THESIS

EFFECTS OF PROLONGED STANDING ON GROUND REACTION FORCE CONTROL AND CORE MUSCLE ACTIVATION

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ABSTRACT

Prolonged standing (PS) is a common activity that is becoming more recommended in the work place. However, there's a strong association between PS and low back pain (LBP) with up to 81% of individuals reporting LBP after 2 hours or less on their feet. There is also a noted sex difference with this LBP development during PS, with women experiencing LBP with a higher frequency than men, while men report higher pain levels of LBP than women. The specific factors involved, and sex related differences are not fully understood. One potential factor may be bilateral asymmetries in posture. The goal of this study was to examine the effect of PS on bilateral weight-bearing, ground reaction force (GRF) control (i.e., center of pressure (CoP)) and core muscle activation within healthy young adult men and women during quiet stance (QS).

Twenty-four healthy, pain-free subjects (12 men, 12 women) voluntarily participated in the study (age = 22.3 ± 2.4 years, height = 1.70 ± 0.09 m, mass = 69.89 ± 11.31 kg, BMI = 24.1 ± 2.5 kg/m^2 [mean ± SD]). Subjects performed two 60 second QS trials (pre-PS & post-PS) separated by one 30 minute free standing trial while bilateral GRFs under each foot and surface electromyography (sEMG) of each lumbar erector spinae (ES), gluteus medius (GM), internal obliquus (IO), and external obliquus (EO) were measured. Muscle activity was normalized to a submaximal reference contraction (%ref). Sway, maximum velocity (maxV), and path length (PL) were calculated from the CoP for both the dominant (D) and non-dominant (ND) foot, as well as net combined values. All CoPs were calculated in both the anterior-posterior (AP) and medial-lateral (ML) directions, and were normalized to standing height (%height). Weight-bearing

(WBAs), muscle activation (MAAs), and CoP asymmetries (CoPAs) were calculated by subtracting the ND limb from their D limb using the symmetry index (%SI) equation.

There were no differences in WBAs, MAAs, or CoPAs between the pre-PS and post-PS trials, nor between the men and the women ($p \geq 0.058$). However, there was an increase in the net PL (both AP and ML), AP sway, and ML maxV after PS exposure ($p \leq 0.003$). With CoP movements, generally the ND limb was a greater contributor than the D limb for both of the QS trials. For the pre-PS trial, the ND limb had greater ML PL, AP PL, ML maxV, and AP maxV ($p \leq 0.032$), while sway did not show significant difference between the two limbs in either the ML or AP directions ($p \geq 0.585$). ML PL, AP PL, and AP maxV was greater for the ND limb ($p \leq 0.001$), while ML sway, AP sway, and ML maxV did not significantly differ between the limbs for the post-PS trial ($p \geq 0.084$). During the pre-PS trial, there was a significant correlation between the WBAs and the GM asymmetry for the women ($p=0.044$, $r=0.615$) but not the men ($p=0.259$, $r=0.354$). This correlation was not significant during the post-PS trial for either sex ($p \geq 0.176$, $r \leq 0.418$). Significant negative correlations were found between WBAs and CoPAs during the pre-PS trial for the ML sway and ML PL variables for the women ($p \leq 0.019$, $r \leq -0.660$), and ML PL and ML maxV variables for the men ($p \leq 0.018$, $r \leq -0.666$). During the post-PS trial, these significant correlations (also negative) were present for the ML sway, ML PL, AP PL, and AP maxV variables for the women ($p \leq 0.024$, $r \leq -0.644$), and ML PL, AP maxV, and ML maxV variables for the men ($p \leq 0.029$, $r \leq -0.628$). There were no significant correlations found between the absolute WBAs and net CoP movements for both of the QS trials, as well as for both sexes ($p \geq 0.082$, $-0.521 \leq r \leq 0.461$) The women had overall higher GM activity than the men (women = 7.6 ± 3.4 %ref, men = 4.8 ± 2.9 %ref; $p=0.041$). Overall ES activity decreased from the pre-PS to the post-PS trial for the men, but not the women (women = 2.1 ± 1.0 %ref, pre-PS men = 2.6 ± 1.8 %ref, post-PS men 1.8 ± 1.5 %ref; p=0.002).

While these results suggest that 30 minutes of PS does not have an effect on WBAs, MAAs, or CoPAs during QS in healthy young adults, there appears to be an effect on net CoP movements, as well as sex related differences in both muscle activity and change in muscle use. Previous studies have indicated fatigue causing increased CoP movements, which suggests that PS may also be inducing low levels of fatigue. There has also been indication that men and women have differences in hip muscle activation strategies, which could be reflected in the GM activity findings. The decrease in ES activity from pre-PS to post-PS that was recorded in men and not women is possibly related to men having higher relative percentages of the more fatigable type II muscle fibers in the ES. These findings shed light on why men and women may respond differently to PS.

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Chapter I: INTRODUCTION

Prolonged standing (PS) is a common activity that is becoming more highly recommended in the work place (Plotnikoff & Karunamuni, 2012). However there's a strong association between PS and low back pain (LBP) with 40-81% of asymptomatic individuals reporting LBP after 2hrs or less on their feet (Gregory & Callaghan, 2008, Nelson-Wong & Callaghan, 2010c, Nelson-Wong et al., 2008, Nelson-Wong et al., 2010). One potential cause to this LBP development has been thought to be functional asymmetries (FAs), such as through association with weight distribution (Childs et al., 2003). FAs are side-to-side differences in kinematics, kinetics, and/or muscle activations during otherwise symmetric tasks. These asymmetries are typically measured during quiet stance (QS) trials of short duration and minimal movement. With a force platform under each foot both weight-bearing asymmetries (WBAs) and center of pressure asymmetries (CoPAs) can be evaluated. Center of Pressure (CoP) is commonly assessed to examine postural stability and balance. Limb dominance has been noted to play a role in CoP movements, with the non-dominant (ND) contributing more to postural stability than the dominant (D) limb (Genthon & Rougier, 2005, Rougier & Genthon, 2009, Sadeghi et al., 2000).

Balance and stability is of interest during PS due to the low-level fatigue that may be accumulating. Body weight (BW) shifts with increasing frequency that level off after the first 30 minutes of PS have been observed in healthy adults (Gallagher et al., 2011) suggesting that the body adapts relatively quickly to the imposed stress of standing. In QS trials, exercise induced fatigue has been noted to cause increases in CoP movements, such as maximum excursion (sway), maximum velocity (maxV), and mean velocity / path length (PL) (Bermejo et al., 2015, Corbeil et al., 2003, Gribble & Hertel, 2004). Additionally, increases in CoP movements have been shown to be associated with WBAs, with greater WBAs causing more movement under the feet (Anker et al., 2008, Genthon & Rougier, 2005, Rougier & Genthon, 2009). With both fatigue and higher WBAs being associated with an increase in CoP movements, it's possible that there's a direct relationship between fatigue and increased WBAs and CoPAs during PS.

Due to the association between WBAs and LBP (Childs et al., 2003), it's likely that the muscles of the lumbar spine and trunk play an significant role, specifically as stabilizers. As indicated, fatigue (due to both exercise and PS) has been noted to cause increased CoP movements and BW shift frequency (Bermejo et al., 2015, Corbeil et al., 2003, Gallagher et al., 2011, Gribble & Hertel, 2004). In addition, fatigue causes changes to muscle use (Gregory & Callaghan, 2008, vanDieën, 1996). With fatigue influencing all of these variables, perhaps there's a relationship between changes in core muscle activation (i.e.; muscle activation asymmetries (MAAs)) and ground reaction force (GRF) control (WBAs and CoPAs).

Within all of these aspects, there are potential differences between men and women during QS when exposed to PS. During PS, women typically experience LBP with a higher frequency than men, but at lower pain levels (Nelson-Wong & Callaghan, 2010c). It's also been reported that men (specifically those that develop pain when standing (PD)) spend the least amount of time in asymmetrical stance at the beginning of the standing trials (Gallagher et al., 2011). While it's not known if it's significant, women who do not develop pain when standing (NPD) appear to spend an increasing amount of time in an asymmetrical stance through the duration of the PS trial (Gallagher et al., 2011). When requiring men and women to undergo functional movements, such as trunk flexion-extension, prior to and after PS, there are differences in muscle activation strategies, with women having this motion originate from the hip rather than the trunk (Nelson-Wong et al., 2012). Another functional movement, single leg stance, conducted around PS trials have indicated that women have better balance than men (Nelson-Wong et al., 2010). As previously indicated, core muscles potentially play a vital role in relation to asymmetries, and more importantly, these muscles are where significant differences between men and women are present with muscle use, size, and fiber type percentage (Gallagher et al., 2013, Mannion et al., 1997, Marras et al., 2001, Miller et al., 1993, Nelson-Wong et al., 2012). Due to the wide variety of the testing protocols used, and the lack of complete measures within a single cohort, it's difficult to understand how some of these differences may or may not be related.

Therefore, the primary aim of this study was to evaluate the effect of 30 minutes of PS on GRF control and core muscle activation within healthy, young adults in QS. A secondary aim was to examine the presence of any sex differences. These results will help provide a basic understanding of healthy NPD. In a clinical setting, these results can be used to help assess whether or not an individual displays healthy asymmetries, muscle use strategies, and postural stability, thus being able to determine if they are at risk for LBP development. Sex-specific assessment techniques may be able to be designed, depending on the results pertaining to differences among men and women. Intervention techniques could also be developed based on the results, specifically those pertaining to PS.

Hypotheses

1. Fatigue due to 30 minutes of PS will cause an increase in the WBAs, MAAs, and CoPAs as tested by QS.
2. Fatigue due to 30 minutes of PS will cause an increase in the net CoP movements during QS.
3. The ND limb will have higher CoP movements than the D limb during QS both pre-PS and post-PS.
4. There will be significant correlations between the WBAs and MAAs during QS both pre-PS and post-PS, though the relationships may change with fatigue.
5. There will be significant correlations between the WBAs and CoPAs during QS both pre-PS and post-PS, though the relationships may change with fatigue.
6. There will be significant correlations between the absolute WBAs and the net CoP movements during QS both pre-PS and post-PS, though the relationships may change with fatigue.
7. There will be significant differences between the men and the women during QS both pre-PS and post-PS in weight bearing, muscle activity, and CoP movements.

Chapter II: LITERATURE REVIEW

Low Back Pain (LBP)

LBP is a prevalent issue with many socioeconomic and personal costs per year (Andersson, 1999, Deyo & Weinstein, 2001). It's estimated that nearly 70-85% of all people experience back pain at some point in their life (Andersson, 1999). In the United States, back pain is the most common cause of limitation to activity in individuals under 45 years (Andersson, 1999). Additionally, it's the second most frequent reason for doctor's visits and the third most common reason for surgical procedures (Andersson, 1999). While women tend to experience more spinal impairments, there hasn't been a noted difference between the sexes as it relates to having LBP (Andersson, 1999). There are a wide variety of causes for LBP, ranging from current/previous injury, to FA and muscle weakness (Childs et al., 2003, Subotnick, 1981). Recently, there's been a noted association between PS and LBP (Gallagher et al., 2011, Gregory & Callaghan, 2008, Nelson-Wong & Callaghan, 2010c, Nelson-Wong et al., 2008, Nelson-Wong et al., 2010). During 2 hours of PS, the percentage of asymptomatic individuals who develop LBP has been found to be 40% (Nelson-Wong & Callaghan, 2010c, Nelson-Wong et al., 2010), 65% (Nelson-Wong et al., 2008), and 81% (Gregory & Callaghan, 2008). There is also a noted sex difference with the development of LBP during PS, with a higher percent of women (48%) reporting LBP than men (32%), but the men reported higher pain levels of LBP than women when it was present (Nelson-Wong & Callaghan, 2010c). These differences may be reflective of the role gender plays in willingness to admit to experiencing pain, with women being more likely to express their own pain development than men (M. Robinson et al., 2001). However, it also could be due to musculoskeletal differences, such as skeletal geometry (Marras et al., 2001, Smith & Smith, 2002) and muscle size/morphology (Gallagher et al., 2013, Mannion et al., 1997, Marras et al., 2001, Miller et al., 1993).

The goal of this literature review is to explore FA of GRFs, core muscle activity, and individual foot CoP movements during QS as potentially important parameters related to LBP that develops in otherwise asymptomatic individuals during PS. The literature review will progress through FAs and their assessment, PS and its relation to LBP, and the effect of fatigue on FAs. Also included in the review will be discussion of QS and specific discussion of how women and men may be affected differently.

Functional Asymmetries (FAs)

FAs, a previously mentioned potential cause of LBP, are the side-to-side differences in kinematics, kinetics, or muscle activation during an otherwise symmetric task. FAs are very common in healthy populations with people exhibiting them during cycling (Daly & Cavanagh, 1976), walking (Herzog et al., 1989), and even just standing quietly (Rougier & Genthon, 2009), to name a few. These differences may be caused by a variety of factors, such as limb/neural dominance (Newton et al., 2006), strength imbalance (Delacerda & McCrory, 1981, Newton et al., 2006), and/or leg length discrepancies (Delacerda & McCrory, 1981). In regards to limb dominance, overall, humans are typically right-footed for actions pertaining to mobilization, and left-footed for postural stability (Sadeghi et al., 2000). When postural movements are involved, the left-foot (which would be referred to as the ND limb) would exhibit higher magnitudes of CoP movements than the right, D limb, due to its role in maintaining balance (Genthon & Rougier, 2005, Rougier & Genthon, 2009).

FAs have also been found to be associated with injury risks (Childs et al., 2003, Herring, 1993, Shambaugh et al., 1991). While its association with LBP was previously noted, more specifically, Childs et al. found that subjects with LBP exhibited higher WBAs than those without LBP during QS (Childs et al., 2003). Additionally, if a subject had higher levels of pain, then it was reflected in higher levels of WBA (Childs et al., 2003). Childs also found that reducing pain through manual manipulation (i.e., chiropractic therapy) reduced the WBAs (Childs et al., 2004). Further, there's been a noted increase in risk of injury to the lower extremities related to asymmetries due to limb dominance (Herring, 1993), and quadriceps angle (Q-angle) of the knee (Shambaugh et al., 1991).

