SMART PHONE USE AND ITS EFFECT ON GAIT, POSTURE, AND MUSCLE ACTIVITY

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Abstract

Smart phone use increases neck flexion and thoracic spine flexion, and coupled with increased cognitive demand, it limits gait performance. The main objective of this study was to quantify the effects smart phone use has on different segments of the spine, and to determine whether postural changes during smart phone use alter gait parameters.

In this study smart phone use saw an increase in both cervical and upper thoracic flexion. In addition the lumbar segment saw decreases in flexion, relative to the pelvis, while the pelvis experienced small increases posterior pelvic tilt. The postural changes during smart phone use did not have a significant effect on gait parameters. Instead, gait velocity reduced and variability increased only with dual-task (texting) conditions.

Relating smart phone use to flexed posture adopted and/or retained in university-aged populations may bring attention to the potential risks and dangers associated with the technology. Further, these findings could help to provide a foundation for successful intervention/prevention strategies.

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Glossary

BoS:	Base of support
CoM:	Centre of mass
CoP:	Centre of pressure
CV%:	Coefficient of variance
EMG:	Electromyography
ES:	Erector spinae muscle
EO:	External oblique muscle
FlexP:	Flexed posture
GlutMed:	Gluteus minimus muscle
Hold-1H:	Hold-one-hand
Hold-2H:	Hold-two-hand
IO:	Internal oblique muscle
LAT:	Latissimus dorsi muscle
LBP:	Low back pain
LES:	Lumbar erector spinae muscle
LT:	Lower thoracic spine

MVC:	Maximum voluntary contraction
PD:	Transient pain-developers
RA:	Rectus abdominis muscle
RoM:	Range of motion
TES:	Thoracic erector spinae muscle
Text-1H:	Text-one-hand
Text-2H:	Text-two-hand
TRAP:	Upper trapezius muscle
UT:	Upper thoracic spine
VAS:	Visual analog scale

1. General Thesis Introduction

Smart phone research is a relatively new focus in the area of biomechanics. Few studies have looked into the effects texting has on human locomotion, even fewer incorporating posture and/or muscle activity during its use. Smart phone use during bipedal locomotion can decrease gait performance by increasing cognitive distraction and strain on working memory. On top of this, the posture adopted during texting increases spine flexion, which can further decrease gait performance, change loading patterns of the intervertebral discs, and increase risk for pain development. The rapid explosion that smart phone use has seen over the past decade is increasing the exposure of poor posture to the user, which may have short-term and possibly long-term effects on the user's health.

In older adults (+65 years), flexed posture has been well documented to reduce mobility, negatively impact quality of life for the individuals affected, and cast a heavy burden on the healthcare system. Reduction or loss of mobility is a major factor in the loss of independence. The older adults of present literature were not exposed to the same potential risks that smart phones have on today's younger generation. Increasing our knowledge and understanding of how smart phone use alters posture, gait performance, and muscle activity in university aged populations is a crucial part of preventing exponential healthcare costs in the not too distant future.

2. <u>Literature Review</u>

The following chapter reviews the relevant literature for the current study. As such, it will be addressing the issues around flexed posture, how it pertains to gait performance and posture, and any relevant issues.

2.1 ***Flexed Posture***

Flexed posture (FlexP) is of large concern in the elderly population (65+ years old) due to its adverse effects on gait and balance. Gait and balance impairments are one of the best predictive factors for identifying fallers from non-fallers. Risk of falling increases as populations age; the associated healthcare costs, in the USA alone, are predicted to be over $54.9 billion by 2020 (Scanaill et al. 2011). FlexP, as reported in the literature, is characterized by increased head protrusion, thoracic kyphosis (hyper-kyphosis) and a rounding of the shoulders (Balzini et al. 2003; Benedetti et al. 2008; de Groot et al. 2014). Reductions in gait performance have been associated with increases in FlexP and further decrease with age. De Groot et al. (2014) reported an increase of stride time variability when comparing FlexP participants (CV%=4.27) to their control group (CV%=3.56) with a p-value of 0.03. The authors also reported reductions in both cadence and velocity, though they were not statistically significant ($p>0.26$). However, significant reductions in both cadence and velocity due to FlexP have previously been reported by Balzini et al. (2003). The authors compared three groups with increasing FlexP severity (mild to severe) to a control group. All three groups had significantly lower velocities than control ($p<0.05$), with the severely FlexP group walking significantly more slowly than the mildly FlexP group (72.7 cm/sec and 83.4 cm/sec, respectively). The authors also reported increase in base of support (BoS) width (the medial lateral distance between foot centres). The severely FlexP group had a BoS 3.2cm wider than the mildly FlexP group ($p<0.05$). Reduction in mobility caused by FlexP is a main contributing factor to deceases in quality of life. Individuals that are severely affected by FlexP can lose the ability to perform daily tasks (bathing, walking, dressing, grocery shopping, etc.) and with it their independence (Bansal et al. 2014). Pain development is another potential risk that can further reduce quality of life and daily function. Increased thoracic kyphosis, as seen in FlexP, has been associated with neck pain in older (66±4.9 years) individuals ($p<0.001$) (Quek et al. 2013). Due to the relative ease of recruitment and the high degree and prevalence of FlexP, a large majority of the related literature has been on community dwelling elderly (Bansal et al. 2014; Benedetti et al. 2008; de Groot et al. 2014; Quek et al. 2013). However, a less studied population is that of young adults (Balzini et al. 2003). Considering the rapid increase of portable technology use, and with it the increased exposure to FlexP, the direction of research needs to move towards a younger population (18-24 years old) in order to quantify the immediate and long-term effects. Postures with increased lumbar flexion can increase the anterior shear component to forces on the intervertebral discs due to the forward translation of the trunk's centre of mass (CoM), putting strain on the posterior longitudinal ligament as well as changing the loading (shear and compressive) characteristics of the lumbar segment (McGill et al. 2007). Essentially this is the same response in the other spine segments: increased flexed spine postures transfers the load from the active (muscles) to the passive tissues of the spine. The passive tissues (including the posterior portion of facet capsule and annulus fibrosis of the intervertebral disc, and vertebral ligaments) are not designed to resist this additional load and will creep (elongate) in response to the flexed exposure which results in further flexed posture. Habitual exposure to this flexed posture induced altered loading in university aged individuals may accelerate the onset of associated muscle weakness and atrophy and kyphotic upper thoracic region often seen in elderly populations. Sagittal viewing of the lumbar erector spinae muscles (ES) via MRI showed that with increased lumbar flexion, the lumbar ES lose their oblique line of action and reorient parallel to the compressive axis of the spine (McGill et al. 2007) (Figure 1.1.). If trunk flexion occurs with pelvic tilt only, the oblique line of action of the lumbar ES is able to generate posterior shear to offset the anterior shear caused by the forward movement of the CoM from trunk flexion (McGill et al. 2007). However, when flexion occurs in the lumbar segment relative to the pelvis, the lumbar ES lose their ability to generate posterior shear to counteract the anterior shear from the forward (McGill et al. 2007).

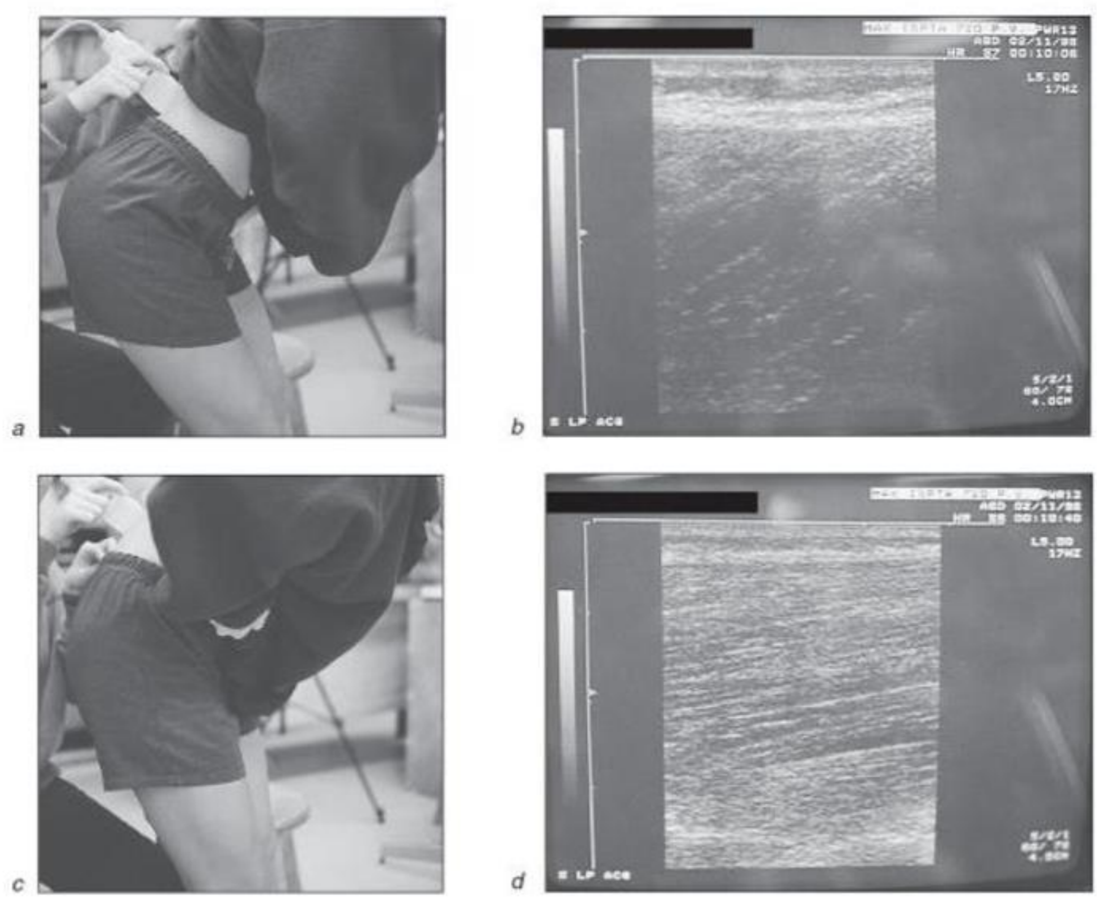


Figure 1.1. The figure illustrates that with lumbar flexion, the lumbar portions of the iliocostalis and longissimus lose their oblique line of action. The oblique line seen in image (b) allows the ES to produce posterior shear to counteract the anterior shear generated by the CoM. As seen in image (d), the oblique line is lost with lumbar flexion and with it, the ability to produce posterior shear (Reprinted with permission from McGill, S. (2007). Low Back Disorders: Evidence-based Prevention and Rehabilitation (2^{nd} ed.). Human Kinetics, Windsor, ON: p. 53, Fig 4.27).

Shear forces in the flexed lumbar spine can exceed 5 times the forces compared to a neutral, lordotic position (McGill et al. 2007). In addition to the loss of the ability to resist anterior shear (increases loading on the passive structures including ligaments and facets), the change in the lumbar ES line of action from oblique to parallel with lumbar flexion results in 100% of the contractile force contributing to compression.

An increase in compressive forces, as well as the frequency (McGill et al. 2007), is known to increase the rate of tissue degeneration, leading to an increased risk for developing flexed posture and musculoskeletal pain (Bansal et al. 2014; Nelson-Wong and Callaghan 2014). Therefore lumbar spine flexion can have negatively effects in two ways: loss of anterior shear resistance and increased compressive forces; prolonged bouts of exposure can significantly increase the risk of injury.

2.1.1 *Thoracic Spine Flexion: Effect on neighbouring structures*

Ablelin-Genevois et al. (2014) found a strong correlation between the thoracic spine and cervical spine (r=0.631) in the sagittal plane; the authors concluded that cervical spine alignment was strongly influenced by thoracic posture. It was mentioned, to a lesser extent, that the sub axial spine (C2-C7) contributes to the orientation of the thoracic spinal segment. The associated interaction between cervical and thoracic segments, however, has yet to be fully understood. An increase in cervical flexion is hypothesized to increase the kyphotic nature of the thoracic region, but this will be to a reduced degree due to the decreased range of motion (RoM) in the thoracic segment caused by the restriction of the costal attachments (Morita et al. 2014). The increased flexion of the spine is known to move the CoM of the body forward (Saha et al. 2008). This forward translation of the CoM causes an increase in anterior shear due to gravity via a flexion moment. Briggs et al. (2007) documented increases in flexion moment, compressive forces, and anterior shear forces in the high thoracic kyphosis group when compared to control of neutral posture (p=0.0054 or less). Muscle activity has also been documented to change with increased thoracic kyphosis. Thoracic ES (Briggs et al. 2007) and the upper trapezius muscle (Gustafsson et al. 2011) of the cervical region increase in activity to offset the increased flexor moment caused by the anterior translation of head and CoM. The increased activity of the ES muscles during flexion (both thoracic and lumbar) can increase compressive and shear forces (Briggs et al. 2007). The direction and magnitude of shear forces is dependent on the spine level. Briggs et al. (2007) measured, in the high kyphosis group, 2x the anterior shear in the T2-T4 range, 2x posterior shear in the T10-L1 range, and 2x the anterior shear in the L3-L5 range. The increases in shear forces on the spine are undesirable, especially if sustained for a long duration or adopted frequently; both can lead to potential pain development and/or injury.

2.1.2 *Flexed Posture & Gait*

Flexed posture can negatively impact gait performance (i.e. reduced stride length, increased temporal variability, and reduced velocity). Specifically, it has been reported that FlexP in the elderly (80±5.2 years) increases average (SD) gait phase variability from 4.1 (1.2) to 5.0 (1.4), ($p=0.02$), which equates to a 22% increase in variability (de Groot et al. 2014). Stride length in community dwelling elderly (76 (5.1) years) with FlexP has also been reported to decrease by 6% ($p=0.003$); this is also associated with a decrease in velocity by 16% ($p=0.004$) (Sinaki et al. 2005). The relationship between FlexP and gait has been a popular research area for community dwelling elderly populations due to previously mentioned reasons in *Chapter 1.1* (ease of access and prevalence of FlexP). This issue has not been as extensively researched in younger populations (18-24 years). Saha (2008) had university-aged populations induce trunk flexion from the hips, at 25^o and 50^o, in order to observe the effect on gait characteristics at three different gait velocities (slow, normal (self-selected), and fast).

The major temporal-spatial findings in the 50^{o} flexion group had increased cadence (7-11 more steps/min or 6-8% more) across all walking speeds, coupled with decreased normalized step length (2-4 less cm/cm or 6-8% less). In short, the participants were taking shorter steps more often to cover the same distance. These changes in gait characteristics are common to those of community dwelling elderly with FlexP. The decreases in gait performance found in the community dwelling elderly population are due to the fact that gait is not entirely autonomic but instead requires a certain level of awareness; gait is further reduced by increases in FlexP and age. As shown in university aged populations (18-26 years old), variability in gait is closely associated with reductions in gait velocity and not with increases of cognitive demand. This is because for this unaffected 'younger' population, gait requires little to no attention. With aging, gait becomes less automatic and requires more attention and thus increases in variability are good indicators that there is increased difficulty with walking (Beauchet et al. 2005). Smart phone use, more specifically texting, puts the user in a position of FlexP and can greatly reduce gait performance (Agostini et al. 2015). However, an issue with studying the effects of smart phone use (i.e. texting) on gait is the dual nature of such a task, in that is requires more cognitive demand or working memory (Plummer et al. 2014). With dual-task style research, such as smart phone use, there may be a compounded effect of cognitive distraction as well as increases in FlexP on gait variables. Dual-task interference on gait and task prioritization will be covered in more detail in *chapter 2.4.* To date, the study of smart phone use on posture, whether sitting or walking, has been limited to neck flexion (Agostini et al. 2015; Gustafsson et al. 2011; Schabrun et al. 2014); without any evaluation of the thoracic and lumbar spine segments. It has been shown that increased trunk flexion can reduce gait performance in university-aged populations (Saha et al. 2008). However, the spine is a multi-joint structure that has different movement patterns and RoM in different “regions” or segments. Increased flexion at lower segments levels can significantly increase the flexion of superior segments as well as reduce the RoM elicited during tasks (Nairn and Drake 2014). Thus, it is important to look at the spine partitioned into segments instead of a rigid column. Investigations of the spine when divided into cervical, upper thoracic, lower thoracic and lumbar segments have shown that both the regional motion and muscle activation sequencing can change depending on task and level of the spine (Schinkel-Ivy and Drake 2015a, 2015b).

2.2 ***Low Back Pain***

Pain development is another concern with poor posture; both duration and frequency of poor posture are factors. The intervertebral discs of the spine lack any direct form of nutrition uptake (arterial supply) and thus rely upon dynamic motions (compression and decompression) to uptake nutrients, similar to a sponge (McGill et al. 2007). Using this logic, long-term static postures reduce the ability of the intervertebral discs to uptake nutrients and thus can reduce their health. FlexP in any region of the spine will alter the natural loading patterns and can change the wear-and-tear to the point of damage or failure. Early thought on pain (or disorder) development in the low back was on acute or high load tolerance of the tissue but with increased research the school of thought is now frequency of exposure (McGill et al. 2007). In other words, low back pain (LBP) development is less likely to come from one excessive load but rather from repeated loads made worse by uneven distribution of force (poor posture).

LBP developers have been documented to have higher levels of co-activation of the back and abdominal muscles: Nelson-Wong and Callaghan (2010) did research on LBP development by exposing participants to a 2-hour standing protocol. The results were significant changes in muscle activation (increased abdominal and lumbar ES co-activation) within the pain developer group, with the majority reporting significant pain increases at the 30-minute mark. Pain developers were defined as any participant that significantly increased their pain rating (10 mm or more) on the visual analog scale (VAS). The VAS is a 100 mm linear scale that rates pain from no-pain (0 mm) to worst pain imaginable (100 mm). This tool was chosen due to strong validity and reliability reported by Summers (2001). The protocol of the VAS is to take a baseline measurement at the start of collections and again every 15 minutes until the testing is over. An increase of 10 mm from the baseline (first VAS) will put that subject in the "pain-developing" group (Nelson-Wong and Callaghan 2010). However, other studies such as Anne-Maree (1998) found that a score of 9 mm was the smallest clinically significant increase, while upwards of 20 mm is the upper limit. The VAS has been used for prolonged standing trials (as previously mentioned) as well as prolonged seating (Nairn et al. 2013). However, the authors of the prolonged seated trial used a 12 mm significance level instead of 10 mm, resulting in a significant increase in LBP occurring after the 30-minute mark that was reported by Nelson-Wong and Callaghan (2010). An issue in the literature is a lack of consensus on what is considered a significant increase on the VAS. The VAS scale has also been used to study perceived back pain in participants with significantly different levels of FlexP (Briggs et al. 2007). How they used it differed from the prolonged studies; instead of repeated measures to quantify increases in pain, the authors used the VAS scale to determine baseline pain perception and related it back to thoracic kyphosis level. They did not find any significant differences between groups, most likely because pain is a subjective measure that can vary from individual to individual; thus, the strengths of the VAS scale lay in measuring increases (possible pain developers) and not absolutes.

2.3 *Hand Held Device*

Mobile phones, initially a luxury for instant communication on the go, are now more of a necessity to everyday life, both for social and business communications. The increasing use of social media (Twitter, Facebook, Instagram, etc.) for instant communication and live updates of news around the world has rapidly increased the prevalence and use of smart phones. Finding evidence of the increased usage of smart phones is as simple as walking down any main street, from pedestrians walking with their heads down to every coffee shop and/or restaurant offering free Wi-Fi. Unfortunately, the increased use and prevalence of this mobile technology is distracting both pedestrians and motor vehiclists. There has been such an increase in motor vehicle accidents that phone use while driving is illegal in most countries. Of new concern is the increased rate of falls or accidental injuries associated with increased phone use and walking (Kao et al. 2015). In 2014, a poll done in the US of 1006 participants (>18 years old) concluded that 98% of young adults, ages 18-29 years, owned mobile phones and that 84% of the devices were smart phones ("Mobile Technology Fact Sheet", 2014). This is further supported by Forgays et al. (2014), who, when conducting their research, found that 85% of US adults (18 years or older) own smart phones with the majority in the 18 to 24 year old range. The adults in that range send, on average, 1299 text messages a month and use about 981 call minutes a month. The authors concluded that communication in younger adults is moving from phone calls towards text messages due to the fact that the latter are less disruptive, more convenient, and have more respect for the recipient's privacy. The focus of the proposed research explores the postures that are habitually adopted while using smart phones and similar technology.

2.4 ***Dual-Task (Gait)***

The simultaneous performance of two or more tasks, in this instance walking and texting, may create a conflict or competition over limited attentional resources (Lim et al., 2015; Yogev-Seligmann et al., 2010). It has been well documented that texting during driving negatively influences performance by increasing attentional, cognitive, and perceptual demands (Lim et al., 2015). However, driving is relatively more difficult than navigating an environment in bipedal locomotion. A study by Demura and Uchiyama (2009) on email use during gait saw participants' gait speed reduce 17% with the introduction of email use on their mobile devices. The authors gave no specific instruction to the subjects to pay more or less attention to either task, which could in fact change outcomes as seen in a recent 2014 study by Plummer et al. Plummer et al. (2014) had their subject's text during gait with given instruction to prioritize either gait or texting. The results were a reduction in gait speed of 8% for the gait priority task and a reduction of 28% for the texting priority task. Yogev-Seligmann et al. (2010) reported similar results of increased gait speed with gait priority and decreased speed with secondary task priority. Variability in gait, specifically stride-time, has been shown to increase with aging populations as well as dual-task conditions. In university or younger aged populations (18-26 years old) the increase in stride time in variability during dual-task conditions is mostly associated with decreases in gait velocity (Beauchet et al. 2005). The conclusions being that in young, unaffected populations, gait requires little to no attention as it is very close to being completely an automatic task. However, dual-task conditions have a greater effect on gait variability in older populations (72±6.8 years old), which were more cognitively taxed during dual-task conditions, showing higher variability in both stride time ($p=0.001$) and gait phases ($p<0.001$) when compared to younger adults (26.8±1.6 years) (Yogev-Seligmann et al. 2010). In the literature, reported outcome measures of dual-task during gait are: speed reductions of 8-24% (depending on task prioritization) (Plummer et al. 2014; Schabrun et al. 2014), 25% increased stride-to-stride variation (Agostini et al. 2015), decreased stride lengths varying from 5-15% (Agostini et al. 2015; Schabrun et al. 2014), 12% increased stride width (Demura and Uchiyama 2009), and variations or changes in gait phases (Agostini et al. 2015; Yogev-Seligmann et al. 2010). The degree to which the previously listed variables were affected is dependent on task difficulty and priority, if given, of either task. If the gait is given higher priority than the secondary task, then the reductions in performance will be less than if the secondary task is given priority (Plummer et al. 2014; Yogev-Seligmann et al. 2010).

2. <u>Introduction</u>

Owning a smart phone, personal computer, and/or a similar device (i.e. tablet) has become an essential part of both work-related and social activities, from adolescents staying current with social media or young professionals checking emails or news on the go. The issue is that, when using these devices, people have a tendency to have their heads and upper bodies bent forward. This can alter gait as well as be a risk factor for pain development. Gustafsson et al. (2011) found that adults who experienced neck pain when texting had their heads flexed over 40^o, whereas pain-free individuals were, on average, less than 30^o. Another postural characteristic of texting is "rounded" shoulders associated with forward head and possibly increased thoracic kyphosis (Raine and Twomey 1997). The smart phone has changed from a luxury to an appendage that is responsible for distracting both drivers and pedestrians (Lim et al. 2015). Questions raised are what effect is this lifestyle having on our physical health? And if flexed posture is a costly epidemic for today's geriatrics, how bad could it get considering the high usage of mobile technology today?

