Participants

Ten males and ten females (mean=25.4 yrs, ±3.1) were recruited form the York University undergraduate and graduate student population. The mean anthropometric measures for the participants are listed in Table 4.1. All participants either owned or had experience with working on a laptop or tablet and reported no current or previous history of shoulder, neck, or back pain or injury which caused them to miss time at work or school over the last year. In addition, participants had prior experience using at least two of the Microsoft Office™ tools (Word, Excel, Powerpoint). The entire data collection was completed on a single day. York University's Office of Research Ethics approved the protocol (Certificate # e2014-375) and all participants read and signed informed consent forms prior to participating in the study.

4.2 Experimental Setup

Two portable devices, laptop and tablet, were tested (Figure 4.1 and 4.2). The laptop computer tested was a 13" MacBook Pro (Apple, Cupertino, CA, USA) with dimensions 2.41 x 32.5 x 22.7 cm and mass 2060 g. The tablet computer tested was an Apple iPad2 (Apple, Cupertino, CA, USA) with dimensions of 0.88 x 24.1 x 18.6 cm and mass 601g. These specific devices were selected as they represent a popular and common size and style of laptop and tablet device. The models of devices were in line with previous research (Young et al., 2012). This study did not receive any funding or support from the manufacturer (Apple). The participants were free to adjust the angle of the laptop screen and tablet as well as the brightness of the screen. No external input peripherals (such as a mouse, keyboard, or monitor) were provided.

Table 4.1: Mean (±SD) anthropometric data of university aged students that participated in the study.

Anthropometrics	Male (n=10)	Female (n=10)	All (n=20)
Age (years)	26.7 ± 2.75	24.2 ± 3.05	25.5± 3.1
Height (cm)	1.8 ± 0.06	1.6 ± .059	1.7 ± 0.11
Weight (kg)	80.7 ± 9.72	60.9 ± 8.43	70.8 ± 13.45
BMI (kg/m^2)	25.3 ± 1.81	22.9 ± 3.69	24.2 ± 3.08
Left leg length (cm)	88.3 ± 4.87	83.3 ± 3.95	85.7 ± 4.99
Right leg length (cm)	88.9 ± 5.01	83.4 ± 4.05	86.1 ± 5.24
Left arm length (cm)	36.4 ± 2.15	32.5 ± 2.06	34.3 ± 2.85
Right arm length (cm)	36.2 ± 2.21	32.3 ± 2.58	34.1 ± 2.85
Left forearm length (cm)	26.8 ± 2.05	24.1 ± 0.09	25.4 ± 2.07
Right forearm length (cm)	27.6 ± 2.13	24.2 ± 0.92	25.8 ± 2.32
Left hand length (cm)	20.5 ± 1.33	17.9 ± 0.79	19.2 ± 1.68
Right hand length (cm)	20.1 ± 1.54	17.7 ± 0.086	18.8 ± 1.69

A case for the tablet was used to allow for two screen tilt angles; 45° and 63°. The case was chosen based on unpublished observations of the most common way the tablet is used in common spaces that was performed as part for the design of this study. In addition, a previous study by Young et al. (2012) found that most users reported that 45° is the most acceptable table tilt when using a tablet on a table. The case was also used to protect the device from damage during the study.

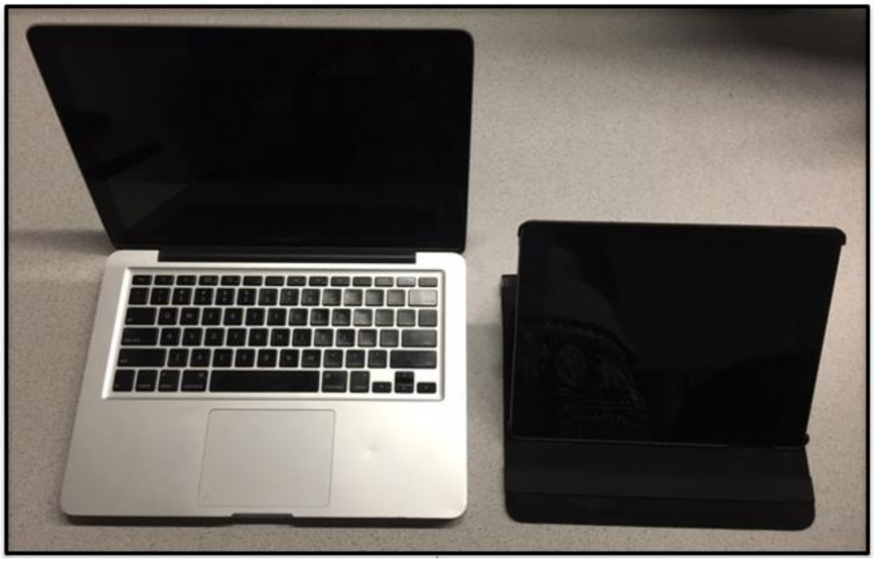

Figure 4.1: View of the two types of devices used. (*Left*: laptop, *Right*: tablet)

Figure 4.2: Sagittal view of the two types of devices used. (*Left*: laptop, *Right*: tablet)

Two workstation layouts were studied: seated in a nonadjustable chair while at a nonadjustable desk and seated in a nonadjustable chair while working on the lap. No external inputs were provided in both workstation layouts. These workstation layouts were designed to represent two common commuting workstation settings observed during portable computer use (libraries, hotel rooms, conference rooms, lecture halls, and coffee shops). The desk layout consisted of a nonadjustable desk height of 74 cm. This desk was selected due to the height as well as the relatively thin legs of the table to limit blocking from video and optoelectronic equipment. To reduce variability associated with keyboard location, participants were instructed to place the laptop or tablet at a comfortable distance from the edge of the desk before testing began (Kotani et al., 2007). As the device placement differed across the configurations, the distance from the edge of the desk to the J key on the internal keyboard of the device was measured for the desk and lap conditions. This was done based on previous findings from Kotani et al. (2007), that position of the keyboard can be protective of neck and shoulder symptoms. Subjective fatigue and muscle activity may increase based on shoulder elevation angle and limiting these factors can decrease the risk of injury in upper extremities (Cudlip et al., 2015). A nonadjustable chair was provided with a seat pan height of 43 cm and a seat pan width of 33 x 35 cm and a back rest 34 cm from the seat pan. The desk and chair chosen in this study was selected based on observations for similar desk and chair design observed in common mobile computing environments in libraries, lecture halls, coffee shops.

All tasks were completed in 15 minute blocks and the tasks were selected and designed to have similar interface requirements as well as represent every day computing tasks. Two tasks were chosen in this study: a reading and typing task and a swiping task. There were four reading and typing tasks, and they consisted of filling out questionnaires on Microsoft Word™ (Appendix C). All participants completed equal number of questions on all four questionnaires. This task was specifically designed to be a combination of keyboard and mouse pad use. This task was chosen based on previous seated research use of standardized computer tasks of typing-mouse combination (Gallagher et al., 2014; Dunk & Callaghan, 2010). The swiping task consisted of playing two popular games (Candy Crush© 2015, King.com Ltd., or Bejeweled© 2001, PopCap Games Ltd.). The swiping task required the participants to perform a combination of pointing and clicking on icons, selecting and dragging of icons, use of the mouse pad, and sliding their finger across the screen (swipe).

4.3 Instrumentation

4.3.1 Electromyography

Muscle activation was recorded from seven muscles bilaterally using pairs of disposable Ag/Ag-Cl surface electromyography (EMG) electrodes (Ambu Blue Sensor N, Ambu A/S, Denmark) placed with apart with a centre-to-centre distance of 2.5 cm (Ambu® Blue Sensor N, Ambu A/S, Denmark). The skin was prepped for placement of surface EMG electrodes similar to previous EMG collection protocols (McGill, 1991; Drake et al., 2006). The skin surface area was shaved and swabbed with alcohol to ensure adherence of surface electrodes and minimal electrical impedance. Electrodes were placed above the muscle bellies of the following muscles: rectus abdominis (RA), external oblique (EO), internal oblique (IO), upper trapezius (TR), latissimus dorsi (LD), thoracic erector spinae (TES), and lumbar erector spinae (LES) (Atterbrant et al., 1995; Drake et al., 2006; McGill, 1991; Mirka & Marras, 1993) (Figure 4.3 and Figure 4.4). Locations for the electrode placements were according to the literature, and are listed in Table 4.2. These seven muscles were chosen because of their involvement in previous prolonged sitting literature (Callaghan & Dunk, 2002; O'Sullivan et al., 2006; Nairn et al., 2013c; Schinkel-Ivy et al., 2013b). Also, the TR muscles are commonly measured in jobs requiring low but sustained engagement of the shoulder muscles, such as computing jobs (Attebrant et al., 1995). EMG signals were differentially amplified (frequency response 10 Hz – 1000 Hz, common mode rejection 115 dB at 60 Hz, input impedance 10 GΩ; model AMT-8, Bortec, Calgary, Canada) and converted from an analog to digital signal at a rate of 2048 Hz (Northern Digital Inc., Waterloo, Canada).

Table 4.2: Electrode placements for the seven muscles that were tested. Location was approximate as the electrodes were placed over the largest portion of the muscle belly.

Muscle	Placement Location
Rectus abdominis (RA)	~ 3 cm lateral to the midline of the abdomen, 2 cm above the umbilicus [β, γ]
External oblique (EO)	~ 15 cm lateral to the umbilicus at an angle of 45° [β, γ]
Internal oblique (IO)	~ Below the external oblique electrodes, just superior to the inguinal ligament [β]
Upper trapezius (TR)	~Centered just proximal to the midpoint of the line from C7 to acromion[δ]
Latissimus dorsi (LD)	~ Most lateral portion of the muscle at the T9 level[α]
Thoracic erector spinae (TES)	~ 3 cm from the midline of the spine at the T9 level [α, β]
Lumbar erector spinae (LES)	~ 4 cm from the midline at L3[α, β]

[δ]Attebrant et al. (1995); [α]Drake et al. (2006); [β]McGill (1991); [γ]Mirka & Marras (1993)

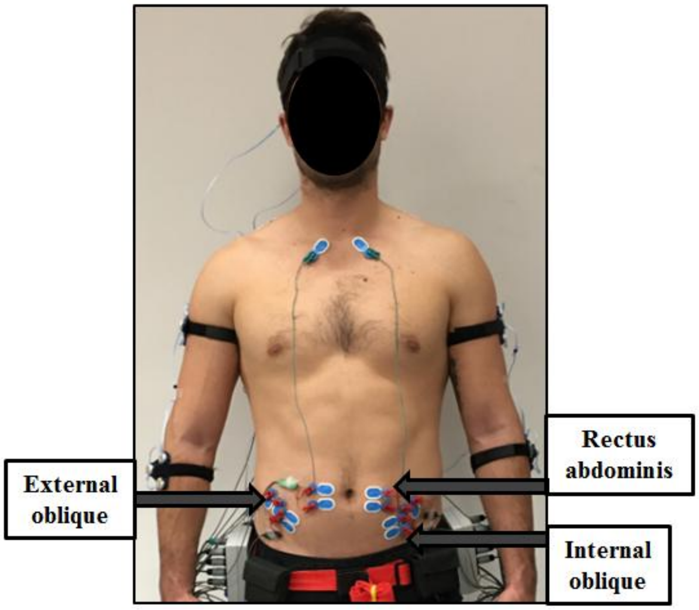

Figure 4.3: Electrode placements for the abdominal musculature.

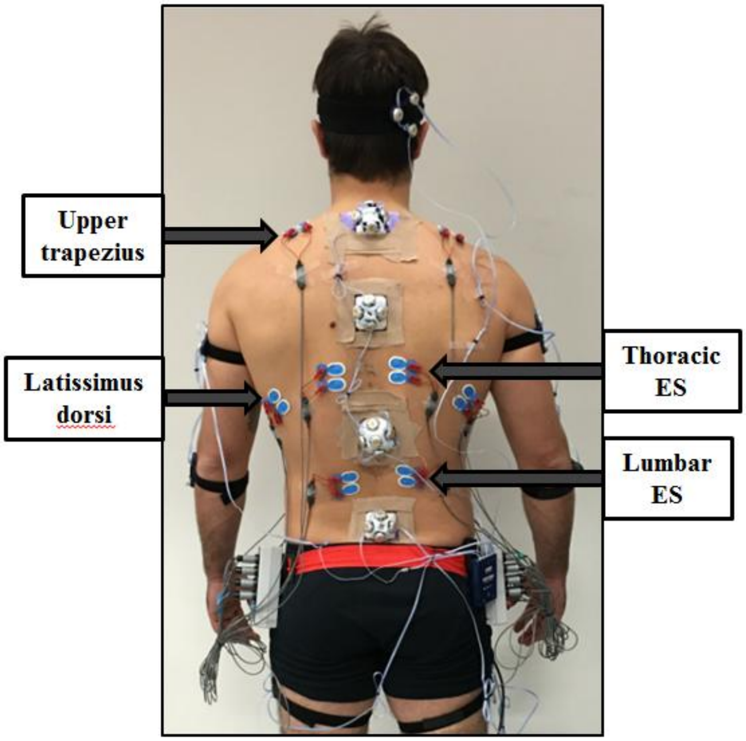

Figure 4.4: Electrode placements for the back musculature (ES: erector spinae).