To understand WBAs and CoP movements, studies typically conduct short (60 seconds or less) QS trials on dual force platforms (Childs et al., 2003, Genthon & Rougier, 2005, Rougier & Genthon, 2009, Wang & Newell, 2012). By having subjects stand relaxed with minimal movement, overall asymmetries can be assessed more easily since dynamic effects are excluded from the analysis, which in return makes the asymmetry assessment easier. The implementation of force platforms under each foot allows for the calculation of the instantaneous CoP under each foot in addition to the combined (i.e., net) CoP. The tracking of CoP movements during QS is used for a variety of purposes, such as assessing balance control and potential fall risks (Boulgarides et al., 2003, Ekdahl et al., 1989).

Some QS studies have induced an asymmetry, asking participants to apply more weight to one foot than the other, essentially causing a WBA (Genthon & Rougier, 2005, Rougier &

Genthon, 2009, Wang & Newell, 2012). This allowed for an understanding of how an increase in WBA could influence other FA, such as CoP movements. Two studies conducted similar experiments, requiring healthy individuals to stand with one foot per force platform for 32 second trials (Genthon & Rougier, 2005, Rougier & Genthon, 2009). Genthon & Rougier (2005) required subjects to undergo trials of differing BW distribution, finding that when WBAs increased, there was an increase in the CoP movements primarily under the unloaded support limb. They also found that while the larger WBAs caused an increase in the net CoP motions, the effect was larger in the medial-lateral (ML) direction rather than anterior-posterior (AP) direction (Genthon & Rougier, 2005). A later study by the same group had the individuals undergo two different standing conditions; one with even BW distribution, and one with two-thirds of the BW on the left foot (Rougier & Genthon, 2009). They found that as the WBA increased, there was more CoP displacement under each foot along both the AP and ML directions (Rougier & Genthon, 2009). This WBA increase also caused a net CoP increase in solely the AP direction. Overall, WBAs heightened the role played by the loaded foot in the production of net CoP, especially in the AP direction (Rougier & Genthon, 2009).

While there was a difference in findings of the two Genthon and Rougier studies regarding whether the loaded or unloaded support had a higher increase in these CoP movements due to increasing WBAs, both studies saw that the left foot was the support that was indicated to have higher movements (Genthon & Rougier, 2005, Rougier & Genthon, 2009). However, there's a concern with what the preferred kicking leg (right versus left) distribution was among the participants, since not all people are right foot D and left foot ND. If all the subjects didn't have the same preferred kicking leg (i.e., D limb), it may have been a better choice to have the increase in BW applied to either the D or ND limb. Due to this, it's difficult to make assumptions on the role limb dominance plays in these increases in CoP movements. Although it could be said that due to the majority of humans having their right limb be their D limb (Sadeghi et al., 2000), that perhaps it's the ND limb that has the higher increase in postural movements than the D limb when large WBAs are applied.

Another study that also had participants apply more weight to one foot (inducing a WBA) required that this weight be applied to either limb, as to prevent fatigue from occurring in a single limb (Anker et al., 2008). Their results indicated that with increasing WBA, there was an increase in both CoP velocity asymmetries and amplitudes. However, they found that these increases were higher in the loaded limb, not related to dominance (Anker et al., 2008). This finding disagrees with Genthon & Rougier (2005) that indicated higher increases of CoP sway in the unloaded limb, but agrees with their follow-up study that indicated higher increases in the loaded limb (Rougier & Genthon, 2009). This disagreement among results could possibly be related to the differences in ways that the WBAs were applied in each of the studies. Additionally it was never indicated whether or not limb dominance was taken into consideration (Anker et al., 2008). So, again, it's difficult to make assumptions related to limb dominance due to the lack of information.

A PS study by Nelson-Wong et al. had subjects undergo different functional movements immediately before and after the PS trial, with one of the functional movements being a single-leg stance trial (Nelson-Wong et al., 2010). It was found with right single-leg stance after the PS trial, there was an increase in the CoP sway (i.e., maximum minus minimum location) in the AP direction. With left single-leg stance, there was an increase in CoP sway in both the AP and ML directions from the pre-PS to post-PS trial. In both single-leg stance cases, the men had an increase in sway from the pre-PS to post-PS trials, while the women had a decrease (Nelson-Wong et al., 2010). Another study found similar results, indicating that women had lower sway and velocity than the men during a left single-leg stance functional test of healthy adults (Ekdahl et al., 1989). Further, in this same study, when individuals were examined in a two-legged stance with their feet close together, the men had greater sway than the women (Ekdahl et al., 1989). This indicates a similarity of results between single-leg and narrow two-legged stance trials as it relates to differences between the sexes (Ekdahl et al., 1989). These findings suggest that women may have better balance than men. However, there are other studies that indicate men have better balance (Mechling, 1986), as well as there not being any balance differences between men and women when adjusted for standing height (Era et al., 1996).

Another study conducting QS trials prior to and after a 30 minute PS trial found differences between healthy subjects and those with LBP with CoP movements (Lafond et al., 2009). Subjects with chronic LBP had generally a lower CoP speed during the PS trial in both the ML and AP directions. However, during the QS trials, the LBP subjects had greater CoP speed than healthy individuals in the AP direction, and lower CoP speed in the ML direction. The PS trial also appeared to have an effect on the movements, with the ML CoP speed increasing during QS after PS exposure, specifically for the LBP group. Additionally, the LBP group presented greater CoP area than the healthy subjects during both of the QS trials (Lafond et al., 2009).

Prolonged Standing (PS)

Prolonged standing (PS) is a common activity that's becoming more highly recommended in the work place (Plotnikoff & Karunamuni, 2012). The adoption of standing desks provide individuals with that option. However, as outlined earlier, there's also strong association between PS and LBP, with even asymptomatic individuals developing LBP (Gallagher et al., 2011, Gregory & Callaghan, 2008, Nelson-Wong & Callaghan, 2010c, Nelson-Wong et al., 2008, Nelson-Wong et al., 2010). While there have been several studies conducting PS trials, the main focus was on the actual development of LBP, and how pain developers (PD) and non-pain developers (NPD) differed (Gallagher et al., 2011, Gregory & Callaghan, 2008, Lafond et al., 2009, Nelson-Wong et al., 2010). This was a primary concern due to 40-81% of the individuals, who were all required to be free of back pain and ailments prior to the study, experiencing LBP within 2 hours of PS (Gregory & Callaghan, 2008, Nelson-Wong & Callaghan, 2010c, Nelson-Wong et al., 2008, Nelson-Wong et al., 2010). During the PS trial, it was found that the level of LBP in individuals who identified as PD increased over time throughout the 2 hours of PS (Gregory & Callaghan, 2008, Nelson-Wong et al., 2010). It was noted that while none of the participants had any perceived LBP at the beginning of the study, the PD were often reporting LBP after the first 15 minutes of the standing (Gregory & Callaghan, 2008, Nelson-Wong et al., 2010).

Throughout most of these studies, often FAs related to body weight distribution and CoP movements are an overlooked cause due to the focus on the actual development of LBP. One PS study had healthy individuals stand for 2 hours, while GRFs under each foot were collected such that CoP movements could be tracked (Gallagher et al., 2011). Both unconscious (shifts, drifts, and fidgets) and conscious (body weight shifts) patterns were calculated. The difference between the two CoP shifts was that a unconscious shift was seen as a fast displacement of the average position of the CoP, while a body weight shift into an asymmetrical stance was viewed as the support of approximately two-thirds of the subject's BW on one leg (greater than 65% of their body weight) for longer than 1 second. A fidget was calculated as a fast, large displacement with the CoP returning to approximately the same position, and a drift was a slow continuous displacement of the CoP. One of the most important findings was that BW shift frequency increased during the first 30 minutes, then leveled off afterwards (Figure 2.1). Women PD demonstrated an equal number of shifts on both their right and left feet, while women NPD and men PD shifted onto their left leg more frequently. However, it was never mentioned whether this was the D or ND limb, making it difficult to relate any findings to limb dominance and compare to other studies. There was only a brief discussion of findings related to WBAs. Subjects spent less than 50% of the time standing in asymmetrical postures (more than 65% of their body weight onto one limb), and while it was not mentioned, it appeared that women had an increase in time spent in asymmetrical stance over time (Figure 2.2). Whether or not it was a significant increase was not reported. Male PD spent less than 10% of the first 15 minutes in an asymmetrical stance while male NPD spent more time in an asymmetrical stance, then had an increase in asymmetry during the first hour (Figure 2.2) (Gallagher et al., 2011). These findings could suggest that standing in a more asymmetrical stance is how men prevent LBP from occurring. Regardless, these differences between the men and the women suggest that different mechanisms may exist in LBP development. However, why the men and women differed was not discussed in these articles, nor was it explored in any follow-up studies.

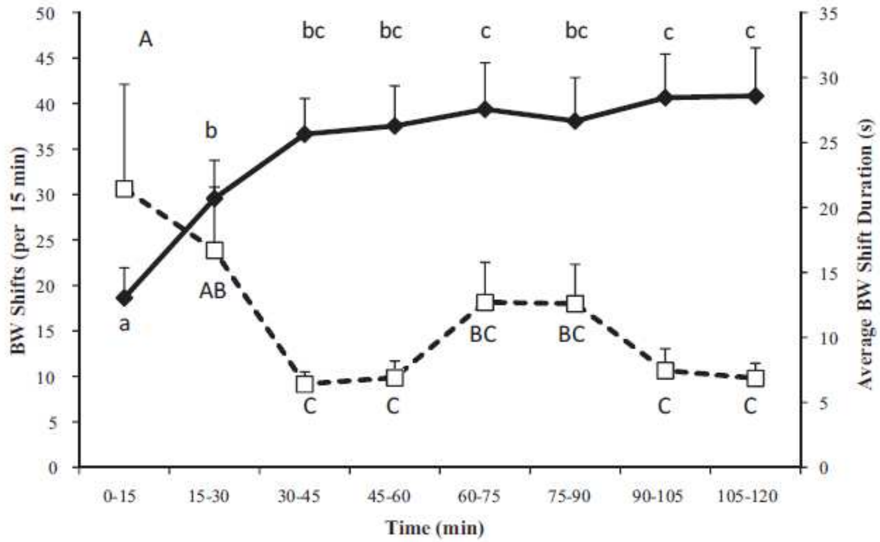


Figure 2.1: Body weight (BW) shift frequency (solid line) and average duration (interrupted line) for all participants. Graph from (Gallagher et al., 2011).

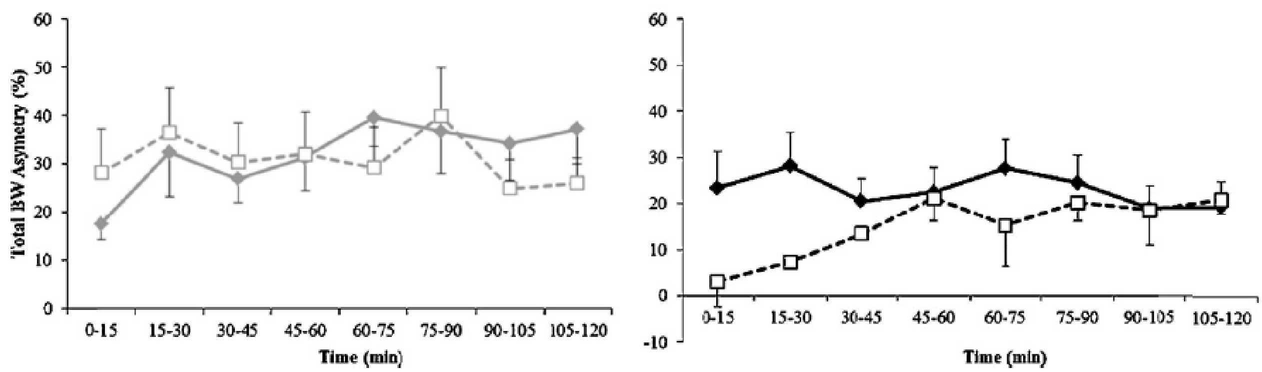


Figure 2.2: Percentage of time spent in an asymmetrical posture for female (grey) and male (black) non-pain developers (solid line) and pain developers (interrupted line). Graphs from (Gallagher et al., 2011).

Another study, briefly discussed previously, has looked into postural control during PS, but similarly, the main focus was on the differences between healthy individuals and those with chronic LBP (Lafond et al., 2009). It was found that subjects with chronic LBP had generally a lower CoP speed and frequency during a 30 minute PS trial in both the ML and AP directions. The CoP speed in the ML direction increased after the PS trial compared to the QS trial prior to

PS for the LBP group (Lafond et al., 2009). Based on these few studies, it's possible that an increase in postural movements is how an individual keeps comfortable during prolonged bouts of standing, and prevents LBP from occurring.

The effect of PS on lumbar spine flexion-extension has been a concern in a few studies, due to it being a common functional task that would be required in an office setting, in addition to there being a relationship between forward flexion impairment and LBP (Nelson-Wong et al., 2010). During this task, the primary focus was on the actual degree of this variable throughout a standing protocol (Gregory & Callaghan, 2008) as well as muscle relaxation during a lumbar flexion task following PS (Nelson-Wong et al., 2010). During the PS trial, the degree of lumbar spine flexion-extension was significantly affected by time (Gregory & Callaghan, 2008). As time increased, participants tended to increase the degree of lumbar flexion (Gregory & Callaghan, 2008). When participants were asked to undergo a forward flexion task prior to and after the PS trial, there didn't appear to be an effect due to PS on the muscle relaxation (Nelson-Wong et al., 2010).