It is well documented that FlexP in elderly (65+ years) populations leads to decreased quality of life, increased risk of slips and falls, and can even lead to mortality (Benedetti et al. 2008; Sinaki et al. 2005). There are various definitions of FlexP with the common characteristics being increased head protrusion and thoracic hyper-kyphosis (De Groot et al. 2014). What is alarming is that the elderly populations (+65 years) in the previously-mentioned literature were not exposed to the new technologies used by today's youth (<30 years of age), nor the frequency of postures that the former tend to introduce. Mobile phones provide voice communications and messaging services. Some also provide Internet services such as web browsing, instant messaging capabilities (texting), and email. A more technologically advantageous device is the smart phone class of mobile phones; they have the standard capabilities of mobile phones with added advanced features that enable them to function more like mobile computers (i.e. higher resolution and multiple cameras, HD video recording, internet browsing, wireless connectivity, and millions of software program applications). Research has shown that younger adults (18-24 years old) have the highest level of smart phone use with over 980 call minutes and 1200 text messages sent per month (Forgays et al. 2014). The higher level of smart phone use in this population is increasing the exposure and duration of FlexP; this could have negative consequences as the population ages. The normal form of communication for younger populations (18-24 years old) is sending messages via text, email, and/or social media, both personally and professionally (Forgays et al. 2014). Gustafsson et al. (2011) have shown that the cervical posture adopted during texting activities can be highly flexed (>40^o), potentially changing the loading pattern of the spine caused by the forward translation of the head. FlexP has also been well documented to have a negative effect on temporal spatial parameters of gait such as reduced gait speed (Balzini et al. 2003; Benedetti et al. 2008; de Groot et al. 2014), decreased stride length (Rispens et al. 2015; Scanaill et al. 2011), and increased stride-time variability (Rispens et al. 2015; Scanaill et al. 2011). However, the most documented populations are older adults (65+ years) (Balzini et al. 2003; Benedetti et al. 2008; de Groot et al. 2014). There is limited research regarding the effect of flexed posture on the gait of healthy young adults (18-24 years old) (Kluger et al. 2014; Saha et al. 2008; Tsai et al. 2014).

Smart phone usage while walking can negatively affect gait parameters but can also be a highly demanding secondary task, further reducing gait performance. Responding to a text message while walking requires visual-motor coordination, bimanual movements of the arms, and a cognitive attention to the content of the message and well as possible responses to messages (Lim et al. 2015). Gait is not a fully automatic biomechanical function; it requires a varying level of cognitive involvement. A secondary task such as texting can create competition for limited attentional resources (Beauchet et al. 2005). Reduced gait speed is one of many measurable outcomes with dual-task conditions. The amount of reduction is dependent on the difficulty of the secondary task and can range from a reduction of 5.4% during backwards counting (Beauchet et al. 2005) to 24.1% during texting predetermined passages (Schabrun et al. 2014). Increased stride length variability is another common measure; however, most related literature has not found significant increases in stride length CV% (Beauchet et al. 2005; Demura and Uchiyama 2009; Schabrun et al. 2014), with some conflicting evidence reported by Kao et al. (2015), who reported an increase of over 10% CV with dual-task. Increased stride-to-stride (stride time) variability has also shown conflicting results in the literature, with reports of significant increases in CV% by 0.47% (Agostini et al. 2015) to a lack of significant findings by Beauchet et al. (2005). Lastly, increases in stance phase of gait of up to 14% have been reported during texting conditions (Agostini et al. 2015). The authors broke stance into 3 parts: heel contact, flat foot contact, and push off. Flat foot contact increased during texting by 14 % ($p<0.001$), while push off decreased by 12% ($p<0.001$) and heel contact showed no significant changes ($p=0.4$). Overall, stance phase was increased by 11%.

A costly epidemic in elderly populations (65+ years old) is that of FlexP and reduced mobility. The exponential increase of mobile technology use in the past 20 years could be a major risk factor in later development of FlexP. The rationale behind this study is to give further insight into how smart phone use is affecting the mobility and posture of young adults. Increased knowledge on this topic can help bring awareness to the potential harm caused by mobile technology and increase interest in preventative strategies against FlexP development.

2.1 ***Research Questions***

The purpose of this thesis is to measure and quantify the effects of smart phone use during texting conditions on both the posture and muscle activations during gait of healthy young adults. The focus will be on the relative angles of different segments from the head to pelvis, specifically: head, cervical spine (neck), upper-thoracic spine (UT), lower-thoracic spine (LT), lumbar spine, and pelvis. The study answered the following questions:

1. Do relative segment angles increase in flexion during holding and texting conditions relative to control conditions?
2. Will gait performance decrease with induced flexed posture and further during texting conditions?
3. Will the texting and holding trials increase erector spine muscle activity as well as upper trapezius? If so, how could this possibly affect loading characteristics?
4. Will users with higher levels of habitual smart phone (and similar device) use report more musculoskeletal pain?

*2.2 **Hypothesis***

Having the participants of this study complete four different testing conditions (normal walking, walking + holding phone with one hand, walking + holding phone with two hands, walking + texting with one hand, and walking + texting with two hands) allowed for the testing of the following hypotheses:

1. Smart phone conditions will induce more cervical and thoracic flexion than control.
2. Smart phone conditions will increase muscle activity in the cervical and thoracic regions (specifically the upper trapezius and thoracic erector spinae).
3. Texting and device holding conditions will increase variability in both spatial and temporal gait characteristics (specifically stride length, stride time, and stance phase %) when compared to control.
4. Pain developers (>9mm on VAS) will report higher levels of habitual smart phone use (hours and number of texts) compared to non-pain developers.

3. <u>Methods</u>

3.1 ***Participants***

Participants for this study consisted of 10 males and 10 females recruited from a university population (26.6 ±2.3 years and 25±1.3 years, respectively). Male participant's average (SD) weight was 82.9 kg (8.6) and 1.80 m (0.08) in height. Female participants were 58.5kg (6.8) and 1.61 m (0.04). Four out of 10 males for this study required corrected vision, and two out of these four wore contacts during testing. Only one female out of the 10 female participants required corrected vision and wore her glasses during testing. The exclusion criteria were as follows: having any prior lifetime history of pain or injury in the back, neck, or legs that required medical attention and/or resulted in more than three days off work or school; any previous back, hip, neck, or leg surgery; inability to stand for more than four hours; an inability to walk for more than 60 minutes; and not owning a smart phone. The participants were recruited in the following ways: posters set up around campus, short presentations in lectures, and word-of-mouth. Both verbal and written (informed consent) was obtained from each participant prior to collection. Any questions participants had were answered prior to collection. All protocols and consent forms were approved by York University's Office of Research Ethics Committee (Certificate # 2014-375).

3.2 ***Instrumentation and Procedures***

3.2.1 Electromyography

Muscle activity was collected using two AMT-8 EMG amplifier systems (Bortec Biomedical Ltd, Calgary, Canada). Muscle activation level was recorded for eight muscles via disposable Ag/AgCl surface electromyogram electrodes placed bilaterally, with a centre-to-centre distance of 2.5 cm (Ambu® Blue Sensor N, Ambu A/S, Denmark). Approximate placements of the electrodes on the rectus abdominis (RA), internal oblique (IO), external oblique (EO), gluteus medius (GM), lumbar erector spinae (LES), thoracic erector spinae (TES), latissimus dorsi (LAT), and upper trapezius (TRAP) muscles are detailed in Table 3.1 (references for electrode placements are included) and illustrated in Figure 3.1. The electrodes were centered over muscle bellies for the best observable signal (Gilmore and Meyers 1983). Two ground (reference) electrodes, one for each amplifier in the system, were placed on the left and right clavicle (an electrically neutral site).

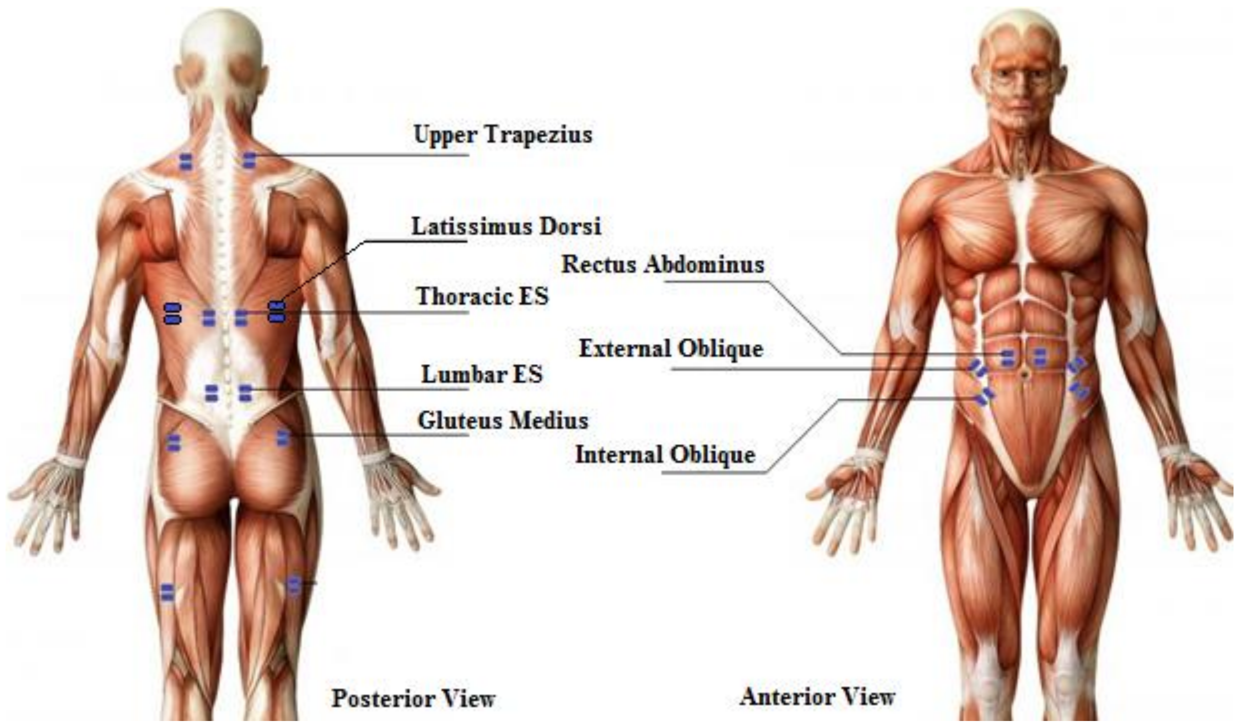


Figure 3.1. Illustration of the approximate locations of the bilateral surface EMG electrodes. All placements will be done using placement guidelines outlined in Table 3.1. (Reprinted with permission from Martini, F.; Nath, J.; Barholomew, E. (2015). Fundamentals of Anatomy & Physiology (10th ed.). Pearson Education, Inc., New York, New York.

Skin locations for electrode placement were first shaved to remove any hair; wiped with 70% isopropyl alcohol to remove dead skin (McGill 1997) and to enhance electrode adherence. The recorded electromyography (EMG) signals were differentially amplified (frequency response 10-1000 Hz, common mode rejection 115 dB at 60 Hz, input impedance 10 G-Ω; model AMT-8, Bortec, Calgary, Canada) and converted from analog to digital at a rate of 2048 Hz using First Principles software (Northern Digital Inc., Waterloo, CA).

Table 3.1. Summary of approximate bilateral surface EMG electrode placements to be placed over bulk of muscle belly.

Muscle	**Placement**
Upper trapezius	50% on the midline between C7 and the acromion process (SENIAM guidelines)
Thoracic erector spinae	Approximately 2.5cm lateral to T9 spinous process (Drake et al. 2006)
Lumbar erector spinae	Approximately 3cm lateral to L3 spinous process (Drake et al. 2006)
Gluteus medius	Midway between the greater trochanter and the sacrum (Nelson-Wong et al. 2008)
Latissimus dorsi	Lateral to T9, running perpendicular to muscle orientation (Drake et al. 2006)
Rectus abdominis	Approximately 3cm lateral to the midline of the abdomen, 2cm above the umbilicus (Drake et al. 2006)
External oblique	Approximately 15cm lateral to the umbilicus at 45^{o} angle (Drake et al. 2006)
Internal oblique	Below the external oblique electors, perpendicular orientation to external oblique electrodes (Callaghan et al. 1998)

3.2.1.1 EMG Calibration

The calibration for EMG signals required a 5 minute rest trial at the start of collection where the participant laid in supine position on a therapy table without interruption. This was done so the baseline bias of muscle activity for each muscle could be recorded and removed from each respected channel. Following the rest trial, the participant was put through several isometric maximum voluntary contractions (MVC) trials for the later purpose of normalization. Each muscle collected had two separate MVC trials with at least 1 minute rest, or until the participant signaled that they were ready to continue, to maximize recovery from any muscle fatigue they may have had from the previous trial. The protocol to obtain the MVC of each muscle is described in Table 3.2, and generally consisted of one or more of the investigators resisting the participant's maximal effort without moving the joint(s) the muscle of interest crossed. Before MVC collection, the protocol was explained to the participants and a practice run of all the maneuvers was done at submaximal to minimal effort. During MVC collection, one or more investigators gave strong verbal encouragement in order to get participants to exert maximal effort.

Table 3.2. The required MVC tasks to elicit maximal activation are listed for each muscle of interest, along with the appropriate reference for each task. Isometric activation of each muscle was achieved through manual resistance applied by one or more investigators.

Bilateral Muscles	**MVC**	**Reference**
Thoracic erector spinae & lumbar erector spinae	Lying prone, with only lower body on a table, cantilevered back extension	McGill, 1992
Rectus abdominis	Sitting on the bench, sit up	McGill, 1992
External oblique	Sitting on the bench, trunk twist left/right	McGill, 1992
Internal oblique	Sitting on the bench, trunk side bend left/right	McGill, 1992
Gluteus medius	Hip abduction in the side lying position, left/right	Nelson-Wong et al., 2008
Latissimus dorsi	Shoulder abducted 90^o, elbow flexed 90^o, resisted adduction of upper arms in the frontal plane	Arlotta et al., 2011
Upper trapezius	Shoulder abducted 90^o, elbow flexed 90^o, resisted abduction of upper arms in the frontal plane	Zipp, 1982

3.2.2 Motion Capture

Kinematics for each participant was recorded at 32 Hz using four 3D Investigator™ position sensors (Northern Digital Inc., Waterloo, CA) and First Principles software (Northern Digital Inc., Waterloo, CA). This optoelectronic motion capture system uses active marker technology: each marker emits infra-red light which is detected by one or more of the position sensors to provide 3D spatial location and orientation. Markers were fixed to either NDI Smart Marker Rigid Bodies (Northern Digital Inc., Waterloo, CA) or to custom made mounts used to define and track the four spine segments (defined later in this chapter). In total, each participant was equipped with 43 active markers (nine rigid bodies consisting of three markers, four rigid bodies consisting of four markers) for the purpose of tracking their full body motion in three-dimensional (3D) space. Rigid bodies of three makers were fixed to the limbs and head while the custom rigid bodies of four markers were attached to the trunk to define and track spine segments. Limb rigid bodies were attached via Velcro straps while the rigid bodies tracking spinal segments were attached via double sided tape on the base and physio-tape around the borders as illustrated in Figure 3.2. After application of electrodes and smart markers, participants were asked to move around as investigators checked each rigid body to make sure there was no movement between skin and rigid body. Joint centres and bony landmarks were digitized in reference to the rigid body tracking that segment. All kinematic data were processed using Visual3D™ (C-Motion Inc., Germantown MD). The version of the Visual3D™ software's V3D full body model was modified in order to better track different levels of spine motion in more detail. The spine segments were created by putting custom rigid bodies on the superior and inferior end of the segment of interest. The segments were as follows: neck from C7 – base of skull, UT from T6 – C7, LT from T12 – T6, lumbar from both posterior superior iliac spine (PSIS) – T12, and pelvis using both PSIS and anterior superior iliac spines (ASIS). Limb segment models were defined by two proximal points (lateral and /medial or joint centre) and two distal points (lateral and medial or joint centre).

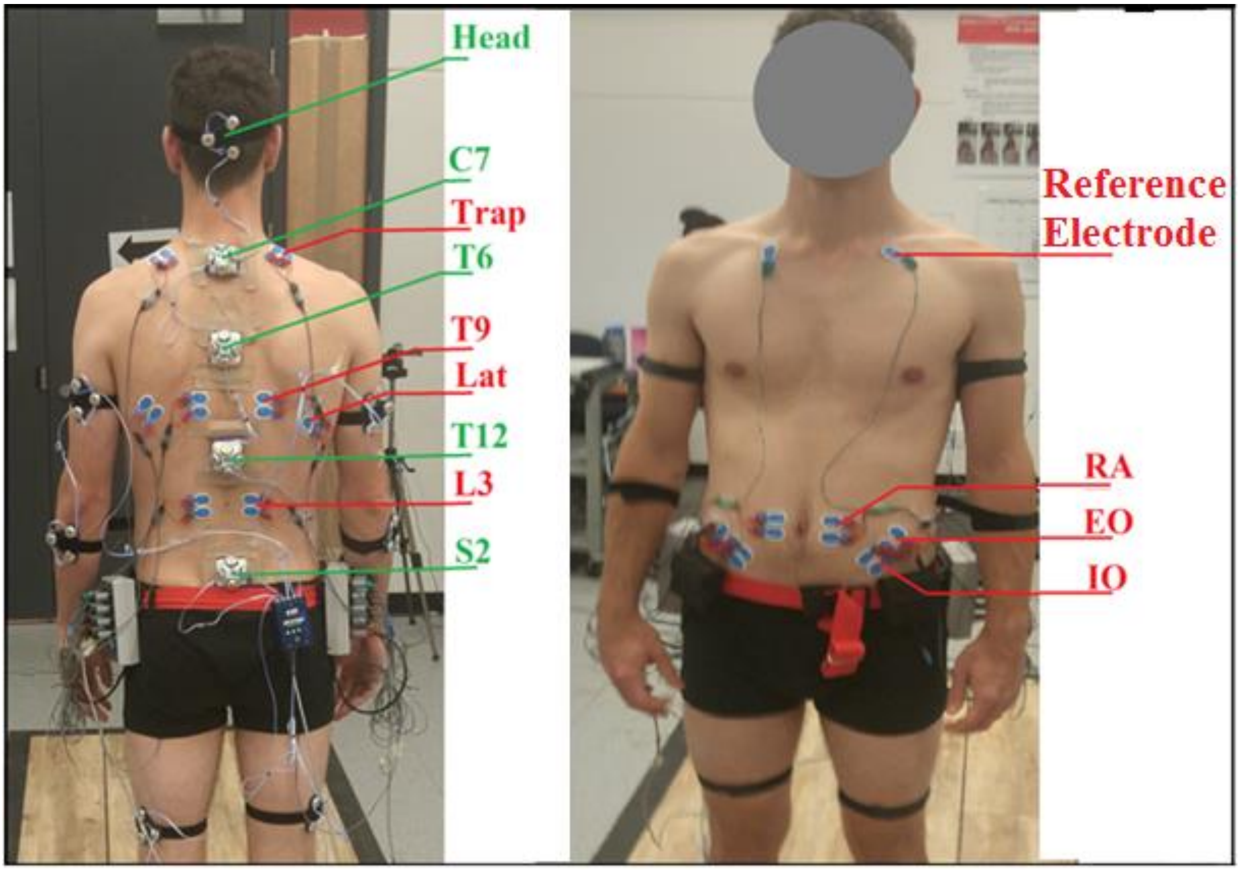


Figure 3.2. Experimental setup with active markers and electrode placements. Limb and head rigid bodies consisted of three markers in a triangle shaped rigid body while trunk/pelvis markers consisted of four makers in a custom rigid body.

The pelvis was constructed based on the Coda model in the Visual3D™ software. The z-axis for all segments ran from distal to the proximal end of the segment, with the x-axis perpendicular to it, pointing anteriorly. Referring to Figure 3.2., the z-axis runs inferiorly down the spine, with the x-axis running back to front, and the y-axis running left to right. The global axis consisted of: X-axis as anterior-posterior, Y-axis as medial-lateral, and Z-axis as vertical. Global and local axes are further detailed in Section *3.4. Data Processing*.

Lastly, arm angles were investigated due to sex differences found in neck angles in order to quantify and explain why sex differences were found. Angles for the upper arm were defined as zero if they were perfectly parallel to the trunk segment (pelvis to C7) while elbow angles were defined as zero if the forearm and upper arm were perfectly parallel (Figure 3.3.). Any positive deviations in either angle equate to increases in either shoulder flexion or elbow flexion.

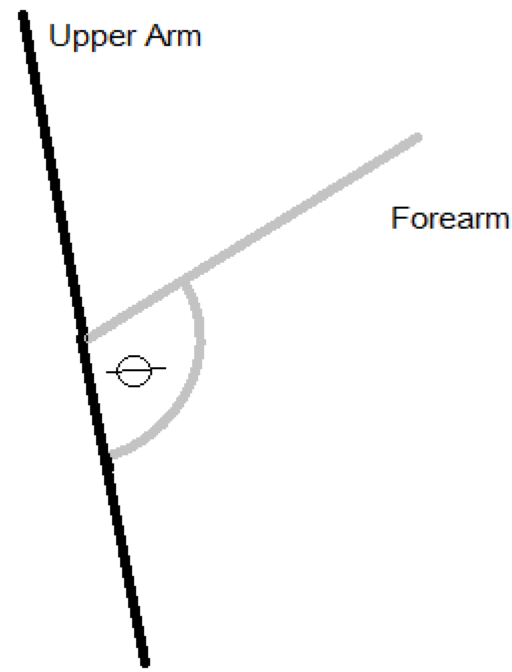


Figure 3.3. Sagittal arm flexion was measured as the relative angle between the upper arm and the forearm. With the arm fully extended (black line) the angle would be 0^{o} and any increases from that would be increases in flexion (grey line).

3.2.2.1 Motion Capture Calibration

A standing T-pose of 3 s was first collected in order to make a 3D model in Visual3D software (Visual3D, C-motion Inc., Germantown, USA). Afterwards a standing reference posture was taken which consisted of a 30 s standing trial before the collection of the random ordered condition blocks. The participant was instructed to stand as if a string was pulling their head towards the ceiling. This standing posture was considered to be neutral position for spine segments and all deviations from this would be either negative (flexion, non-dominant side lateral flexion, or rotation towards non-dominant side) or positive (extension, dominant side lateral flexion, or dominant side rotation). Any flexion-extension during the conditions was measured and occurred in the sagittal plane, lateral bending occurred in the frontal plane, and transverse movement occurred in the horizontal plane (Schinkel-Ivy et al. 2015a, 2015b). The head and arm positions described by Schinkel-Ivy et al. (2014) were used to obtain the participants' maximal voluntary ROM values. Specifically, the head moved with the trunk motion (i.e. flexed forward during flexing trial and lateral during lateral bend trial) with the arms hanging free and reaching towards the direction of motion (i.e. reaching towards ground during max flexion trial). Lastly, for twisting motions the arms were crossed over the chest (Schinkel-Ivy et al. 2014). Standing postures were also taken in-between trial blocks (roughly every four minutes) to permit quantification if any changes occurred in-between and after condition blocks, as well as over the duration of the one hour collection.