4.3.2 Kinematics

Kinematic data were collected at 32 Hz using four 3D Investigator™ position sensors (Northern Digital Inc., Waterloo, Canada) and First Principles software v1.5™ (Northern Digital Inc., Waterloo, Canada). The four position sensors provide three-dimensional (3D) spatial location and orientation through active marker technology. Briefly, each marker emits a signal, which is detected and received by one or more of the position sensors. A total of 44 active markers were used, and the markers were attached to NDI Smart Marker Rigid Bodies™ (Northern Digital Inc., Waterloo, Canada). Nine clusters of three active markers were attached to NDI Smart Marker Rigid Bodies™ (Northern Digital Inc., Waterloo, Canada) and placed as tracking markers on the head, trunk, arms, and legs (Figure 4.5 & 4.6). The trunk was subdivided into sections by four custom rigid bodies placed at C_7, T_6, T_{12}, and S_2 used for segment definition as well as tracking of the segment. Previous studies have shown that a multi-segmental analysis has advantages and provides insight into complex movement of the trunk, and uneven distribution of motion between spine levels (Preuss & Popovic, 2010). An additional 6 active markers were placed on the laptop and tablet (Figure 4.7). The locations of specific bony landmarks relative to their NDI Smart Marker Rigid Bodies™ (Northern Digital Inc., Waterloo, Canada) were digitized using the systems digitizing probe (Figure 4.8). The digitizing probe has a square rigid body containing four markers on each corner and is attached to a point (a known location) at the end of the probe (Gallagher et al., 2014). There were 41 landmarks used to digitize segments, beginning with the head (left and right canthus and tragus; 4 total), arms (acromia, lateral shoulder joint spaces, lateral and medical epicondyles, ulnar and radial styloids; 12 total), trunk (acromia, sternum, C_7 vertebra, T_6 vertebra, T_{12} vertebra, S_2 vertebra; 11 total) pelvis (iliac crests (IC), anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS); 6 total), and legs (greater trochanters (GT), lateral and medial knee epicondyle joint spaces, lateral and medical malleoli; 8 total). Also, the four corners on the screen of the laptop and tablet were used to digitize the devices (top right, top left, bottom right, bottom left; 8 total). The locations of the landmarks were calculated based on movement of each active marker rigid body, and this allowed the modeling of each body segment as a rigid body.

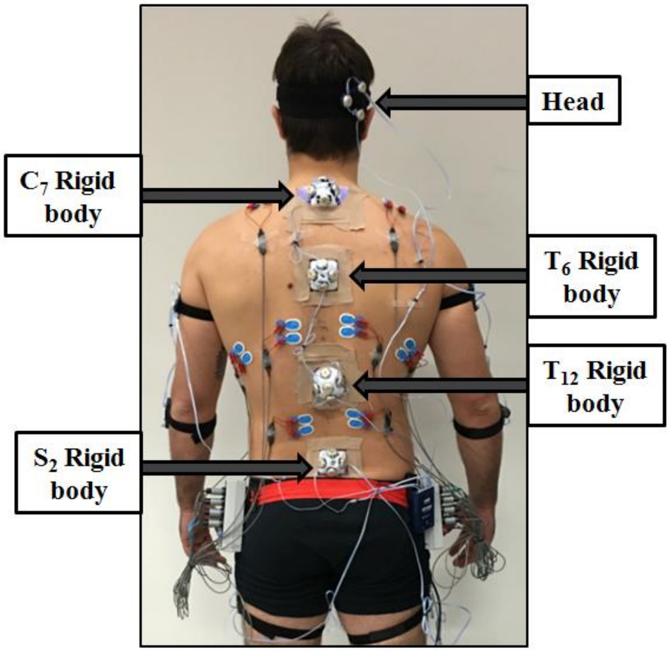

Figure 4.5: Set up of motion tracking rigid bodies in the posterior view. Custom rigid bodies, containing 4-5 markers, were designed and placed on the C_7, T_6, T_{12}, S_2.

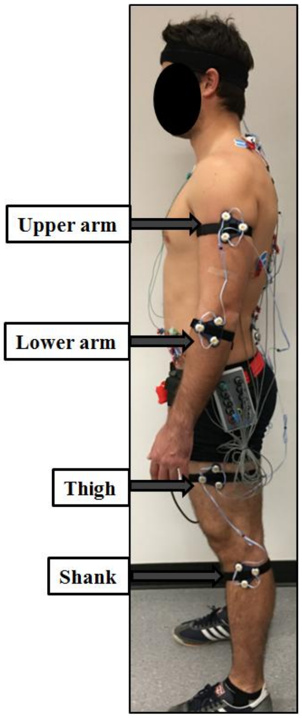

Figure 4.6: Set up of rigid bodies on the upper and lower limbs in the sagittal view (only the left side is shown). The same rigid bodies were placed on the right side.

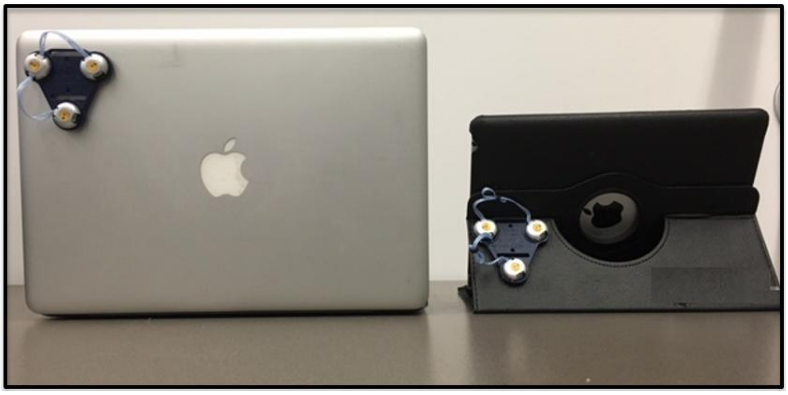

Figure 4.7: The devices used in the study (*Left:* Laptop, *Right:* Tablet) and the rigid body locations. The screen angle of the laptop and tablet can be adjusted.

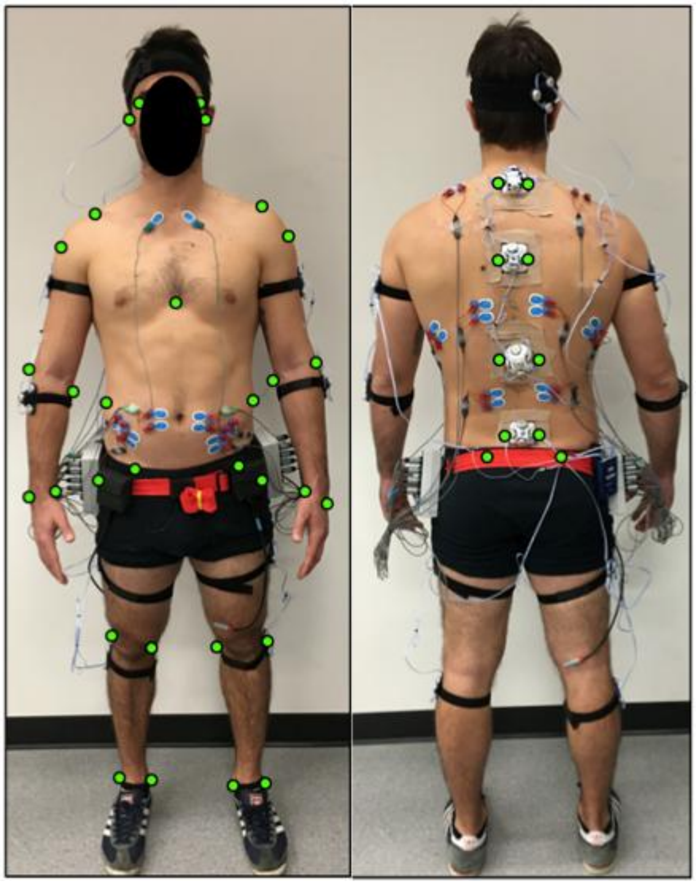

Figure 4.8: *Left:* A frontal view showing anatomical landmarks (green) digitized to define segments. *Right:* A posterior view showing anatomical landmarks (green) digitized to define segments.

All local coordinate systems were adjusted to provide anatomical angles. Zero degree postures for the head, neck, trunk, and pelvis were defined by upright standing. For the global reference frame, the X and Y axes were aligned with the desk and Z was parallel to gravity. Positive values indicate flexion, right lateral bend, and right axial twist whereas negative values indicate extension, left lateral bend, and left axial twist.

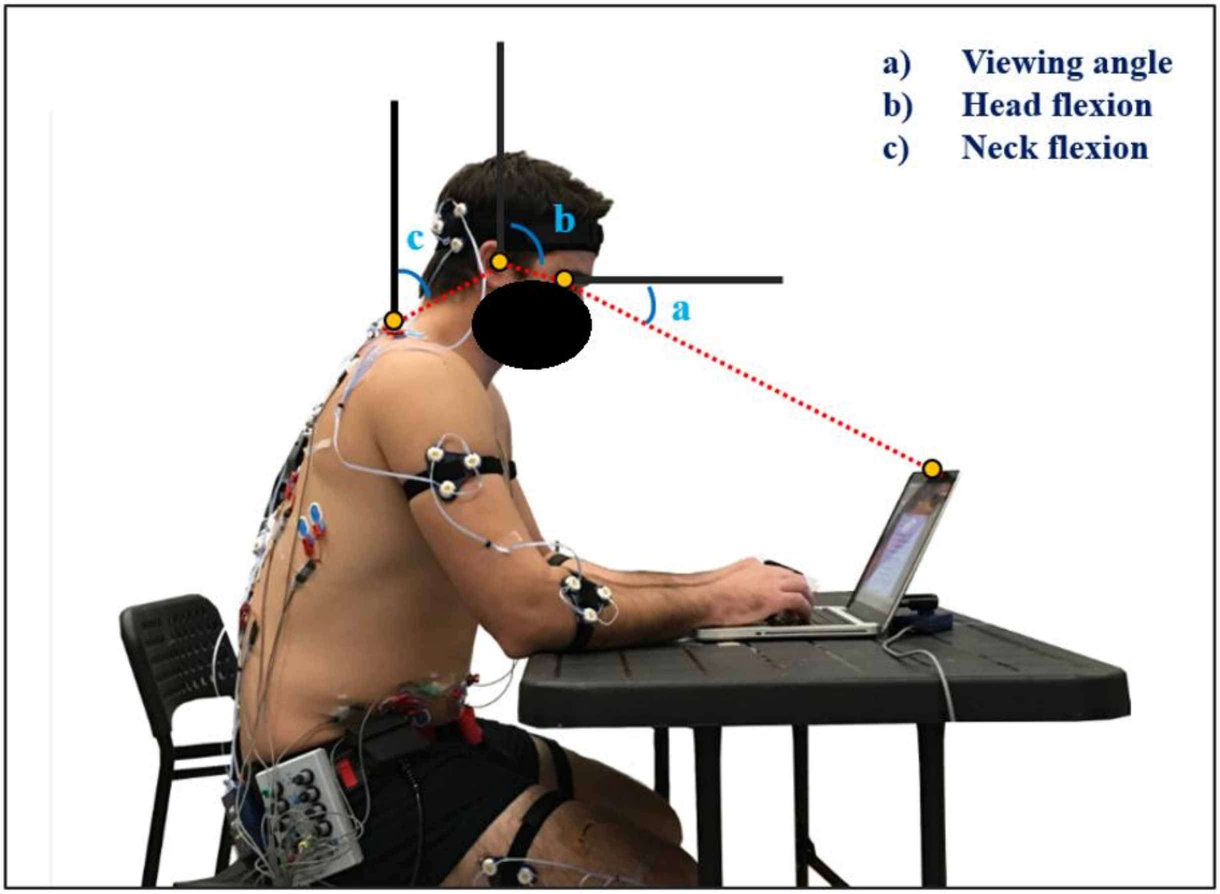

Figure 4.9: Sagittal view of a participant working on a laptop computer at a fixed desk height and chair height. Note the orientation of the global axis system is: Z is up, X is forward, Y is left or right.

Viewing angle was defined as the angle between the global horizontal axis and the line from the midpoint of the participants' right and left canthus to the top-centre of the device (Figure 4.9) (Sommerich et al., 2002). The location of the laptop and the tablet device were defined by the horizontal position of the bottom midpoint of the display relative to the participant's sternum (Asundi et al., 2012). Viewing distance for each configuration was calculated as the distance between the midpoint of the subject's right and left canthus to the top midpoint of the display (Asundi et al., 2012). In each configuration, participants were free to adjust the position of the notebook and angle of the screen. Head flexion was defined as the angle between the vertical axis of the trunk and the line from the midpoint between the canthi and the midpoint between the tragi (Figure 4.9) (Asundi et al., 2012). Neck flexion is between the midpoint of the tragi to C_7 relative to the upper thoracic (UT) (C_7-T_6) (Figure 4.9). Upper thoracic flexion was relative to lower thoracic (LT) (T_6-T_{12}). LT flexion is relative to the lumbar (T_{12}-S_2). Lumbar flexion is relative to the pelvis.

4.3.3 Discomfort

During the protocol, participants perceived level of discomfort was measured using a visual analogue scale (Figure 4.10). They were given a blank 100 mm scale, with two fixed end points labeled "no-pain" and "worst pain imaginable". Participants were asked to mark on the line to indicate the current back pain level they were experiencing. The VAS scale was recorded at the beginning of the study and after every 15-minute block for a total of 9 VAS scores. The participants were given a fresh sheet for each configuration. This scale has been shown to have validity and good repeatability (Summers, 2001), with a history of being used in prolonged exposures including sitting (Dunk & Callaghan, 2010; Nairn et al., 2013; Schinkel-Ivy et al., 2013; De Carvalho & Callaghan, 2015). During previous standing research, individuals have been shown to experience pain symptoms within 15 to 45 minutes (Nelson-Wong et al., 2010). Previous research has shown that a 9 mm cutoff has shown clinical significant difference in VAS score (Kelly, 1998). Based on this cutoff, Nelson-Wong & Callaghan (2010a) determined that individuals could be separated into two distinct groups of non-pain developers and pain developers (PD) if they reported an overall average VAS score greater than 10 mm from baseline during a 2 h prolonged standing task. Non-pain developers remained at a level close to zero throughout the 2-h standing protocol (Nelson-Wong & Callaghan, 2010a).