As previously indicated, potential differences between men and women are commonly assessed. Beyond those noted related to WBAs, additional focus has been on the differences found pertaining to muscle use. With some of the PS studies, muscle activity was recorded via surface electromyography (sEMG) on various axial core and hip muscles, to include co-activation of the multiple muscles assessed (Nelson-Wong et al., 2012, Nelson-Wong & Callaghan, 2010a, 2010c, Nelson-Wong et al., 2008). It was found that while there weren't any sex differences relating to hip muscle co-activation (Nelson-Wong & Callaghan, 2010c), there were differences in hip muscle activation responses (Nelson-Wong & Callaghan, 2010a). During a trunk extension exercise prior to a PS trial, used to asses differences in neuromuscular strategies, it was seen that men and women had different muscle activation strategies (Nelson-Wong et al., 2012). Women had a larger contribution to standing trunk flexion originating from the hip. This was shown by the women activating their gluteus maximus prior to the thoracic erector spinae (TES), while men demonstrated the opposite recruitment order (Figure 2.3). Since there weren't any sex differences in velocity of the movement or in total range of motion, it indicates that the women spent relatively more time moving at the hip (Nelson-Wong et al., 2012). These results support similar findings from another study, indicating that men have a greater percentage of total trunk flexion originating from the lumbar spine, while women have a greater contribution from the hip (Hoffman et al., 2012).

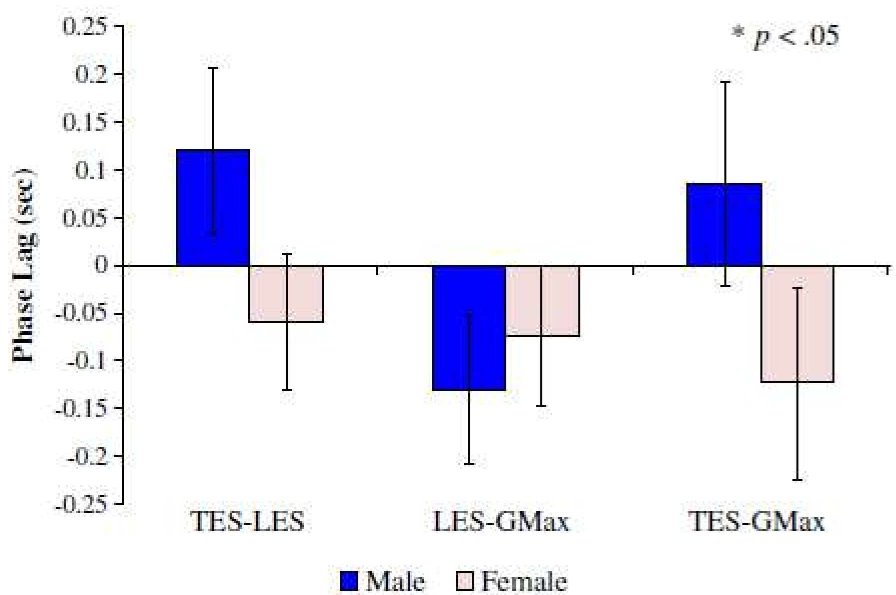


Figure 2.3: Phase lags of the thoracic erector spinae (TES), lumbar erector spinae (LES), and gluteus maximus (GMax). Phase lag calculated as relative timing between maximum cross-correlation of the two muscles. Positive lag indicates the cephalic muscle of the pair activating first. Graph from (Nelson-Wong et al., 2012).

With such high levels of participants experiencing LBP, preventative measures have been looked into as an attempt to help reduce this LBP development during PS. When there was an exercise intervention implemented, there was a significant effect on levels of LBP during PS (Nelson-Wong & Callaghan, 2010a). After 4 weeks of a relatively high intensity exercise program emphasized on strengthening of the trunk musculature, PD showed an overall decrease in levels of LBP, as compared to the PD control group that did not receive the intervention (Nelson-Wong & Callaghan, 2010a). Co-activation of the gluteus medius (GM) was also looked into during this study, and it was found that male PD showed significant change in this co-activation during PS (Nelson-Wong & Callaghan, 2010a). After intervention, male PD had a decrease in this co-activation, as well an increase in rest periods for the right gluteus medius (Nelson-Wong & Callaghan, 2010a). Another attempt to reduce LBP development has been implementing standing on sloped surfaces (Gallagher et al., 2013, Nelson-Wong & Callaghan, 2010b). This method has shown positive results with PD having a significant decrease in levels of LBP while standing on a sloped surface (Nelson-Wong & Callaghan, 2010b). The decrease was so substantial, that there was no longer a significant difference between reported levels of LBP between PD and NPD when they were standing on sloped surfaces. Participants also preferred to stand on a decline slope more often (Nelson-Wong & Callaghan, 2010b), which could be related to the increase in lumbar flexion this standing position provides, as compared with the increased lumbar extension (more lumbar lordosis) that an incline slope induces (Gallagher et al., 2013). When evaluating co-activation of the GM, PD showed a decrease in co-activation during sloped standing, while NPD showed an increase in this co-activation (Nelson-Wong & Callaghan, 2010b). This was indicated to be an interesting find due to hip muscle co-activation typically being associated with susceptibility to pain development (Nelson-Wong et al., 2008). Female PD also had an overall decrease in their trunk flexor/extensor co-activation during sloped standing, while male PD had no change in this measure (Nelson-Wong & Callaghan, 2010b). These findings may support the idea that there are sex-specific mechanisms underlying the effectiveness of intervention techniques (Nelson-Wong & Callaghan, 2010b). A seated break has also shown to have a significant decrease on LBP levels for PD (Gallagher et al., 2014). When individuals (specifically the PD) took a 15 minute seated break after 45 minutes of standing, it was found that the levels of LBP decreased substantially and almost reversed the LBP development caused from the PS (Gallagher et al., 2014).

Effect of Fatigue on Quiet Stance (QS)

PS may induce some muscular fatigue. Considering the limited number of PS studies that have examined QS pre-post, it is valuable to look at how fatigue effects QS from other tasks. In many experimental designs, fatigue is induced via exercise. More specifically, there's a focus on primarily fatiguing a specific muscle group or joint (Bermejo et al., 2015, Corbeil et al., 2003, Gribble & Hertel, 2004, vanDieën, 1996). While there's a variety of different fatigue methods and stance styles across studies, there's consensus with the findings; fatigue causes an increase in CoP movements during QS (Bermejo et al., 2015, Corbeil et al., 2003, Gribble & Hertel, 2004).

With running induced fatigue, there's an increase in the CoP ellipse area and mean velocity in both the ML and AP directions (Bermejo et al., 2015). A single leg stance (on the D limb) study found similar findings, with fatigue causing an increase in the CoP movements

(Gribble & Hertel, 2004). Another study found an increase in the CoP maxV after ankle plantar-flexor fatigue (Corbeil et al., 2003). However, they noted that there wasn't an effect on the range of the CoP (sway). This study had subjects stand barefoot on the force platform with their feet together, which suggests that this decreased stance width played a role in the sway outcomes of the study (Corbeil et al., 2003).

All of these studies employed a single force platform, which doesn't allow for comprehension of an individual foot's contribution to the changes in CoP movements during bilateral stance, but rather just the net CoP (Bermejo et al., 2015, Corbeil et al., 2003, Gribble & Hertel, 2004). While an overall increase in CoP movements possibly suggests that both feet along with the net have an increase as well, the specifics of this (such as differences due to limb dominance) can't be assumed due to the lack of individual foot data. Furthermore, these studies typically had an all-male population, so the differences between the sexes were never examined (Bermejo et al., 2015, Corbeil et al., 2003).

Some studies have taken into consideration the effect of fatiguing only a single limb, with the D limb of the subject being fatigued (Vuillerme, 2010, Vuillerme et al., 2009). WBAs were not affected due to fatigue, but one study saw an increase in CoP area on the non-fatigued (ND) limb (Vuillerme et al., 2009), while another study noted an increase in both the limbs, with a larger increase occurring with the non-fatigued (ND) limb (Vuillerme, 2010). The non-fatigued limb also saw an increase in mean speed (Vuillerme, 2010). This suggests a fatigue-induced adaptive change that's unrelated to any asymmetrical BW distribution, meaning that as one limb is fatigued, the other limb is then required to contribute more to the overall postural control. Both of the studies had only male participants, so sex differences in regards to single-leg fatigue are unable to be assessed. This could indicate that these differences are an extremely overlooked field.

There has been research looking into the effect of spinal fatigue within specific back muscles (vanDieën, 1996). A study recorded sEMG of the bilateral erector spinae (ES), iliocostalis lumborum, and longissimus thoracis muscles of an all-male subject population. By conducting a series of contractions tests at varying percentages of the maximum voluntary contraction along with differing degrees of twisted posture, they were able to induce fatigue in the muscles. It was found that with fatigue, the more laterally oriented muscles had higher increases in activity than the other muscles. This suggests a shift in activity to the more lateral muscles when spinal fatigue occurs (vanDieën, 1996). However, this study included only male subjects, so it is not clear if women would respond the same way.

Musculoskeletal Sex Differences

It is clear from the literature presented that subtle, but potentially important, differences exist between men and women in their risks for LBP and potentially how this LBP develops. However, the underlying mechanisms have not been revealed. Musculoskeletal differences between men and women may provide some insight.

When looking at muscle thickness, significant differences between men and women have been found for the transversus abdominis, internal oblique (IO), and external oblique (EO), with men having thicker muscles than the women (Gallagher et al., 2013). While muscle thickness of the ES was not significantly different between the sexes for this study ($p=0.0630$), it appeared to follow a similar trend of men having slightly thicker ES than the women (Gallagher et al., 2013). However, another study found that men did, in fact, have significantly larger anatomical cross-sectional areas for the ES (Marras et al., 2001) It was not noted if these size differences were scaled to account for mass differences between the sexes (Gallagher et al., 2013, Marras et al., 2001). Although not a sex-specific difference, a noted size difference with the multifidus muscle was recorded between ballet dancers with and without LBP, with the multifidus CSA being larger for the NPD (Gildea et al., 2013). However, there was not a difference in size found with the ES between the two groups (Gildea et al., 2013).

In addition to muscle size differences, there are also several skeletal differences between the sexes. One of the more well-known differences is that men and women have differences in hip geometry (Smith & Smith, 2002). In women, the pelvis is more widely set, and also has a larger, more rounded pelvic inlet and outlet in comparison to men (Smith & Smith, 2002). It's speculated that this wider pelvis often contributes to knee, ankle, and foot problems in women (Smith & Smith, 2002). Additionally, this width is suggested to cause an increased Q-angle, femoral anteversion, and external tibial torsion (Smith & Smith, 2002). Beyond the wider pelvis, there has also been research showing that men have larger cross-sectional areas of the thoracic and lumbar vertebral bodies (Marras et al., 2001).

Due to women having a wider pelvis, in addition to greater thigh girth and narrower shoulder width, their relative center of mass (CoM) is lower than it is with men (Pawlowski & Grabarczyk, 2003). These significant differences have been suggested to be primarily due to evolution, with women essentially being "weighed down" by a heavier burden during late pregnancy and with having to carry their infants frequently (Pawlowski, 2001). With a CoM lower to the ground, it could be suggested that women are more stable.

Differences between men and women pertaining to fiber type size and distribution have been noted in previous research (Mannion et al., 1997, Miller et al., 1993). In the thoracic and lumbar ES, men have significantly larger fibers of both Type I (slow twitch) and Type II (fast twitch) (Mannion et al., 1997). Further, women have higher relative percentages of the less fatigable Type I fibers (Mannion et al., 1997, Miller et al., 1993). These less fatigable fibers prevent fatigue from happening as quickly, allowing women to sustain submaximal contractions for longer durations than men (Clark et al., 2005, Hunter & Enoka, 2001, Hunter et al., 2006). It's seen that women only have the increased contraction time until fatigue when compared against stronger men (Hunter et al., 2006). When men and women contract with similar strength, there isn't a significant difference in time to task failure (Hunter et al., 2006).

Summary/Conclusions

From the literature, it's obvious that PS has an effect on a multitude of variables, such as body weight distribution (i.e., WBA), CoP movements, and muscle use (Gallagher et al., 2011, Gregory & Callaghan, 2008, Lafond et al., 2009). A primary focus within a majority of the PS literature has been on LBP development and the effect it could have on FAs (Gallagher et al., 2011, Gregory & Callaghan, 2008, Nelson-Wong et al., 2008, Nelson-Wong et al., 2010). This indicates that there is a need for a basic understanding of healthy individuals who classify as NPD. These effects appear to be reflected in QS, although examination of QS pre-PS to post-PS is still an overlooked area. How all of these effects appear in QS may prove to be important due to QS being an easy assessment style for calculating asymmetries and CoP movement.

There also appears to be similarities between PS and fatigue study findings, such as increases in CoP movements and muscles changes, suggesting that fatigue is occurring during PS (Bermejo et al., 2015, Corbeil et al., 2003, Gribble & Hertel, 2004, vanDieën, 1996). When looking at CoP movements and their relation to limb dominance, several studies have indicated that the ND limb contributes more to these movements (Genthon & Rougier, 2005, Rougier & Genthon, 2009, Sadeghi et al., 2000). In regards to time duration, a study lasting longer than 30 minutes may be unnecessary due to BW shifts only increasing during those first 30 minutes, then leveling off afterwards (Gallagher et al., 2011). Further, Gregory & Callaghan (2008) concluded that LBP development may be more related to how a person initial stands, not how they change with time. These changes to postural movements have also been captured during QS after 30 minutes of standing (Lafond et al., 2009). This could indicate that 30 minutes is long enough to cause the effects that are related to PS and have them reflected in QS. Beyond 30 minutes, there seems benefit of having a break, thus, having a 30 minute PS trial may be practical in the sense that individuals will not require a break during the study (Gallagher et al., 2014).