3.2.3 Gait Measures

Spatiotemporal parameters of gait were recorded on a 4.9 m by 0.60 m pressure sensor Protokinetics® Zeno Walkway System (Protokinetics, Florida, USA) containing 16-level 1.0 cm square pressure sensing pads able to accurately collect gait data in real time. Participants wore running/athletic shoes and were instructed to start 1 metre before the walkway and finish 1 metre afterwards. Participants were allowed to practice first to get used to the environment and attached equipment. The Zeno Walkway recorded all data in real time but for the purposes of this study only the following were collected: stride length (cm), stride time (sec), stride width (cm), stance as percent of gait phase, swing as percent of gait phase, gait velocity (cm/sec.), and cadence (steps/min.). The stance phase was further analyzed in terms of double support and single support percentage of gait cycle. Illustrations of gait measurements (step length, stride length, and stride width) are shown in figure 3.4. All spatial parameters and velocities were normalized to the participant's height for comparison purposes.

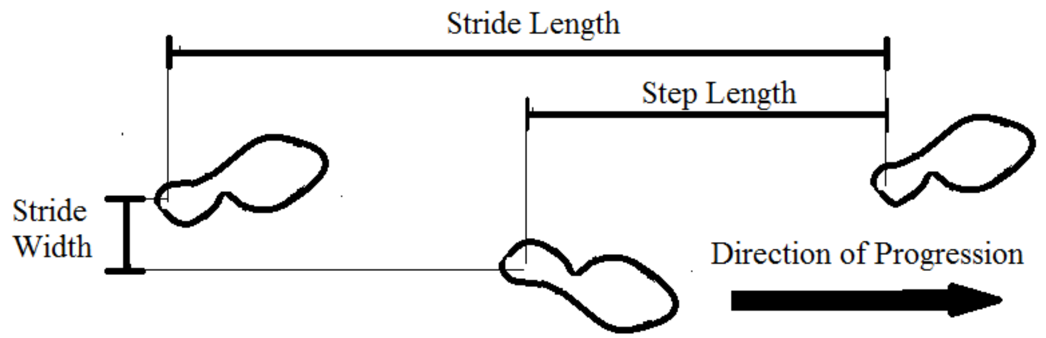


Figure 3.4. Spatial gait parameters are illustrated above. The distances measured are from the heel centre of each foot.

3.2.3.1 Gait Calibration

Protokinetics™ Zeno Walkway System (Protokinetics, Florida, USA) performs real time calculations of the temporal-spatial parameters. To account for both acceleration and deceleration the participant was instructed to start one metre back from, and end one metre away from the pressure mat. In some circumstances where this was not met, the first and/or last footwall was removed from the trial during processing. Participants were given a few practice walks before the recording of the block trials to get them accustomed to the lab environment, the equipment on them, and to make sure they were comfortable.

3.2.4 Discomfort Measures

Participants' back and neck discomfort during the collection were monitored using the VAS at the start, roughly every four minutes (end of each trial block), and at the end of the collection. Participants were provided with a paper version of the VAS, where they marked their current pain level along the scale. An increase of over 9 mm during collection was chosen to classify pain-developers due to it being the minimum clinically significant difference (Anne-Maree 1998).

*3.3 **Data Collection Protocol***

3.3.1 Pre-Collection

Instrumentation and calibration previously outlined in sections 3.2.1.1, 3.2.2.1, and 3.2.3.1 were done prior to all collections. Consent forms were also filled out prior to collection.

3.3.2 Condition blocks

There were five different trial conditions for this study that were completed in blocks, with each block being presented in random order. The conditions were as follows: control, holding one hand (Hold-1H), holding two hands (Hold-2H), texting one hand (Text-1H), and texting two hands (Text-2H). Each of the five condition blocks had 10 walks, for a total of 50 walks for the collection.

For the control condition, the participants were instructed to walk along the pressure walkway at their preferred, self-selected pace with their focus on the door at the end of the walkway. In the holding conditions (Hold-1H and Hold-2H) the participants were instructed to focus on their phone and hold it as if they were to text or read a message. The screen was turned off to avoid participants reading messages or shuffling through their apps. For the Hold-1H trials the participants were instructed to hold their phone with their dominant hand.   The instructions that were given to the participants were to walk towards the door (at the end of the walkway) and focus on the smart phone screen. They were allowed to look up to avoid walking off the Zeno Walkway (navigate their environment) as they normally would when walking and using their phone. Texting conditions (Text-1H and Text-2H) had the participants responded on their smart phone in a notepad application to verbally asked questions. An investigator read the participants a question prior to gait initiation; the orders of the questions were randomly selected prior to each collection (Table 3.3.). The participants were instructed to start walking after they started to respond to the question on their phone via text. This was done to ensure that the participant was texting throughout the walking trial, with question design prompting longer answers so that they could not be finished in the time span required to walk to the end of the Zeno Walkway. Prior to collecting, participants were informed that not completing answer fully was part of the experiment designed and that they should not slow down or stop to finish answers. Participants were instructed to use and hold their smart phone with their dominate hand during the Hold-1H and the Text-1H trials. At the end of each block, control, Hold-1H, Hold-2H, Text-1H, and Text-2H, participants stood for 30 s and were given a VAS for them to indicate any back and/or neck discomfort that they may be experiencing at that time.

Table 3.3. The list of questions asked during texting conditions. The questions were randomly order prior to each collection and read out by an investigator. (Modified with permission from Demura and Uchiyama (2009). Influence of cell phone email use on characteristics of gait. Journal of Sport Science Vo1.9:5: p.304, Table 1. www.tandfonline.com).

Write all the colours of the rainbow
What is your favourite colour and why?
List as many animals as you can.
What is your favourite quote?
Describe what you do for work or discuss a previous job or educational experience.
Write numbers one to 10 in words (i.e. one two three etc.).
List your three favourite sports.
List your top five favourite songs.
List five of your friend's first names.
List five of your favourite movies.
List five of your favourite Actors/Actresses names.
What did you eat for breakfast/lunch?
What are the first three things you do in the morning?
In a sentence use the words dog and ball.
In a sentence use the words red and house.
In a sentence use the words sun and warm.
In a sentence use the words blue and car.
In a sentence use the words fast and turtle.
In a sentence use the words fun and party.
In a sentence use the words slow and boat.

3.4 ***Data Processing Procedures***

3.4.1 Kinematic Model Construction

Three-Dimensional kinematic processing took place using a custom model created in Visual3D (Visual3D, C-motion Inc., Germantown, USA). For the purpose of this study the spine was partitioned into four segments. The following segments listed superior to inferior were tracked: neck from base of skull to C7, upper thoracic (UT) from C7 to T6, lower thoracic (LT) from T6 to T12, and lumbar from T12 to S2. The rigid body locations (C7, T6, T12, and S2) were chosen based on the trunk kinematic findings of Schinkel-Ivy and Drake (2015a, 2015b). These authors concluded that to accurately track the different segments of the spine (cervical, thoracic, and lumbar) could be completed using only four tracking bodies at C7, T6, T12, and L5 (Schinkel-Ivy and Drake 2015a, 2015b). For the purpose of this thesis collection the location of the L5 tracking body, S2, was changed from L5 (Schinkel-Ivy and Drake 2015a, 2015b) to be used to better track the pelvis. Imaginary markers were digitized on the right and left sides of each of the four rigid bodies that were used to track the spine segments as well as the left and right side of the head tracking rigid body (illustrated in Figure 3.5. as red dots). The right side imaginary markers were arbitrarily defined as lateral while the left sides were medial. To complete the construction of the segment coordinate system for each of the spine rigid bodies, the superior side for the constructed spine segments were defined as distal ends, while the inferior side were defined as the proximal ends (the pelvis was considered as the model origin). The z-axis of the segment system runs through the segment from proximal to distal (-z being towards the lab ground when in anatomical position, represented by the red arrow in Figure 3.5.), the y-axis was then created in the program by drawing a vector from the medial to lateral side of the distal portion of the segment (represented by a blue arrow in Figure 3.5.), and the cross product of that vector and the z-axis gives the y-axis (V3D Help: Constructing the Segment Coordinate System). A vector perpendicular to both z-axis and y-axis gave the x-axis. Each spine segment was tracked with the rigid body on the distal end and proximal ends while limbs were tracked with rigid bodies in the centre of the segment.

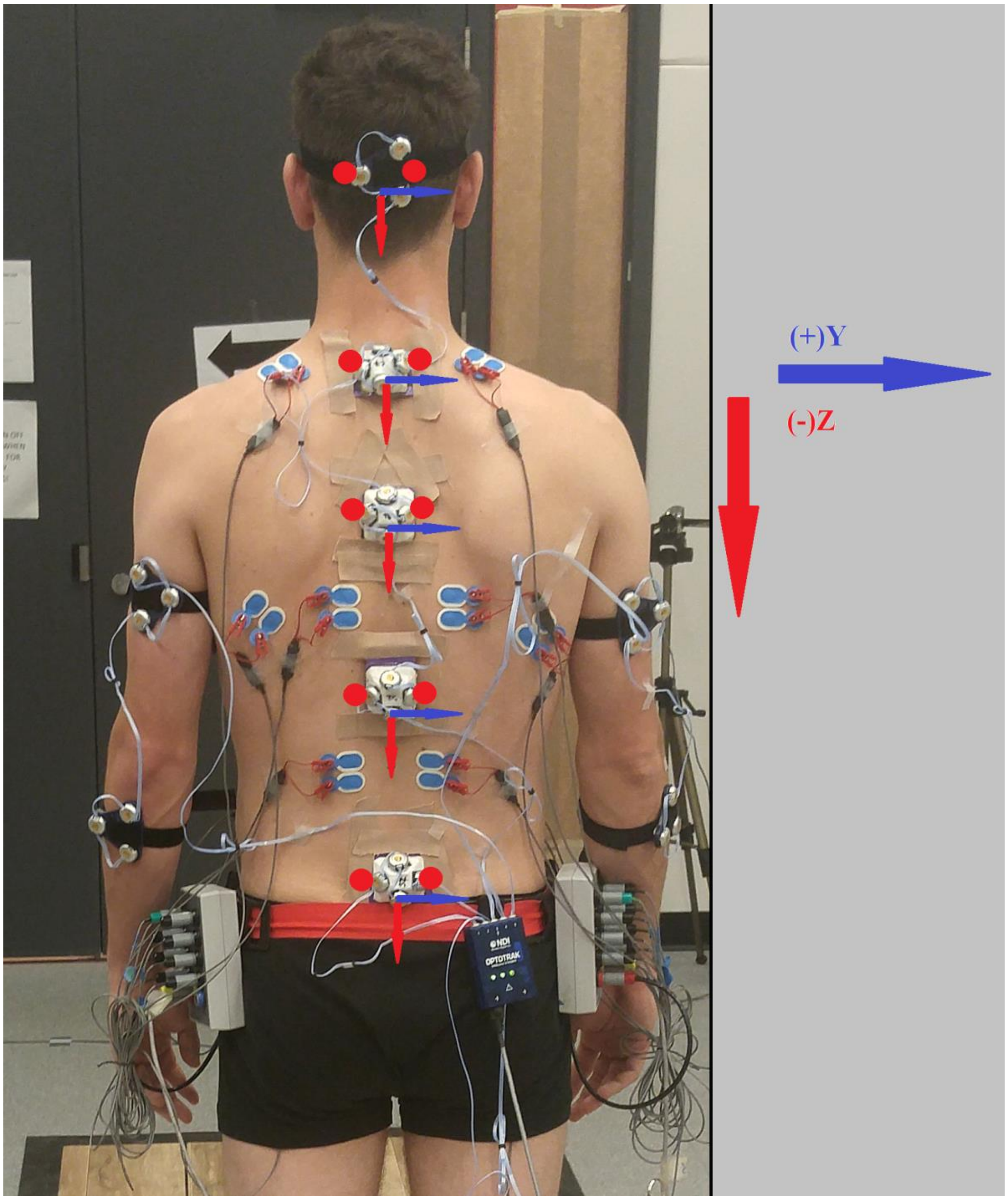


Figure 3.5. Illustrating the orientation of the axes as well as the location of the digitized markers that were used to create the spine segments. The red arrow in this image represents the z-axis of the spine segments, it travels down the segment towards the pelvis while the y-axis (blue arrow) is perpendicular to it travelling from medial (left) to lateral (right). The red dots in the image show the approximate locations of the digitized markers used to create the spine segments in Visual3D.

3.4.2 Kinematic Data Processing

Raw kinematic signals were first low-passed filtered using a dual pass 4th order Butterworth filter with a frequency cut-off of 6 Hz (Winter, 2005). This cut-off frequency was selected based on the findings of Winter (2005) who reported that 99.7% of the signal power was contained in the lower seven harmonics (6Hz and below) for human gait. Both relative and absolute joint angles for the spine segments were calculated with respect to the proximal segment and to the lab coordinate system, respectively. The relative angles were as follows: neck with respect to UT, UT with respect to LT, LT with respect to lumbar, and lumbar with respect to pelvis. The relative and absolute angles were normalized to their respective data from the standing neutral posture trial. A positive value in the sagittal plane would indicate an increase in segment extension, while a negative value indicating an increase in flexion from neutral posture. While positive value in the frontal plane indicates lateral bending to the right, and positive value in the horizontal plane indicates rotation to the right. All negative values were corrected (*-1) for interpretation purposes in the results.

3.4.3 EMG Data Processing

EMG processing was completed using Visual3D program. All EMG data (rest, MVC, and trials) were inspected for heart rate contamination and high-pass filtered (HPF) at 30 Hz to remove when needed (Drake and Callaghan 2006). After which, the signals were full-wave rectified by taking the absolute value of the signal. The signals were then low-pass filtered (LPF) at 6Hz (dual-pass 4^{th} order Butterworth) (Bertrand-Arsebault et al. 1986). The result was the linear envelope of the EMG signals (Winter 2005). A 30 s window was selected based on visual confirmation of no contamination present (no visible spikes) and the average EMG values from the window were removed from each of their respected channels. The average was removed from all MVC and walking trials. Peak values from the MVCs of each muscle were used to normalize all muscle activity during walking blocks and express muscle activity as a percentage of MVC (%MVC).

3.4.4 Gait

The gait data were processed in real time in the PKMAS built-in software (Zeno Walkway system, Protokinetics, Florida, USA). If needed the first and last step of a trial was removed to minimize the risk of capturing any acceleration in gait. Stride length and stride width were normalized to the participant's height for comparison purposes (Bohannon 1997; Saha et al. 2008). Gait phases were also normalized to percent gait phase. Furthermore, coefficient of variation (CV) was calculated in PKMAS built-in software for each variable measured (Equation 1).

Equation 1: CV% = (SD/Mean) * 100%
(Zeno Walkway system, Protokinetics, Florida, USA)

*3.5 **Data Analysis***

Statistical analyses were done using the program SPSS v23 (Chicago, IL, USA) at an alpha 0.05. A series of repeated measure ANOVAs were completed to compare differences between conditions for average EMG, relative and absolute segment angles, and spatiotemporal data previously mentioned *Instrumentation and Procedures*. EMG data had three independent variables (condition, sex, and side) while gait and posture only had two (condition and sex). If significance was found, then data were analysed pairwise using a Bonferroni correction to adjust for Type I error. If a sex difference was not found, nor did sex have an effect on condition outcome, the results were collapsed and analyses were rerun with a sample size of 20. EMG was analyzed for sex and side differences, and where there were no differences the data were collapsed and rerun with a sample size of 20.

4. **Results**

4.1 Kinematics

The results of the kinematic data included flexion/extension in the sagittal plane, rotation about the z-axis, lateral bending, and RoM (maximum value – minimum value) for all respected planes. The order of kinematic findings will be presented in a top-down manor, starting at the neck segment and moving towards the pelvis. The primary interest of this study is the level of sagittal flexion; therefore sagittal plane will be the majority of focus and will be presented first. Lastly, the responses of the participants that wore glasses (n=3) during the study were near the means of rest of the participants (data were not the largest/smallest values), which was taken to indicate that the use of glasses in this population did not introduce new responses.

4.1.1 Sagittal Plane

The degrees of flexion from standing, neutral position will be presented both as relative and global angles. The 5 conditions (control, Hold-1H, Hold-2H,Text-1H, Text-2H) had significant difference in the level of relative neck flexion ($F(4, 72) = 71.06$, $p<0.001$) which was expected. However, there was an unexpected sex difference ($F(1, 18) = 71.06$, $p<0.001$). Females were 9.2^o (2.3) to 12.6^o (1.8) more extended during smart phone conditions (holding and texting) conditions ($p=0.001$ or less) than males (Table 4.1.). Females also had 3.9^o (1.0) more flexion during Text-2H when compared to Text-1H which was not seen with the male participants. During control conditions both males and females had their neck more extended than their neutral standing positions, 6.6^o (1.4) and 3.4^o (1.4), respectively. Flexion increased significantly for both sexes during holding and texting conditions with the most flexed state for both sexes occurring during the Text-2H condition; females 8.4^o (1.7) flexion and males 18.8^o (1.7) flexion as shown in Figure 4.1 and illustrated in Figure 4.2. Further investigation into neck

RoM and arm position (how they held phone) was done to shed light on potential reasons why the sex difference occurred and will be presented later in this section.

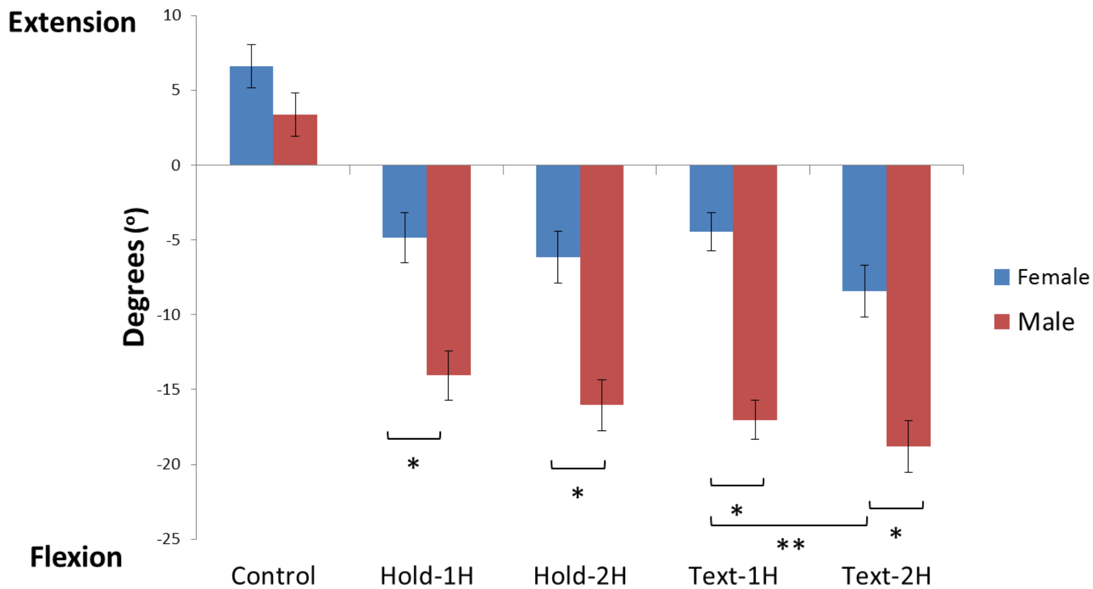


Figure 4.1. This figure illustrates average levels of relative neck angles in the sagittal plane during each condition separated by sex. Smart phone conditions induced higher levels of neck flexion with no significant difference between holding and texting conditions (p=0.216 or greater) with the only exception being females whom showed more flexion during Text-2H condition when compared to Text-1H (**) (p=0.010). Females were also less flexed in all smart phone conditions when compared to males (*) (F (1, 18) =3.94, p=0.006).

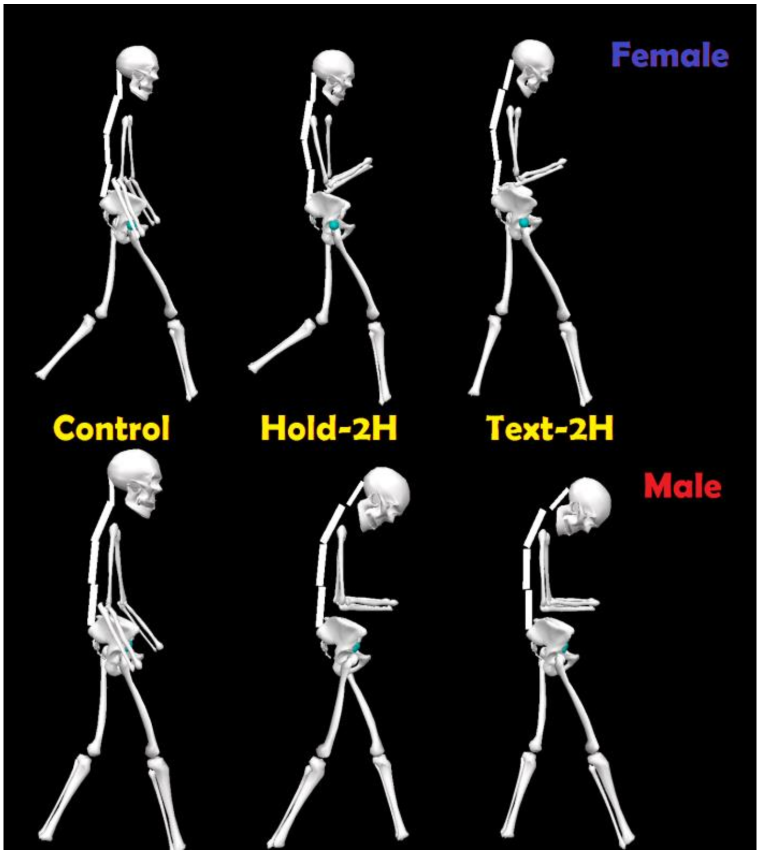


Figure 4.2. Female participants (top) had increases in neck and UT flexion during both the Hold-2H and Text-2H condition relative to control. This is also true for the male participants. What this image contrasts is the visible difference between males and females. Males have a higher level of neck flexion as well are holding their phone at a 90° angle to their body while females flex less and hold their phone closer to their face.

Global and relative neck angle changes between conditions were highly correlated (Pearson coefficient of 0.995). This indicates that changes in the relative neck angle can be attributed mostly to the global movement of the neck segment. If there lacked a strong correlation between global and relative angles that would imply that majority of motion was between segments (increased relative neck flexion was caused by both global neck flexion but also global UT extension). Global neck angle differences between conditions in the sagittal plane, on average were only 0.24^{o} larger than relative neck angle differences (Table 4.1.).

Table 4.1. Average (SEM) values for both relative and global neck angles. Due to sex difference (*) ($p<0.001$) the data are presented separately for males (n=10) and females (n=10). There was a high correlation ($r=0.995$) between global and relative angles indicating that majority of the increased flexion is caused by the global motion of the segment and not the relative movement between segments (neck and UT).