Figure 4.10: Sample visual analog scale (VAS) score sheet. The line is 100 mm in length on which the participants marked their perceived level of pain.

4.4 Procedures

Participants were provided with verbal and written description of the research study and objectives, and completed informed consent documents prior to any data collection. After electrode application, EMG calibration began with a five-minute rest trial, where participants lay quietly in a supine position to determine a baseline bias within the signal of each channel. To facilitate normalization, maximum voluntary contractions (MVCs) of each muscle channel were obtained. MVCs are typically performed for normalizing muscle activity (Mirka, 1991). The maximal values for RA, EO, IO were obtained using a modified sit-up protocol in which participants were seated with their knees bent and feet flat on the therapy table. Participants were braced by the investigator and instructed to F, LB, and AT (McGill, 1992). Next, a modified back extension was used as the MVC protocol to collect the maximum contractions of the back extensor muscles (TES, LES). The back extension required participants to lay prone on a therapy table with their anterior-superior iliac spines (ASIS) at the edge of the table and upper body hanging over while the researcher provided manual resistance across the shoulders as the participant extends their upper body (McGill, 1992). The LD MVC was obtained by using a modified lateral pull down in which the shoulder was abducted 90° and externally rotated (so that the upper arm was parallel to the floor), and the elbow flexed to 90° (so that the lower arm was vertical). Participants attempted to adduct the upper arm against manual resistance (Arlotta et al., 2011), that is to pull their elbows down and toward their body. The TR MVC were collected by having participants in a seated position with their upper arms abducted at 90° and the elbow flexed to 90° (upper arm and forearm parallel to the floor). Participants were instructed to lift their elbows against manual resistance provided by an investigator (Attebrant et al., 1995). For all MVC trials, participants were verbally encouraged and three trials of each protocol were performed for 3-5 seconds. Participants were given a minimum of 3 minutes rest between MVC trials, with the duration of rest determined by the participant to make sure they were sufficiently rested, to help minimize the effects of fatigue (Schinkel-Ivy et al., 2015). The maximum value obtained from any of the three trials was chosen as the MVC.

The 3- and 4-marker rigid bodies were then applied to the participants using double-sided carpet tape and straps to the participants while they were standing. Again, the rigid bodies were placed on the head, C_7, T_6, T_{12}, S_2, right upper arm, right forearm, right thigh, right shank, and left upper arm, left forearm, left thigh, and left shank (Figure 5 & 6). At the start of the collection, a quiet 30 s standing trial in the anatomical position with palms forward was recorded to establish the neutral upright position. Next, participants were asked to stand with their feet shoulder width apart and move through their full range of spine motion in each plane: maximum flexion (MF), maximum lateral bend to the right and left, and maximum axial twist to the right and left. The full ROM was assessed to obtain a voluntary maximum in order to normalize joint angles observed during the experiment as a percentage of maximum ROM to account for individual differences.

Following completion of movement through ROM, participants were asked to sit at the desk workstation and find a comfortable position using the laptop and tablet. The distances of laptop and tablet placement on the desk were measured based on previous literature by Kotani et al. (2007) and described in section 3.3 and are displayed in Table 4.3, Figure 4.11, and Figure 4.12. This measurement process also allowed participants to familiarize with the lab environment and workstation set up. Participants were encouraged to move the desk and device to a position to minimize any glare on the laptop and tablet screens.

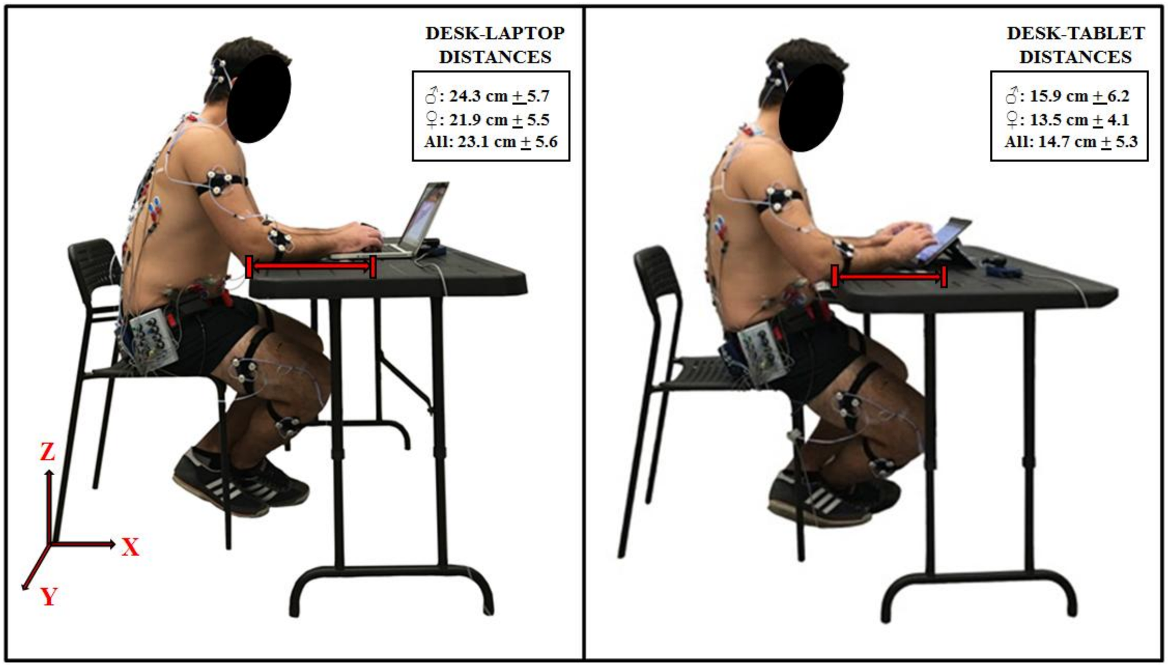

Figure 4.11: Participant working on the desk workstation (fixed desk height and chair) using a laptop (left) and tablet (right). The mean (±SD) of device measurements are reported by measuring the distance from the edge of the desk to the J key on the internal keyboard of the device. Note the orientation of the global axis system in the DESK LAPTOP configuration.

A repeated measures design was used to compare muscle activity, posture, and discomfort across workstations, type of device, and tasks. There were eight configurations and the order was randomized across participants (Figure 4.13). Participants completed a RT or swiping task for 15 minute blocks in a different combination of workstation layout and device. The combinations included: using a laptop on a desk, using a laptop on the lap, using a tablet on the desk, and using a tablet on the lap. For each combination, participants performed a RT task and a swiping task for a total of eight configurations (Figure 4.13).

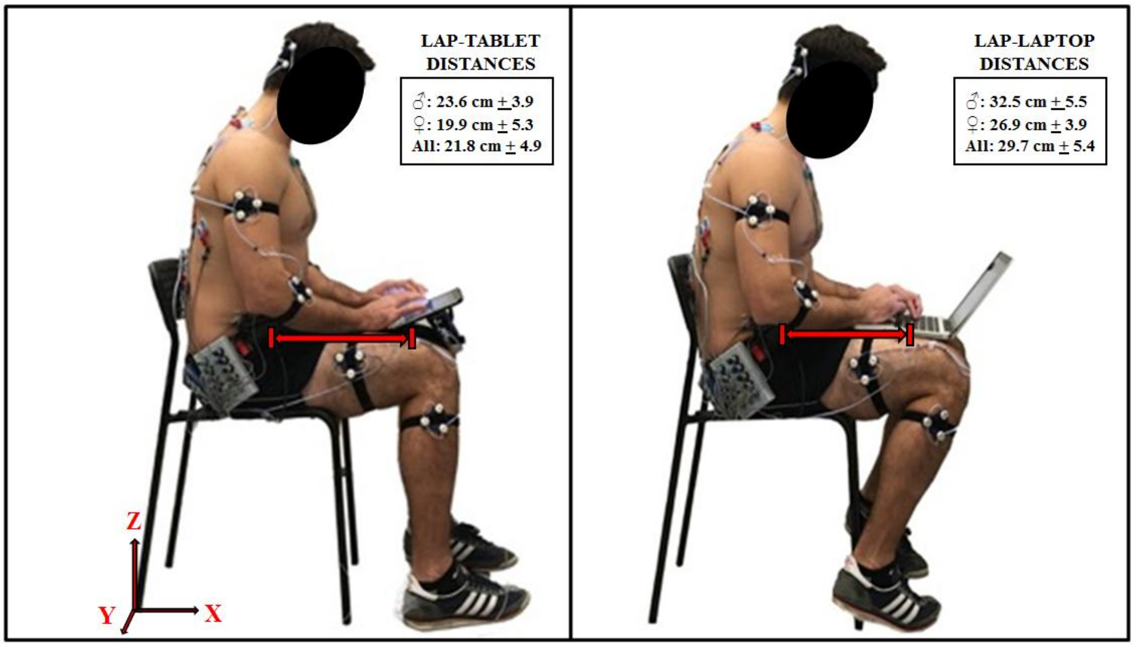

Figure 4.12: Participant working on the lap workstation (fixed chair height) using a tablet (left) and laptop (right). The mean (±SD) of device measurements are reported by measuring the distance from the subject's ASIS to the J key on the internal keyboard of the device was measured. In both workstation layouts, the tablet was placed closer to the participant. Note the orientation of the global axis system in the LAP TABLET configuration.

The configurations were presented in a random order and participants were given a 2-minute rest period between. During this rest period, participants were allowed to move freely within the limits of the systems cables. Upon completion of the configurations, all instrumentation was removed and the collection was considered complete. The time for this study was 4 hours.

Table 4.3: Mean (±SD) distances of portable computer distance (cm) and viewing distance (cm) for all eight configurations. Participants placed the laptop at a greater distance than the tablet. However, the participant's viewing distance of the tablet is greater than the laptop.

	1	2	3	4	5	6	7	8
Configurations	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
Portable computer distance to Sternum (cm)	45.2 ± 3.8	47.4 ± 3.6	46.6 ± 8.4	39.8 ± 6.7	41.8 ± 4.8	42 ± 6.1	40.7 ± 9.1	43.5 ± 6.7
Viewing distance (cm)	53.4 ± 7.1	52.5 ± 6.9	56.4 ± 9.1	53.2 ± 7.4	60.2 ± 5.9	61.1 ± 7.4	61 ± 11.5	65.7 ±11.2

4.5 Data Processing

4.5.1 EMG

Data were processed using Visual3D v5™ (C-Motion, Inc., Germantown, USA). The raw EMG signals were high-pass filtered with a dual-pass, fourth-order Butterworth filter with a cutoff frequency of 30 Hz to remove potential electrocardiogram contamination (Drake & Callaghan, 2006). Next, EMG signals were full-wave rectified then low-pass filtered with a dual-pass, fourth-order Butterworth filter with a 2.5 Hz cut-off frequency to produce a linear envelope of the EMG signals (Brereton & McGill, 1998). The maximum value was taken from the MVC for each muscle to be used for normalization and expressed as %MVC. Mean activation levels were determined for each muscle for upright stand and for the eight configurations. Maximum activation levels were also determined for the eight configurations.

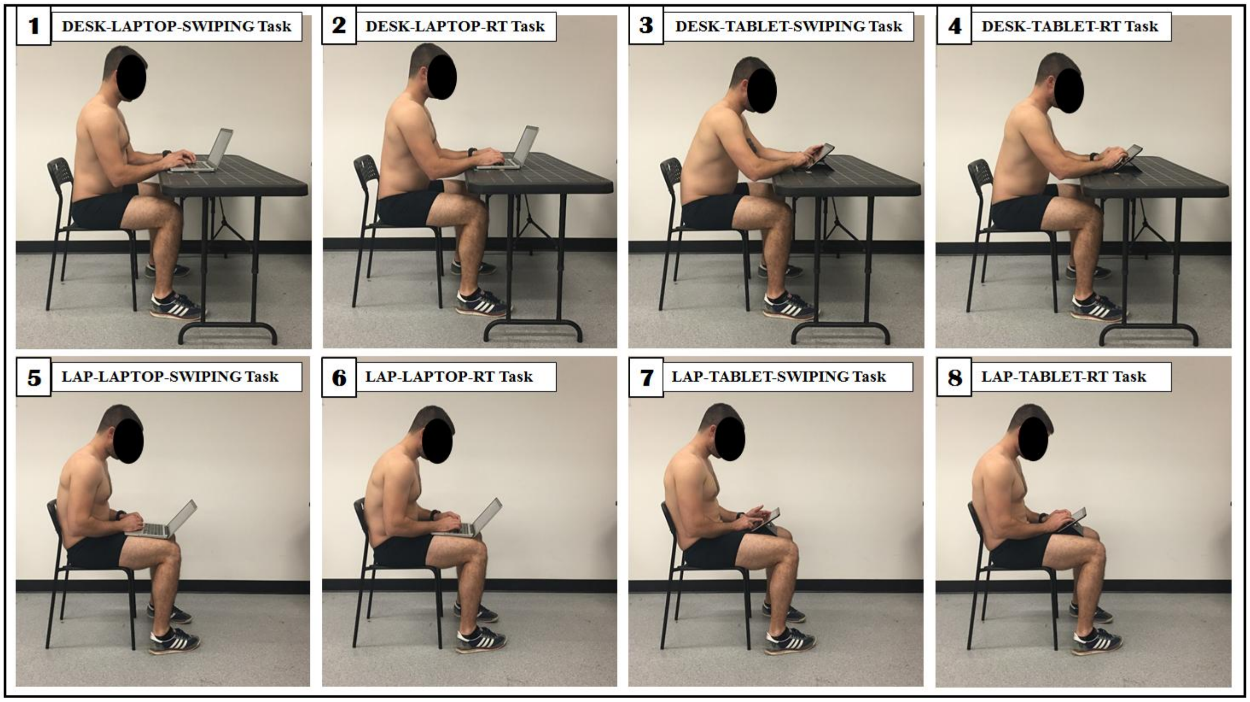

Figure 4.13: Example of a participant in all eight configurations (combination of workstation layout, device type, and task). There are postural differences in the head, neck, and spine as the configuration changes. (RT: Reading-typing).