The primary muscles that receive attention during these PS studies are typically those of the trunk (IO and EO), hip (gluteus medius and maximus), and lumbar spine (ES) (Gallagher et al., 2013, Nelson-Wong & Callaghan, 2010a, 2010c, Nelson-Wong et al., 2008, vanDieën, 1996). With all of these, differences between men and women have been recorded in muscle size and use (Gallagher et al., 2013, Marras et al., 2001, Nelson-Wong et al., 2012). Thus, it would be important to record activity on the IO, EO, GM, and lumbar ES. As mentioned previously, there are potentially important differences existing between men and women, with some, if not all, of these being related to musculoskeletal differences. However, this appears to be an overlooked field, particularly when effects of fatigue are an area of concern. This sheds light onto the importance of comparing the sexes.

Therefore, the goal of this study was to examine the effect of 30 minutes of PS on GRF control and core muscle activation within healthy young adults who are reportedly comfortable for at least 30 minutes during QS, and assess any sex differences present. These results will help provide a basic understanding of healthy NPD. In a clinical setting, these results can be used to help assess whether or not an individual displays healthy asymmetries, muscle use strategies, and postural stability, thus being able to determine if they are at risk for LBP development. Sex-specific assessment techniques may be able to be designed, depending on the results pertaining to differences among men and women. Intervention techniques could also be developed based on the results, specifically those pertaining to PS.

Chapter III: METHOD AND MATERIALS

Subjects

Twenty-four healthy young adult volunteers (12 men, 12 women) between the ages of 18-30 years old were selected after volunteering to participate in the study. A health history questionnaire was completed to insure that every subject qualified before enrolling them in the study (Appendix A). All subjects were free from any pain or injury, and had not sustained a previous injury that would cause them to favor one side of the body while performing otherwise symmetric tasks. They were required to be free of any spinal impairments. Subjects could not have any orthopedic or arthritic problems, or use any bilateral corrective devices. Additionally, they could not have any balance disorders and not be on any medication that could affect balance. Women could not be pregnant. Individuals who were involved in an occupation requiring prolonged periods of static standing (4+ hours at a time) were excluded from the study. Subjects had to be able to stand for 30 minutes without needing to sit down. Subjects also had to verify that they were comfortable with receiving a dual-energy x-ray absorptiometry (DXA) scan, and willing to have small areas shaved free of hair for electrode placement.

Prior to testing, each subject was given instructions for their testing day. They were to be well rested with no rigorous activity within the past 24 hours, and have their regular caffeine consumption that morning. They were told to wear comfortable, non-restrictive clothing and typical walking shoes (e.g.; t-shirt, gym shorts, and tennis shoes).

On the day of testing, after verifying eligibility, each subject signed a university-approved consent form (Appendix B). Their height and weight were recorded, and leg lengths measured via palpation. Caffeine intake prior to the study, amount of time in hours spent standing still per day, amount of time in hours spent on their feet per day, preferred kicking leg (D limb), and preferred throwing arm were also recorded. Functional leg length differences were performed with subjects lying supine on the examination table with their shoes on, knees flexed, and their feet flat on the table aligned next to each other. They were instructed to raise their pelvis upward approximately 6-10 inches before relaxing and setting it back down. The subject's legs were then passively extended by the student investigator, and equal pressure applied to the soles of the feet. Visual approximation was used to assess and record the difference in how far one sole extended off the edge of the table compared to the other (Hinson & Brown, 1998). Though not analyzed, anatomical leg length measures were also measured supine on the exam table (Evans, 1994). Project approval was gained from the Colorado State University Human Subjects Committee prior to initiation (Appendix C).

Dual-Energy X-ray Absorptiometry (DXA) Protocol

A DXA machine (Hologic, Bedford, MA, version 3.4) was used to obtain whole body radiologic measurements. Each subject received a DXA scan at the beginning of their study. They were scanned in the supine position as per manufacturer instructions, with a block between their feet such that all subjects would have similar foot positioning. Additionally, they were required to have their hands flat on the table by their sides. Bone mass density (BMD) and body fat percentage (%BF) were recorded from the scan results. Leg length was calculated bilaterally by measuring from the center of the pelvic hip joint to the center of the ankle joint, and the values recorded. All scans and analyses were performed by a student investigator after completing all mandated training protocols and obtaining all necessary certifications.

Surface Electromyography (sEMG) Electrode Placement

Pre-gelled, disposable, bipolar sEMG electrodes (Noraxon USA, Scottsdale, AZ, USA) were used to record muscle activity on four sets of core muscles; ES, IO, EO, and GM. Before the electrodes were placed, subjects had the skin removed of hair (if necessary), lightly debraded, and then cleaned with an alcohol swab. The ES electrodes were placed on either side of the L3 spinous process (Figure 3.1). The IO electrode was situated approximately 2 cm medial to the anterior-superior iliac spine (ASIS) and 2 cm beneath the line joining the bilateral ASIS (Figure 3.2). The EO electrode was placed below the rib cage along a line connecting the inferior costal margin and the contralateral pubic tubercle (Figure 3.2, 3.3). The GM electrode was place approximately 2.5 cm distal to the midpoint of the iliac crest (Figure 3.2, 3.3). Each electrode was placed bilaterally as symmetrical as possible. All sEMG electrode placements were based off previous research (Ng et al., 1998).

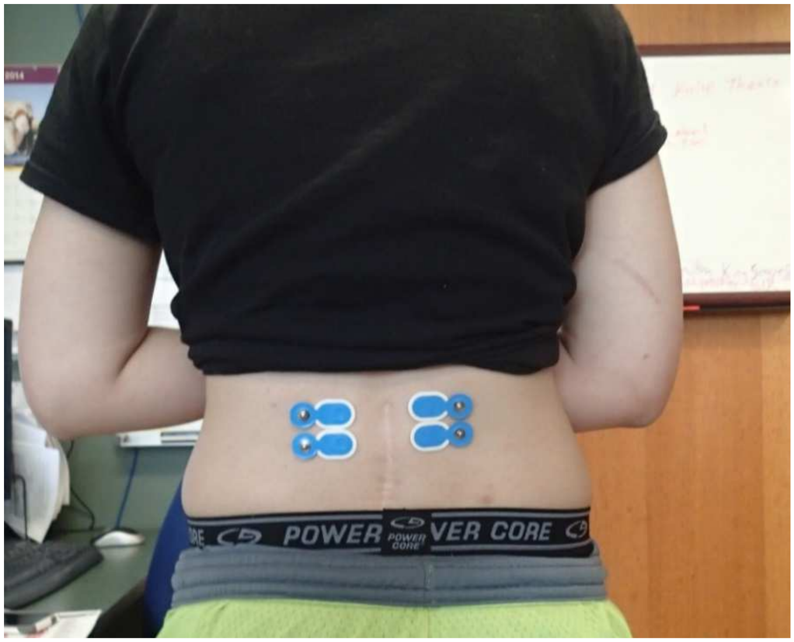


Figure 3.1: Posterior lumbar erector spinae (ES) surface electromyography (sEMG) electrode placement.

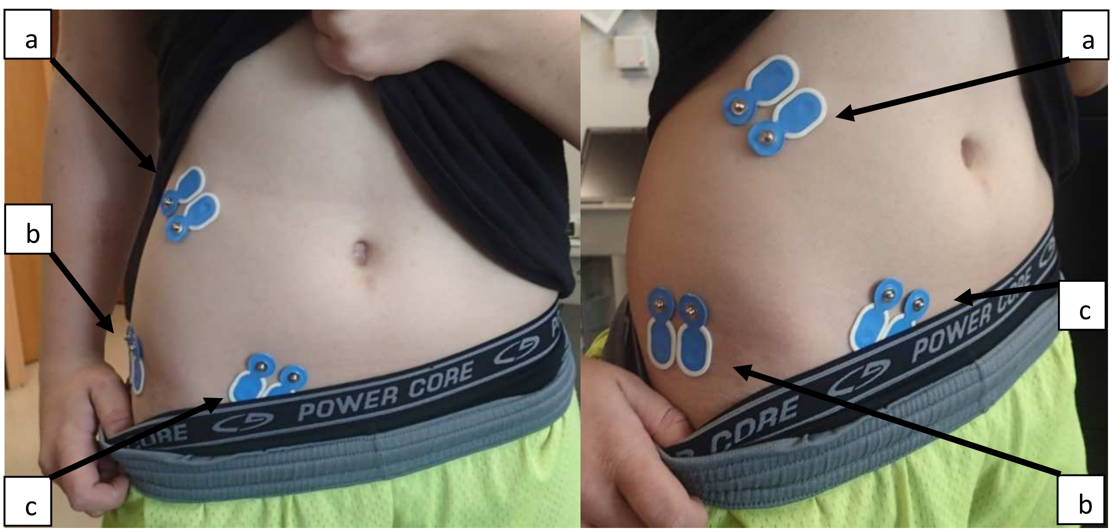


Figure 3.2: Anterior (left) and anterior-lateral (right) views of the external obliquus (EO) (a), gluteus medius (GM) (b), and internal obliquus (IO) (c) surface electromyography (sEMG) electrode placement.

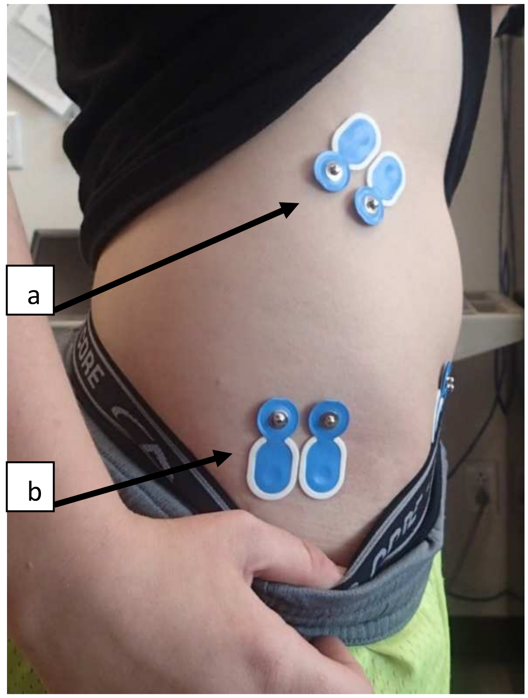


Figure 3.3: Lateral view of the external obliquus (EO) (a) and gluteus medius (GM) (b) surface electromyography (sEMG) electrode placement.

Reference Contractions Protocol

Subjects underwent a series of four exercises to obtain submaximal reference contraction values for each muscle. Submaximal contractions were selected over maximal voluntary contractions due to the sensitive nature of this area of the body and reliability found previously (Dankaerts et al., 2004). There was an exercise for the ES, right GM, left GM, and one that incorporated both the IO and EO. For each exercise, they would begin in a relaxed starting position. A countdown from 3 would occur, they conducted the required lift and held for 3 seconds (counted out loud by the instructor), then set back down. Three trials of each exercise were performed in a particular order; left GM, IO and EO, right GM, then ES. This order was chosen due to the GM, IO, and EO sEMG electrodes being put on first and their exercises conducted before the ES sEMG electrodes were put on and its exercise performed. All sEMG was collected at 100 Hz using Noraxon Myosystem 1200 (Scottsdale, AZ) coupled with Vicon Nexus (Centennial, CO).

The starting position for the GM exercise involved the subject lying on their side with their bottom knee flexed comfortably at roughly 90^0, as to provide support. The top leg remained extended. The bottom hand was placed under the head with the elbow flexed, and the top hand rested across the rib cage (Figure 3.4). The contraction involved the top leg being lifted until it was horizontal. The leg remained straight and directly above the body without sway or movement to either side throughout the exercise (Figure 3.5). This method was repeated for both the right and left GM. A single exercise incorporated both the IO and EO. The starting position involved lying supine with the hips flexed at 45^0, knees flexed at 90^0, and feet flat on the table. The knees and feet were kept together, and hands were resting on the table alongside the body (Figure 3.6). For the contraction, the subject lifted their feet approximately 1-2 cm off the table while keeping their knees and feet together. They were instructed to not arch their back during the exercise (Figure 3.6). For the ES exercise, the starting position consisted of lying prone with their knees flexed at 90^0. Knees and feet were kept together, and their hands were resting on the table along their sides (Figure 3.7). The contraction involved the subject lifting their knees off the table approximately 5 cm with their knees and feet remaining together (Figure 3.7). These exercises are similar to those performed in a previous studies (Dankaerts et al., 2004, Nelson-Wong et al., 2010).

Figure 3.4: Starting position for the gluteus medius exercise.

Figure 3.5: Contraction position for the gluteus medius (GM) exercise.

Figure 3.6: Starting position (left) and contraction position (right) for the internal (IO) and external obliques (EO) exercise.

Figure 3.7: Starting position (left) and contraction position (right) for the erector spinae (ES) exercise.

Quiet Stance (QS) Trials

Two 60 second QS trials were conducted. One was immediately prior to the prolonged standing trial (pre-PS), and the other was immediately after (post-PS). The subjects stood with one foot per platform on a dual belt force-measuring treadmill (Bertec, Columbus, OH), with a stance width set at 10% of their standing height. For the duration of the trial, they were instructed to stand relaxed with minimal movement, keep their arms at their sides, and keep their eyes focused straight ahead (Figure 3.8). sEMG activity, forces, and moments under each foot were collected at 100 Hz using the same software as the reference contractions.