	Relative Neck Angle (^{o})			
Condition	Female	Male	Mean Difference (^{o})	p-value
Control	6.6 (1.4) extension	3.4 (1.4) extension	3.2 (2.0)	0.130
Hold-1H	4.9 (1.7) flexion	14.1 (1.7) flexion	9.2 (2.3)	0.001*
Hold-2H	6.2 (1.7) flexion	16.0 (1.7) flexion	9.9 (2.4)	0.001*
Text-1H	4.5 (1.3) flexion	17.0 (1.3) flexion	12.6 (1.8)	<0.001*
Text-2H	8.4 (1.7) flexion	18.8 (1.7) flexion	10.4 (2.5)	0.001*
	Global Neck Angle (^{o})			
Condition	Female	Male	Mean Difference (^{o})	p-value
Control	1.4 (1.4) extension	2.3 (1.4) flexion	3.7 (2.0)	0.079
Hold-1H	10.3 (2.0) flexion	20.5 (2.0) flexion	10.1 (2.8)	0.002*
Hold-2H	9.5 (2.2) flexion	22.5 (2.2) flexion	13.1 (3.1)	0.001*
Text-1H	10.3 (1.9) flexion	24.0 (1.9) flexion	13.7 (2.7)	<0.001*
Text-2H	13.8 (2.3) flexion	24.6 (2.3) flexion	11.8 (3.3)	0.002*

There was a difference between conditions for both relative ($F(4, 72) = 54.26$, $p<0.001$) and global neck RoM ($F(4, 72) = 9.06$, $p<0.001$). There was no sex difference or interaction in neck RoM (all p-values 0.061 or greater). Neck RoM decreased first with the introduction of the smart phone (holding conditions) and further when participants responded to questions (texting conditions). Relative neck RoM was its highest (7.0^o (0.5)) during the control condition and lowest during Text-2H (2.8^o (0.2)). As illustrated in Figure 4.3., texting conditions were significantly lower than holding and control by at least 1.1^o (0.3) and both holding conditions were significantly lower than control by 2.7^o (0.6) ($p=0.012$ or less). Global RoM was larger than relative RoM for each condition and did not decrease as much as relative RoM, only having a significant difference when comparing texting conditions to control ($p=0.014$ or less) (Figure 4.3.). It is worth noting that the holding conditions had a p-value of 0.077 or more when compared to the control and may have been significant the conservative correction had not been used. The larger RoM in the global neck segment may be due to the fact that the relative angle reference segment is dynamic and moving with it (i.e. the movement of the neck segment hinges on the dynamic underlying UT segment instead of a static lab) while the global reference is static (the neck segment is relative to the lab environment). RoM decreased during holding conditions when participants were looking at the phone during walking and further when participants had to focus on the screen to type reply.

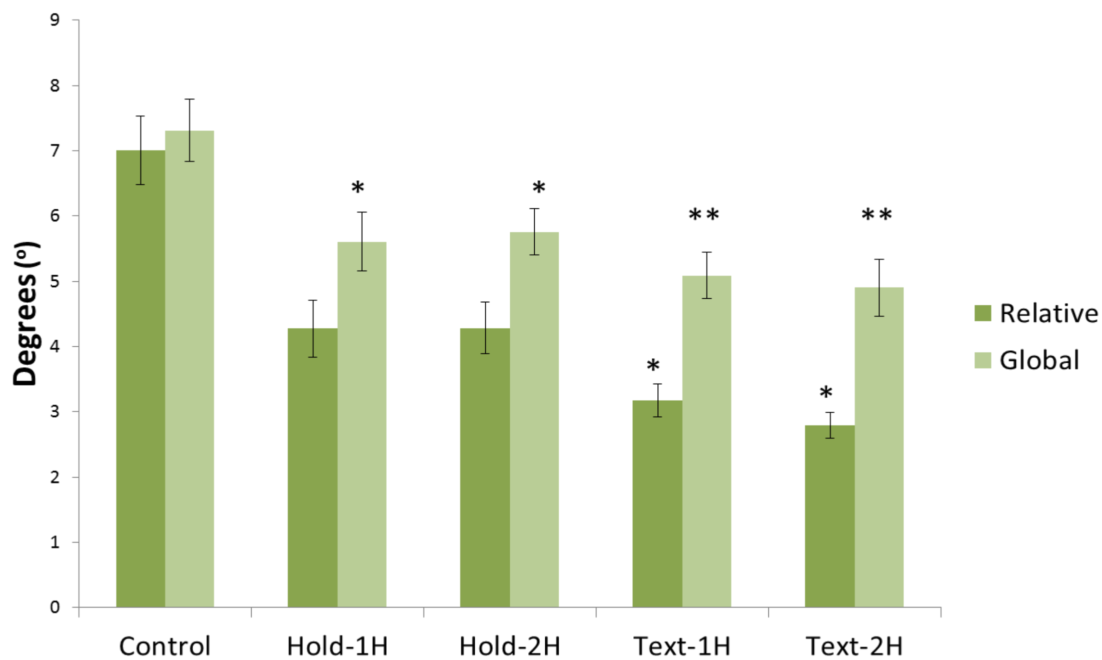


Figure 4.3. Relative and Global neck RoM in the sagittal plane. Relative neck RoM during both texting conditions was significantly lower by at least 3.8^o (0.5) when compared to control condition and at least 1.1^o (0.3) when compared to holding conditions (**) (p=0.012 or less). However, global RoM was only 2.2^o (0.5) significantly lower during texting conditions when compared to control (*) (p=0.014 or less), with no significant differences between texting and holding. RoM decreased by holding and further when texting.

Relative UT segment values had a significant difference between conditions (F (1, 18) =34.17, p<0.001). All smart phone conditions (holding and texting) were significantly more flexed than control which was almost neutral; 0.1^o (0.5) of flexion (p<0.001 for all comparisons).

The trends were texting conditions having the most segmental flexion (3.0^o (0.6) to 3.3^o (0.6) of flexion), as seen in Figure 4.4. However, Text-1H was only significantly different than Hold-1H and control (p=0.014 and <0.001, respectively). Text-2H was more flexed than all conditions but only significant when compared to control, Hold-1H, and Hold-2H (p=0.019 or less). Globally, there was less flexion in the UT segment than relative, as well as no condition difference or sex interaction in the UT segment (p= 0.099 or greater). Illustrated in Figure 4.4. is the comparison of global and relative UT segmental flexion. As seen in this figure there is no global difference between conditions but, however, there is a difference between the smart phone conditions and control when looking at relative angles. The implication of this is that there is an increase in flexion between the UT and the inferior segment (LT) when using the smart phone. The increases in relative flexion may be due to the relationship with the inferior segment, LT. Relative UT RoM was significantly different between conditions (F (1, 18) =3.51, p=0.011) with no sex interaction (p= 0.75 or greater). However, the post hoc did not show any significant differences between means (p=0.114 or greater). In contrast, global RoM for the UT is more than twice that of relative RoM and was significantly different between conditions (F (1, 18) =4.89, p=0.002) with the post hoc revealing that Hold-1H, Text-1H, and Text-2H had significantly less RoM than control (p=0.037 or less) as illustrated in Figure 4.5. As seen, RoM decreases during smart phone tasks but only significantly for the global means mentioned before (Hold-1H, Text-1H, and Text-2H).

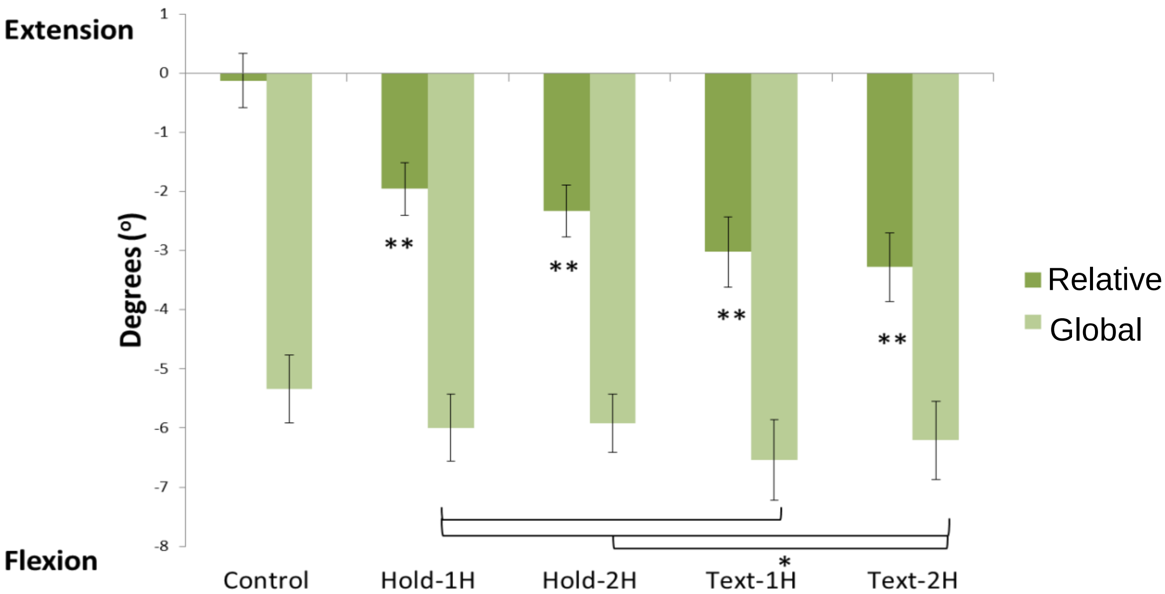


Figure 4.4. Global and relative UT angles in the sagittal plane. No significance was found globally between conditions (F (1, 18) =20.29, p=0.099). However, all smart phone conditions were significantly more flexed than control (**) (p<0.001 for all comparisons). Smart phone conditions (holding and texting) tended to increase flexion of the UT segment, with texting conditions having higher levels of flexion. Significantly, both texting conditions were more flexed than Hold-1H (*) (p=0.014 or less) while only Text-1H was more flexed than Hold-2H (*) (p=0.019).

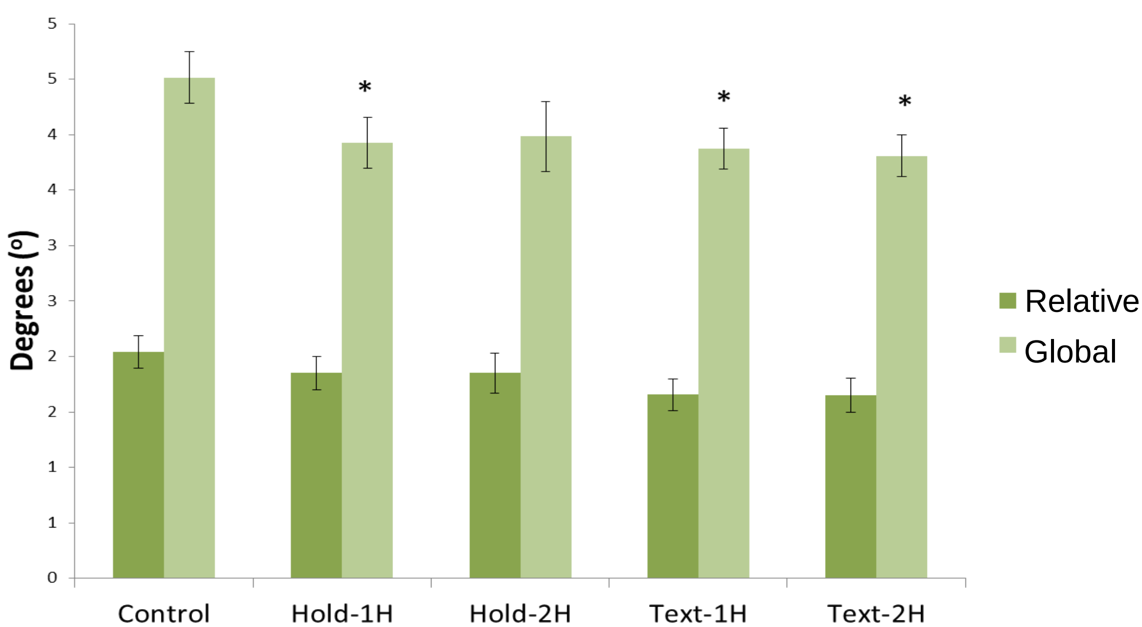


Figure 4.5. Global and relative UT RoM. No significant changes in relative RoM (p=0.114 or greater); however, global RoM tended to decrease with smart phone conditions, with Hold-1H, Text-1H, and Text-2H having significantly less RoM than control (*) (p=0.037 or less).

Relative LT flexion differed significantly between conditions (F (1, 18) =4.43, p=0.003) with no sex interaction (p= 0.439 or greater) but post hoc analysis lacked significance (p=0.089 or greater). Globally, LT was significantly different between conditions (F (1, 18) =3.25, p=0.016) with the post hoc also showing no significance (p=0.248 or greater). Concerning relative angles, the LT segment tending to increase flexion from control (0.2^{o} (0.8) flexion) to Text-2H (2.4^{o} (0.8) flexion), though not significantly (p=0.089 or greater). In contrast, the global angles of the LT segment tended to increase in extension from control (4.6^{o} (1.0) flexion) to Hold-2H (2.9^{o} (0.5) flexion), again, not significantly (p=0.248 or greater). The difference between relative and global angles could be explained by the relationship between LT and the lumbar segment. As the lumbar segment increases in extension it can ultimately cause the LT segment to increase in relative flexion as illustrated in Figure 4.6. There was also no significant difference in relative RoM between conditions (F (1, 18) =1.86, p=0.126) or sex interaction (p=0.634 or greater). Global LT RoM showed significant difference (F (1, 18) = 5.82, p<0.001) with the post hoc revealing that Hold-1H, Text-1H, and Text-2H had between 0.6^{o} to 0.8^{o} less RoM than control (p=0.049 or less). These results are similar to that of the UT segment where the post hoc was only significant for global RoM for the same three conditions when compared to control (Hold-1H, Text-1H, and Text-2H).

Relative lumbar flexion had a difference in flexion angles between conditions (F (1, 18) =10.84, p=0.002) and no sex interaction (p=0.730 or greater); post hoc analysis showed that Hold-1H and Hold-2H were both more extend than control by 1.0^{o} (0.4) and 1.9^{o} (0.5), respectively (p=0.005 and 0.043, respectively). Globally, the lumbar segment was significantly different between conditions (F=19.44, p<0.001). Post hoc analysis showed that holding conditions were 1.7^{o} (0.3) or more extended than control ($p<0.001$). Texting conditions were 3.0^{o} (0.5) or more extended than control; 1.2^{o} (0.4) or more extended than holding conditions ($p=0.048$ or less) (Table 4.5.). However both relative (F (1, 18) =2.47, $p=0.052$) and global (F (1, 18) =2.32, $p=0.061$) RoM had no condition difference or sex interaction ($p=0.798$ or greater). Though not all results were significant, the tendency was for the lumbar segment to increase in extension for smart phone conditions and reduce RoM, more so during texting.

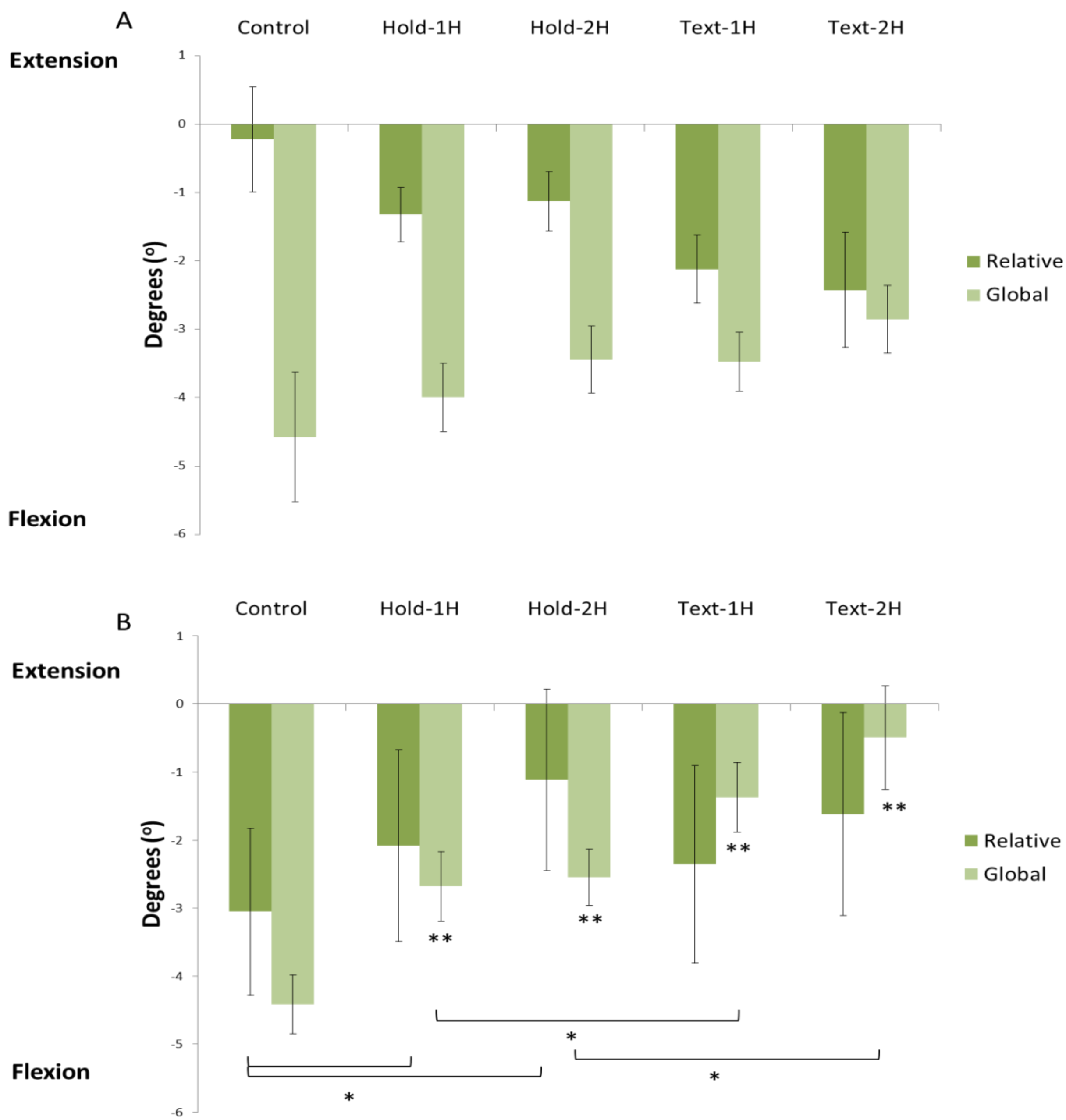


Figure 4.6. Global and relative segment angles for the (A) LT segment and (B) lumbar segment. Post hoc analysis found no significant differences between conditions for LT segment; neither relative nor global angles (p=0.089 or greater). Relative lumbar angles were found to differ significantly with Hold-2H 1.9^o (0.5) more extended than control (*) (p=0.005) and 1.0^o (0.3) more extended than Hold-1H (p=0.043). Globally, all smart phone conditions were more extended than control (**) (p<0.001 for all comparisons). Texting conditions were also more extended than holding (*) (p=0.048 or less).

The pelvis segment showed difference between conditions (F (1, 18) =19.67, p<0.001) but no sex interaction (p=0.757 or greater), post hoc revealing that the texting conditions had at least 2.4^{o} (0.4) more extension (posterior pelvic) than control and at least 1.5^{o} (0.3) more than holding conditions (p=0.002 or less) (Figure 4.7.). RoM had no difference between conditions (F (1, 18) =1.00, p=0.413) ranging between 6.3^{o} (0.4) and 6.8^{o} (0.5) nor any sex interaction (p=0.136 or greater).

After each condition block (10 walks) there was a 30 second standing trial for the purpose of quantifying, if any, change in posture during the length of the collection. However, results showed that there were no significant changes in sagittal segment position during the standing conditions after condition blocks (p>0.546 for all comparisons).

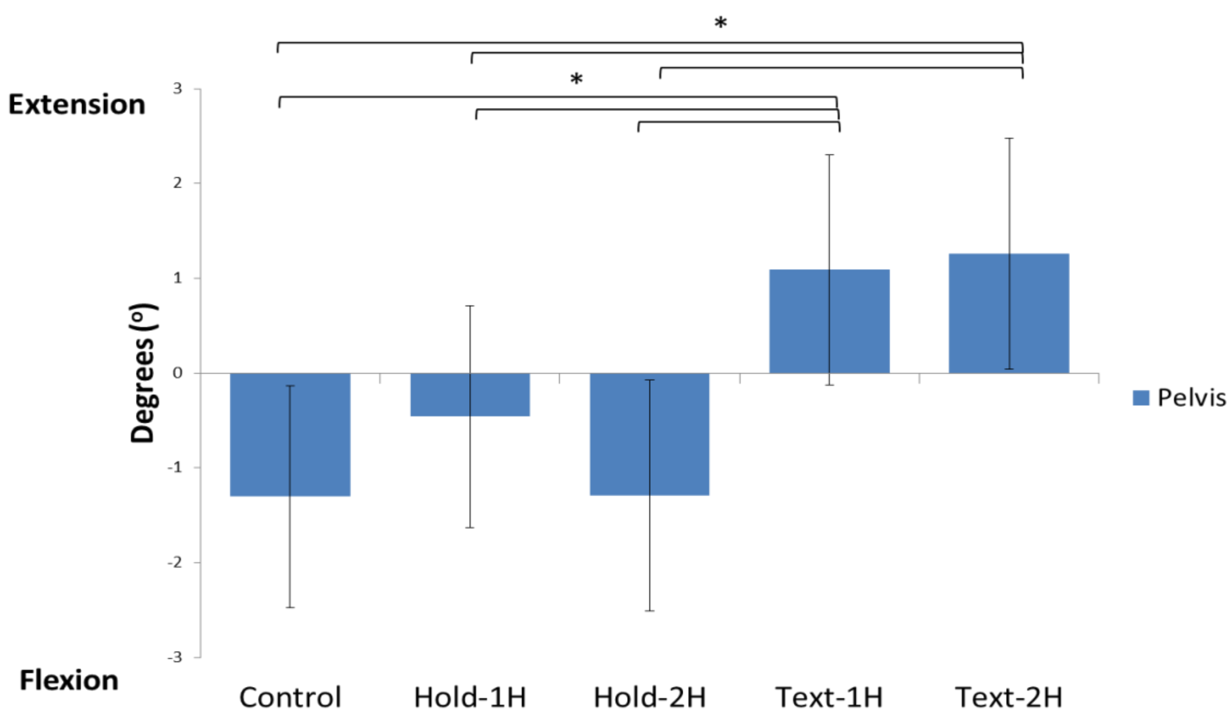


Figure 4.7. The pelvis segment was significantly more extended (posterior tilt) during texting conditions only (*) (p=0.002 or lower).

4.1.2 Lateral movement

Relative neck movement in the frontal plane was found to be significantly different between testing conditions (F (4, 72) =4.12, p=0.005) with no sex interaction (p=0.433 or greater). Post hoc analysis revealed that Text-1H condition had the participants head on average (SEM) 1.3^{o} (0.4) and 1.6^{o} (0.4) more to their non-dominant side than Holding-2H and Texting-2H, respectively (p=0.032 or less). Both 2 handed conditions (Hold-2H and Text-2H) had angles of or less than 0.4^{o} (0.6) which was similar to the control condition of 0.0^{o} (0.5) (p=1.00 for both) as illustrated in Figure 4.8. Frontal plane RoM for the neck segment was significantly smaller during smart phone conditions (both holding and texting) when compared to control (p=0.006 or less) as well as having no sex interaction (p=0.159 or greater). RoM was highest for the control condition at 6.1^{o} (0.6) of motion, decreasing with smart phone conditions, and lowest during the Text-2H condition at 2.8^{o} (0.2) of motion, as illustrated in Figure 4.9.