4.5.2 Kinematic

Using Visual3D v5™ software (C-Motion Inc., Germantown, MD), the kinematic data were processed by using the active markers bound to rigid bodies at each location. The calibration cube was placed on a marked point on the floor (to establish the origin), and a Y-X-Z plane (flexion/extension-lateral bend-axial twist) was used to calculate angles in the three planes for: the head (relative to global coordinate system), neck (relative to global coordinate system), UT (C_7 relative to T_6), LT (T_6 relative to T_{12}), lumbar (T_{12} relative to S_2), trunk (trunk relative to global coordinate system), and pelvis (pelvis relative to global coordinate system. Kinematic data were low-pass filtered with a dual-pass, fourth-order Butterworth filter with a cutoff frequency of 2.5 Hz (Winter, 2005). The mean angles during upright stand were calculated and used to zero the angles from the configuration trials. Mean angles for each configuration trials were determined for flexion-extension (rotations around the Y axis), lateral bend (rotations around the X axis), and axial twist (rotations around the Z axis). The following sign conventions were used: positive angles represent flexion, right lateral bend, and right axial twist. Negative angles represent extension, left lateral bend, and left axial twist.

4.6 Data Analysis

For all configurations, a four way repeated measures analysis of variance (ANOVA) was used to analyze the kinematic measures, with repeated measures of workstation layout (two levels: desk, lap), device type (two levels: laptop, tablet), and task (two levels: RT, swiping) and between-group factor of sex. For all configurations, a five way repeated measures analysis of variance (ANOVA) was used to analyze the EMG measures, with repeated measures of side (two levels: left, right), workstation layout (two levels: desk, lap), device type (two levels: laptop, tablet), task (two levels: RT, swiping) and between-group factor of sex. This was accomplished using SAS® 9.3 (SAS Institute Inc., Cary, NC, USA). Where there were no significant effects involving these factors, the data were collapsed. When the assumption of sphericity was not met, degrees of freedom were determined using the Huynd-Feldt corrections. Alpha was set to 0.05 and significant *F*-tests were evaluated using post-hoc Tukey's to establish whether any of the trial sets demonstrated significant differences form others. A statistician from York University was consulted prior to the proposal for guidance on using appropriate analyses for this study.

5. **Results**

As previously mentioned, workstation layout refers to a fixed chair with the participant working on a fixed desk height or on their lap. The devices used were a laptop or tablet, and the tasks are RT or swiping task. Lastly, the configuration refers to participants completing two types of tasks (RT or swiping) in each different combination of workstation layout and device: laptop-desk, laptop-lap, tablet-desk, and tablet-lap for a total of eight configurations. Table 5.1 is a legend used to differentiate the three factors represented in the figures below.

Table 5.1: A legend used to distinguish between the three factors (workstation layout, device, task).

Factor		**Symbol**
Workstation layout	Desk	🟪
	Lap	⬛
Task	Swiping	▥
	RT	▩
Device	Laptop	🟥
	Tablet	▚

5.1 Participant Background Information

Information about the participants in this study are presented in Appendix A. Participants filled out a questionnaire regarding their portable computer use, computer habits, and computer set up. This questionnaire provided background information that determined that using the laptop and tablet in these configurations was not a novel task and there was no learning component that influenced the findings.

5.2 Muscle Activity

Muscle activity during each 15-minute workstation, device, and task combination was compared in this study. A detailed table in Appendix B shows mean muscle activity levels in the eight configurations (Table B2). Muscle activation levels were low for all configurations (1-6 %MVC). The low level of muscle activity was expected as the participants were in a seated position for each configuration and should have minimal activation (Dunk & Callaghan, 2002). A summary of statistical analysis is shown in Table 5.2.

For muscle activation, no significant main effects of sex and muscle side were identified for all muscles in all configurations ($F_{1,18}$=0.03, p=0.869). Therefore, the data was collapsed across sex and side and a three way ANOVA was run for workstation layout, device and task. No interactions were found between workstation layout, device, and task. However, workstation layout revealed a significant difference in muscle activity (Table 5.2). Within this factor, the desk layout showed higher mean muscle activations in the LES, TR, and IO (Figure 5.1) than the lap. The EMG ranged from 1.4%MVC (TR, Lap) to 5.9%MVC (LES, Desk). With regards to device type, Table 5.2 shows the significant difference in device type is found on the right side in the TR and IO. The EMG ranges from 1.4%MVC (TR, Laptop) to 3.5%MVC (TR, Tablet).

Of the remaining factors, Table 5.2 shows significant differences in the TR muscle for each task. Figure 5.2 demonstrates that LTR and RTR was affected by RT task, and resulted in the highest muscle activation. The EMG ranged from 1.4%MVC (TR, Swipe) to 3.5%MVC (TR, RT).

Table 5.2: Summary of statistical analysis results for the mean EMG of all eight configurations. The main effects were workstation layout, device and task. The muscles found to be significantly different ($p<0.05$) within each main effect are bolded and marked with an asterisk (*).

Effect	Workstation Layout *F*-Statistic	Device *F*-Statistic	Task *F*-Statistic
Right side			
RA	$F_{1,19}=3.93, p=0.062$	$F_{1,19}=1.6, p=0.221$	$F_{1,19}=2.11, p=0.163$
IO	$F_{1,19}=15.79, p=0.001$	**$F_{1,19}=6.56, p=0.019*$**	$F_{1,19}=0.16, p=0.697$
EO	$F_{1,19}=0.05, p=0.818$	$F_{1,19}=0.34, p=0.564$	$F_{1,19}=0.35, p=0.563$
TR	**$F_{1,19}=29.98, p<0.001*$**	**$F_{1,19}=7.14, p=0.015*$**	**$F_{1,19}=10.33, p=0.005*$**
LD	$F_{1,19}=1.93, p=0.181$	$F_{1,19}=1.66, p=0.213$	$F_{1,19}=1.29, p=0.271$
TES	$F_{1,19}=3.45, p=0.079$	$F_{1,19}=0.34, p=0.968$	$F_{1,19}=0.13, p=0.723$
LES	**$F_{1,19}=9.08, p=0.007*$**	$F_{1,19}=0.03, p=0.869$	$F_{1,19}=0.52, p=0.479$
Left side			
RA	$F_{1,18}=0.16, p=0.694$	$F_{1,18}=0.16, p=0.695$	$F_{1,18}=0.16, p=0.695$
IO	**$F_{1,18}=2.04, p=0.172*$**	$F_{1,18}=1.1, p=0.969$	$F_{1,18}=0.01, p=0.906$
EO	$F_{1,18}=2{,}76, p=0.114$	$F_{1,18}=0.2, p=0.657$	$F_{1,18}=2.39, p=0.139$
TR	**$F_{1,17}=9.13, p=0.008*$**	$F_{1,17}=1.42, p=0.249$	**$F_{1,17}=5.78, p=0.028*$**
LD	$F_{1,18}=1.6, p=0.222$	$F_{1,18}=2.25, p=0.151$	$F_{1,18}=1.32, p=0.266$
TES	$F_{1,18}=1.29, p=0.272$	$F_{1,18}=2.91, p=0.105$	$F_{1,18}=3.04, p=0.098$
LES	**$F_{1,18}=11.07, p=0.004*$**	$F_{1,18}=0.7, p=0.413$	$F_{1,18}=0.02, p=0.881$

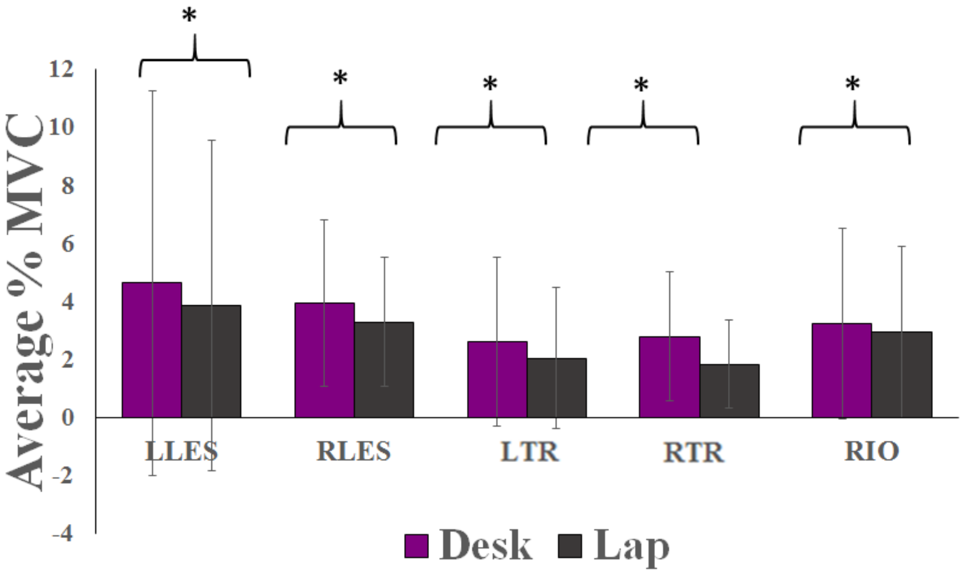

Figure 5.1: Significantly greater LES, TR, and IO mean (±SD) EMG (%MVC) during the desk workstation layout ($p<0.02$). Significant values are bolded and marked with an asterisk (*). LLES: Left lumbar erector spinae; RLES: Right lumbar erector spinae; LTR: Left upper trapezius; RTR: Right upper trapezius; RIO: Right internal oblique.

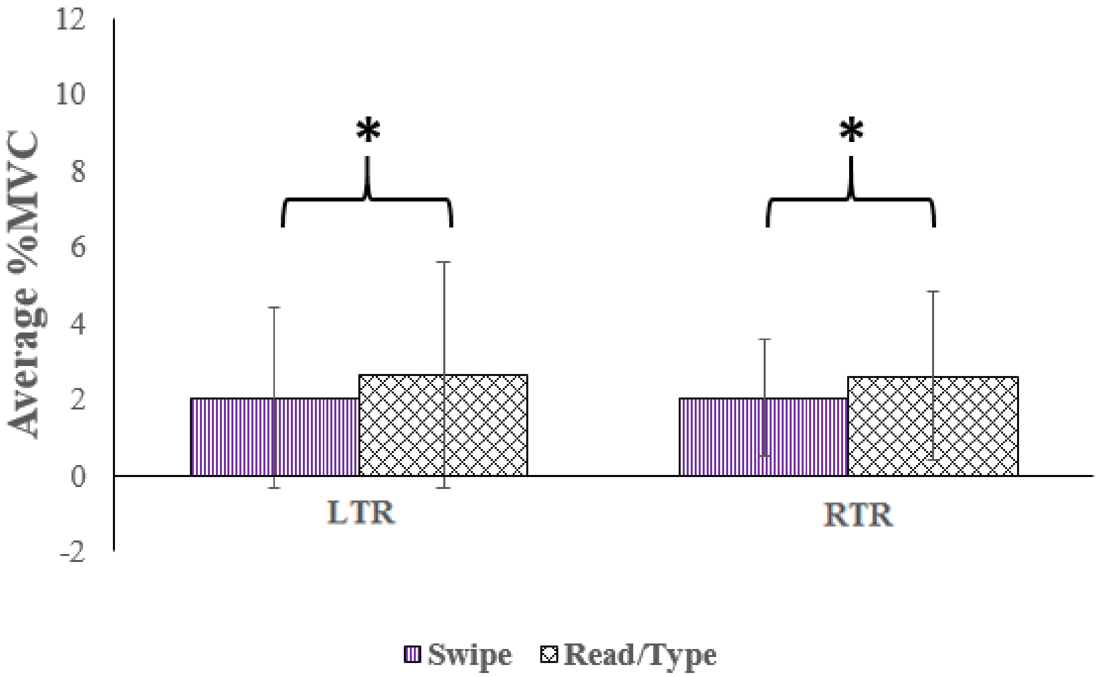

Figure 5.2: Significantly greater TR mean (±SD) EMG (%MVC) was observed during the RT task relative to the swiping task ($p<0.005$). Significant values are bolded and marked with an asterisk (*). (Swipe: Swiping task, Read/type: Reading-typing task). LTR: Left upper trapezius; RTR: Right upper trapezius.

5.3 Angles

A detailed summary of the absolute mean angles (flexion/extension, lateral bend, axial twist) and relative mean angles (flexion/extension, lateral bend, axial twist) for each configuration of each segment are presented in Appendix B. A summary table for statistical analyses is presented in Table 5.3.

There was only one interaction effect found for kinematic data and this is shown in Table 5.3. A significant workstation layout by task interaction effect was found to affect the LT (Figure 5.3) and global trunk angle (Figure 5.4) ($F_{2,17}=5.53$, $p=0.035$). An increase in LT flexion from

15.8° ± 6.7 (LT, Lap) to 22.3° ± 8.9 (LT, Desk) was found when working on a RT task on the lap compared to working on the desk. This contributes to an increase in the slumped posture that is examined in the literature (Callaghan & McGill, 2001). An increase in global trunk angle flexion was found only in the desk workstation from 12.7° ± 11.0 (Trunk, Desk) to 19.2° ± 9.8 (Trunk, Desk) (Figure 5.4). Global trunk angle on the lap workstation layout was not influenced by task. Working on the lap workstation layout shows that participants maintain a fixed posture with very minimal changes in global trunk angle.