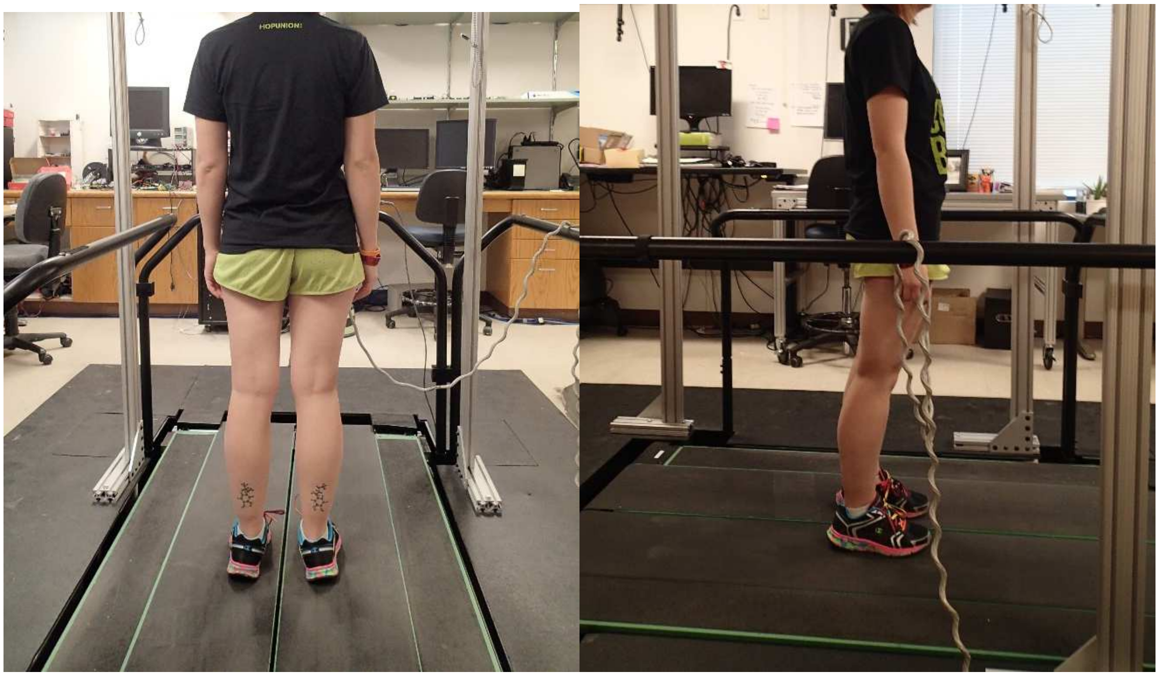


Figure 3.8: Subject position for quiet stance (QS) trials.

Prolonged Standing (PS) Trial

The PS trial lasted 30 minutes, with the subjects standing with one foot per force platform. For the duration of the trial, they were allowed to shift/move their feet and sway to keep comfortable. However, their feet weren't allowed to cross over onto the opposite platform (Figure 3.9). Subjects were asked to have their arms not touch/interfere with the sEMG electrodes, meaning they were allowed to keep their arms at their sides, crossed over their chest, or low behind their back. A documentary was provided to decrease boredom, displayed on a 42-inch television screen placed approximately 8 feet from where the subjects stood. sEMG activity, forces under each foot, and moments under each foot were collected at

100 Hz for the duration of the trial using the same software as the reference contractions and QS trials.

Figure 3.9: Subject during prolonged standing (PS) trial.

Repeatability

Eleven subjects returned to test for repeatability of the force platform data. sEMG activity was not collected due to previous findings indicating its repeatability (Nelson-Wong & Callaghan, 2010d). Testing day requirements for the subjects were the same as with the original visit. The visit consisted of the two QS trials and the PS trial.

Data Processing and Analysis

Post-processing was coded in Matlab version R2014a version 8.3.0.532 (The Mathworks, Inc., Natick, MA, USA). The sEMG activity data underwent a high-pass filter (dual-pass Butterworth, fourth order, effective cut-off frequency of 30Hz) for removal of movement artifacts before being zero-meaned and full-wave rectified. The data then underwent a low-pass filter (dual-pass Butterworth, four order, effective cut-off frequency of 2.5Hz) to create a linear envelope. The force platform data received a low-pass filter (dual-pass Butterworth, fourth order, effective cut-off frequency of 10Hz) to remove noise.

For each of the reference contractions, the maximum value of the contraction was extracted for each trial. These values were then averaged over the 3 trials for each muscle. While the QS trial data underwent analysis, the data collected from the PS trial will be analyzed in the future. For the QS trials, the average activity of each muscle and average force under each foot were calculated. The forces were normalized to percent body weight (%BW), and the muscle activity normalized to the reference contraction (%ref). Individual foot and net CoP was calculated using the force and moment data from the force platforms. Three main CoP movement variables were calculated from the data in both the AP and ML directions; sway, maxV, and PL. Sway was calculated by subtracting the minimum CoP value from the maximum CoP value. MaxV was computed as the maximum of the absolute value of the instantaneous CoP velocity calculated from one time step ahead minus the CoP value of one time step behind. PL was the summation of the absolute value of the CoP value from one time step ahead minus the current CoP value. These values were normalized to percent standing height (%height). The values for the left and right sides of the body were converted to be associated with either the D or ND side of the body, based on the subject’s preferred kicking leg. From this, pooled values were calculated by averaging the D and ND sides.

Asymmetries were calculated using Equation (3.1) (R. Robinson et al., 1987). WBAs were calculated by subtracting the percent vertical GRF under their ND limb from their D limb. MAAs were calculated in a similar fashion, using the average muscle activity from the ND and D sides of the body. CoPAs were also calculated similarly by using the values of the ND and D limbs. Leg length asymmetries were calculated using the leg lengths extracted from the DXA scans.

$$\%SI = \frac{D-ND}{\frac{1}{2}(D+ND)} * 100 \quad (3.1)$$

Statistical Treatment

IBM SPSS Statistics version 22 (Armonk, NY, USA) was used for all statistical analysis. Before any statistical comparisons were performed, the data was examined for outliers within each variable and tested for normality. All extreme outliers using a box plot analysis were removed (i.e., those greater than three box lengths from the end of the box). Normality was tested with the Shapiro-Wilk test. If variables weren't normal ($p<0.05$), then the variables were transformed with either a cubic root or logarithmic transformation, or moderate outliers were removed. Moderate outliers were only removed if the data was not initially normal and there were difficulties with transforming the data. If outliers (extreme and moderate) existed, a maximum of 3 subjects were removed from the data set for any given variable. Independent-sample double-sided T-tests were used to compare characteristic variables between the men and women.

To examine the differences between D and ND limb measurements, a 2x2 (sex x limb) repeated measure ANOVA was used for all of the previously described variables. To examine the effect of PS, a 2x2 (sex x pre-PS/post-PS) repeated measure ANOVA was used for each calculated asymmetry. If significance was found in the interaction between the sexes, appropriate post hoc T-tests were performed to explore the differences. Relationships between asymmetry measures of the pre-PS and post-PS QS trials were evaluated with Pearson correlations. Correlations greater than or equal to 0.800 were considered strong, between 0.700 and 0.800 were considered moderate, and below 0.700 were considered weak. Repeatability was assessed with intra-class correlation coefficient Cronbach's Alpha. Significance was set at $p<0.05$.

Chapter IV: RESULTS

Subject Characteristics

Twenty-four subjects completed the data collection with equal numbers for each sex. A few significant subject characteristic differences were found between the sexes, with men typically being taller and weighing more, while women had higher body fat percentage ($p \leq 0.005$). All other characteristic variable showed no significant difference between the men and the women ($p \geq 0.169$) (Table 4.1). Three subjects reported their left leg as their preferred kicking leg, while the remaining 21 reported their right leg. However, all subjects reported that their preferred throwing arm was their right arm. Leg length asymmetry was found to be small with no significant correlation to any of the WBA, MAA, and most CoPA measures ($p \geq 0.056$), with the exception of the AP maxV asymmetry for the women during only the pre-PS trial ($p=0.023, r=0.646$).

Table 4.1: Subject Characteristics

	Men		Women		Total	
	Mean	SD	Mean	SD	Mean	SD
Age [years]	22.3	(2.7)	22.3	(2.3)	22.3	(2.4)
Height [m]*	1.76	(0.08)	1.64	(0.06)	1.70	(0.09)
Mass [kg]*	76.1	(11.0)	63.7	(8.0)	69.9	(11.3)
BMI [kg/m^2]	24.5	(2.8)	23.6	(2.2)	24.1	(2.5)
BMD [kg/m^2]	1.45	(0.12)	1.45	(0.08)	1.45	(0.10)
Body Fat [%]*	21.7	(4.1)	32.7	(4.3)	27.2	(6.9)
Leg Length [%height]	47.3	(1.3)	47.4	(1.0)	47.4	(1.2)
Leg Length Asymmetry [%height]	0.1	(0.6)	-0.3	(0.7)	-0.1	(0.7)
Functional LLD [%height]	0.0	(0.2)	0.0	(0.1)	0.0	(0.1)

* $p<0.05$ between men and women
Leg length differential (LLD)

Weight Distribution and Asymmetries

Though individuals had WBAs, with some favoring the D limb and others the ND limb (Figure 4.1), overall, the subject group was highly symmetric with no significant difference between weight applied to the D versus ND limb (pre-PS p=0.452, post-PS p=0.328). Additionally, there were no significant differences in the WBAs between the pre-PS and post-PS trials (main effect p=0.701) nor between the men and the women (main effect p=0.888).

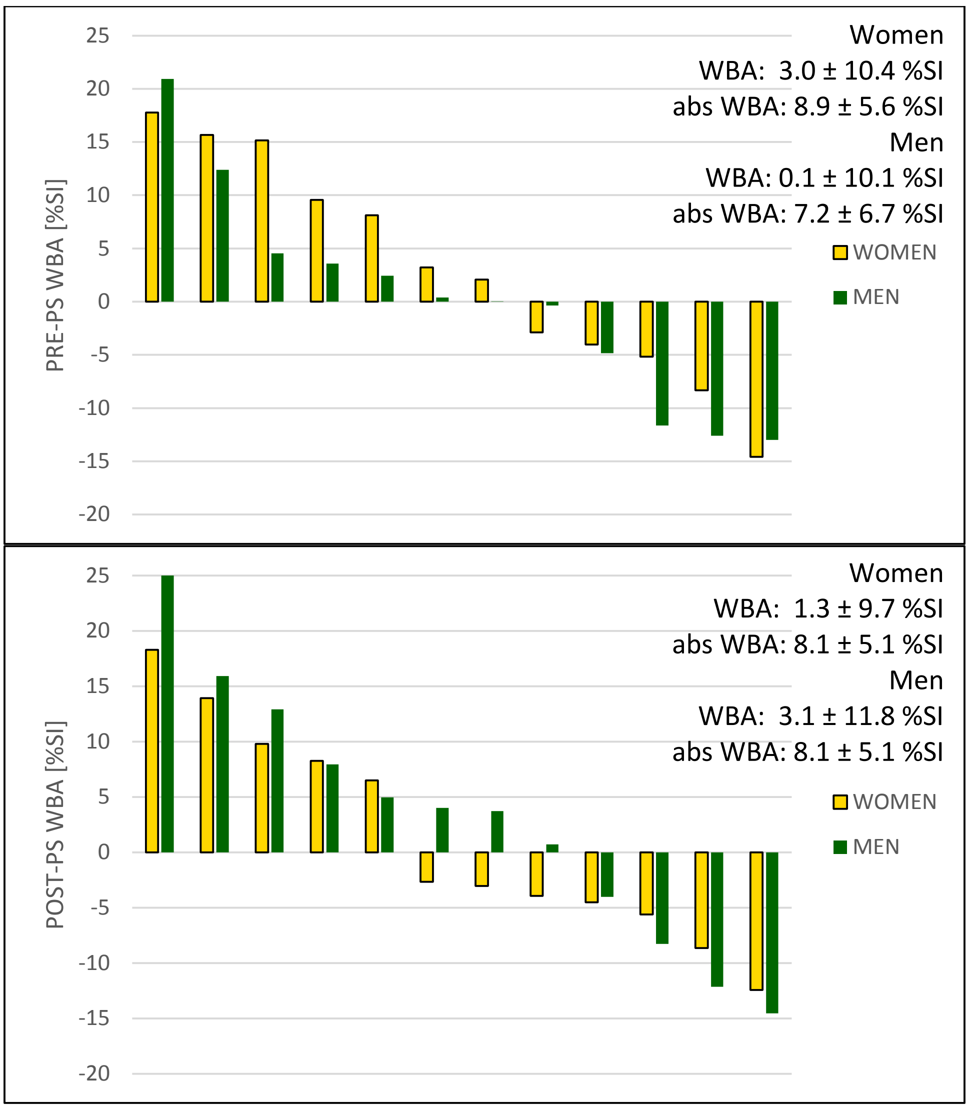


Figure 4.1: Weight-bearing asymmetries (WBAs) for the men and women during the pre-prolonged standing (PS) (top) and post-PS (bottom) trials. A positive value indicates placement of more weight on the dominant (D) limb. Average asymmetry values displayed [mean ± SD].

Typically, the direction of the asymmetry stayed similar between the pre-PS and post-PS trials and were highly correlated (women p=0.016 & r=0.676; men p=0.002 & r=0.807) (Figure 4.2). This meant that if they had a positive asymmetry during the pre-PS trial, they usually had a positive asymmetry during the post-PS trial and vice versa. However, seven subjects (3 men, 4 women) did not conform to this and applied weight to the contralateral limb in the post-PS trial compared to their pre-PS trial. Three of these subjects switched from a negative asymmetry to a positive asymmetry, while the remaining four switched from a positive asymmetry to a negative asymmetry from the pre-PS to post-PS trials. While some of these switches involved levels of asymmetry that were relatively low (i.e.; -0.37% SI to 3.27% SI), some involved higher asymmetry levels (-11.62% SI to 7.95% SI). Due to the number of switches and the levels of asymmetry associated with them, the overall levels of asymmetry essentially evened out again, thus making no significant difference between the pre-PS and post-PS trials, as previously indicated.