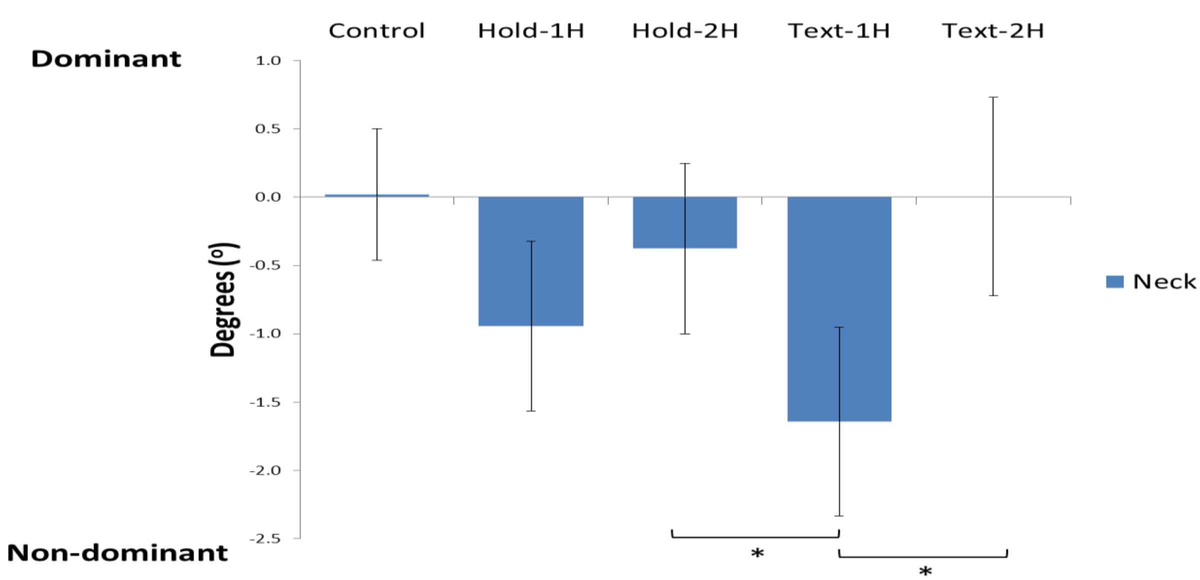


Figure 4.8. Lateral movement of the neck segment during conditions. The neck during Text-1H was significantly more to the non-dominant side than both Hold-2H and Text-2H (p=0.032 or less). The 2-handed conditions (Hold-2H and Text-2H) were similar to control condition with head close to 0^{o}.

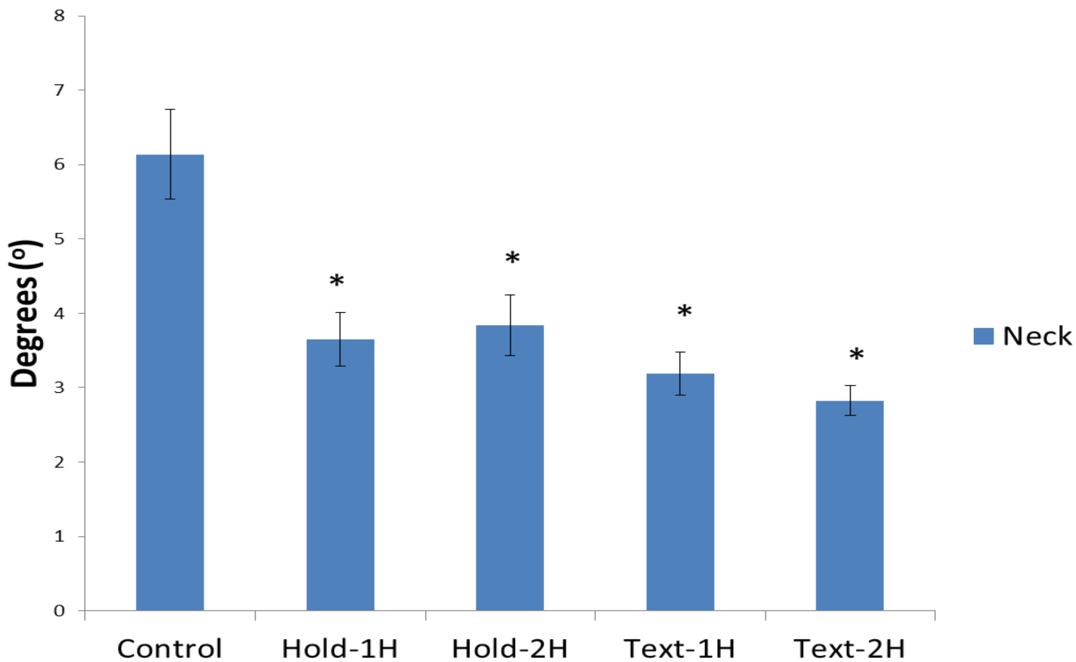


Figure 4.9. The neck segment had significantly lower lateral RoM during all smart phone conditions when compared to control (*) (p=0.006 or less).

No significance was found in the frontal plane movement of the UT segment (F (4, 72) =0.83, p=0.510) nor any sex interaction (p=0.225 or greater). Control condition was 1.0° (1.2) to the participants dominant side while the other four conditions (Hold-1H, Hold-2H, Text-1H, and Text-2H) were ± 0.9°. RoM for the UT segment in the frontal plane also lacked significant differences between conditions (F (4, 72) =1.50, p=0.212) as well as having no sex interaction (p=0.193 or greater). Lateral motion in the thoracic segment was expected to be minimal due to lack of RoM in the thoracic region from costal attachments.

LT segment also lack significant differences between conditions in the frontal plane (F (4, 72) =0.61, p=0.659) and did not have any sex interaction (p=0.153 or greater). All conditions were angled to the participants dominant side with the control (0.4° (0.3)) being closest to neutral and the one-handed conditions (Hold-1H and Text-1H) angled furthest to the participants dominant side (0.8° (0.3) and 0.7° (0.2), respectively). RoM also lacked significance (F (4, 72)

=2.40, p=0.055), with no sex interaction (p=0.575 or greater) but is it worth noting that the lowest RoM was during texting conditions (2.2^{o} (0.2) or lower) with the highest during control (2.6^{o} (0.3)).

Lumbar movement in the frontal plane did not differ significantly between conditions (F (4, 72) =0.872, p=0.485) or have a sex interaction (p=0.22 or greater). The values for the mean lateral angles for the lumbar segment ranged from 0.8^{o} (1.0) to 1.5^{o} (0.9), all results were towards the participants dominant side. RoM for the lumbar segment lacked significance between conditions (F (4, 72) = 2.34, p=0.61) but did have differences between sexes (F (1, 18) = 7.82, p=0.012). Females had, on average (SEM), 3.6^{o} (1.3) more lateral motion than males (p=0.012). The difference between RoM between sexes for the lumbar segment is illustrated nicely in Figure 4.10.

Lateral motion in pelvis did not change between conditions (F (4, 72) = 1.18, p=0.325) with values ranging between 1.8^{o} (0.8) to 2.3^{o} (0.9), all towards the participants non-dominant side. Nor was there any sex interaction with the segment (p=0.271 or greater). Like the lumbar segment, there was a significant difference between sexes (F (1, 18) = 36.15, p<0.001) for the average RoM. Females had 4.7^{o} (0.8) more lateral RoM than their male counterparts (p<0.001). This equates to females having 36% more frontal plane motion in the pelvis than males and may be a reason females were also seen to have more RoM in the lumbar segment since it is measured relative to the pelvis (Figure 4.10).

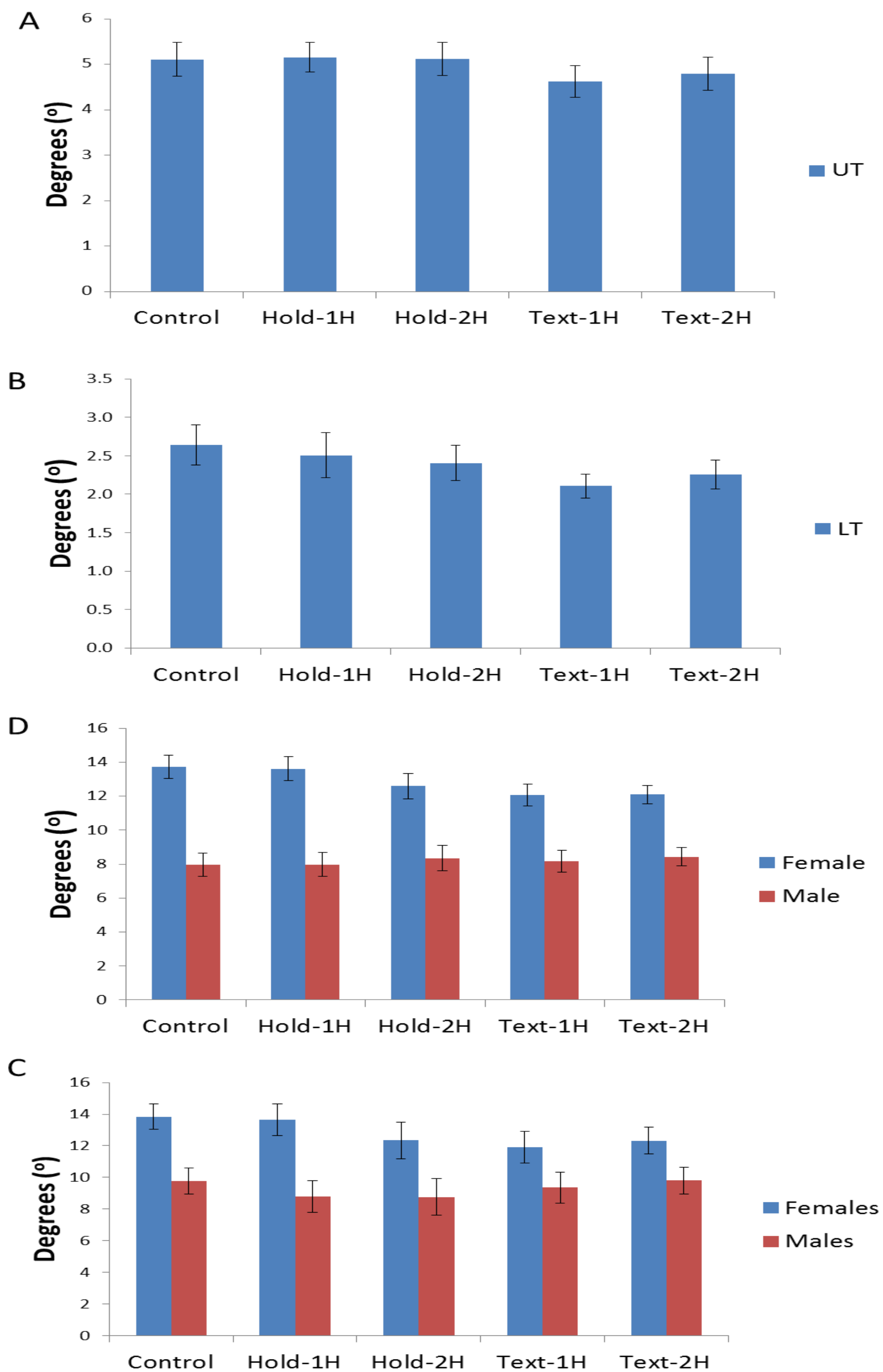


Figure 4.10. Lateral RoM for the (A) UT (B) LT, (C) lumbar, and (D) pelvis segments. Both lumbar and pelvis segments had a significant difference between sexes (p=0.012 or less) and thus were graphed separately, illustrating that females had more lateral RoM in those segments. No differences were found in either the LT or UT segments (p=0.512 or greater).

4.1.3 Rotation

Concerning the horizontal plane, the neck had significant differences between conditions ($F(4, 72) = 12.94$, $p<0.001$) and did not have any sex interaction ($p=0.060$ or greater). Text-1H had the largest level of rotation to the participant's dominant side of 2.0^o (0.8), Hold-1H having the second largest level of rotation of 1.1^o (0.8), and the control condition was rotated to the participant's non-dominant side at 1.2^o (0.5). Text-1H was significantly more rotated to the dominant side when compared to control, Hold-2H, and Text-2H ($p=0.010$ or less). Hold-1H was only significantly more rotated than control ($p=0.030$). This is due to the fact that during the one-handed conditions, the phone was held in the participant's dominant hand and caused the participants gaze to be towards their dominant side. RoM in the horizontal plane also showed significant difference between conditions ($F(4, 72) = 6.07$, $p<0.001$) with post hoc showing that only Text-2H had 1.2^o (0.4) less RoM than control ($p=0.038$) which was 4.6^o (2.1). There was no sex interaction in neck rotational RoM ($p=0.495$ or greater). Significance was not found for the UT, LT, lumbar, and pelvis segment; possibly due to high levels of variability as seen in Table 4.5. ($p=0.334$ or greater). RoM also lacked significance for UT, LT, lumber, and pelvis segments ($p=0.436$ or greater). The RoM for each segment can be found in Table 4.2.

Table 4.2. The table below gives the values for the RoM (difference between the most dominant side rotation and the most non-dominant side rotation) of each segment as well as the average rotation of the segment during each condition. A value of zero would be obtained if there was no rotation; any deviations from this are listed as either D(dominant side) or ND (non-dominant side). RoM tended to decrease for all segments with the smart phone conditions, with the lowest RoM during texting.

	Segment							
Condition	UT		LT		Lumbar		Pelvis	
	Rotation (^{o})	RoM (^{o})	Rotation (^{o})	RoM (^{o})	Rotation (^{o})	RoM (^{o})	Rotation (^{o})	RoM (^{o})
Control	1.5 (1.8) ND	3.6 (0.3)	2.5 (2.3) D	4.9 (0.5)	0.3 (0.7) ND	9.7 (1.0)	0.5 (0.5) D	11.4 (0.7)
Hold-1H	0.5 (0.3) D	3.6 (0.3)	0.3 (0.3) D	4.6 (0.5)	0.1 (0.4) ND	9.0 (0.9)	0.9 (0.4) ND	10.8 (0.6)
Hold-2H	0.4 (0.4) D	3.7 (0.4)	0.2 (0.4) D	4.6 (0.4)	0.4 (0.6) ND	8.7 (0.9)	0.7 (0.4) ND	10.0 (0.6)
Text-1H	0.1 (0.3) D	3.3 (0.3)	0.2 (0.5) ND	4.3 (0.4)	0.3 (0.4) ND	8.2 (0.6)	1.3 (0.4) ND	11.1 (0.6)
Text-2H	0.2 (0.3) D	3.4 (03)	0.1 (0.4) D	4.3 (0.4)	0.0 (0.4)	7.6 (0.7)	1.0 (0.5) ND	10.9 (0.6)

4.1.3 Arm angles

Having a sex difference in neck flexion mean angles lead to further investigation into possible reasons; one being arm angles. Dominate arm (1 left handed male, 1 left handed female, and rest right handed), shoulder angle (angle between body and upper arm) had a sex difference ($F(1, 18) = 8.71$, $p=0.009$), but no condition difference ($F(4, 72) = 0.79$, $p=0.535$). Results showed that on average (SEM), females had 7.1^o (2.4) more shoulder flexion than males ($p=0.009$). More specifically, females had their dominant shoulder more flexed by: 8.4^o (3.4) during Hold-1H ($p=0.024$), 5.7^o (3.2) for Hold-2H ($p=0.09$), 9.2^o (2.8) for Text-1H ($p=0.004$), and 5.3^o (2.6) for Text-2H ($p=0.059$). Elbow flexion angle was defined relative to the upper arm; angles are expressed as deviations from the z-axis. An angle of 0^o would indicate the arm is fully extended, whereas any value larger than 0^o would indicate increased elbow flexion (see Figure 3.3.). Dominant arm elbow flexion did not have a difference between sex ($F(1, 18)$

=2.84, p=0.109), but did have a condition difference (F (4, 72) =774.36, p<0.001) and a sex did have an effect on condition (F (4, 72) =5.03, p=0.001). Females had their dominant arms elbow (1 left handed, 9 right handed), on average (SEM), 4.9^{o} (2.9) more flexed than males (1 left handed, 9 right handed) for all phone conditions but only significantly for Hold-2H and Text-1H (p=0.003 and 0.042, respectively) as illustrated in Figure 4.11. The sex difference between phone conditions for relative neck flexion was highly correlated to differences between sexes for dominant arm elbow flexion and shoulder flexion (Pearson co=0.719 and 0.812, respectively). Suggesting that increased elbow flexion could be a large reason why females had less neck flexion than males.

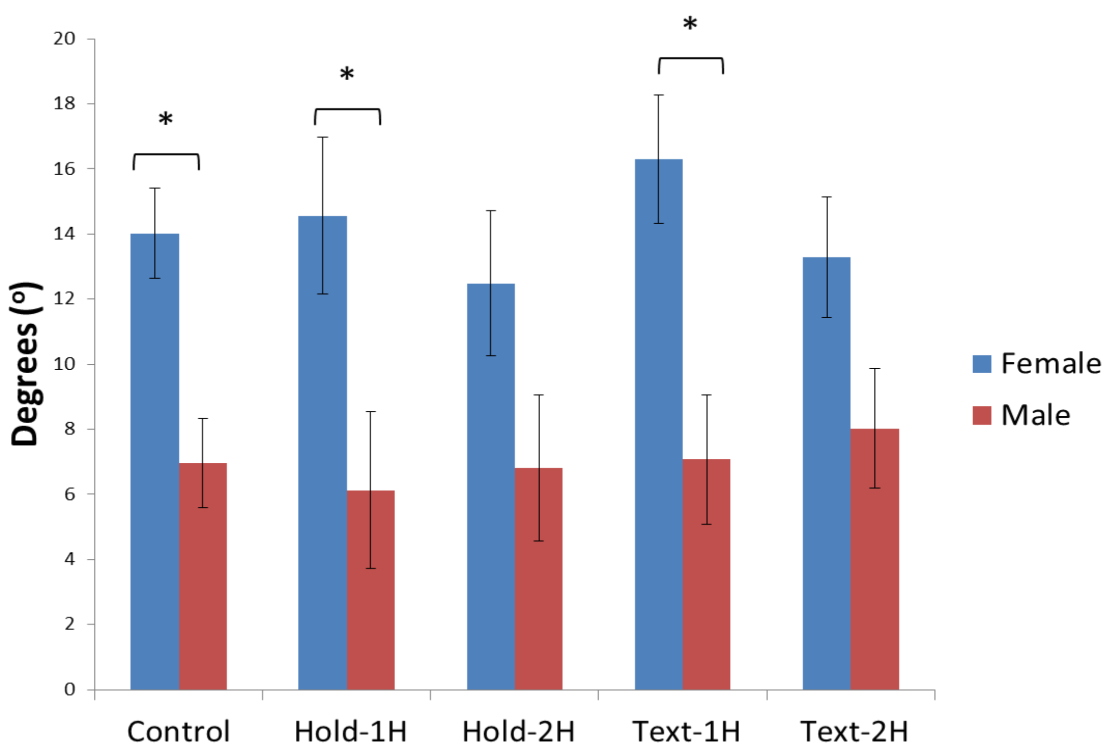


Figure 4.11. Dominant shoulder angles. During smart phone conditions, females (1 left handed, 9 right handed) had their dominant shoulder flexed more than males (1 left handed, 9 right handed) but only significantly for control (p=0.002), Hold-1H (p=0.024) and Text-1H (p=0.004).

Non-dominant side shoulder flexion for females was significantly larger than control during Hold-2H by 7.3^{o} (1.3) and Text-2H trials by 5.6^{o} (1.5) ($p<0.001$ and 0.013, respectively). Males did not show any significant differences in post hoc ($p=0.052$ or greater). Females during the 2 handed conditions had their non-dominate elbow more flexed than males. For the Hold-2H condition females had 13.9^{o} (4.0) more flexion and for Text-2H they had 6.3^{o} (4.2) more flexion ($p=0.050$ or less).

4.1.4 The summary of kinematic findings

The neck segment increased flexion significantly during the smart phone conditions with the UT segment showing similar trends. An unexpected difference between sex for neck flexion angles lead to further investigation on to possible reasons. Arm angles (shoulder and elbow) were significantly more flexed in female participants during smart phone conditions - holding the phone higher and closer to their face. Mid spine, the LT segment did not show any difference upon further investigation while the inferior segments, lumbar and pelvis, increased in extension with the smart phone conditions. Relative RoM significantly decreased only for superior segments, neck and UT, during smart phone conditions. However all segment saw reductions in RoM (maximum extension – maximum flexion), more so during the texting conditions. During 1 handed smart phone conditions (Hold-1H and Text-1H) participants had their head tilted towards their non-dominant side and were rotated slightly to their dominant side. The 2 handed conditions did not see similar results and instead had their head forward and generally not rotated. Finally, female participants had more lateral motion in their hips and lumbar segment than males.

4.2 Gait

Temporal and spatial data were collected to see if there was a difference in mean values between conditions as well as if there was a difference in variability that might indicate decreases in stability, distraction during task, and possibly priority over task. The focus will be stride length, stride width, velocity, cadence, gait phases, and any variability in those parameters (Figure 3.4.).

Normalized stride length was significantly different between testing conditions ($F(4, 72) = 29.53$, $p<0.001$) with no sex interactions ($p=0.168$ or greater). Texting conditions had significantly shorter stride lengths, ranging from 7.2 cm/m to 9.5 cm/m less in length than all other conditions ($p<0.002$ for all comparisons) (Figure 4.12.). Specifically, control was 77.4 (3.5) cm/m. Hold-1H was 75.3 (3.4) cm/m, Hold-2H was 75.5 (3.4) cm/m, Text-1H was 68.3 (3.1) cm/m, and Text-2H was 67.9 (3.3) cm/m).

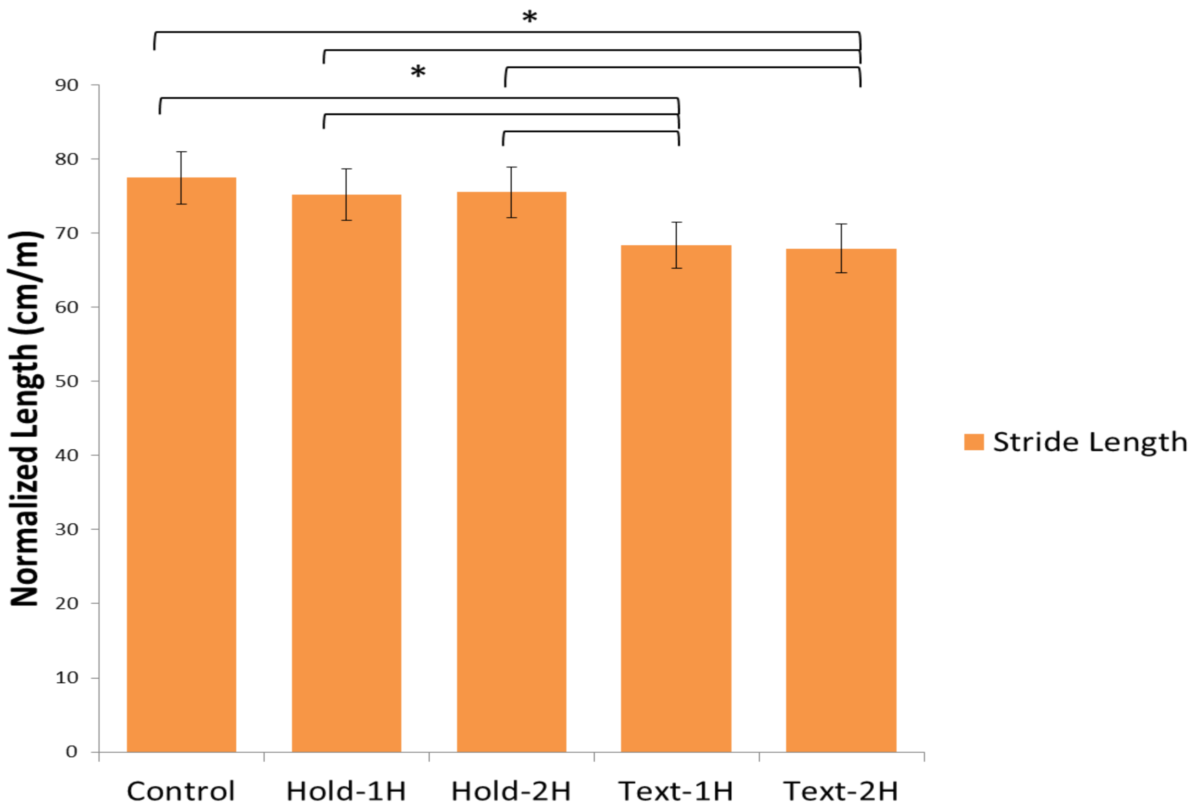


Figure 4.12. Normalized stride lengths for each condition. Text-1H and Text-2H had significantly shorter stride lengths than control and holding conditions (*) (p<0.001 for all comparisons).