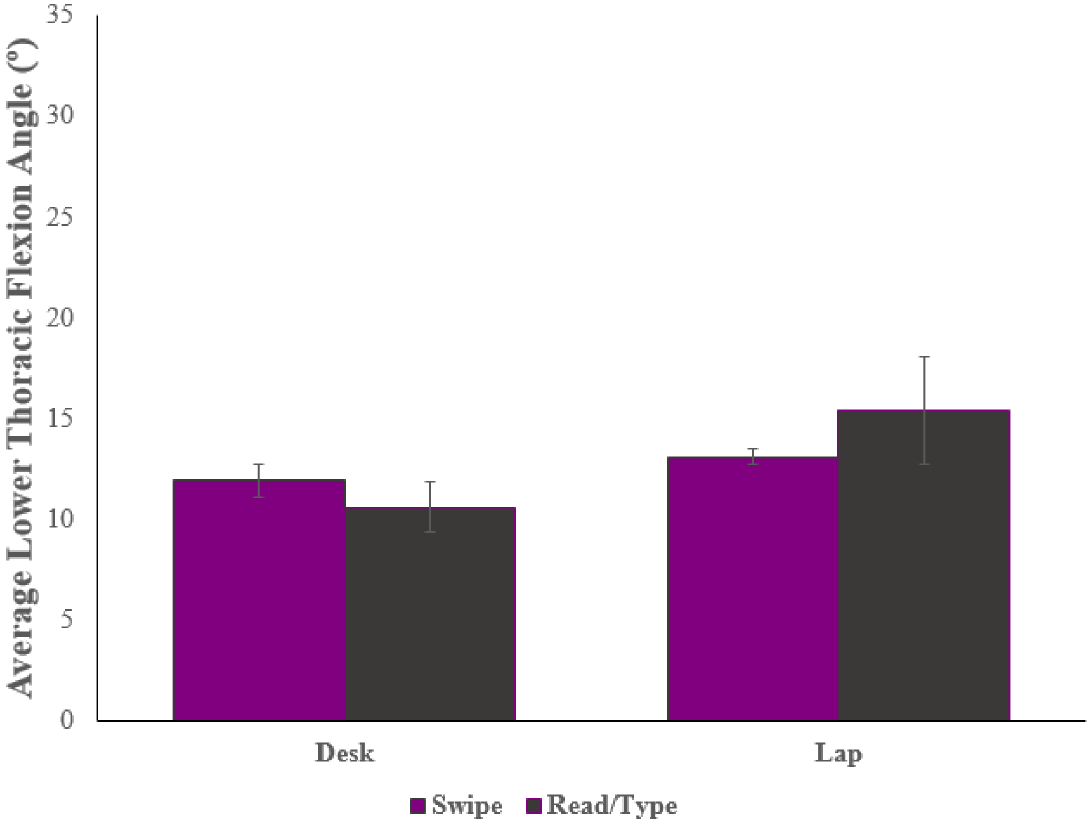

Figure 5.3: An interaction effect of the mean (±SD) LT flexion angles (°) between workstation layout and task was observed (*p*<0.031). Regardless of task, working on the lap showed the greatest LT flexion. Significant values are bolded and marked with an asterisk (*).

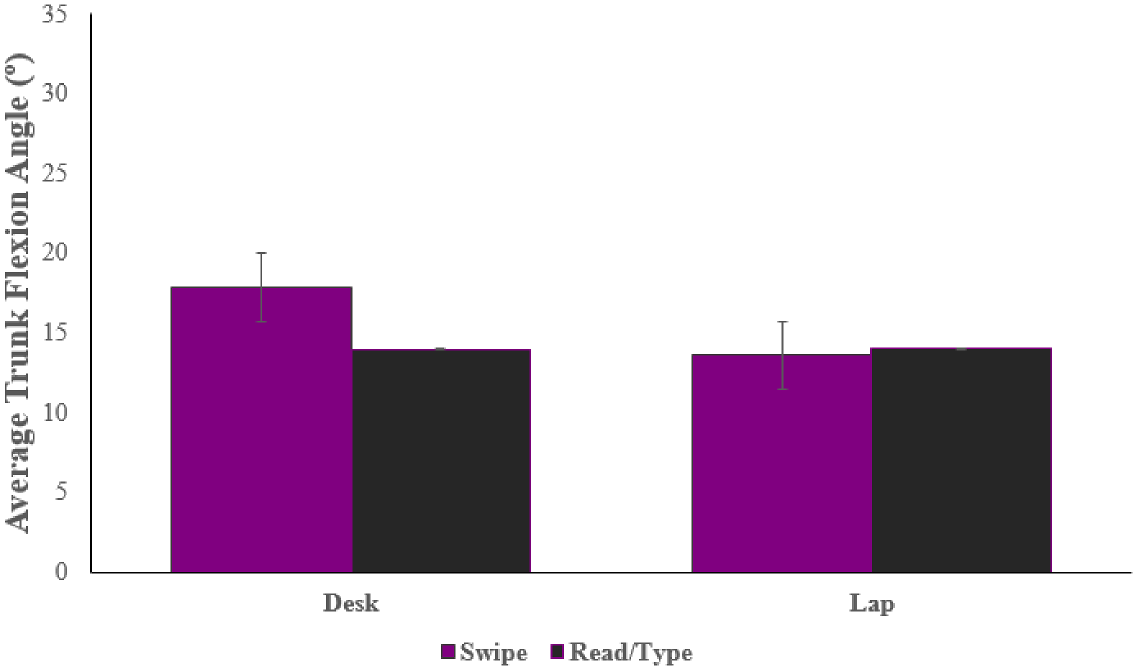

Figure 5.4: An interaction effect of the mean (±SD) global trunk flexion angles (°) between workstation layout and task was observed (*p*<0.035). The greatest global trunk flexion was observed while working on the desk workstation while doing the swiping task.

There were no significant main effects of sex identified for all angles in eight configurations ($F_{1,18}$=0.01, *p*=0.922). Likewise, the data were collapsed across sex and a three way ANOVA was run across workstation layout, device, and task. The workstation layout yielded a significant effect on the absolute angles of the head, neck, UT, lumbar and pelvis measures ($F_{2,17}$=66.29,p<0.001)(Figure 5.5). Working on the lap was found to increase head, neck, UT and lumbar flexion in comparison to working on the desk from 3° ± 6.7 (Lumbar, Desk) to 27.3° ± 1.7 (Neck, Lap). There were no differences found in the LT region. The mean differences found between the head (5.13° ± 1.19), neck (4.58° ± 4.5), UT (1.31° ± 0.7), lumbar

(1.63° ± 1.57), and pelvis (7.9° ± 1.36). Changing from desk to lap lowers the working height which has a significant effect on upper and lower regions of the spine.

During the study, switching from the laptop to the tablet changed the absolute angles of the head and neck by increasing flexion (Figure 5.7). During tablet use, the lumbar angle moves more toward neutral (flattening) and the pelvis is rotated posteriorly (Figure 5.7). The difference between head angles during tablet use was 2.23° ± 0.69 and -2.31° ± 1.44 for pelvis angle, indicating an adoption of slump posture during tablet use. In addition, using the tablet produced a greater viewing angle than the laptop (Figure 5.6). The difference in viewing angles between the laptop and tablet are 9.32° ± 1.31, with a greater viewing angle during tablet ($F(2,18) = 128.71$, $p<0.001$). This demonstrates changing the device type has a significant impact of lowering the viewing angle as well as increasing the flexion angles on the head.

There were no significant differences found for the absolute angles in lateral bend (around the x axis). The overall change in angles for the UT, LT, and lumbar was less than 2°. The range for UT was -1.4° to -0.2°, -0.6° to 1.3° in the LT, -0.1° to 1.7° for the lumbar, and -0.6° to 0.1° for the trunk. There were also no significant differences found for the absolute angles in twist (rotation about the z axis). The overall change in angles was less than 5°. The range for the UT was -1.3° to -1.7°, LT -4° to -2.7°, lumbar -3.7° to -2.3°, and trunk -4° to -1.7°. A detailed list outlining the average values for axial twist and lateral bend for each configuration of each segment are presented in Appendix B.

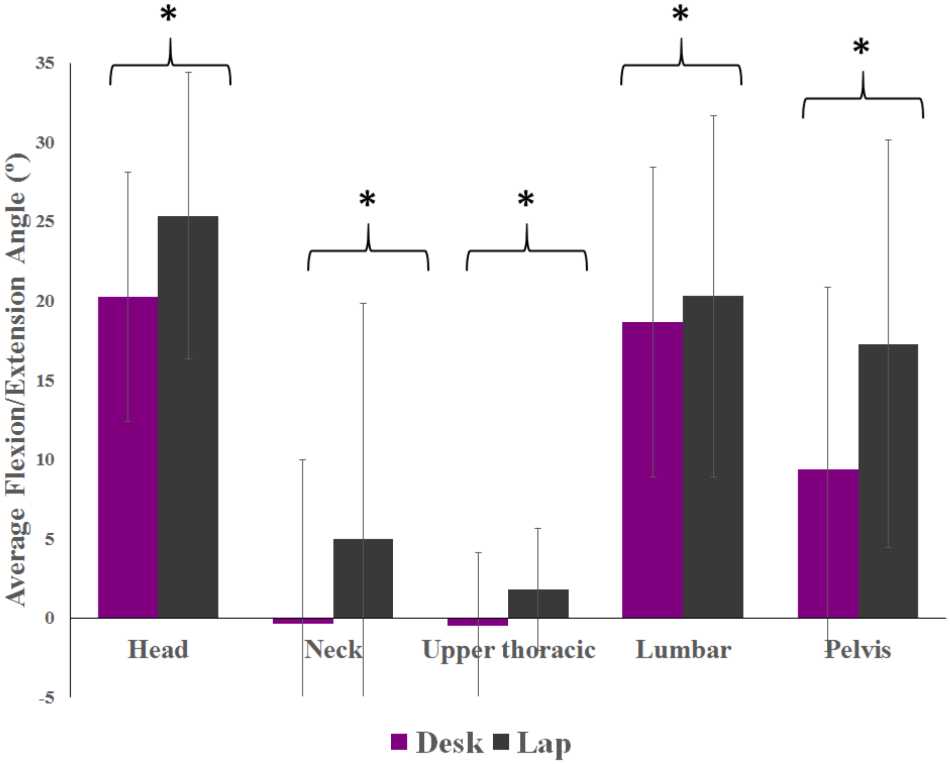

Figure 5.5: Head, neck, UT, lumbar, and pelvis mean (±SD) flexion and extension angles (°) are significantly greater when working on the lap ($p<0.001$). Significant values are bolded and marked with an asterisk (*). Positive values indicate flexion.

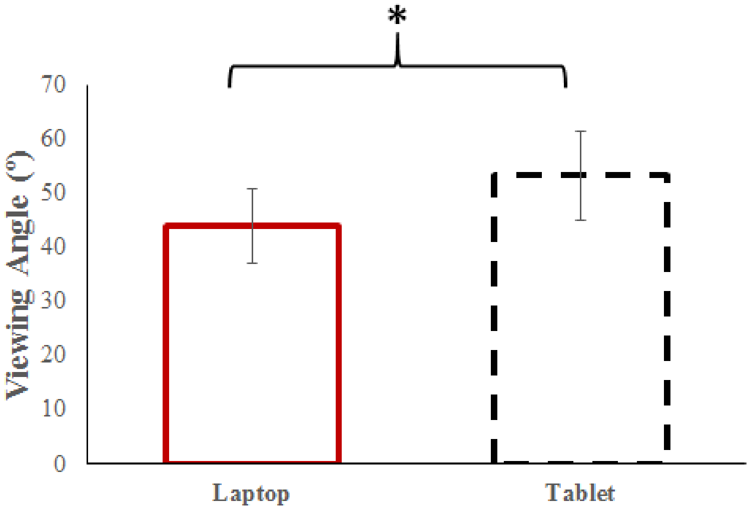

Figure 5.6: Mean (±SD) of viewing angle (°) (in the sagittal plane) showing the tablet had a significantly greater viewing angle ($p<0.001$). Significant values are bolded and marked with an asterisk (*).