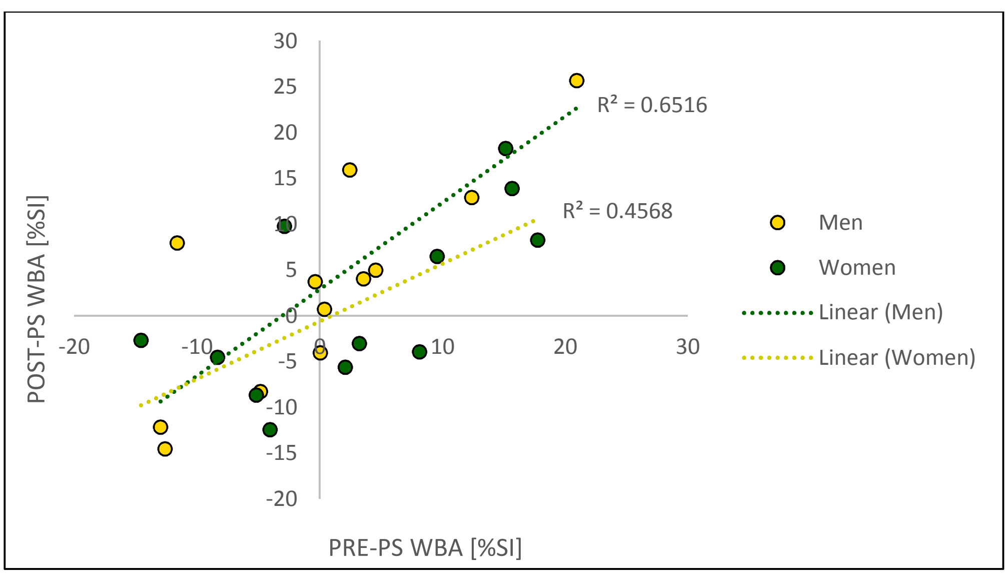


Figure 4.2: Correlation between pre-prolonged standing (PS) and post-PS weight bearing asymmetries (WBAs).

Muscle Activity and Asymmetries

As a group, there were no significant differences bilaterally at any of the four muscles in activity between the D and ND sides of the body for both the pre-PS and post-PS trials ($p \geq 0.054$). However, as with the WBA, individual values varied highly. Women had higher pooled (bilateral averaged) GM activity than the men for both the pre-PS and post-PS trials ($p = 0.041$) (Figure 4.3). In general, there were no significant pre-PS to post-PS differences with the pooled activity for each muscle ($p \geq 0.063$), with one exception. The men had a decrease in pooled ES activity from the pre-PS to post-PS trial ($p = 0.002$), while the women did not have any significant change in activity levels (Figure 4.4). There were no significant differences in any of the MAAs between the pre-PS and post-PS trials ($p \geq 0.074$) nor between the men and the women ($p \geq 0.399$) (Table 4.2).

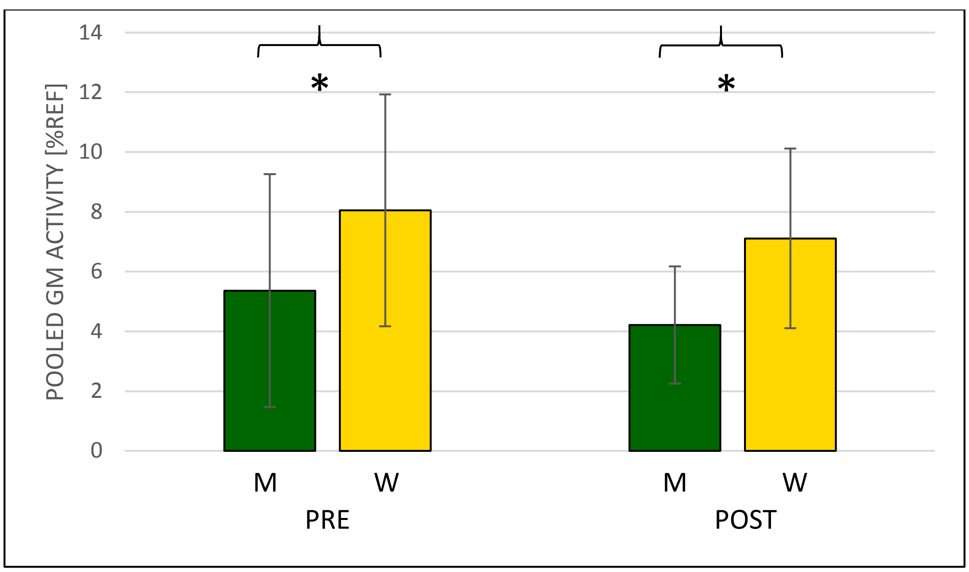


Figure 4.3: Gluteus medius (GM) activity levels for the men (M) and women (W) with the dominant (D) and non-dominant (ND) sides pooled. *main effect with p<0.05 between men and women.

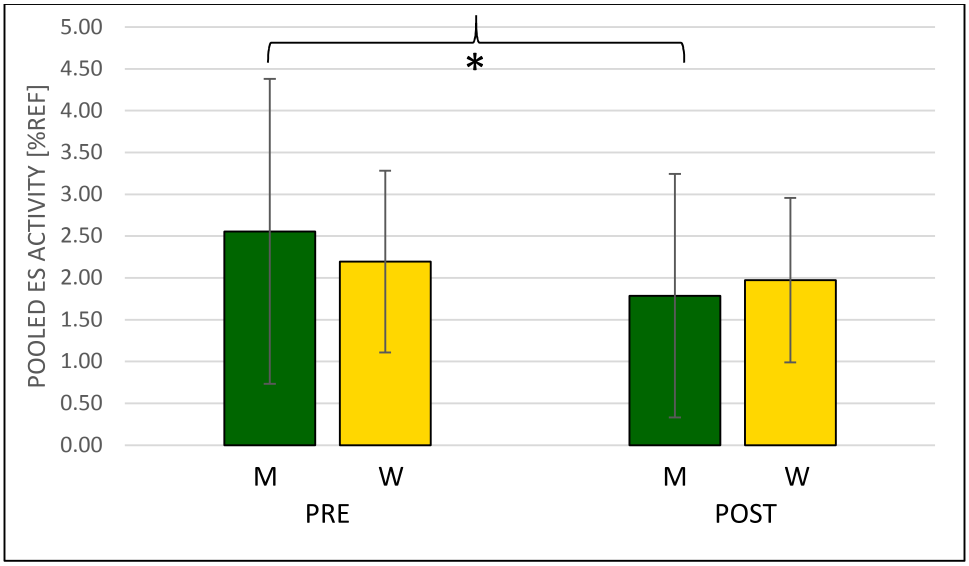


Figure 4.4: Erector spinae (ES) activity levels for the men (M) and women (W) with the dominant (D) and non-dominant (ND) sides pooled. *interaction with p<0.05 for men only between pre-prolonged standing (PS) and post-PS.

Table 4.2: Muscle Activation Asymmetries (MAAs) (%SI)

	Men		Women	
	Mean	SD	Mean	*SD*
ES				
Pre-PS	-4.3	(38.8)	-1.9	(44.8)
Post-PS	13.3	(42.1)	4.4	(33.1)
IO				
Pre-PS	-19.2	(72.8)	-33.0	(87.8)
Post-PS	-22.1	(69.9)	-28.4	(82.1)
EO				
Pre-PS	-16.1	(49.4)	-19.3	(35.2)
Post-PS	-0.9	(53.0)	-19.1	(37.3)
GM				
Pre-PS	-37.0	(87.1)	4.0	(77.0)
Post-PS	-10.9	(106.7)	8.0	(70.6)

Erector Spinae (ES), Internal Obliquus (IO), External Obliquus (EO), Gluteus Medius (GM), Prolonged standing (PS)

Center of Pressure (CoP) Movements

In general, the CoP under the ND foot had more postural movement than that under the D foot in both the pre-PS and post-PS trials ($p \leq 0.032$) (Figure 4.5, Figure 4.5, Table 4.3), with the exception of the ML and AP sway in both trials ($p \geq 0.409$), and the ML maxV in the post-PS trial ($p=0.084$) (Table 4.3). The women had overall higher CoP movement than the men for both the D and ND feet for the ML maxV (Table 4.3), and both the ML and AP PL during the pre-PS trial ($p \leq 0.014$) (Figure 4.5, Figure 4.6). For the post-PS trial, the women had overall higher maxV (Table 4.3) and PL in both the ML and AP directions ($p \leq 0.029$) (Figure 4.5, Figure 4.6).

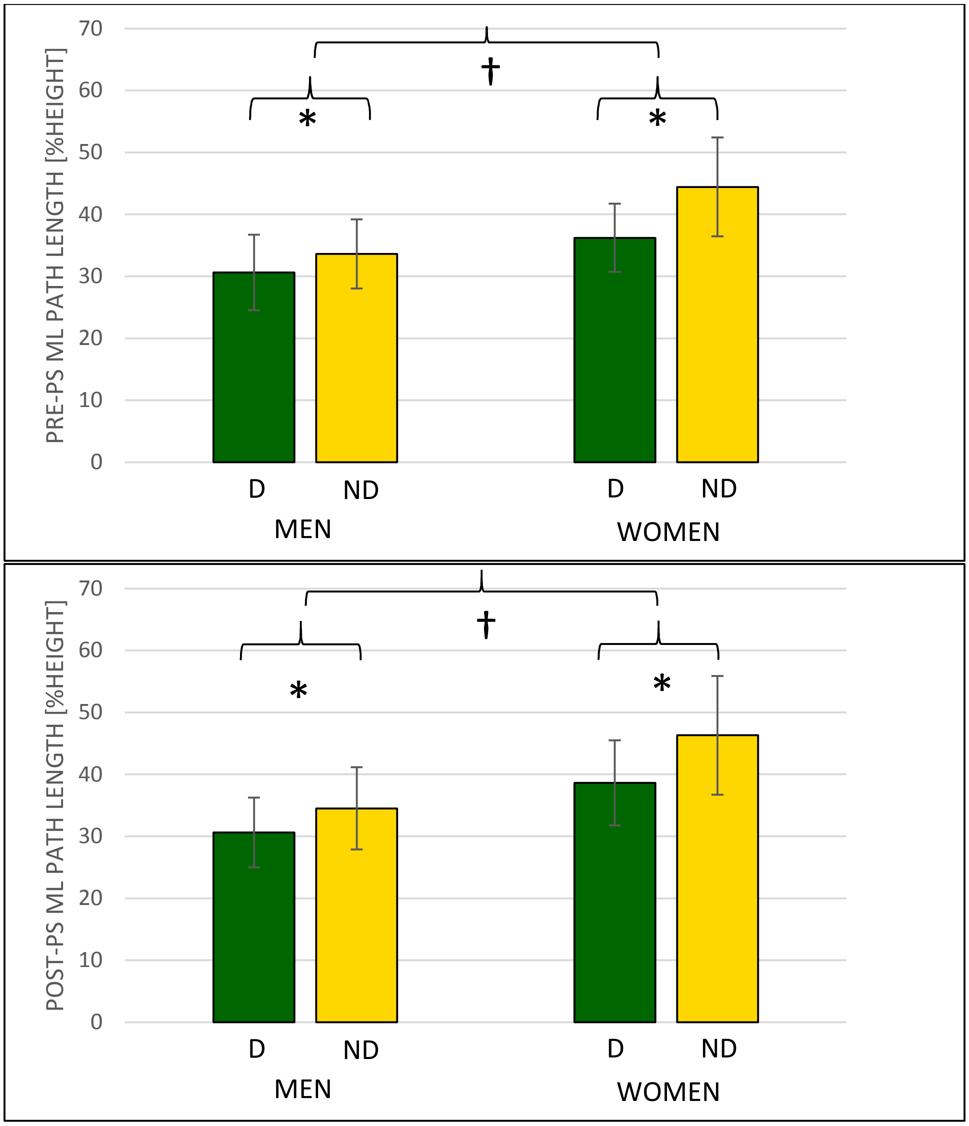
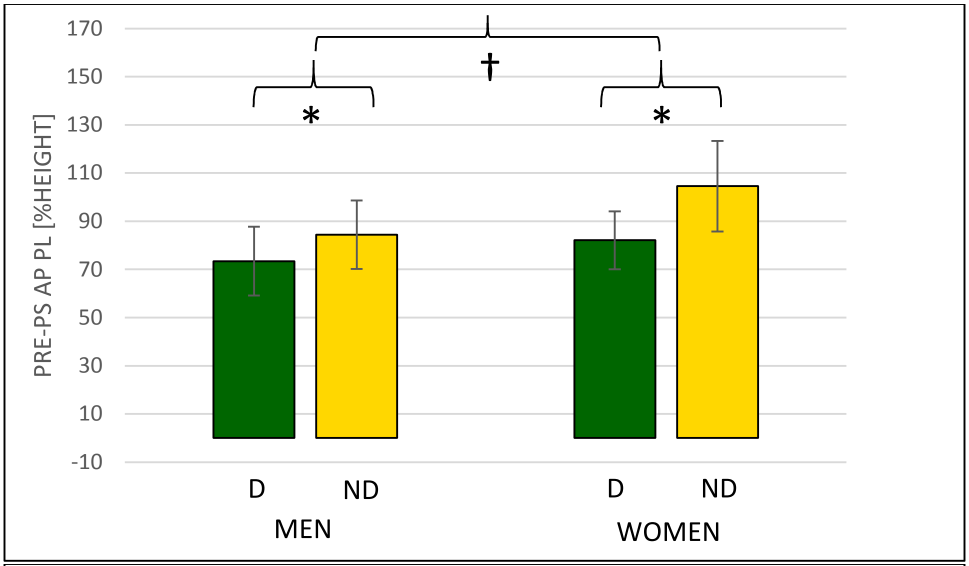


Figure 4.5: Medial-lateral (ML) path length (PL) in the dominant (D) and non-dominant (ND) limbs for men and women in the pre-prolonged standing (PS) trial (top) and post-PS trial (bottom). *main effect with p<0.05 between D and ND limbs. †main effect with p<0.05 between men and women.