Stride length variability (CV) changed with conditions (F (4, 72) =5.84, p<0.001), with the post hoc revealing that texting conditions had the highest level of variability (1.23% (0.11) to 1.25% (0.11)). Specifically, Text-1H and Text-2H were 37.1% and 34.8% more variable than Hold-2H (p=0.015 and 0.043, respectively). No significance was found with stride width (F (4, 72) =0.12, p=0.734), nor was there a difference in variability (F (4, 72) =1.20, p=0.318). Stride time variability was another gait parameter only affected by the texting conditions. Text-1H had 47.9% more variability than control, 46.2% more than Hold-1H (p=0.001), and 35.9% more than Hold-2H (p=0.058). Whereas Text-2H was 73.9% more variable than control (p=0.001), 71.9% more than Hold-1H (p=0.003), and 59.8% more than Hold-2H (p=0.030). Neither stride length variability, stride width, nor stride time reported any sex interactions (p=0.610 or greater).

Participant velocity (not normalized) was significantly reduced during texting conditions (p=0.010 or less), as illustrated in Figure 4.13. However, there was a sex difference (p=0.022) with females, on average (SEM) walking 14.6 cm/s faster than their male counterparts. This was not expected as sex differences in velocity have not been widely reported in the literature. Female participants ranged from 131.0 (4.6) cm/s to 126.3 (4.2) cm/s during control and holding conditions, dropping to 107.5 (5.5) cm/s for Text-1H and 103.0 (5.8) cm/s for Text-2H (p=0.005 or less). Males saw less reductions, with control and holding ranging from 116.9 (4.6) cm/s to 109.6 (4.3) cm/s and dropping to 92.5 (5.5) cm/s for Text-1H and 93.6 (5.8) cm/s for Text-2H (p=0.010 or less). Though males walked slightly slower than females, the velocity reductions that occurred in response to the different conditions were similar for both sexes. Reductions in velocity only occurred during the texting conditions and ranged between 16.0 cm/s to 24.4 cm/s for males and 18.8 cm/s to 28.0 cm/s for females.

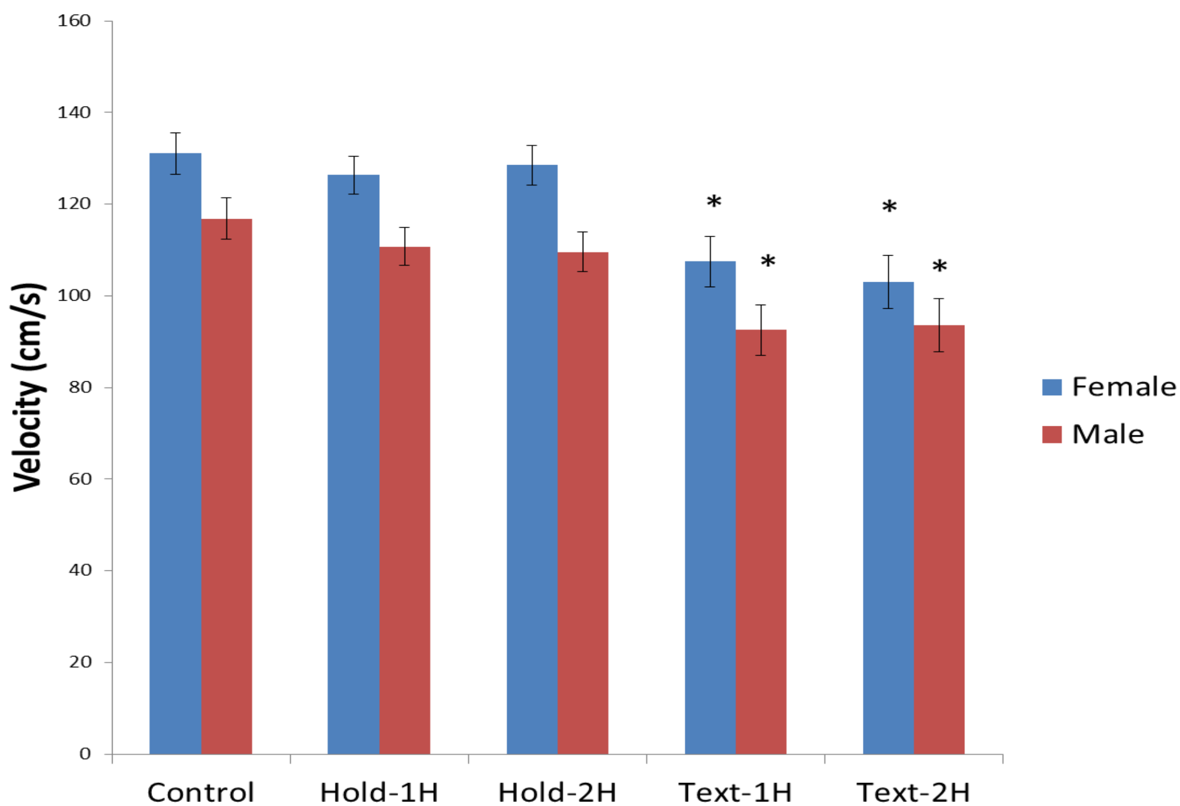


Figure 4.13. Velocity separated by sex due to females walking, on average (SEM), 14.6 cm/s (5.8) faster than males. Texting conditions for both males and females were significantly slower than both control and holding conditions (*) (p=0.010 or less).

Concerning participant cadence, there was a significant difference between conditions (F (4, 72) =14.51, p<0.001) as well as a difference between sex (F (1, 18) =8.28, p=0.010). Females had at least 17.3 (7.5) more steps/min in all conditions when compared to males. More specifically females for control, Hold-1H, Hold-2H, Text-1H, Text-2H took 20.6 steps/min (7.8), 21.0 steps/min (7.3), 22.7 steps/min (7.3), 21.0 steps/min (74), and 17.3 steps/min (7.5) more than males (p=0.032 or less). Concerning condition outcomes, post hoc analysis showed that there were no significant differences between conditions for males (p=0.088 or greater). Females only had significantly less steps for Text-2H condition when compared to holding and control (p=0.029 and greater) while Text-1H showed no difference (p=0.077 or greater).

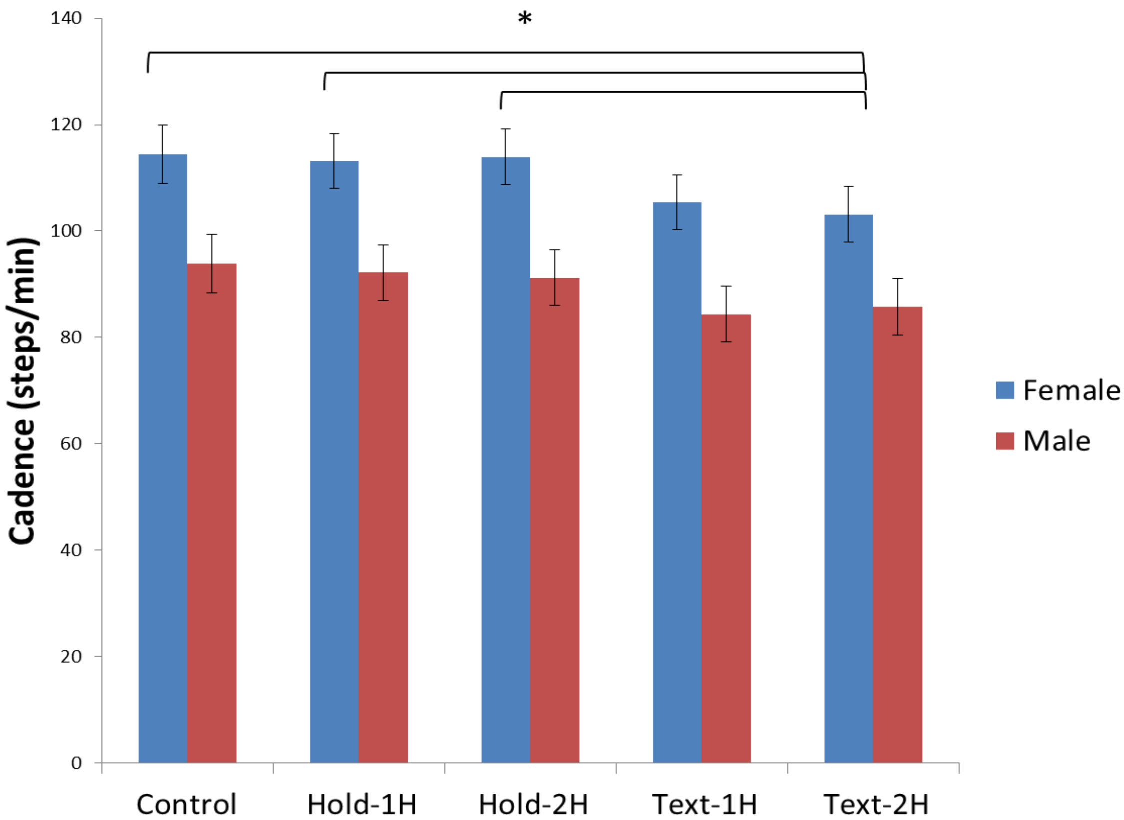


Figure 4.14. Sex difference between conditions for cadence (F (1, 18) =8.28, p=0.010). Females took significantly more steps/min then their male counterparts. For control, Hold-1H, Hold-2H, Text-1H, Text-2H females took 20.6 steps/min (7.8), 21.0 steps/min (7.3), 22.7 steps/min (7.3), 21.0 steps/min (74), and 17.3 steps/min (7.5) more than males (p=0.032 or less). Only females had significantly less steps/min during Text-2H (p=0.029).

Concerning stance phase of gait there was significance between conditions (F(4,72) =14.66, p<0.001) as well as no sex difference (p=0.385 or greater). Stance phase was significantly longer in duration during texting conditions relative to both control and holding conditions (p=0.020 or less). Text-1H ranged from 1.5% (0.3) to 1.8% (0.3) more time spent in stance while Text-2H ranged from 1.3% (0.2) to 1.6% (0.3) more time spent in stance. Swing phase decreased with increases in stance. Texting conditions had significantly less swing phase compared to control and holding conditions (p=0.022 or less). This is to be expected since to have more stance phase there needs to be a reduction in swing, the results are illustrated in Figure 4.15.

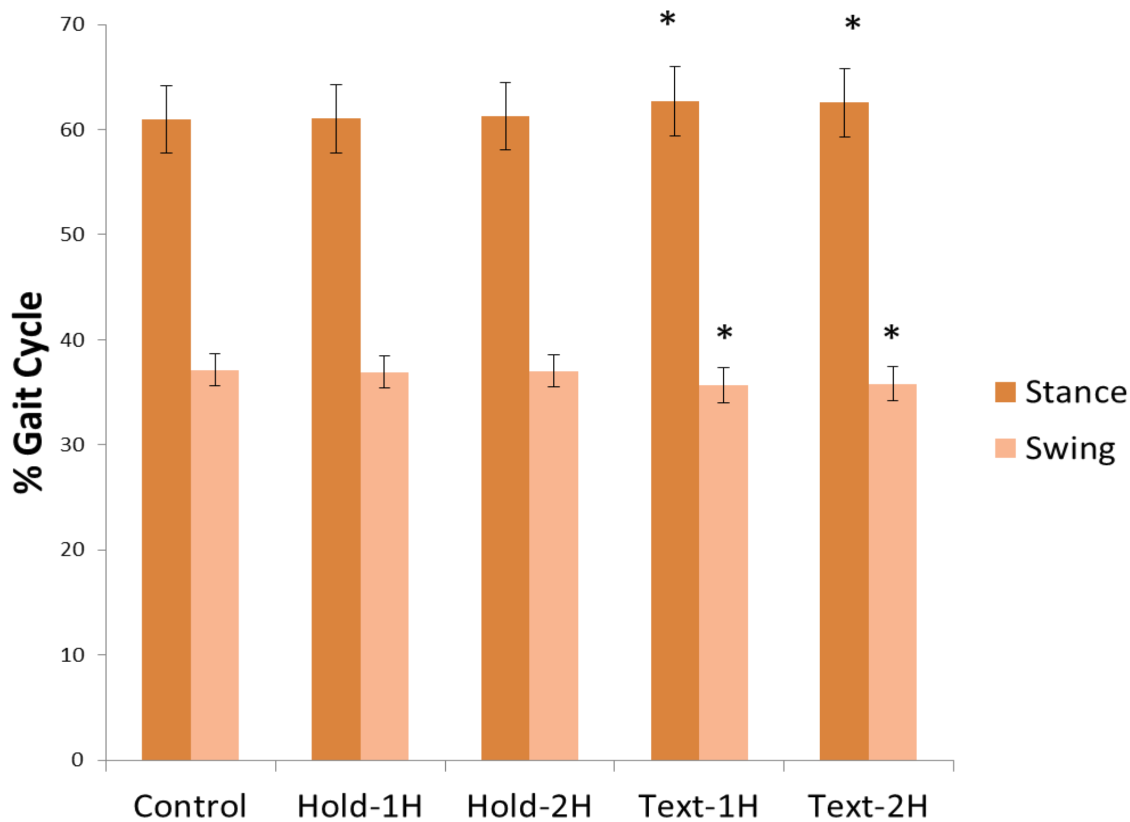


Figure 4.15. Phases of gait changed significantly with texting conditions. More time was spent in stance phase and less in swing during both texting conditions relative to control and holding conditions (*) (p=0.022 or less).

Variability (CV) of gait phases (stance and swing) were significantly different between conditions. Stance phase showed significant differences between conditions (F (4, 72) =1.19, p<0.001) and a difference between sexes (F (1, 18) =8.11, p=0.011). Specifically, males had a higher average (SEM) variability in stance of 1.7% (0.1) compared to females 1.3% (0.1) throughout all conditions (p=0.011). Variability increased during texting conditions for both sexes but only significantly for the Text-2H trial when compared to control (p=0.048 for females and 0.020 for males). The differences are illustrated in Figure 4.16. Swing phase, like stance, was also significantly different between conditions ($F(4, 72) = 14.30$, $p<0.001$) and also had a sex difference ($F(1, 18) = 7.94$, $p=0.011$). Responses to texting conditions were similar with both males and females with increasing variability. However, males only had significant increase in variability between Text-2H and control ($p=0.015$) while females were significantly more variable in Text-2H compared to both control and Hold-1H ($p=0.043$ or less). As illustrated in Figure 4.16, variability tended to increase with introduction of texting condition and was significantly higher in males across the board, however, significance was only found during Text-2H.

Gait can also be reported as single support and double support stance. With the texting conditions there was an increase in double support as a percent of gait cycle. Control and holding conditions ranged between 28.4% (0.5) and 29.1% (0.6) of gait cycle while the texting conditions increased by over 2.6% (0.5) to range between 32.0% (0.6) for Text-1H and 31.8% (0.6) for Text-2H ($p<0.001$ for all comparisons). With increases in double support percentage there was decreases in single support. Single support percent dropped from 35.5% (0.3) during control and holding conditions to 34.0% (0.3) for both texting conditions ($p=0.003$ or less).

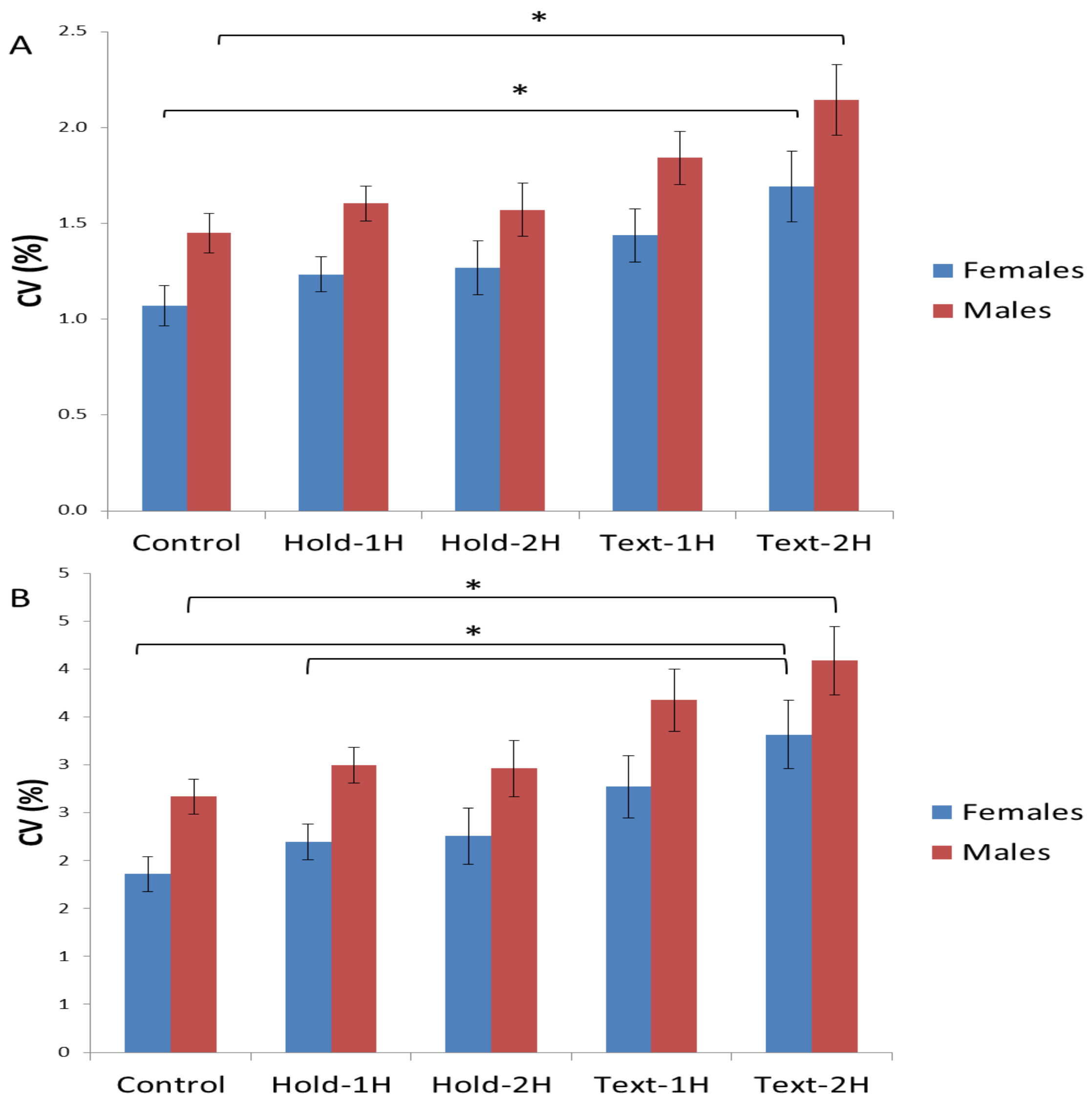


Figure 4.16. Variability (CV%) for both (A) stance phase and (B) swing phase of gait. Males had more variability in all conditions (p=0.011 or less). No significant increases in phase variability with holding conditions. Increases in variability came with the introduction of the texting conditions. Text-2H had more variability than control in stance phase (*) (p=0.048 or less) while variability was higher in swing for Text-2H relative to control (for males and females) and Hold-1H (females only) (*) (p=0.043 or less).

4.2.1 Summary of Gait Findings

Gait changes seemed to be largely due to the introduction of the texting conditions. No differences existed between texting with one hand when compared to two handed texting. Further, there were not any significant changes between holding conditions and control conditions. The decreases in velocity, cadence, and stride length were all results of texting conditions. Increases in stride time variability, stride length variability, and gait phase variability were also results of the texting conditions. Finally stance phase increased during texting conditions, more specifically time spent in double support.

4.3 ***Electromyography***

The abdominal muscles (EO, IO, and RA) had significantly different average activity between conditions (p=0.014 or less) and no sex difference for either EO or RA (p=0.124 or greater). Average abdominal activity ranged between 0.41 %MVC to 3.36% MVC and was lowest during the texting conditions with post hoc show only significance for the Text-2H condition as illustrated in Figure 4.17. However, one trend that was unique to the EO muscles were that sex had an effect on condition outcome (F (4, 72) =3.05, p=0.022) with males having no difference between conditions (p=1.00 for all comparison) and females having significantly lower activity during both texting conditions when compared to control and Hold-2H (p=0.038 or less).