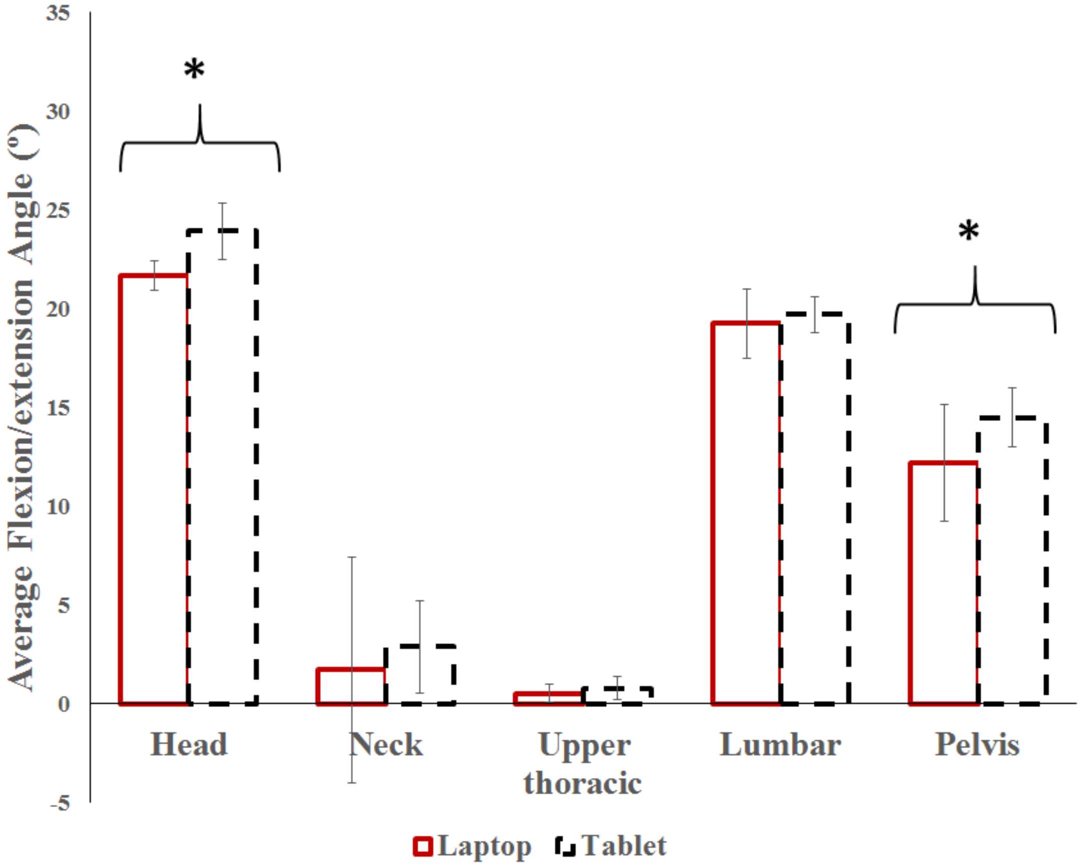

Figure 5.7: Head and pelvis mean (±SD) flexion and extension angles (°) are significantly greater when using the tablet ($p<0.001$). Significant values are bolded and marked with an asterisk (*). Positive values indicate flexion.

Table 5.3: Summary of statistical analysis results for the kinematic measures for all eight configurations. One interaction effect of workstation and task was found in the lumbar and global trunk angle. The main effects were workstation layout, device, and task with significant values ($p<0.05$) bolded and marked with an asterisk (*).

Effect	**Workstation*Task** *F*-Statistic	**Workstation Layout** *F*-Statistic	**Device** *F*-Statistic	**Task** *F*-Statistic
Head	$F_{1,19}=1.96$, $p=0.178$	**$F_{1,19}=46.21$, $p<0.001$***	**$F_{1,19}=10.4$, $p=0.005$***	$F_{1,19}=1.17$, $p=0.293$
Neck	$F_{1,19}=1.66$, $p=0.214$	**$F_{1,19}=44.19$, $p<0.001$***	$F_{1,19}=0.39$, $p=0.542$	$F_{1,19}=0.24$, $p=0.631$
Upper thoracic	$F_{1,19}=0.43$, $p=0.519$	**$F_{1,19}=31.89$, $p<0.001$***	$F_{1,19}=0.97$, $p=0.338$	$F_{1,19}=0.06$, $p=0.802$
Lower thoracic	**$F_{1,19}=5.53$, $p=0.031$***	**$F_{1,19}=17.33$, $p=0.005$***	$F_{1,19}=6.06$, $p=0.024$	$F_{1,19}=0.13$, $p=0.721$
Lumbar	$F_{1,18}=0.04$, $p=0.836$	$F_{1,19}=5.32$, $p=0.033$	$F_{1,19}=0.57$, $p=0.459$	$F_{1,19}=3.43$, $p=0.079$
Trunk	**$F_{2,17}=5.15$, $p=0.035$***	$F_{1,19}=6.81$, $p<0.001$	$F_{1,19}=1.89$, $p=0.185$	$F_{1,19}=4.98$, $p=0.038$
Pelvis	$F_{1,19}=0.37$, $p=0.552$	**$F_{1,19}=66.19$, $p<0.001$***	**$F_{1,19}=5.18$, $p=0.035$***	$F_{1,19}=0.29$, $p=0.973$
Viewing angle	$F_{1,18}=0.5$, $p=0.488$	**$F_{1,19}=45.57$, $p<0.001$***	**$F_{1,18}=128.71$, $p<0.001$***	$F_{1,19}=0.82$, $p=0.378$
Discomfort	$F_{1,19}=0.01$, $p=0.953$	$F_{1,19}=2.25$, $p=0.151$	$F_{1,19}=3.14$, $p=0.092$	**$F_{1,19}=4.43$, $p=0.049$***

5.4 Discomfort

Figure 5.8 represents the score (millimetres) difference from the baseline measure taken at the start of each time interval. There was a difference in discomfort score found between task ($F_{2,17}$=4.43, $p<0.049$). Again, a change in VAS score larger than 10mm is considered to be the development of clinically significant pain (Nelson-Wong et al., 2008). The clinically significant level of 10mm was passed in three configurations: Desk-Tablet-Swipe, Lap-Laptop-RT, Lap-Tablet-RT. The configuration with the most self-reported pain was found in Lap-Laptop-RT (Figure 5.8).

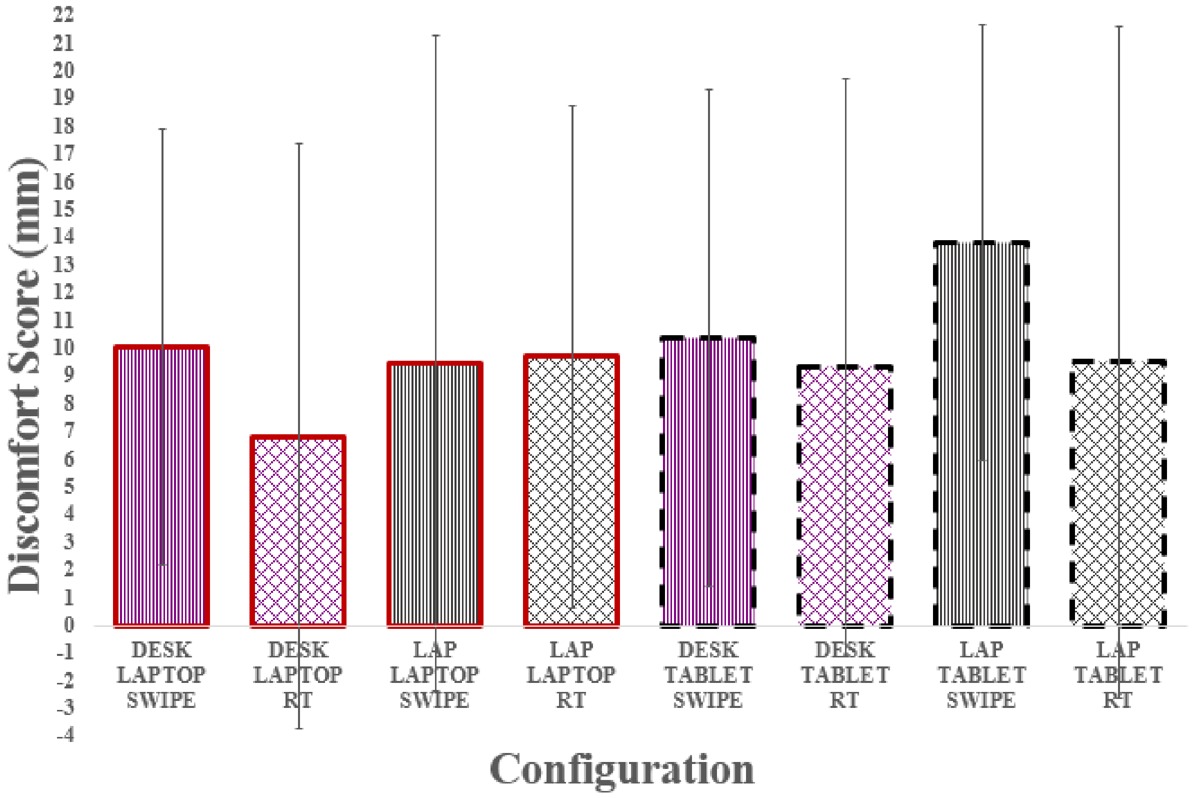

Figure 5.8: Mean discomfort (VAS scores) for all eight configurations. The Lap-Tablet-Swiping task was the configuration with the highest reported amount of discomfort.

5.5 Summary of Key Points

Table 5.2 and Table 5.3 show that kinematic, muscle activation and self-reported VAS were affected by workstation layout, device, and task. The amount of activation focused mainly on the shoulder region (TR muscles) and lower back region (ES) (Table 5.2). The desk layout showed higher mean muscle activations in the LES, TR, and IO (Figure 5.1) than the lap and Figure 5.2 demonstrates that LTR and RTR was affected by RT task, and resulted in the highest muscle activation.

However, working on the lap was found to increase head, neck, UT and lumbar flexion in comparison to working on the desk from 3° ± 6.7 (Lumbar, Desk) to 27.3° ± 1.7 (Neck, Lap) showing that the decreased muscle activity observed in the lap condition could be a result of relying on the posterior passive structures of the spine. Only one significant workstation layout by task interaction effect was found to affect the LT flexion (Figure 5.3) and global trunk flexion (Figure 5.4) ($F_{2,17}$ =5.53, *p*=0.035).When comparing devices, switching from the laptop to the tablet changed the absolute angles of the head and neck by increasing flexion (Figure 5.7) and using the tablet produced a greater viewing angle than the laptop (Figure 5.6). In addition, Table 4.3 shows that the distance of the tablet was closer to the participant's body and the viewing distance was increased which correlates to the greater viewing angle and increased flexion seen in the head angle during tablet use.

Self-reported VAS was affected by task ($F_{2,17}$=4.43, *p*=0.049). As previously mentioned, greater flexion was observed during the lap workstation layout and during tablet use, so it is expected that participants reported the greatest amount of self-reported pain during the Lap-Tablet-Swipe configuration.

6. **Discussion**

Overall, the findings of the present study supported the hypothesis in that muscle activity, posture, and discomfort was affected by each of the factors (workstation layout, device type, and task).

Previous epidemiological findings have provided evidence that time spent in sedentary activities, such as sitting, has shown deleterious associations with cardio-metabolic health and premature mortality in adults (Healy et al., 2011). Although no direct link has been made between prolonged sitting and LBP, biomechanics research has shown that prolonged sitting could increase low back discomfort through low prolonged muscle contraction or loading of the passive structures (Callaghan & McGill, 2001; Callaghan & Dunk, 2002). Similar to previous research on prolonged sedentary postures, the trunk muscle activations in the spine regions throughout the study were between 1-6 % of MVC (Table B2). Previous studies evaluating prolonged EMG recordings during every day activities show that the trunk extensors are active at low intensities below 10% of maximum (van Dieen et al., 2009). However, muscle activation, even at a low level, if sustained for a long time can result in muscle fatigue. McGill et al. (2000) showed that contraction levels of the trunk extensors as low as 2% of MVC have been shown to impair oxygenation in these muscles. These results can be applied to prolonged postures that require isometric contractions held for extended hours, such as sitting (McGill et al., 2000). Previous studies have shown that maintaining low level activity of trunk extensor muscles can lead to impaired function and development of LBP (van Dieen et al., 2009).

Healy et al. (2011) found that reducing and regularly breaking up sedentary time showed beneficial associations with cardio-metabolic health. These findings may be beneficial in settings where prolonged sitting time occurs, such as portable computer use to provide relief for the active and passive structures of the low back when working at a nontraditional workstation (Callaghan & McGill, 2001). Based on the findings of this thesis study, it is recommended that users take advantage of the portability of the laptop and tablet and change positions frequently to avoid sitting in these non-neutral postures for a prolonged period of time to allow the spine freedom to move and change distribution of internal loading conditions and preserve spinal health (Zemp et al., 2013; Pope et al., 2002). Although no specific ratio and duration of breaks is known, incorporating breaks during computer use to reduce sedentary time has potential health benefits to reduce discomfort and risk of musculoskeletal disorders (Callaghan et al., 2015). In addition, previous research has shown positive benefits of work-related musculoskeletal discomfort from an ergonomics intervention consisting of flexible physical workspace design and ergonomics training in an office setting (Robertson et al., 2008).

6.1 Comparison Between Workstations

Sustained flexion in the UT and lumbar regions were observed in both desk and lap configurations. There are numerous factors that affect LBP and sustained flexion has been well documented in the literature of LBP generation (Callaghan & McGill, 2001; O'Sullivan et al., 2002; De Carvalho et al., 2010). Sustained lumbar spine flexion can increase spinal loading (Dunk et al., 2009), is associated with decreases in passive spine stiffness (Beach et al., 2005) and may cause severe detrimental effects on passive structures of the spine (Dunk et al., 2009). The findings in this study were consistent with previous study by Callaghan & McGill (2001) examining lumbar spine kinematics, joint loads, and muscle activity during a 2 h period of sitting. When people work at a desk while performing computer work, they often lean forward and do not rest against the back support of a chair (Callaghan & McGill, 2001). Therefore, it is not surprising that muscle activity of the LES and IO muscles observed in this study were found to differ across workstation layout. The LES muscles showed low muscle activation while working on the lap. The decreased muscle activity observed during the lap condition could be a result of individuals who habitually adopt flexed postures, deactivating the stabilizing muscles of the lumbar spine region (O'Sullivan et al., 2002). Participants adopted greater anterior flexion during the lap condition, the decreased muscle activation and the most non-neutral postures observed during this workstation layout provide further evidence that the passive forces created by the viscoelastic structures (posterior ligaments, discs, and capsules) are resisting the effect of gravity of the upper trunk and head mass (Solomon et al., 2003). Prolonged static flexion has been shown to develop creep in the lumbar viscoelastic structures that can alter loading patterns, potentially increasing the risk of developing LBP (Solomon et al., 2003).