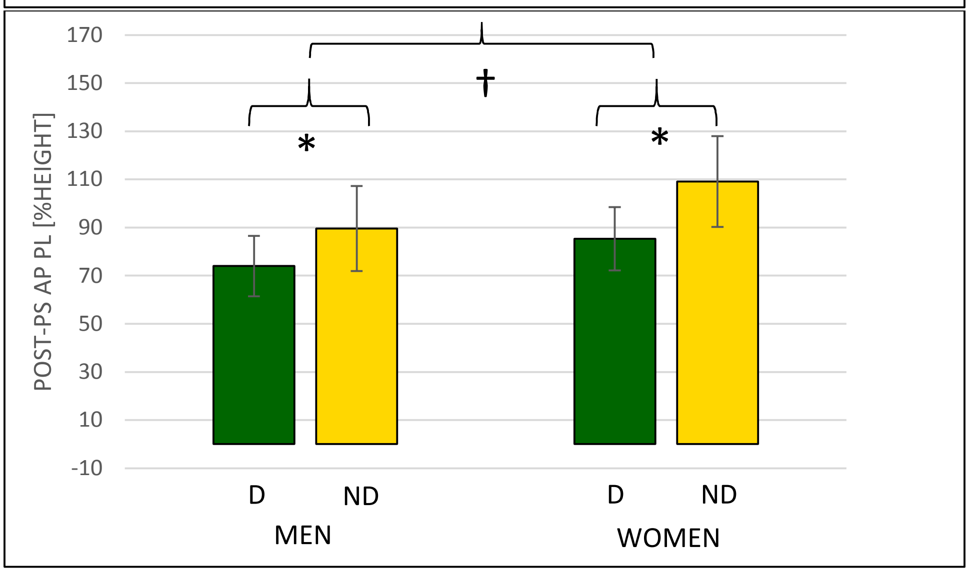


Figure 4.6: Anterior-posterior (AP) path length (PL) in the dominant (D) and non-dominant (ND) limbs for men and women in the pre-prolonged standing (PS) trial (top) and post-PS trial (bottom). *main effect with p<0.05 between D and ND limbs. †main effect with p<0.05 between men and women.

Table 4.3: Sway and Maximum Velocities (maxV) For Dominant (D) and Non-dominant (ND) Limbs (%height)

	Men				Women			
	D		ND		D		ND	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ML Sway								
Pre-PS	0.3	(0.1)	0.3	(0.2)	0.3	(0.1)	0.3	(0.1)
Post-PS	0.3	(0.2)	0.3	(0.2)	0.4	(0.1)	0.5	(0.3)
AP Sway								
Pre-PS	1.5	(0.6)	1.5	(0.5)	1.4	(0.4)	1.4	(0.3)
Post-PS	1.7	(0.6)	1.9	(0.7)	1.8	(0.6)	1.8	(0.6)
ML maxV								
Pre-PS*†	2.5	(0.7)	2.8	(0.7)	3.3	(0.9)	3.9	(1.0)
Post-PS†	2.5	(0.6)	2.8	(0.6)	3.6	(1.4)	4.1	(1.5)
AP maxV								
Pre-PS*	6.2	(1.0)	7.2	(1.7)	7.2	(0.9)	8.6	(2.3)
Post-PS*†	6.2	(1.0)	7.5	(1.4)	7.1	(1.5)	8.9	(1.8)

*main effect with $p<0.05$ between D and ND limbs. †main effect with $p<0.05$ between men and women.

Medial-lateral (ML), Anterior-posterior (AP), Prolonged standing (PS)

Net CoP

Net CoP movements typically increased from the pre-PS to post-PS trials ($p \leq 0.003$), except for ML sway and AP maxV ($p \geq 0.13$). Women had higher values compared to men for the ML maxV, and for both the ML and AP PL ($p \leq 0.006$). A comparison of PL for the pre-PS and post-PS trials are shown below (Figure 4.7).

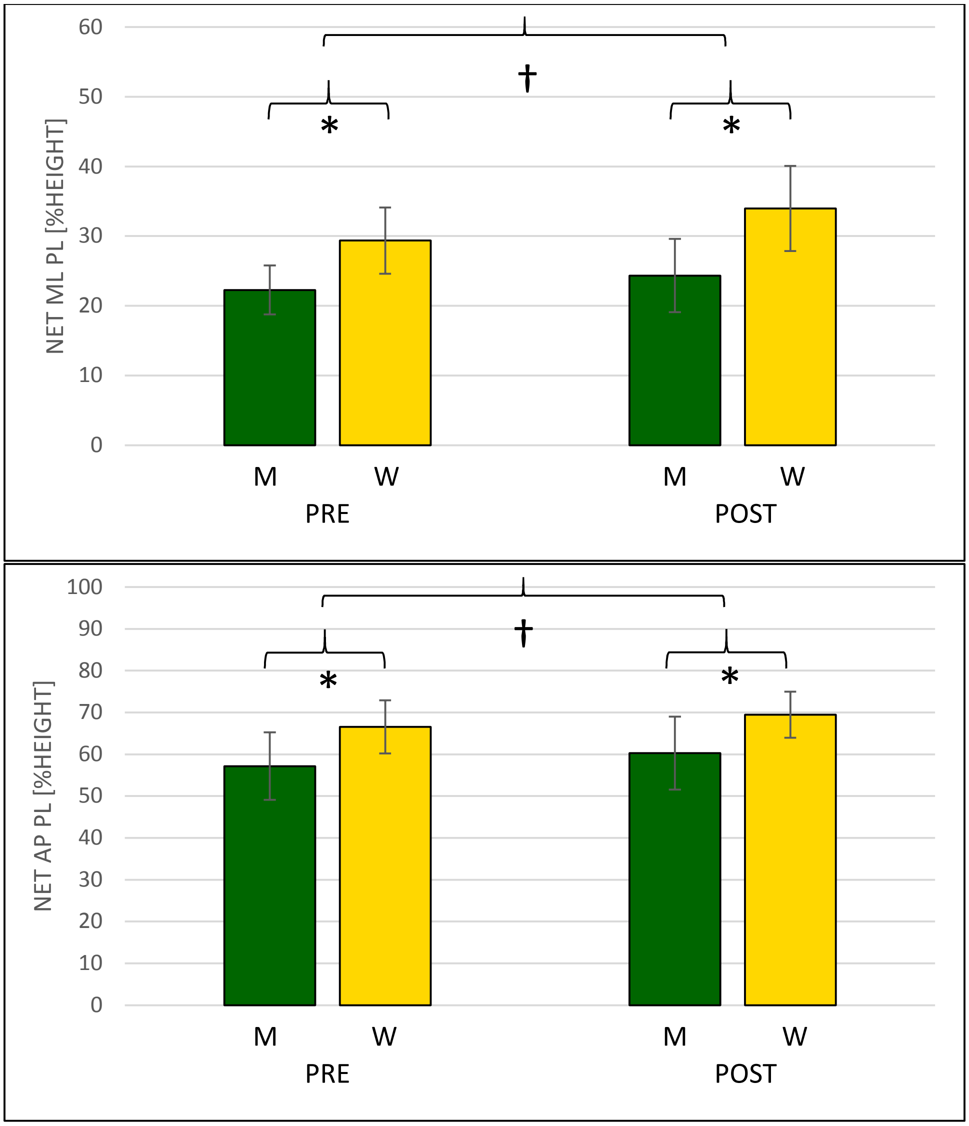


Figure 4.7: Net path length (PL) in medial-lateral (ML) (top) and anterior-posterior (AP) (bottom) directions. *main effect with p<0.05 between men and women. †main effect with p<0.05 between men and women.

Table 4.4: Net Sway and Maximum Velocities (maxV) (%height)

	Men		Women	
	Mean	SD	Mean	SD
ML Sway				
Pre-PS	0.8	(0.4)	0.8	(0.4)
Post-PS	0.9	(0.5)	1.0	(0.5)
AP Sway*				
Pre-PS	1.2	(0.3)	1.3	(0.2)
Post-PS	1.7	(0.6)	1.6	(0.5)
ML maxV*†				
Pre-PS	2.0	(0.5)	2.5	(0.6)
Post-PS	2.3	(0.8)	3.4	(1.1)
AP maxV				
Pre-PS	4.8	(0.6)	5.2	(0.5)
Post-PS	4.9	(0.7)	5.4	(0.4)

*main effect with $p<0.05$ between pre-PS and post-PS. †main effect with $p<0.05$ between men and women.
Medial-lateral (ML), Anterior-posterior (AP), Prolonged standing (PS)

CoP Asymmetries (CoPAs)

There were no significant differences between the pre-PS and post-PS trials, nor between the men and the women for the CoPAs (Figure 4.8, Table 4.5). As previously indicated, individuals had greater CoP movements for their ND limb compared to their D limb. This is reflected in the subjects typically having a CoPA towards the ND limb (i.e., a negative %SI).

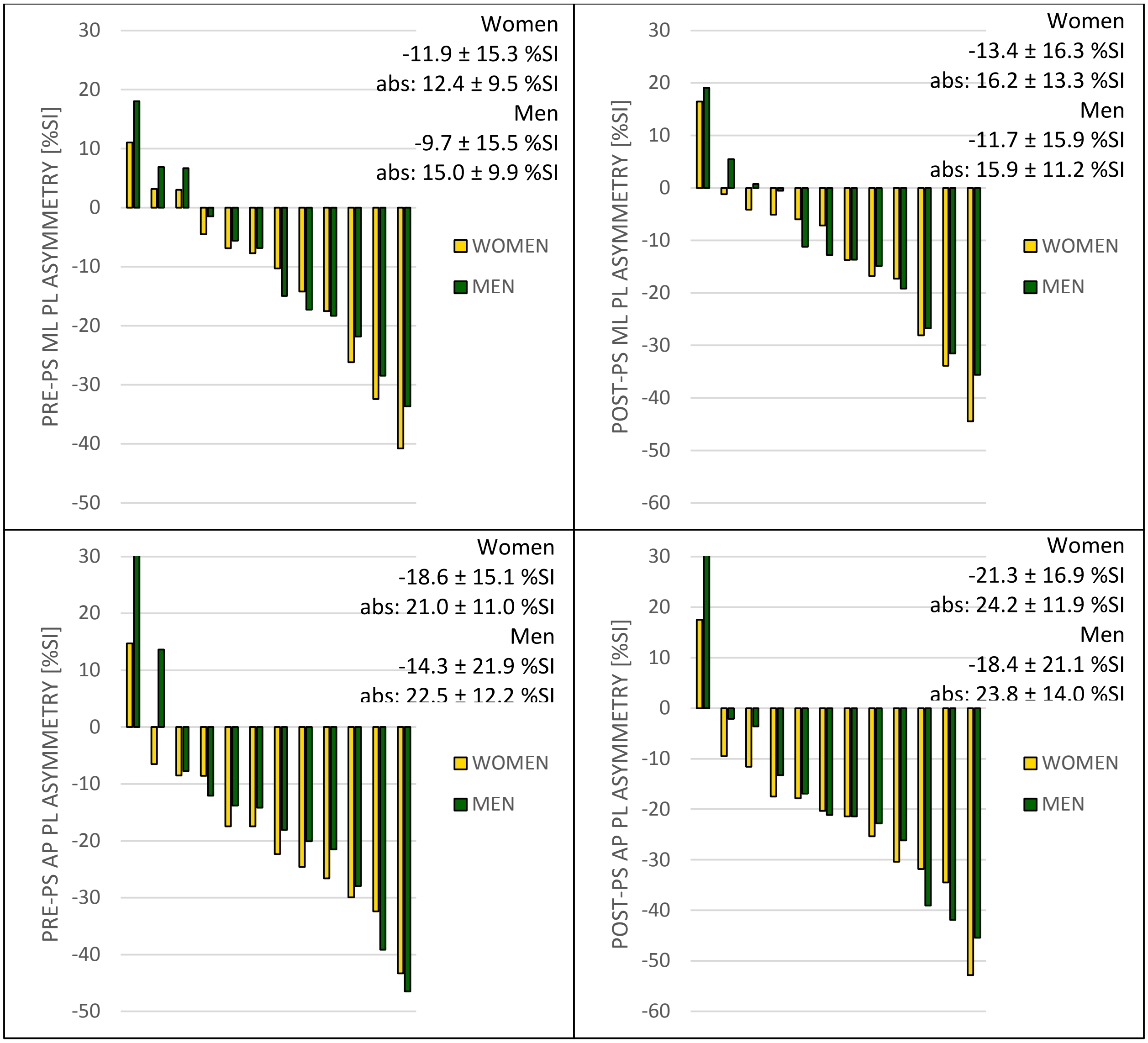


Figure 4.8: Path length (PL) asymmetries for medial-lateral (ML) during pre-prolonged standing (PS) (top left), ML during post-PS (top right), anterior-posterior (AP) during pre-PS (bottom left), and AP during post-PS (bottom right). Average asymmetry values displayed [mean ± SD]

Table 4.5: Sway and Maximum Velocities (maxV) Asymmetries (%SI)

	Men		Women	
	Mean	SD	Mean	SD
ML Sway				
Pre-PS	-4.7	(26.9)	6.9	(19.3)
Post-PS	-10.2	(42.7)	0.3	(43.5)
AP Sway				
Pre-PS	-2.0	(25.1)	-3.8	(29.1)
Post-PS	-6.9	(28.0)	-2.9	(28.4)
ML maxV				
Pre-PS	-13.6	(24.7)	-17.1	(20.2)
Post-PS	-13.0	(30.5)	-12.3	(37.0)
AP maxV				
Pre-PS	-12.7	(30.6)	-8.3	(11.3)
Post-PS	-17.6	(22.1)	-19.5	(26.1)

Medial-lateral (ML), Anterior-posterior (AP), Prolonged standing (PS)

Correlations

WBAs and MAAs

In general, the correlations between the WBAs and MAAs were relatively low ($p \geq 0.176$) (Table 4.6). However, there was one significant correlation, although weak, between the WBAs and the GM MAAs during the pre-PS trial for the women ($p=0.044$).