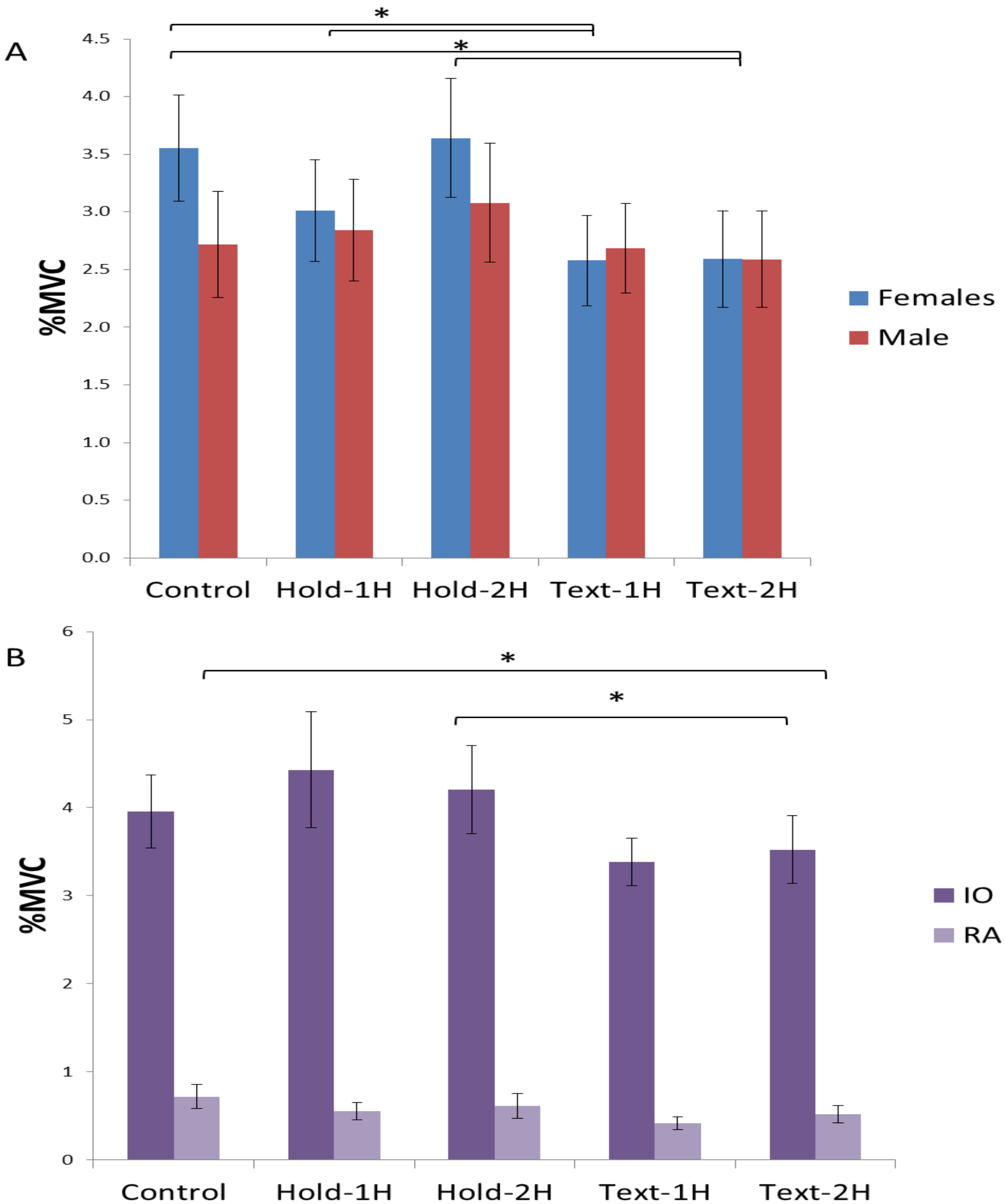
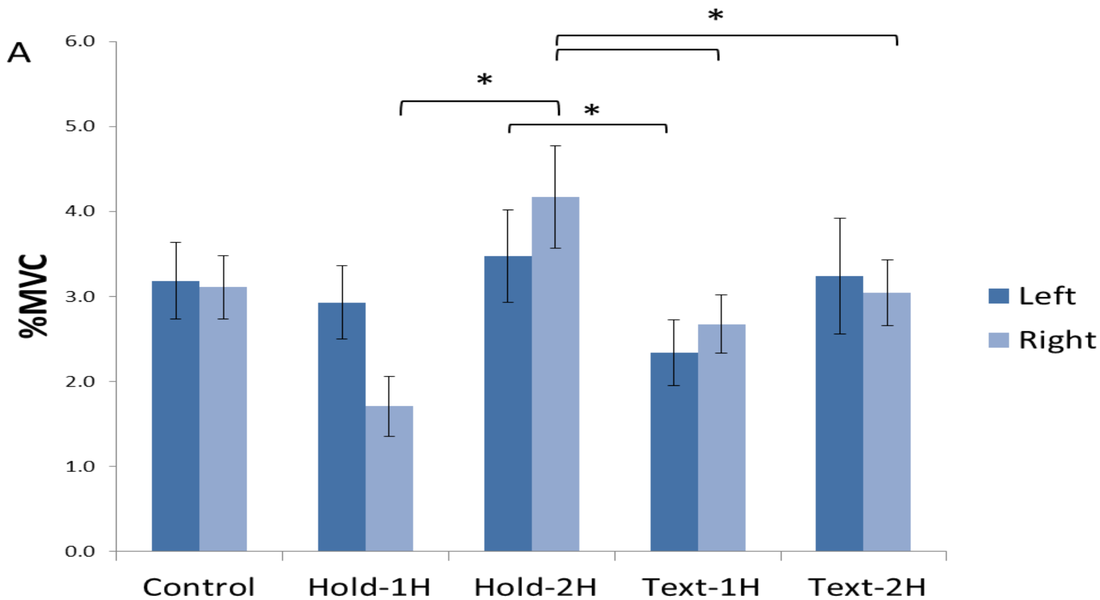


Figure 4.17. Average abdominal muscle activity for the (A) EO, (B) IO and RA. Abdominal muscle activity tended to decrease during texting conditions; however, not all results were significant. Males and females responded differently with regards to EO activity during conditions (p=0.022); males did not experience any significant differences. Females, on the other hand, had decreased EO activity during texting conditions (*) (p=0.038 or less). IO and RA activity was also lowest during texting conditions, with Text-2H significantly less than Hold-2H for IO and significantly less than control for RA (*) (p=0.014 or less).

Concerning the back musculature there existed a significant difference between conditions for the LES (F (4, 72) =5.63, p=0.001) as well as a compounded effect of sex and side on condition outcome (F (4, 72) =5.20, p=0.001). Outcomes are split by both side and sex due to interactions. There were no significant results for male participants who's LES activity ranged from 2.0% (1.1) to 3.3% (1.4) between conditions(p=0.240 or greater), however, females had lowest level of muscle activity in the left LES during Text-1H (2.3% (1.0)) but only significantly lower than Hold-2H (3.5% (2.0)) (p=0.013). The right LES for females had all smart phone conditions, other than Hold-2H, significantly lower than Hold-2H which was 4.1% (2.5) (p=0.045 or less). Specifically, Hold-1H was 2.5% (0.7) lower, Text-1H was 1.5% (0.4), and Text-2H was 1.1% (0.3) lower as illustrated in Figure 4.18.



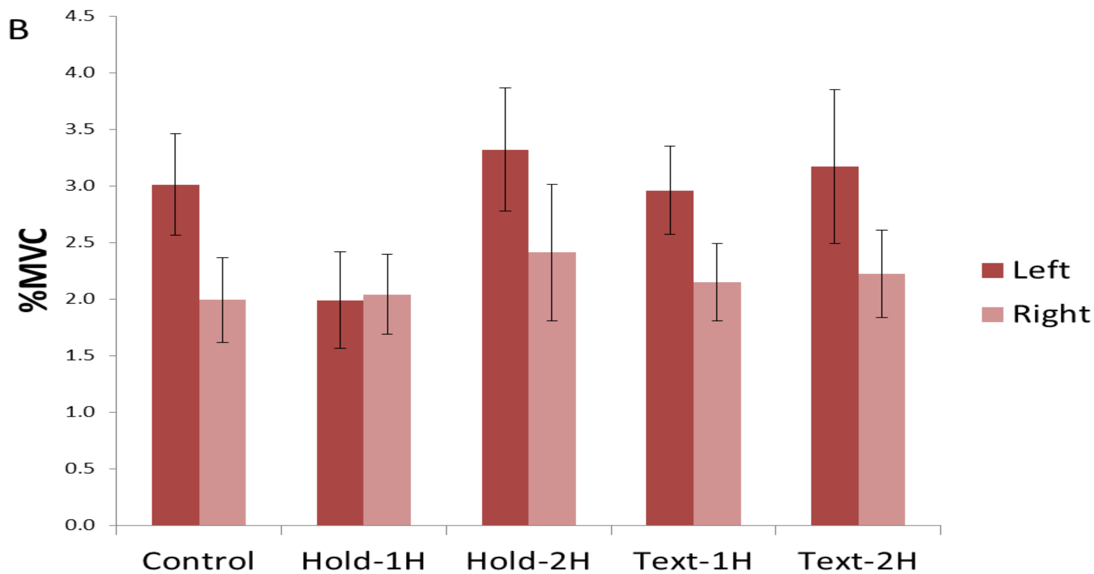


Figure 4.18. Left and right LES activity for both (A) female and (B) male participants. Male participants lacked any significant differences between conditions (p=0.240 or greater). Females had highest activity in both right and left LES during Hold-2H condition. Left side LES tended to be higher in almost all conditions but not a significant amount (p=0.117).

TES activity was 0.4% (0.1) higher on the left side (F (4, 72) =6.87, p=0.017) and 1.1% (0.5) higher for females (F (1, 18) =5.34, p=0.033). There also existed a condition difference (F

(4, 72) =6.89, $p<0.001$) with the post hoc analysis showing no significant difference for male participants between conditions or side ($p=0.055$ or greater), similar to LES activity. Female participants had their lowest activity (2.6% (1.5) to 3.3% (1.8)) for both left and ride sides during texting conditions as seen in Figure 4.19. Specifically, females had a 0.7% (0.2) decreased left TES activity during Text-1H when compared Hold-2H and a 0.8% (0.2) decrease when comparing Text-2H to Hold-2H ($p=0.030$ or less). However, the only significant difference on the right side was a 0.7% (0.2) increase in TES activity during the Hold-2H when compared to control ($p=0.032$). As illustrated in Figure 4.19, muscle activity was highest during the holding conditions for both sides, specifically Hold-2H; with texting conditions lower or on par with control.

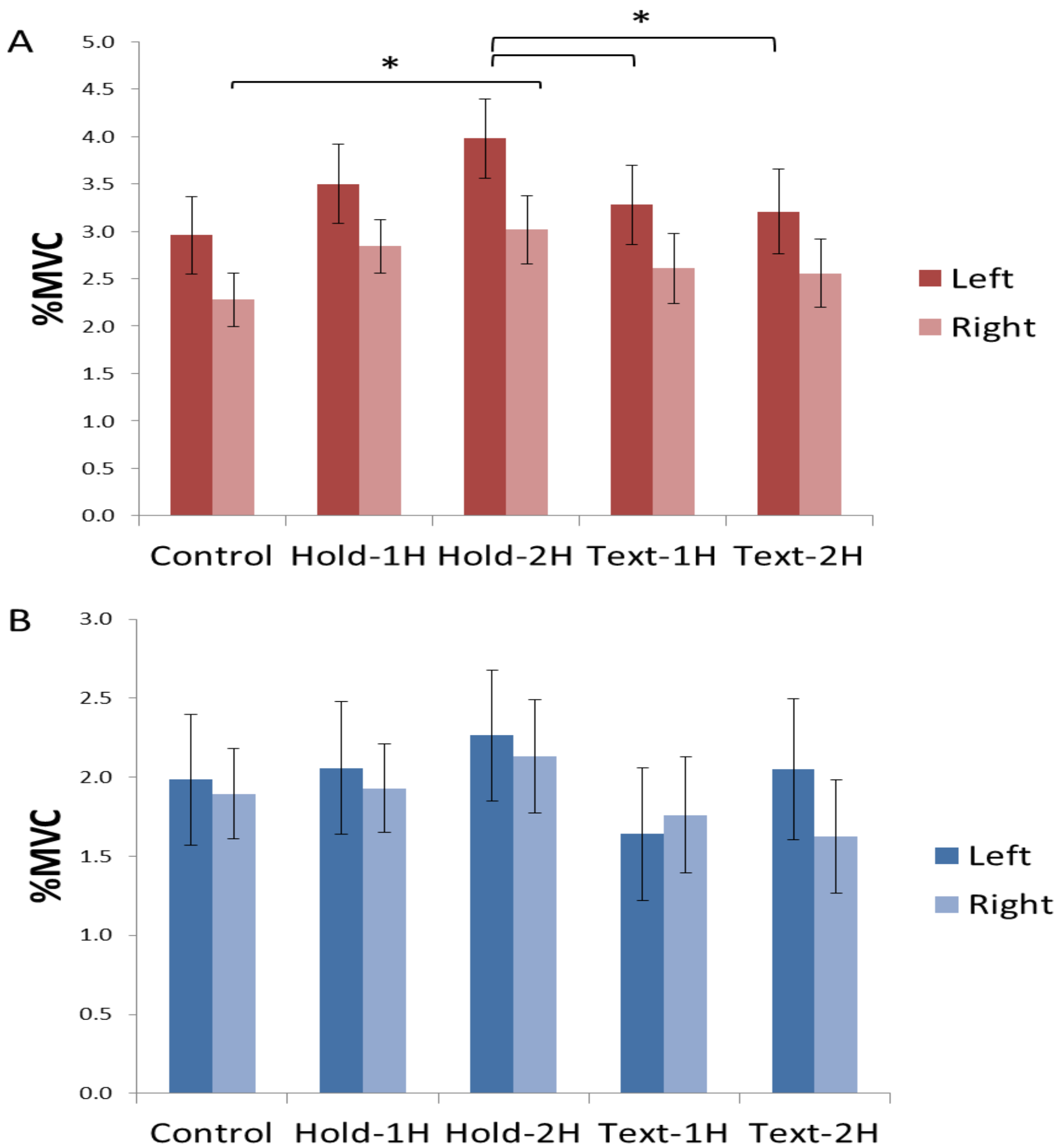


Figure 4.19. Average EMG for the TES of (A) female and (B) male participants. Males lacked any significant differences, whereas females had significantly higher levels of TES activity during Hold-2H condition (*) (p=0.032 or less). Like LES activity, TES tended to have highest level of activity on the left side; 0.4% (0.1) higher than right side (p=0.017).

LAT activity during conditions did not have any significant difference between left or right sides ($F(4, 72) = 0.060$, $p=0.809$) nor a difference between sexes ($F(1, 18) = 1.28$, $p=0.273$). There was a significant difference between conditions ($F(4, 72) = 2.83$, $p=0.031$) with post hoc showing a decrease of 0.5% (0.1) from 1.5% (0.2) during Hold-2H to 1.0% (0.1) during Text-2H ($p=0.002$). TRAP and GlutMed activity had no significant differences found ($p=0.149$ or greater) and ranged between 2.7% (0.3) to 3.7% (0.7) and 3.2% (0.3) to 3.6% (0.4), respectively.

4.3.1 Summary of EMG

There EMG data collected during this research lacked the amount of significance and patterns seen in both the gait and postural data. The being said, the abdominal EMG (EO, IO, and RA) tended to be lowest during the texting conditions. There was also a trend for the left ES (both LES and TES) to be higher in activation than the right side, though only significantly for the TES ($p=0.117$). Both groups of muscles also had highest level of activity during the Hold-2H condition. Lastly, the LAT had largest level of activity during Hold-2H while both the GlutMed and TRAP muscles lacked any significant findings or trends.

4.4 VAS

VAS scores were taken directly prior to collection of the first block condition and then again after each block, roughly 3 minutes. An increase of at least 9mm is considered significant but those were studies that had static conditions over 30 minutes (Anne-Maree 1998), whereas this study was relatively quick (~20 minutes) and dynamic. That being said, no participant had a significant increase in their VAS score for either neck or low back. The largest increase seen was 6.5 mm and 7.0 mm for the low back and neck, respectively. The average (SD) increase of the VAS scores was 1.6 mm (2.0).

4.5 Questionnaire

All participants owned more than 2 devices out of laptop, desktop, smart phone, and tablet with 12/20 owning 2, 4/20 owning 3 and 4/20 owning 4. The average (SD) time spent on a smart phone was 3.5 hours (2.0) per day with the average (SD) amount of text messages sent a week 50.8 messages (35.1) with a high of 120 messages. Additional information collected was the average amount of work hours in a week, time spent on smart phone, and hours spent at a desk. The results are: 35.3 hours (16.8), 3.5 hours (2.0), and 6.8 hours (3.7), respectively. None of these factors had a significant effect on the postural position of any of the spine segments ($p=0.242$ or greater).

5. Discussion

This study was designed to further investigate the effects of smart phone use on posture, gait, and muscle activity. To date and to the knowledge of the experimenters, no study has quantified separate levels of spinal posture to the same level as this study, nor have they investigated muscle activity of the ES and gait spatial-temporal parameters. The research into the effects of mobile technology on gait and posture is relatively new and has generally focused solely on gait (Agostini et al. 2015; Demura and Uchiyama 2009; Lim et al. 2015), neck posture (Gustafsson et al. 2011; Schabrun et al. 2014), and upper trapezius muscle activity (Gustafsson et al. 2011). The goal of this thesis was to quantify the effects of smart phone use during texting conditions on both the posture and muscle activations during gait of healthy young adults. As expected, there was significant difference displayed between spine segment postures between conditions ($p=0.003$ or less). The hypothesized results of the study were that the only postural effects would be increased flexion in the neck and UT segment. This was possible to observe due to the segmentation of the spine during collection but unexpectedly, there was large difference between males and females and neck flexion angles. Females flexed their necks, on average (SEM), 9.1^{o} (1.6) less in all smart phone conditions, which lead to further investigation. It was determined that female participants were holding their smart phones higher than male participants. Specifically, females had their shoulders 7.1^{o} more flexed, which put their phones further away from their bodies. They also had their elbows 2.8^{o} to 12.8^{o} more flexed, which brought their phones closer to their faces. It is believed that both of these factors brought the females' phones higher up and closer to their faces, resulting in less neck flexion required to properly focus on the screen. Differences in anthropometrics, specifically chest size, may be driving the sex difference and why females held their phones higher; due to possible obstruction and/or impact on arm positioning comfort. Addressing corrected vision; there were a total of three participants (2 males, 1 female) who wore glasses during the study which may of lead to an exaggerated increase in neck flexion in order to focus better on their device. However, these individuals were near the mean of the test population, and did not produce the largest or smallest values, as stated earlier. Specifically the female participant had the 6th (6/10) highest level of neck flexion while the males were 3rd and 8th (3/10 and 8/10) out of 10 female/male participants, respectively. Considering that the participants with glasses did not have the highest relative position when compared to participants without glasses, it is unlikely eye-wear to correct vision played a role in the increases in neck flexion in this study. This study found no significant sex difference ($p=0.061$) in neck RoM, though females tended to have less. Previous evidence has been published supporting that females have a larger cervical RoM than males (Seacrist et al. 2012), as well as conflicting results showing no difference in cervical RoM between sexes (Greaves et al. 2009; Panyakaew and Bhidayasiri 2013). Evidence from this research supports no sex difference in RoM but that may be attributed to the testing conditions. Females holding their phones higher and closer to their faces could have less neck movement, ultimately reducing the RoM. A related study, Schabrun et al. (2014) looked at full body kinematics during walking, texting, and reading conditions. The authors found a significant decrease in cervical RoM during reading and texting conditions ($p<0.001$ for both), but no sex difference. In their study, the control had the largest cervical RoM ($7.1^{o)}$, reading 5.1^{o}, and texting had significantly less at only 3.9^{o} RoM ($p<0.001$). The results of this study are very similar to Schabrun et al., with the control having a RoM of 7.0^{o}, holding conditions of 4.3^{o}, and texting with the least RoM at 3.0^{o} (Figure 4.3.). In other words, neck RoM decreased with task, holding conditions were significantly lower than control ($p=0.004$ or less), and texting condtions were significantly lower than both ($p=0.012$ or less). Schabrun et al. (2014) found that the head and neck were more "in phase" with the thorax, suggesting that the upper body, the head in particular, was more stable with less RoM to optomize the relationship between the head, trunk, arms, and phone. The results of this current study support the rationale of Schabrun et al. (2014), who suggested that focusing on the screen during gait takes increased trunk/head stability, while focusing on the keypad and actually responding takes even more stabilization. Further investigation revealed that the neck's lateral RoM was also reduced during smart phone conditions (holding and texting); this further supports the need for increased stability in the superior segments during those tasks (Figure 4.3.). The values of lateral neck RoM (control 6.1^o, holding 3.7^o, and texting 3.0^o) of this current study are very similar to Schabrun et al. (2014), who also found a significant decrease in relative lateral neck. Schabrun et al. (2014) reported lateral neck RoM of 5.6^o for their control, 4.1^o for reading a message, and 3.1^o for typing a response ($p=0.003$ or less). This supports the notion that participants reduce their movements (increasing stability) to be able to increase focus on the secondary task, typing a message.

The UT responded similarly to the neck segment, with all conditions more flexed than control, with texting as the most flexed condition. Further, there was a high correlation between the increase of neck flexion and the increase in UT flexion ($r=0.931$ and 0.966 for females and males, respectively). This is not surprising, since a neck flexion and forward head posture has been demonstrated to increase thoracic kyphosis in the underlying thoracic spine (Abelin-Genevois et al. 2014; Quek et al. 2013). The relationship between the cervical and upper thoracic spine is supported with the findings of this current study. The increased neck and UT flexion translates the participant's head and upper body mass forward, resulting in an increase in the kyphotic nature of the thoracic segment. The neck, however, having far larger RoM, saw 21^o

of change between conditions, whereas the UT only saw 3^{o}, suggesting that the neck could have far more influence on the underlying segment (UT).

There has also been evidence that increased neck flexion during smart phone use (Gustafsson et al. 2011), as well as increased thoracic kyphosis, can increase muscle activity in the upper trapezius and ES. Specifically, Gustaffson et al. (2011) found signficant increases in upper trapezius activity during smart phone use; this contradicts the current study's results, which found no changes in TRAP activity. The reason for the difference between findings is most likely due to experimental differences. This current smart phone study invloved TRAP EMG measurements during a highly dynamic task (gait) and was normalized to %MVC whereas Gustaffson et al. (2011) and other similar studies (Caneiro et al. 2010) have static standing/sitting conditions when measuring muscle activty that were normalized to a submaximal effort. Another expectation of the increase in FlexP, specifically thoracic flexion, was to observe an increase in TES activity. TES activity did have significant results but lacked any pattern, meaning that the muscle activity was only statistically higher during the Hold-2H condition and not other conditions (Hold-1H and texting) even though flexion was not different. Similar expectations were also applied to LES activity, with slightly different results. The lumbar segment was at its least flexed state during both two-handed trials (Hold-2H and Text-2H); LES activity was also at its highest activation level (for both sexes and sides) during those conditions. The results were only significant during the Hold-2H condition, but showed a trend of increased LES muscle activity with lumbar extension. The increased LES activity can most likely be attributed to the increased flexion moment generated by the forward translation of the body's CoM due to upper body flexion. Since the lumbar is not in a highly flexion state, the lumbar ES (LES) can contribute to posterior shear to counteract the anterior shear (McGill et al. 2007). The pelvis saw an increase in posterior tilt during Text-1H and Text-2H (1.1^o (1.2) and 1.3^o (1.2), respectively) but was nearly identical in the other 3 conditions. The increase in posterior tilt of the pelvis has been demonstrated in flexed trunk walking in healthy individuals as an adaptation to offset the forward translation of bodies CoM due to increased flexion of the superior segments (Saha et al. 2008). However, that does not explain why there was no increase in posterior pelvic tilt during holding conditions. It is more likely that the increase in posterior pelvic tilt is multi-factorial and likely due to the reductions in gait velocity and stride length.

Another key focus of this study was to quantify the effect posture and the dual task nature of texting had on gait. As shown in previous research, increased trunk flexion during walking in abled-bodied individuals can significantly reduce gait performance (Saha et al. 2008). However, the trunk in this study was lumped results were limited to trunk flexion measured using a goniometer (no regional spine information). Flexion being measured as increases from vertical (neutral standing). Nairn and Drake (2014) showed that increased lumbar flexion during different movement tasks significantly increase upper thoracic segment flexion as well as altered the RoM within the spine’s regions. Thus it is important to look investigate the spine in partitioned segements to improve our understanding of how posture could be altering and/or impacting gait performance. It has also been documented that gait is adversely affected by dual-task (Agostini et al. 2015; Lim et al. 2015; Yogev-Seligmann et al. 2010), with the magnitude of the effect dependent on task difficulty and task priority (Beauchet et al. 2005; Plummer et al. 2014; Yogev-Seligmann et al. 2010). It has also been shown, in older populations (65+ years), that increased FlexP can lead to decreases in gait performance (Balzini et al. 2003; Benedetti et al. 2008; de Groot et al. 2014). Saha et al. (2008) reported similar results in a younger population (26±2.6 years) by having participants induced various levels (0^o, 25^o, and 50^o) of trunk flexion. Concerning gait performance, this current study saw significant reductions in velocity and step length only with the introduction of texting (Figure 4.13. and Figure 4.12., respectively). There was also a significant increase in gait variability (stride length, stride time, and gait phases). As these reductions in gait performance were not present in the holding conditions, and posture was not different between holding and texting, they can be attributed to the introduction of the secondary task. This is not in-line with the findings of Saha et al. (2008) but is most likely due to experimental differences, specifically the much larger (25^o to 50^o) level of flexion induced at the hips during Saha et al. (2008) protocol and the fact that this current study had a secondary task, whereas Saha et al. (2008) did not.