Numerous studies have evaluated postures during portable device use in configurations similar to our desk configuration (Straker et al., 2008) and lap configuration (Moffet et al., 2002). The EMG values obtained in this study were comparable to those reported in previous literature by Moffet et al. (2002) evaluating the impact of laptop designs and work situations on neck and upper limb posture, muscle activity, and productivity in eight healthy subjects. Working on the lap is associated with greater head and neck flexion, and higher muscle activity was observed in the trapezius muscle in the desk workstation compared to the lap (Moffet et al., 2002). These same authors have shown a relationship between keyboard distances and where the device is placed on desk or lap (Moffet et al., 2002). In this study, the device positioning when working on the lap was influenced by anthropometric characteristics and comfortable positioning on the thigh. When working on the lap, users stabilize the portable device with their arms and legs to decrease the risk of dropping the computer. This may restrict their movement and promote more static postures. In the present study, participants working on the lap placed the tablet 8 cm closer to the abdomen compared to the laptop. It is possible that participants compensated for the closer keyboard placement by adopting greater head and neck flexed postures in this study. Continuous usage of portable devices in shared communal workspaces or commuting environments should always use the portable device on a desk surface and avoid lap level workstation layouts.

6.2 Comparison Between Device Types

The physical dimensions of the laptop and tablet were considerably different in size and adjustability. The inability to adjust the laptop screen relative to the keyboard and the integrated keyboard and monitor of the tablet are potential factors that contributed to the compromised postures observed when using these devices. Previous research has suggested that the position of keyboard and screen are determinants of posture (Asundi et al., 2010). In this study, the position of the screen on the portable device impacted the viewing distance. The viewing distance of the tablet screen from the participant’s eyes were on average 10 cm lower than the laptop. Therefore, a potential factor to adjust for the lowered screen were the observed postural changes in head and neck flexion angles. The results showed that the compromise occurred mainly in head and neck angles, similar to findings by Straker et al. (1995).

The observed difference in head flexion across configurations is influenced by the viewing angle. Young et al. (2012) determined how head and neck postures varied when using two media tablet computers in four common user configurations. They reported greater head and neck flexion angles during tablet compared to previously reported angles for desktop and laptop computing. They concluded that viewing angles were the driving factor for postural changes between head and neck configurations. Comparing to previous literature (Young et al., 2012), this study found that viewing angles changed in similar fashion to the head flexion angle. The viewing angle during tablet use ranged from 46-51°, similar to the range found in Young et al. (2012). Previous research has found a general linear relationship between head flexion versus viewing angle (Straker et al., 2008) and forward head postures are associated with increased compressive loading of the spine (Asundi et al., 2010). The change in head flexion and viewing angle are likely due to the integrated monitor and keyboard during tablet use (Werth & Babski-Reeves, 2014). In addition, previous literature has reported that positioning of a computer keyboard and screen is important in encouraging suitable neck postures (Villaneuva et al., 1996). As previously mentioned, screen height strongly influenced neck flexion, with lower screens resulting in greater neck flexion. Although no consensus on trunk postures has been reached (O'Sullivan et al., 2012), there is more consensus on the obligation for minimal neck flexion (Straker et al., 1995). Adopting increased head and neck flexion postures during more integrated compact portable computer use, such as a tablet, are likely to increase the risk for injury or development of pain in the neck and spine (Werth & Babski-Reeves, 2014). Using the laptop slightly improves the viewing angle and the head and neck angle compared to using the tablet. It is recommended for employees who work remotely or often work outside of the traditional office work setting that when presented with a choice between a laptop and a tablet, users should choose to work on the laptop to reduce head and neck flexion. It is important for tablet users to elevate the tablet to improve the viewing angle to promote better head and neck postures.

*6.3 Comparison Between Task*s

The computer tasks in this study were used to simulate real world tasks, where both keyboard and mouse pad are both used (typing, completing and editing forms, browsing the internet, playing games). In a study by Dennerlein & Johnson (2006), the authors simulated computer tasks ranging from exclusive mouse use, mixed mouse and keyboard use to exclusive keyboard activity and compared the muscle activity across these tasks. Dennerlein & Johnson (2006) observed slightly higher values of EMG for the trapezius muscle during typing compared to only mouse-intensive tasks. Similar to previous literature, the results in this thesis also reported higher TR muscle activity during reading and typing task compared to the swiping task. In addition, the results indicate that tasks involving the keyboard were associated greater posture variability, whereas the task involving the mouse pad (swiping task) were associated with less variable and relatively constrained postures (Dennerlein & Johnson, 2006). This is shown in the LT flexion angle, where reading and typing task shows an increase in flexion whereas the swiping task flexion angles remain fairly constant. It is important to note that higher discomfort score ratings occurred during the swiping task compared to the reading task. The highest discomfort score rating was reported during the use of a tablet on the lap layout, while performing a swiping task. Therefore, it is crucial to consider job specific tasks for employees who work remotely or work in a mobile environment to develop a better understanding on musculoskeletal disorders (Dennerlein & Johnson, 2006).

6.4 Limitations

As with many biomechanical research studies, there are limitations that need to be considered. Participants in this study were tested in a controlled laboratory setting with instrumentation constraints. Surface markers were used to measure spinal motion which introduced artefact from movement. However, previous work has been shown that mounting surface markers directly over spinous processes is correlated to the positions of the spinous process (Morl & Blickhan, 2006). Also, the low functional tasks required in this study would minimally affect skin movement. Therefore, it is important to evaluate how users interact in a field setting. Another limitation is that the data is only reflective of a healthy, young population that has all been asymptomatic for back pain. However, this group of participants represents a primary computer user population and these individuals will be progressing into the work force within a few years. Also, the chair used in this study offered no lumbar support. Lumbar support during sitting is advocated since it preserves lumbar lordosis and prevents pelvic rotation (Williams et al., 1991; De Carvalho et al., 2010).

7. General Thesis Overview

7.1 Revisiting Hypotheses

Hypothesis #1: As workstation layout changes to working on the lap, the lap layout will elicit:

a. The greatest head, neck, thoracic and lumbar spine flexion than the desk setting.

b. Lower muscle activity in the back musculature (TES, LES).

This hypothesis was ACCEPTED.

Working on the lap while seated at a chair was found to negatively impact posture. There was increased flexion in the head, neck, UT and lumbar regions. In addition, there was higher muscle activation in the desk configuration.

Hypohtesis #2: As device changes to working with the tablet, the tablet will elicit:

- ***a. The greatest head, neck, and thoracic flexion than the laptop.***
- ***b. Lower muscle activity in the back musculature (TES)***
- ***c. Reporting of higher discomfort ratings.***

This hypothesis was ACCEPTED.

The tablet device was found to be more detrimental to posture. Table device use resulted in increased flexion in head, increased posterior pelvic tilt, and increased viewing angle.

Hypothesis #3: As task changes to the RT task, the RT task will elicit:

- ***a. No changes in flexion angles of the head, neck, thoracic, lumbar, and pelvis compared to the swiping task***
- ***b. Higher muscle activity in the shoulder muscle (TR)***

c. Reporting of higher discomfort ratings.

This hypothesis was REJECTED.

Although there was an increase in muscle activity in the TR in RT and typing task, participants reported more discomfort in the swiping task.

8. Conclusion

It is important to consider the impact of workstation layout, device type, and task have on postural angles, muscle activation, and discomfort in fixed computing environments as demonstrated by the results of this study. Although the postural differences and muscle activation levels across workstation layout, device, and task were modest, the exposure duration was relatively short at 15 minutes. Likewise, the discomfort experienced in the observed non-neutral postures may be magnified over time depending on the frequency and duration of exposure (Asundi et al., 2010).

All configurations evaluated in this study demonstrated less than ideal posture, suggesting that users working in communal work settings and other mobile environments with variation from the traditional office set up should be conscious of the postures they adopt. The current study shows the importance of choosing a workstation layout, because the use of any device on the lap exhibited more non-neutral postures compared with the use of the device on the desk. Users should also be aware that using a tablet device imposes greater flexion on the head and neck region compared to the use of a laptop. When given the choice, portable computer users should use a laptop since it allows for more neutral postures in the head and neck. The design of laptop allows for an adjustable screen separate from the keyboard and provides a higher screen height to allow the monitor to be closer to eye level than using the tablet.

To address the popularity of portable computing outside a traditional office workstations, future studies on ergonomics training should be expanded and implemented into a high school education program to examine the health and performance effects ergonomics training on portable computer use to promote healthy commuting habits. Future studies should also look to assess how posture is affected during portable computer use in workspaces offering flexible workstations, including stand up bars, different types of chairs, and adjustable desks.

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Appendix A: Questionnaire

Participant Questionnaire

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The following questionnaire is voluntary and we only ask that you answer the questions to the best of your ability. If for any reason you do not feel comfortable answering any or some of the questions, you may leave them blank. Leaving answers blank is acceptable and there are no penalties for doing so.

Date:

Participant code:

1. What is the brand of your personal laptop?	Apple: 50% / Other: 50%
2. What is the size of your personal laptop?	11”: 10% / 13”: 65% / 15”; 20% / 17”: 5%
3. What is the brand of your personal tablet?	Apple: 75% / Other: 25%
4. Any increase in daily computer use during the past year?	Yes: 55% / No: 45%
5. On average, total hours of laptop use per day during the weekday?	0-1 hours per day: 5% / 2-4 hours per day: 25% / 4-6 hours per day: 10% / 6-8 hours per day: 40% / >8 hours per day: 20%
6. On average, total hours of tablet use per day during the weekday?	Hardly ever: 10% 0-1 hours per day: 60% / 1-2 hours per day: 5% / 2-4 hours per day: 25%
7. Do you use a mouse when using a laptop?	Yes: 25% / No: 75%
8. Do you take breaks during computer use?	Yes: 50% / No: 50%
9. Do you perform stretch exercises during computer work?	Never: 45% / Sometimes: 45% / Often: 5% / Always: 5%
10. Do you notice any back discomfort during tablet use?	No: 40% / Once in a while: 55% / Frequently (for a long time): 5%

11. Do you use an external monitor when using a laptop?	Yes: 30% / No: 70%
12. Do you notice any neck discomfort during laptop use?	No: 20% / Once in a while: 45% / Frequently: 35%
13. Do you often work for >1 hour without a break?	Yes: 85% / No: 15%
14. When using your tablet, is your screen free from glare?	Yes: 30% / No: 70%
15. Do you use a case for your tablet?	Yes: 55% / No: 45%
16. If you answered Yes to question #13, is it set to a low angle (<45°) or high angle (>45°)?	Low: 35% / High: 20% / Not applicable: 45%
17. Do you notice any neck discomfort during tablet use?	No: 30% / Once in a while: 55% / Frequently: 15%
18. What is your overall health?	Bad: 0% / Moderate: 0% / Good: 100%
19. Please indicate if spend time on your tablet in these positions:	**Standing?** Yes: 45% / No: 55% **Sitting at a desk?** Yes: 75% / No: 25% **Sitting – other (ex: On the bus, subway, train, car)?** Yes: 75% / No: 25% **On your lap?** Yes: 80% / No: 20%
20. Do you use a foot rest when using a tablet?	Yes: 0% / No: 100%
21. What is the frequency of short (<15 min) breaks during computer use?	Hardly ever: 40% / Sometimes: 45% / Regularly: 15%
22. Do you use any supports for elbow, wrist, or forearm during keyboard use?	Yes: 20% / No: 80%
23. Do you use an external keyboard when using a tablet	Yes: 0% / No: 100%
24. Do you use a height adjustable table when using a tablet?	Yes: 0% / No: 100%
25. Do you notice any back discomfort during laptop use?	No: 30% / Once in a while: 45% / Frequently: 20%

26. Do you use a foot rest when using a <u>laptop</u>?	Yes: 10% / No: 80%
27.Please indicate if you spend time on your <u>laptop</u> in these positions:	**Standing?** Yes: 15% / No: 85% **Sitting at a desk?** Yes: 90% / No: 10% **Sitting – other (ex: On the bus, subway, train, car)?** Yes: 25% / No: 75% **On your lap?** Yes: 70% / No: 30%
28.Do you get up and take a short walk (<5 min) in between work?	Yes: 80% / No: 20%
29.Do you use an external monitor when using a <u>tablet</u>?	Yes: 0% / No: 100%
30.Do you use a height adjustable table when using a <u>laptop</u>?	Yes: 0% / No: 100%
31.When using your <u>laptop</u>, is your screen free from glare spots?	Yes: 30% / No: 70%

Appendix B: Additional Tables and Figures

Table B1: Mean (±SD) activation levels obtained in all eight configurations. EO: external oblique; IO: internal oblique; LD: latissimus dorsi; LES: lumbar erector spinae; RA: rectus abdominis; TR: upper trapezius; TES: thoracic erector spinae. Significant values (p<0.05) are bolded and marked with an asterisk (*).