Gait performance reductions in this current study were associated with the dual-task nature of texting while walking and not postural changes. Participants had reductions in gait velocity ranging from 18.5% to 21.9% (females) and 17.2% to 18.2% (males) for one-handed texting and two-handed texting, respectively. Contrary to majority of the literature on gait velocity, the female participants on average walked significantly faster than the male participants in this study. This finding remained even when normalized for height. Perhaps the female participants felt less comfortable in the testing conditions, which may have led to faster than normal walking. However, the reductions in velocity to the conditions in this study are in general agreement with other similar studies; gait velocity reductions, during phone conditions, reported (for both sexes) have ranged from 10% (Agostini et al. 2015), 22% (Demura and Uchiyama 2009), 24.1% (Schabrun et al. 2014), and 18.5% - 27.7% (Plummer et al. 2014). However, to the author’s knowledge, no previous study has reported sex differences in gait velocity during similar conditions. The values in the literature are not all in agreement, ranging from 10%-27.7%, but differences can be attributed to protocol. Agostini et al. (2015) protocol was very similar to this current study, with a key difference being continuous walking for 3 minutes. This may have let the participants become more habituated with the testing parameters, resulting is a less effected gait.

The protocol used by Demura and Uchiyama (2009) was the most similar to the current study, with walking distances of 5 m and responses to questions being given via email. As expected, the gait velocity reductions are similar. The largest reduction reported, 27.7%, was by Plummer et al. (2014), and was a result of participants being instructed to give priority to texting; when no priority was given the reduction in velocity was 18.5%. The degree to which the secondary task affects gait velocity is dependent on the priority given to each task (Plummer et al. 2014). With no priority given in the current study, the results are similar to those of previously reported studies (Demura and Uchiyama 2009; Schabrun et al. 2014) and of Plummer et al. (2014) when their participants were not given instruction to prioritize the secondary task. Therefore, the current study's findings show that the increased cognitive demand created by the secondary task (smart phone texting) was the main reason for the reduction in gait velocity.

Reductions in gait performance during texting were not limited to velocity. The current study also had significant increases in stride variability, stance time, and phase variability. Variability in stride time increased from 1.4% during control to 2.0% during Text-1H and 2.4% during Text-2H. The increases during the texting conditions equate to 47.9% and 73.1%, respectively. The values for stride time variability are similar to a study by Beauchet et al. (2005), who reported that participant stride time variability increased from 1.8% (0.8) during a single task to 2.1% (1.1) during dual-task, an increase of 16.7% ($p=0.015$). Their dual-task was to count backwards from 50 during a self-selected pace walking trial, which these authors admitted was relatively easy. The larger stride time variation in this current study could be due to a more complex task that requires visual-motor coordination, bimanual movements (for two handed conditions), and cognitive attention to content and response (Agostini et al. 2015). Yogev-Seligmann et al. (2010) did a similar study using a cognitive test on a handheld screen; they reported an increase in stride time variability by 11.3%. The cognitive test in the Yogev-Seligmann et al. (2010) study was also relatively easy, requiring the participants to connect numbers in order on a screen. In contrast, Agostini et al. (2015), who tested stride time variability while texting during gait, reported increases of 25.3%. Variability in gait in older populations is a good predictor of risk of falls as it indicates increased attention into the task (Rispens et al. 2015). The more automatic gait is the less variability it should be. However, variability is not always negative as it is necessary to navigate uneven ground and obstacles in the environment. As this study was on an unobstructed flat surface, the increased variability is a good indicator that attentional resources were taxed more during the texting condition. Therefore, the results in the literature and the current study suggest that texting is a highly demanding secondary task that can significantly increase variability in gait, reducing control and balance.

Gait phase changes were another area where significant changes occurred in the current study. Stance phase of gait during texting conditions increased, with similar reductions in swing phase (Figure 4.15.). The gait phases during the control were 61.0% stance and 39.0% swing, which is normal for a healthy population. During the texting conditions, there was an increase of 1.6% to 1.8%, so that Text-2H was 62.6% stance and Text-1H was 62.7% stance. The results are comparable to Agostini et al. (2015), who found a 1.1% increase ($p<0.001$) in stance phase during texting. The previously mentioned literature's authors further broke their stance phase results into heel contact, flat foot contact, and push off. What they reported was a 2.6% increase in flat foot contact ($p<0.001$) and a 2.8% decrease in push off phase ($p<0.001$). The gait phase changes seen in their study were attributed to a reduction in gait velocity. The results of this current study are in line with those outcomes reported: overall increased stance phase, less swing, and reduced velocity. Further, this current study found the increases in stance were mainly double-support. More time spent in double supported stance decreases the exposure to instability during gait and may serve to reduce the attentional demands during swing phase as well as reducing the exposure to instability. Again, the only reductions in gait performance were during the texting conditions. The results of this current study give evidence that this population was not significantly affected by the postural adaptations (FlexP) during texting but rather the dual-task nature of it.

Muscle activity of the ES muscles in the thoracic region (TES) and lumbar region (LES) had no significant difference between conditions for the male participants. However, like females participants, activity was highest during the Hold-2H condition, with left muscle (TES and LES) activity higher than right. Females had the largest values for LES and TES activity during the Hold-2H condition (Figure 4.18. and Figure 4.19., respectively). The TES increase in activity during the Hold-2H did not coincide with the highest level of extension in the thoracic region (UT or LT segment), like expected. Other studies have shown increases in thoracic ES activity during erect upright sitting (increased thoracic extension) and decreases in activity during slumped sitting (increased thoracic flexion) (Caneiro et al. 2010; O'Sullivan et al. 2002). Caneiro et al. (2010) reported increases of TES activity of 3 %MVC during their upright (thoracic most extended) posture. Alternatively, during their slumped seated posture, the authors (Caneiro et al. 2010) reported 20^{o} of increased neck flexion, which coincided with the lowest level of TES activity (2 %MVC). The results of the current study reported increases of neck flexion between 14% -20% for the smart phone conditions (texting highest) with lowest level of TES activity occurring during texting conditions (1.6%-3% MVC), similar to the slumped posture of Canerio et al. (2010) and slumped posture of O'Sullivan et al. (2002). As gait is a dynamic task relative to seated postures, it was still expected to see significant increases in average TES activity during smart phone conditions to counteract the forward translation of the head via increased extensor moment. However, this was not the case: instead, with increased neck flexion and subsequent UT flexion, the participants of the study had their lowest level of TES activity during the highest level of flexion. It appears that increased flexion in the superior segments (neck and UT) during gait are similar to those of seated postures reported by Canerio et al. (2010) and O'Sullivan et al. (2002). EMG results for TES activity were not significant, with comments being made based off of trends.

LES activity, like TES, was highest during Hold-2H condition (2.9% for males and 3.8% for females), with the lumbar segment at its lowest level of flexion (most extended) during that condition (0.7^{o} for males and 1.5^{o} for females). Superficial lumbar ES muscle activity has been shown to increase with extension of the lumbar and decrease in slumped seated postures (O' Sullivan et al. 2006). Despite not all of these values having significance (Table 4.17.), the results of this current study indicate that LES activity increased relative to lumbar segment extension. This is in agreement with the findings of O'Sullivan et al. (2006), who reported that lumbar ES activity increased with increased lumbar extension in seated postures. As previously mentioned, the increase in LES activity with lumbar extension is most likely to counteract the anterior shear from the forward translation of the bodies CoM. When the lumbar spine is not flexed, it maintains its oblique line of action and is able to generate posterior shear (McGill et al. 2007).

Concerning upper trapezius activity, this study expected to see increases of upper trapezius (TRAP) activity during smart phone conditions, but this did not occur. Recent research focusing on upper limb EMG during seated texting reported increases in ipsilateral trapezius activity during one-handed typing (Lee et al. 2015). Their activation levels during one-handed texting were 6.6%-9.0% MVC, while two-handed texting was 5.84 % MVC. The current study showed no difference between conditions nor between one- or two-handed use, with an average trapezius activity of ~3%. The dynamic nature of gait might be a reason why significance was not found in average EMG levels, but to date no mobile device study has looked at muscle activation of the trapezius during gait for comparison. In the future, a static standing condition and/or normalizing EMG to a submaximal task may yield more meaningful results.

Changes in posture and gait associated with smart phone and similar device use may undermine functional walking, impact safety, and be potential risk factors for developing thoracic hyper kyphosis in advanced years. This study demonstrated that the superior spine segments (cervical and upper thoracic spine) had increased flexion during smart phone conditions, and with this potentially more strain on passive tissues since ES of the thoracic region did not change significantly in most circumstances. By increasing flexion there is an increase in the shear load and a shift in the load distribution from the back musculature to the passive tissues of the spine. This can increase the risk for developing FlexP through damaging the passive tissues (lose ability to resist the loading) and indirectly weakening the ES. As previously stated, changes in upper spine regions (cervical and thoracic) can have a significant impact on the lumbar region, as well as gait and gait performance. Further, texting significantly reduced gait performance by decreasing velocity and increasing variability in strides. Though postural changes in this population were not a significant factor in gait changes, they may be more prevalent in older populations or ones with cognitive/physical illnesses or injuries. More work needs to be done in the area of mobile technology and how its use affects individual attention, posture, and muscle activity.

6. Limitations

Some important limitations need to be addressed. First, the participants for this study were healthy, university-aged persons recruited from a university campus. The results and conclusions from this study therefore cannot be generalized to other populations as they may not be of accurate representation of populations outside of the one recruited.

The large amount of equipment required to gather full body kinematics, as well as bilateral EMG of the eight muscles recorded, was another obstacle in this study, as seen in Figure 3.2. The equipment had the possibility to restrict movement due to the wiring and the unnatural "feel" of wearing it. The restrictive nature of the cabling was controlled for by appropriating taping to minimize cable sway and make sure that the participants did not get tangled in the wires. Also, the equipment required three cables to connect participants to EMG and motion capture. To reduce any tugging of the cables or cable sway, one investigator held the cables (releasing them as needed) during the conditions. Smaller participants were more affected due to lack of room on them for setting up and taping down the equipment and thus could have less accurate results than the taller participants.

Furthermore, some participants were more nervous than others when asked to move around with the large amount of equipment on them, fearing they might damage it. To increase comfort levels, participants were given time to get familiar with the equipment and reassured not to worry about possibly damaging it as that responsibility falls upon the investigators present.

Lastly, due to the limited size of the pressure walkway (4.9 m), walks were very short, with some being less than six consecutive foot falls. Though only three foot falls are needed to gather gait and stride data, longer walkways such as 8m or more, are often reported in related literature (Agostini et al. 2015; Plummer et al. 2014; Schabrun et al. 2014), may have produced even more consistent results.

7. Conclusion

An ever-growing percentage of our lives are spent behind smart phones, whether we are using them for work or personal use–they are how we stay connected. Previous studies have examined the effects of mobile phone use on neck (cervical) and/or trunk posture, spatial-temporal characteristics of gait, and muscle activity, but never in the same study as this current study does. Previously, flexion during texting conditions has only been measured in the neck but with the results of this current study it was possible to identify that flexion occurs further down the spine into the upper thoracic region as well as an increase in extension in the lower regions (lumbar).The difference between no-task gait (control), holding smart phone, and texting on a smart phone were measured to quantify the effects of smart phone use on gait and posture. Postural changes did not occur between holding and texting conditions; however, spatiotemporal gait characteristics did. Velocity slowed with decreased stride lengths during texting conditions. Further, gait had increased variability in both phases of gait as well as stride-time. In unaffected, young adults, variability in gait is mostly attributed to the reductions seen in velocity but still, variability in level ground walking with no obstacles shows increased demand for attention and possibly resulting in gait being less automatic during texting. Lastly, postural changes during smart phone use may affect the loading patterns of the spine during gait but it is the dual-task nature of smart phone use during gait that significantly reduces gait performance in university-aged populations. Not only is increased smart phone use reducing our situational awareness, it is also increasing our exposure to poor posture. Adopting a more flexed spine posture, or ‘poor posture’, for longer periods of time in this population may accelerate the onsetof kyphosis so it occurs at a younger age, as well as increase the prevalence and severity of kyphosis in this population as they age.

8. <u>Revisiting Hypotheses</u>

This research investigated smart phone use on the posture, muscle activity, and gait of 20 university-aged participants. There were no differences between posture of smart phone holding conditions and texting; however, gait performance was reduced during texting. EMG results showed a trend of increased LES activity with increased lumbar extension, while TES activity decreased during texting conditions.

Hypothesis #1 states: ***Smart phone conditions will induce more cervical and thoracic flexion than control (standing and walking).***

This hypothesis was ACCEPTED

Smart phone use during smart phone conditions (holding and texting) had at least 11.1^{o} (females) and 17.4^{o} (males) more flexion than control conditions. The UT segment, with less RoM than the neck segment, had at least 1.8^{o} more flexion during smart phone conditions than control. LT segment had 0.9^{o} more flexion during smart phone conditions, though comparisons were not significant.

Hypothesis #2 states: ***Smart phone conditions will increase muscle activity in the cervical and thoracic regions (i.e. upper trapezius and thoracic erector spinae).***

This hypothesis was REJECTED

Muscle activity in the upper trapezius muscle did not change significantly during any condition relative to control. The TES muscles did not show any trends or patterns of increased muscle activity during texting conditions, while the LES had larger values during the condition with the highest level of lumbar extension.

Hypothesis #3 states: ***Texting and device holding conditions will increase variability in both spatial and temporal gait characteristics (i.e. step length, step time, gait phases, etc.) when compared to control.***

This hypothesis was REJECTED

Spatiotemporal gait variables only changed significantly with texting conditions even though all smart phone conditions had participants instructed to look at screen. Variability of gait phases, stride lengths, and stride times increased significantly with the introduction of texting.

Hypothesis #4 states: ***Pain developers (>9mm on VAS) will report higher levels of habitual smart phone use (hours and number of texts) compared to non-pain developers.***

This hypothesis was REJECTED

No participant had a clinically significant increase (over 9 mm) of reported back and/or neck pain during the collection. Nor were there any significant differences between the duration and frequency of use between participants. Most studies that report significant increases in VAS scores are over 30 minute sedentary postures (Nairn et al. 2013; Nelson-Wong and Callaghan 2010) and could be a reason why significant increases did not occur in this current study.

9. Relevance/Future Direction

This study is important in the field of biomechanics because of the further insight obtained into the effects smart phone use has on posture, muscle activity, and gait. Segmentation of the spine into neck (cervical), UT, LT, and lumbar portions gave increased detail on how posture changes during use. To date related literature has only examined neck flexion (C7 and up) during smart phone use but did not consider the inferior spine segments. As the results of this study show, flexion occurs in the upper thoracic segment as well as a tendency for increase lumbar extension during the use of a smart phone. This study also controlled for postural effects from texting by having holding and texting conditions, which aids in quantifying changes caused by posture and changes caused by dual-task competition.

It is known that increased sagittal flexion in the spine is a serious problem faced by older populations (65+) today, causing a reduction in quality of life. What is concerning is that the negative effects of thoracic kyphosis in older populations of today is that they were not exacerbated by the increased sedentary lifestyle and poor posture that smart phones and related technologies tend to introduce. It is very possible that increased exposure to poor posture and lack of physical activity can have long-term consequences. This was the first study to quantify sagittal spine angles at various levels as well as examine effects of posture and smart phone use on gait. Findings revealed that increased flexion occurred in both the cervical and upper thoracic region, while the lower body saw increased lumbar extension and posterior pelvic tilt. This information gives increased detail into how posture changes during smart phone use. Gait performance only decreased during texting conditions, illustrating that in healthy, university-aged populations, the dual-task nature of smart phone use significantly reduces performance outside the effects of posture. However, increased exposure to long durations of flexed postures will change the loading distribution to rely more on the passive tissues of the spine, may decrease ES strength through less use, and may increase the risk factor for developing thoracic kyphosis in the future. More work needs to be done to quantify both the short-term and long-term effects smart phone use can have on posture, muscle activity, loading patterns, and mobility.

A possible next step for muscle activity and loading patterns during smart phone use could be the collection of data on longer duration standing postures while texting. This may give further, isolated, results on the effects the adopted posture has on the posterior chain musculature. Static standing postures would control for the cyclical effect of gait on postural changes and related EMG. Also, more research needs to be done in the quantification of different spine levels (i.e. cervical, upper thoracic, lower thoracic, and lumbar levels) during mobile phone use, as the literature rarely looks past cervical levels. Finally, the addition of a purely cognitive dual-task condition similar to the texting conditions would give further insight and control for the physical interaction with the device. For example, asking similar questions as seen in texting conditions but during upright, self-selected pace walking. This would investigate whether the act of typing out the message played a role in gait reductions or if it was purely due to the secondary task.

This study has only given insight into the short-term effects of smart phone use; future directions should be to increase knowledge of short-term use and to start exploring potential long-term effects. A potential starting point would be quick postural measurements of a large sample population, such as the occiput-to-wall distance, and a survey of smart phone use (duration, frequency, etc.). The increased knowledge generated by this current study, previous studies, and future studies could help reduce future occurrences of FlexP by educating the public on causes of back pain and poor posture. As well as through the development and implementation of exercise and awareness programs, either as a new addition to physical education classes in elementary school and/or walk breaks every few hours for seated jobs.

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Appendices

Appendix A. Questionnaire

YORK UNIVERSITÉ UNIVERSITY

Date: DD/MM/YYYY ______ **Participant Code:**____________

Date of Birth: DD/MM/YYYY ______ **Handness:** R/L ______

Pre-Test Questionnaire

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.

1. What devices do you typically use (please circle all that apply)

Desktop Computer   Laptop   Tablet   Smart Phone

2. How much time do you spend on your **laptop/computer/tablet** during the typical day? (Circle one)

0 Hours   1-2 Hours   3-4 Hours   4-5 Hours   5-6 Hours   6-7 Hours   7+ Hours

3. How much time on either device in question 1 do you spend (Please circle):

A. Playing video games	0 hours	<1	1	2	3	4	5	6	7+
B. Doing work	0 hours	<1	1	2	3	4	5	6	7+
C. Browsing internet	0 hours	<1	1	2	3	4	5	6	7+
D. Watching TV/Movies	0 hours	<1	1	2	3	4	5	6	7+
E. Texting/Emails	0 hours	<1	1	2	3	4	5	6	7+
F. Phone calls	0 hours	<1	1	2	3	4	5	6	7+

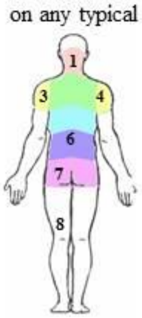
4. Please indicate what postures you adopt while using your **laptop/computer** (Please circle)

A. Standing	0 hours	<1	1	2	3	4	5	6	7+
B. Sitting (device on desk)	0 hours	<1	1	2	3	4	5	6	7+
C. Sitting (device on lap)	0 hours	<1	1	2	3	4	5	6	7+
D. Lying down	0 hours	<1	1	2	3	4	5	6	7+

5. Please indicate what postures you adopt while using your **tablet** (Please circle)

A. Standing	0 hours	<1	1	2	3	4	5	6	7+
B. Sitting (device on desk)	0 hours	<1	1	2	3	4	5	6	7+
C. Sitting (device on lap)	0 hours	<1	1	2	3	4	5	6	7+
D. Lying down	0 hours	<1	1	2	3	4	5	6	7+

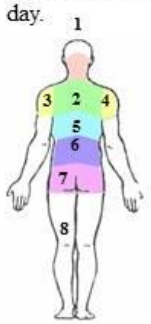
6. Please indicate the level of pain/discomfort, in the labelled regions, when using your **laptop/computer**. on any typical day.   (0 = no pain, 6 = very painful)



(1)Neck:	1	2	3	4	5
(2)Left Shoulder:	1	2	3	4	5
(3)Right Shoulder:	1	2	3	4	5
(4)Upper-back:	1	2	3	4	5
(5)Mid-Back:	1	2	3	4	5
(6)Lower-Back:	1	2	3	4	5
(7)Buttocks:	1	2	3	4	5
(8)Legs:	1	2	3	4	5

Participant Code:_____________

7. Please indicate the level of pain/discomfort, in the labelled regions, when using your **tablet** on any typical day. (0 = no pain, 6 = very painful)



(1)Neck:	1	2	3	4	5
(2)Left Shoulder:	1	2	3	4	5
(3)Right Shoulder:	1	2	3	4	5
(4)Upper-back:	1	2	3	4	5
(5)Mid-Back:	1	2	3	4	5
(6)Lower-Back:	1	2	3	4	5
(7)Buttocks:	1	2	3	4	5
(8)Legs:	1	2	3	4	5

8. Do you use an external mouse when using a laptop? ☐Yes ☐No

9. How much time do you spend on your **smart phone** during the typical day? (Circle one)

0 Hours 1-2 Hours 3-4 Hours 4-5 Hours 5-6 Hours 6-7 Hours 7+ Hours

10. Please indicate what postures you adopt while using your **smart phone** (Please circle)

A. Standing	0 hours	<1	1	2	3	4	5	6	7+
B. Sitting	0 hours	<1	1	2	3	4	5	6	7+
C. Lying down	0 hours	<1	1	2	3	4	5	6	7+

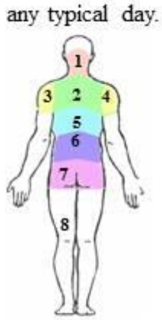
11. How many Texts do you send on a typical day (please circle one or specify other)?

0-20 21-40 41-60 61-80 80-100 over 100 Other:________

12. Do text/email while walking?

Never Sometimes Often Very Often Always

13. Please indicate the level of pain/discomfort, in the labelled regions, when using your **smart phone** on any typical day. (0 = no pain, 6 = very painful)



(1)Neck:	1	2	3	4	5
(2)Left Shoulder:	1	2	3	4	5
(3)Right Shoulder:	1	2	3	4	5
(4)Upper-back:	1	2	3	4	5
(5)Mid-Back:	1	2	3	4	5
(6)Lower-Back:	1	2	3	4	5
(7)Buttocks:	1	2	3	4	5
(8)Legs:	1	2	3	4	5

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Participant Code:______________

14. Do you workout, play sports, or participate in any other other physical activities? ☐Yes ☐No
    a. If yes to above, please indicate which sports or activities and frequency (times per week and length)

____
____
____
____
____
____

15. What is your occupation (student, cashier, construction worker, etc.)?__________________________
    a. How many hours a week do you work? ________hours
    b. How many hours do you spend sitting at a desk ________hours
    c. How many hours do you spend on phone calls? ________hours
    d. How many hours do you spend texting/emailing? ________hours

16. Do you have part time work, if so, list job(s) and answer the following)?_________________________

	Job 1	Job 2
a. How many hours a week do you work?	________hours	________hours
b. How many hours do you spend sitting at a desk	________hours	________hours
c. How many hours do you spend on phone calls?	________hours	________hours
d. How many hours do you spend texting/emailing?	________hours	________hours

17. Have you ever had back that caused you to miss a day of work/school? ☐Yes ☐No
    a. If yes, what was the general location? ______________________________________
    b. If yes, did you seek medical attention and if so, what was the diagnosis______________________

18. Have you had low back pain in the last six months? ☐Yes ☐No
    a. If so, did it require medical attention
    b. If so, how frequent infrequent often very often
    c. If so, indicate on the line below the level

No pain —————————————————— Worst pain imaginable

19. Please indicate the level of back pain you are currently experiencing

No pain —————————————————— Worst pain imaginable

This is the end of the questionnaire. Please return to researcher.

Appendix B. Reprint Permissions

Figure 1.1: Reprinted with permission from McGill, S. (2007). Low Back Disorders: Evidence-based Prevention and Rehabilitation (2nd ed.). Human Kinetics, Windsor, ON: p. 53, Fig 4.27).

Table 3.3: Modified with permission from Demura and Uchiyama (2009). Influence of cell phone email use on characteristics of gait. Journal of Sport Science Vo1.9:5: p.304, Table 1. www.tandfonline.com

Figure 3.1: Reprinted with permission from Martini, F.; Nath, J.; Barholomew, E. (2015). Fundamentals of Anatomy & Physiology (10th ed.). Pearson Education, Inc., New York, New York.