	1	2	3	4	5	6	7	8
	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
Right side								
RA	3.3 + 3.2	3.1 ± 2.8	3.1 ± 2.8	3.1 ± 2.8	3.2 ± 3	3.1 ± 2.7	3.1 ± 2.9	3.1 ± 2.9
IO	**3.4 + 3.8 ***	**3.2 ± 3.8 ***	**3.1 ± 3.1 ***	**3.1 ± 3.1 ***	**2.9 ± 2.1 ***	**3.1 ± 3.1 ***	**2.8 ± 2.8 ***	**2.8 ± 3 ***
EO	4.1 ± 6.8	4.1 ± 6.7	4.1 ± 6.7	4.1 ± 6.7	4.1 ± 6.6	4.2 ± 6.7	3.7 ± 6.7	4.2 ± 6.6
TR	**2.1 ± 1.5 ***	**2.8 ± 2.1 ***	**2.6 ± 1.7 ***	**3.5 ± 3.5 ***	**1.4 ± 1.1 ***	**1.7 ± 1.4 ***	**1.8 ± 1.6 ***	**2.2 ± 1.8 ***
LD	4.1 ± 5.3	4.1 ± 5.3	5.1 ± 5.8	4.2 ± 5.3	4.5 ± 4.8	4.9 ± 6.2	5.3 ± 5.3	4.5 ± 5.3
TES	4.3 ± 6.1	4.4 ± 6.2	4.4 ± 5.8	4.2 ± 5.6	3.9 ± 4.9	4.4 ± 5.3	4.3 ± 5.1	4.1 ± 4.6
LES	**3.8 ± 2.6 ***	**4.2 ± 3.8 ***	**3.7 ± 2.6 ***	**3.9 ± 2.4 ***	**3.1 ± 1.8 ***	**3.1 ± 2.2 ***	**3.4 ± 2.2 ***	**3.5 ± 2.5 ***
Left side								
RA	4.5 ± 5.2	4.2 ± 4.7	4.5 ± 5.2	4.5 ± 5.3	4.7 ± 6.1	4.3 ± 4.4	4.6 ± 5.7	4.6 ± 5.5
IO	3.7 ± 3.2	3.4 ± 3.1	4.6 ± 6.2	3.6 ± 2.9	4.7 ± 5.8	5.3 ± 7.9	4.7 ± 5.5	5.6 ± 8.2
EO	3.4 ± 3.4	3.5 ± 3.8	4.1 ± 4.6	3.7 ± 4.6	4.1 ± 5.8	3.4 ± 3.7	3.7 ± 4.7	3.7 ± 4.7
TR	**1.7 ± 1.2 ***	**2.2 ± 1.4 ***	**2 ± 1.9 ***	**2.7 ± 2.1 ***	**1.4 ± 3.9 ***	**1.6 ± 4.1 ***	**1.5 ± 4.8 ***	**1.7 ± 5.1 ***
LD	3.1 ± 2.7	3.8 ± 5.1	4.8 ± 8.3	4.6 ± 7.9	4.4 ± 7.3	4.8 ± 7.7	4.8 ± 8.5	4.9 ± 7.8
TES	3.2 ± 3.5	3.7 ± 4.1	3.5 ± 4.3	3.6 ± 3.4	3.3 ± 3.3	3.6 ± 3.3	4.1 ± 4.1	3.8 ± 3.2
LES	**5.9 ± 11.7***	**4.3 ± 5.1 ***	**4.2 ± 4.6 ***	**4.1 ± 5.0 ***	**3.8 ± 7.3 ***	**3.2 ± 3.1 ***	**4.3 ± 6.5 ***	**4.1 ± 5.8 ***

Table B2: Mean (±SD) of flexion and extension absolute angles (°) (rotations around the Y axis) for all 8 configurations. Positive values indicate flexion. (RT: Reading-typing).

	1	2	3	4	5	6	7	8
	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
Head	9.8 ± 7.9	11.1 ± 8.2	17.2 ± 7.0	18.7 ± 8.4	21.9 ± 9.4	21.4 ± 7.8	24.2 ± 8.5	25.5 ± 10.5
Neck	19.9 ± 6.9	19.1 ± 5.4	22.2 ± 4.1	19.7 ± 4.2	23.9 ± 2.1	23.8 ± 2.8	26.2 ± 3	27.3 ± 1.7
Upper thoracic	21.2 ± 8.6	18.7 ± 8.7	21.3 ± 7.6	17.8 ± 10.6	18.2 ± 9.0	18 ± 6.7	17 ± 9.1	19.5 ± 10.3
Lower thoracic	22.3 ± 8.9	19.6 ± 9.3	21.6 ± 8.7	19.8 ± 7.9	17 ± 8.4	15.8 ± 6.7	16.3 ± 7.8	20 ± 6.6
Lumbar	11.1 ± 9.6	9.8 ± 6.9	8.5 ± 7.4	8.8 ± 7.8	3 ± 6.7	3.1 ± 6.6	3.4 ± 5.9	1.7 ± 8.7
Trunk	19.2 ± 9.8	15.2 ± 8.1	16.6 ± 7.3	12.7 ± 11.0	14.2 ± 7.4	13.6 ± 5.1	13 ± 8.4	14.4 ± 10.1
Pelvis	-7.9 ± 15.0	-8 ± 9.0	-10.6 ± 9.8	-11 ± 12.1	-17.2 ± 11.5	-15.6 ± 15.0	-16.8 ± 13.5	-19.5 ± 11.3

Table B3: Mean (±SD) of lateral bend absolute angles (°) (rotations around the X axis) for all eight configurations are shown. Positive values indicate right lateral bend. (RT: Reading-typing).

	1	2	3	4	5	6	7	8
	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
Head	-3.1 ± 8.1	-5.3 ± 8.3	-1.9 ± 8.6	-5.6 ± 7.6	-2.6 ± 8.6	-4.7 ± 7.4	-2.5 ± 6.7	-3.5 ± 8
Neck	-1.8 ± 5.5	-2.8 ± 5.4	-1.5 ± 5.7	-2.3 ± 4.5	-0.6 ± 5.7	-1.8 ± 5.6	-1.2 ± 5	-1.4 ± 5.4
Upper thoracic	-1.4 ± 2.6	-1 ± 2.6	-0.9 ± 4.1	-1.2 ± 3.3	0.7 ± 3	-0.4 ± 2.6	-0.2 ± 3.6	-0.5 ± 3.1
Lower thoracic	-0.6 ± 2.6	0.1 ± 2.6	-0.3 ± 4.2	0.4 ± 3	1.2 ± 1.6	1.1 ± 1.6	1.1 ± 2.5	1.3 ± 1.8
Lumbar	-0.1 ± 2.5	1.4 ± 2.9	0.7 ± 3	1.5 ± 3.6	0.2 ± 2.7	0.6 ± 3.3	0.6 ± 2.2	1.7 ± 2.6
Trunk	-0.6 ± 2.1	0.1 ± 2.4	-0.4 ± 3.3	0.1 ± 2.5	-0.1 ± 2.5	0.1 ± 1.7	0.4 ± 2.1	0.5 ± 1.9
Pelvis	-2.1 ± 5.2	-1.8 ± 4.5	-1.7 ± 4.9	-1.1 ± 4.8	-1.5 ± 4	-1.9 ± 4.6	-1.8 ± 5	-1.2 ± 4.7

Table B4: Mean (±SD) of axial twist absolute angles (°) (rotations around the Z axis) for all eight configurations are shown. Positive values indicate right lateral twist. (RT: Reading-typing).

	1	2	3	4	5	6	7	8
	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
Head	-2.9 ±5.3	-4.1 ±6.3	-2.7 ±8.0	-4.9 ±6.9	-2.7 ±6.3	-4.7 ±5.0	-3.6 ±6.1	-4.7 ±6.4
Neck	-1.3 ±2.9	-1 ±3.9	-1.7 ±6.5	-2.6 ±7.3	-1.2 ±6.2	-4.9 ±5.2	-1.5 ±3.4	-2.7 ±4.3
Upper thoracic	-2.2 ±6.0	-3.3 ±7.6	-9.7 ±35.7	-11 ±36.7	-1.7 ±7.3	-12.2 ±38.1	-10.7 ±36.5	-13 ±36.9
Lower thoracic	-3.7 ±6.5	-4 ±8.4	-3 ±8.5	-4.2 ±7.8	-2.8 ±7.7	-3.4 ±6.6	-3.9 6.5	-3.9 ±7.0
Lumbar	-3.7 ±7.0	-3.6 ±8.5	-2.7 ±7.9	-3.3 ±7.9	-2.3 ±7.6	-2.8 ±7.3	-3 ±7.0	-3.4 ±6.8
Trunk	-3.4 ±6.3	-4 ±8.3	-2 ±7.9	-2.9 ±7.0	-1.7 ±8.2	-3.1 ±6.4	-3.1 ±7.2	-3.9 ±7.0
Pelvis	-2.1 ±6.3	-2.5 ±7.5	-0.8 ±7.0	-0.9 ±7.5	-0.7 ±7.8	-2 6.8	-1.2 ±6.7	-0.4 ±7.8

Table B5: Mean (±SD) of flexion and extension relative angles (°) (rotations around the Y axis) for all eight configurations are shown. Positive values indicate flexion. (RT: Reading-typing).

	1	2	3	4	5	6	7	8
	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
C_7	-1.3 ±5.1	0.4 ±4.6	-2 ±13.9	1.3 ±17.8	5.7 ±6.4	1.9 ±16.7	5.6 ±16.9	6.6 ±19.5
T_6	-0.7 ±4.3	-0.7 ±4.9	-0.1 ±4.6	-0.5 ±4.5	1.2 ±4.0	2.2 ±3.9	1.6 ±4.1	2.2 ±3.4
T_{12}	11.4 ±9.2	9.7 ±10.2	12.5 ±8.5	11.5 ±9.4	13.4 ±9.7	13.5 ±7.5	12.8 ±9.8	17.3 ±8.2
S_2	19.4 ±10.7	18.2 ±9.1	19.5 ±10.0	17.5 ±9.3	20.5 ±10.5	18.9 ±13.3	20.1 ±11.5	21.7 ±10.1

Table B6: Mean (±SD) of lateral bend relative angles (°) (rotations around the X axis) for all eight configurations are shown. Positive values indicate right lateral bend. (RT: Reading-typing).

	1	2	3	4	5	6	7	8
	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
C_7	0.3 ±3.8	-0.7 ± 3.3	0.6 ±4.4	0.1 ±4.2	-0.7 ±4.7	0.1 ±5.4	0.5 ± 5.0	0.6 ± 4.5
T_6	0.3 ± 1.6	0.5 ±2.0	0.5 ±1.6	-0.1 ±1.7	0.5 ±1.7	0.9±1.4	0.1 ± 1.6	-0.3 ± 1.6
T_{12}	-0.1 ±2.6	-0.9 ±2.7	-0.7 ±3.1	-0.8 ±3.2	0.6 ±2.6	0.1 ±3.6	0.3 ± 2.6	-0.5 ± 2.8
S_2	-0.2 ±3.8	1.4 ±3.8	0.8 ±4.6	1.5 ±4.8	0.5 ±3.7	1.1 ±4.5	0.9 ± 3.9	1.3 ± 4.5

Table B7: Mean (±SD) of axial twist relative angles (°) (rotations around the Z axis) for all eight configurations are shown. Positive values indicate right axial twist. (RT: Reading-typing).

	1	2	3	4	5	6	7	8
	Desk Laptop Swipe	Desk Laptop RT	Desk Tablet Swipe	Desk Tablet RT	Lap Laptop Swipe	Lap Laptop RT	Lap Tablet Swipe	Lap Tablet RT
C_7	-1.6 ±3.3	-1.6 ±2.2	6.4 ±33.3	4.9 ±32.6	-0.7 ±3.7	7.1 ±35.9	6.8 ±34.5	5.5 ±32.8
T_6	1.1 ±1.8	0.9 ±1.8	-6.7 ±34.6	-6.8 ±35.1	1.3 ±1.5	-7.8 ±37.7	-6.7 ±35.7	-7.9 ±36.4
T_{12}	-0.5 ±1.7	0.2 ±2.3	-0.4 ±2.6	-0.4 ±2.4	-0.3 ±1.7	-0.7 ±2.4	-0.8 ±2.1	-0.5 ±2.4
S_2	1.6 ±2.3	0.9 ±1.8	1.6 ±1.5	1.5 ±1.7	1.5 ±1.8	1.1 ±1.6	1.6 ±1.8	2.6 ±5.7

Table B8: Summary of statistical analysis results for muscle activity for all eight configurations. No significant values were found for sex differences and side differences ($p<0.05$).

Effect	**Sex** *F*-Statistic	**Side** *F*-Statistic
RA	$F_{1,18}=1.93$, $p=0.182$	$F_{1,18}=1.36$, $p=0.259$
IO	$F_{1,18}=0.97$, $p=0.337$	$F_{1,18}=3.36$, $p=0.084$
EO	$F_{1,18}=0.93$, $p=0.347$	$F_{1,18}=0.93$, $p=0.349$
TR	$F_{1,18}=2.79$, $p=0.112$	$F_{1,18}=2.21$, $p=0.154$
LD	$F_{1,18}=2.96$, $p=0.069$	$F_{1,18}=0.03$, $p=0.869$
TES	$F_{1,18}=1.52$, $p=0.134$	$F_{1,18}=0.04$, $p=0.839$
LES	$F_{1,18}=2.72$, $p=0.116$	$F_{1,18}=0.19$, $p=0.666$

Table B9: Summary of statistical analysis for flexion/extension angles for all eight configurations. No significant values were found for sex differences ($p<0.05$).

Effect	**Sex** *F*-Statistic
Head	$F_{1,18}=1.13$, $p=0.235$
Neck	$F_{1,18}=1.96$, $p=0.259$
Upper thoracic	$F_{1,18}=0.79$, $p=0.387$
Lower thoracic	$F_{1,18}=1.79$, $p=0.197$
Lumbar	$F_{1,18}=0.01$, $p=0.922$
Trunk	$F_{1,18}=1.02$, $p=0.325$
Pelvis	$F_{1,18}=2.5$, $p=0.131$
Viewing angle	$F_{1,18}=0.52$, $p=0.482$
Discomfort	$F_{1,18}=0.48$, $p=0.499$