Table 4.6: Pearson Correlations (r) for Weight-bearing (WBAs) and Muscle Activation Asymmetries (MAAs)

	Men		Women	
	Pre-PS	Post-PS	Pre-PS	Post-PS
WBA & ES MAA	0.088	0.237	0.088	-0.028
WBA & IO MAA	0.180	0.039	0.040	0.286
WBA & EO MAA	-0.063	-0.259	-0.358	0.074
WBA & GM MAA	0.354	0.418	0.615*	0.042

*p<0.05

Prolonged standing (PS), Erector Spinae (ES), Internal Obliquus (IO), External Obliquus (EO), Gluteus Medius (GM)

WBAs and CoPAs

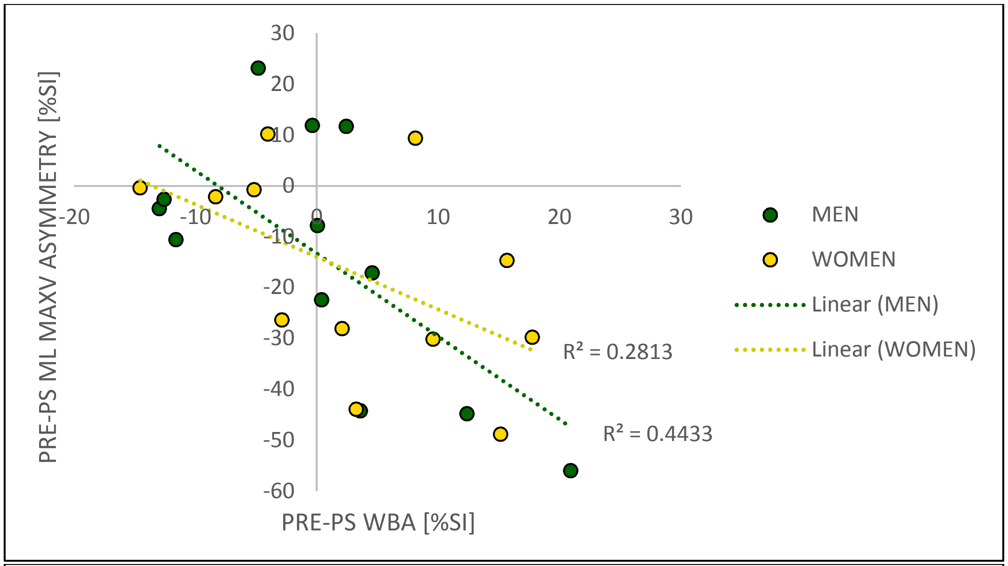
There were several significant correlations found between the WBAs and CoPAs (Table 4.7). There were some sex differences among the significant correlations, with the women possessing significant correlations between the WBA and ML sway asymmetry, then between the WBA and AP PL asymmetry during the post-PS trials while the men did not possess significant correlations in these variables. The most unique of the correlations were those involving the maxV in both the ML and AP directions. For the ML maxV, there was only a significant correlation found among the men for both the pre-PS and post-PS trials (Table 4.7, Figure 4.9). The correlation during the pre-PS trial was weak (p=0.018) and increased to a moderate level during the post-PS trial (p=0.000). For the correlation between the WBA and AP maxV asymmetry, there weren't any significant correlations found during the pre-PS trial for the men or the women. However, during the post-PS trials, there was a weak correlation found among the men (p=0.029) and a moderate correlation found in the women (p=0.007) (Table 4.7, Figure 4.10).

Table 4.7: Pearson Correlations (r) Between Weight-bearing (WBAs) and Center of Pressure Asymmetries (CoPAs)

	Men	Women
WBA & ML Sway Asym		
Pre-PS	-0.065	-0.734*
Post-PS	-0.112	-0.663*
WBA & AP Sway Asym		
Pre-PS	0.043	-0.256
Post-PS	-0.027	-0.435
WBA & ML PL Asym		
Pre-PS	-0.696*	-0.66*
Post-PS	-0.827**	-0.716**
WBA & AP PL Asym		
Pre-PS	-0.46	-0.373
Post-PS	-0.512	-0.644*
WBA & ML maxV Asym		
Pre-PS	-0.666*	-0.53
Post-PS	-0.873**	-0.334
WBA & AP maxV Asym		
Pre-PS	-0.197	-0.079
Post-PS	-0.628*	-0.73**

*p<0.05, **p<0.01

Medial-lateral (ML), anterior-posterior (AP), path length (PL), maximum velocity (maxV), prolonged standing (PS)



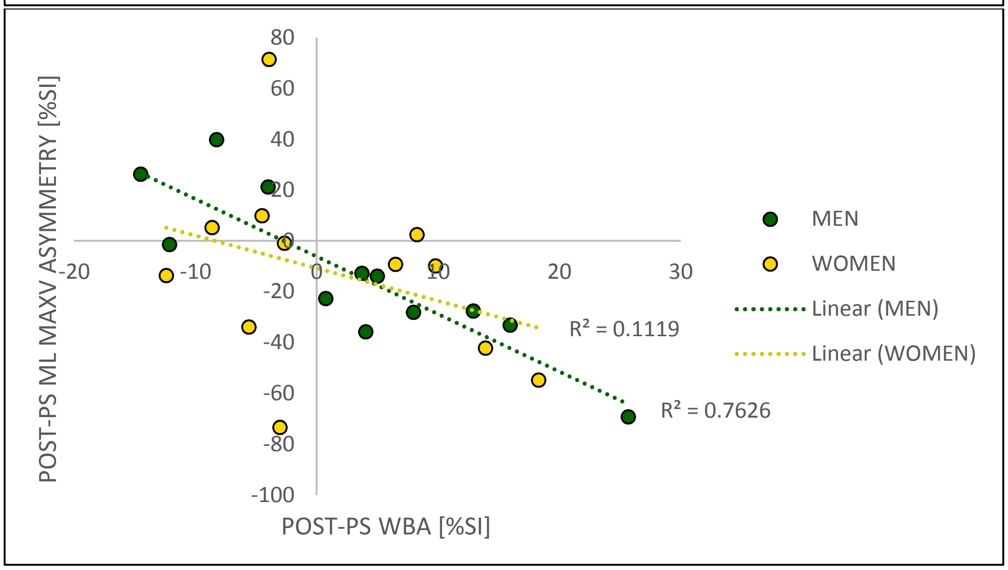


Figure 4.9: Correlation plots for pre-prolonged standing (PS) weight-bearing asymmetries (WBAs) and medial-lateral (ML) maximum velocity (maxV) asymmetry (top) and post-PS WBA and ML maxV asymmetry (bottom).

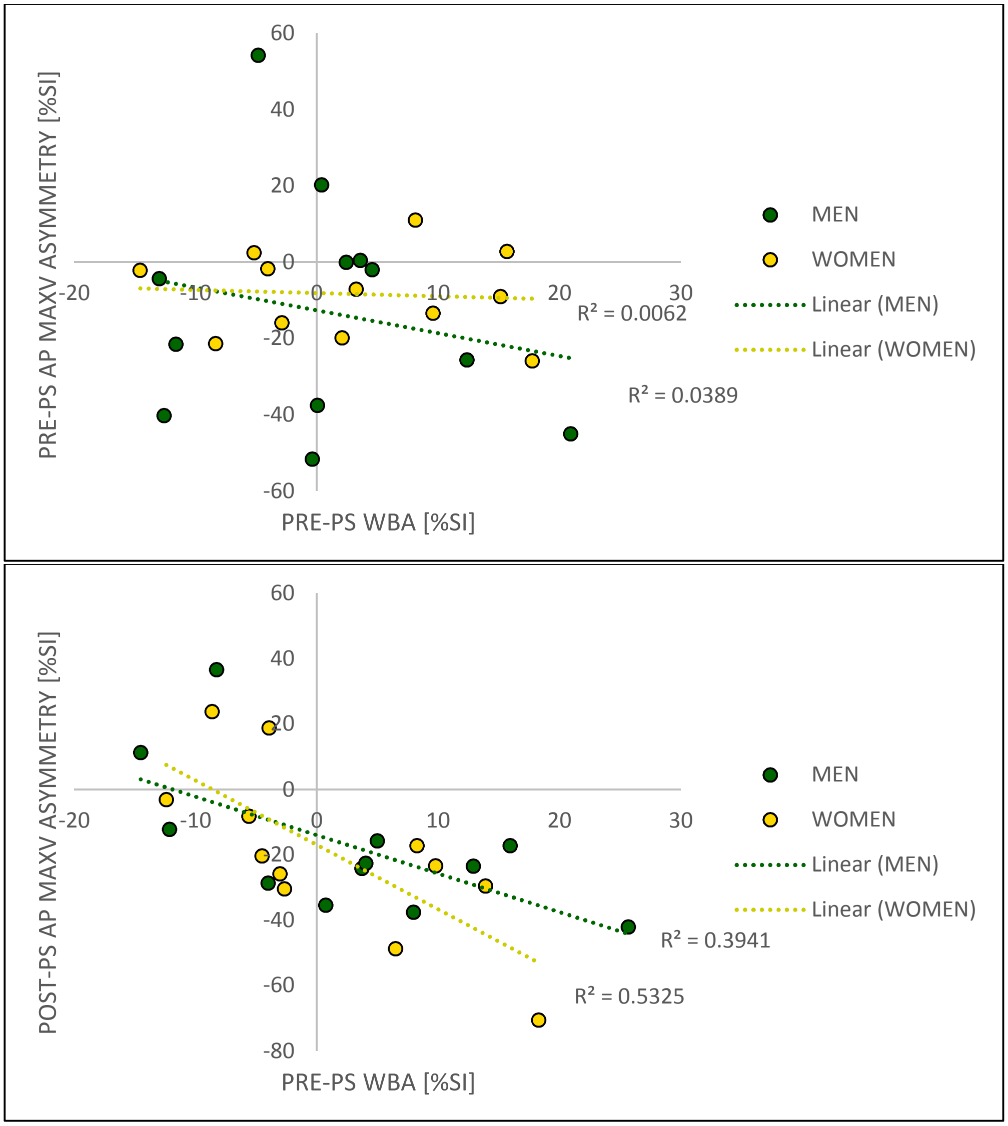


Figure 4.10: Correlation plots for pre-prolonged standing (PS) weight-bearing asymmetries (WBAs) and anterior-posterior (AP) maximum velocity (maxV) asymmetry (top) and post-PS WBA and AP maxV asymmetry (bottom).

Absolute WBAs and net CoP Movement

Significant correlations between the absolute WBAs and the net CoP variables were not found for both the pre-PS and post-PS trials ($p \geq 0.082, -0.521 \leq r \leq 0.461$). This held true for both the men and the women.

Repeatability

The intraclass correlation (Chronbach's alpha) analysis examining those that came back for a second visit (n = 11) showed that there were weak to moderate repeatability within most of the variables (Table 4.8). If the intraclass correlation was less than 0.50 for the pre-PS trials, it always rose to a weak correlation level (alpha ≥ 0.50) for the post-PS trials. Due to an issue with the left force platform, only variables pertaining to the right foot could be assessed, and thus asymmetries couldn't be tested for repeatability. The weak Cronbach's alphas involving force was due to the number of individuals who put more weight onto one limb during their first visit, then applied more weight to the contralateral limb during the repeat visit. For the pre-PS trial, only 3 individuals made this switch, and while two of them had small changes of 1-2% of body weight (BW) shift across the 50% BW symmetry line, one subject had a shift consisting of applying 55.23% BW to the right foot during the original trial then only 47.93% BW during the repeatability trial. The lowest Cronbach's alpha value belonged to the maxV in the AP direction during the pre-PS trial, and investigation into the calculated values showed that while the majority of the subjects had relative similar values between the original and repeatability tests (~1% height differences), there were three subjects who had 3-5% height changes between the two visits.

Table 4.8: Repeatability of The Pre-Prolonged Standing (PS) And Post-PS Trials For The Right Foot Of Those That Returned For A Second Visit (n = 11)

	Cronbach's Alpha	
	Pre-PS	Post-PS
GRF [%BW]	0.478	0.644
ML Sway [%height]	0.847	0.599
AP Sway [%height]	0.749	0.619
ML maxV [%height]	0.666	0.603
AP maxV [%height]	0.354	0.626
ML PL [%height]	0.465	0.559
AP PL [%height]	0.711	0.756

Ground reaction force (GRF), body weight (BW), medial-lateral (ML), anterior-posterior (AP), maximum velocity (maxV), path length (PL)

Chapter V: DISCUSSION

The primary aim of this study was to evaluate the effect of 30 minutes of PS on GRF control and core muscle activation within healthy, young adults during QS. A secondary aim was to determine the sex differences present. It was hypothesized that fatigue due to PS would cause an increase in both the WBAs, MAAs, CoPAs and CoP movements during QS. It was also believed that the ND limb would exhibit greater CoP movements than the D limb. There were hypotheses that there would be significant correlations between WBAs and MAAs, WBAs and CoPAs, and the absolute WBAs and net CoP movements. Lastly, it was hypothesized that men and women would behave differently during QS. In general, PS did not cause an increase in WBAs, MAAs, nor CoPAs during QS. However, it did cause an increase in the net CoP movements. It was typically seen that the ND limb did exhibit greater CoP movements than the D limb. There was only one significant correlation present between the WBAs and MAAs, existing for the GM MAA for women during the pre-PS trial. There were several significant correlations between the WBAs and CoPAs, while none were present between the absolute WBAs and net CoP movements. Differences between men and women were present in GM activity, ES use, net CoP movements, and correlations among WBAs/MAAs and WBAs/CoPAs.

Effects of Fatigue

Due to the lack of changes occurring with WBAs, MAAs, and CoPAs when exposed to 30 minutes of PS, the first hypothesis, related to asymmetry increases due to fatigue, cannot be accepted. However, it brings the idea of fatigue into question as well as the magnitudes necessary to expect changes to occur. There were signs of fatigue with muscle activity and use from pre-PS to post-PS, although they were not reflected in these asymmetries. This suggests that fatigue may not have an effect on asymmetries, or that it didn't occur at a high enough level to cause any changes to the asymmetries. The most directly related research available suggested that there existed a noted relationship between greater WBAs and increased CoP movements (Anker et al., 2008, Genthon & Rougier, 2005, Rougier & Genthon, 2009) in addition to CoP movement and BW shift frequency increases occurring with fatigue (Bermejo et al., 2015, Corbeil et al., 2003, Gallagher et al., 2011, Gribble & Hertel, 2004), which brought belief that asymmetries would increase as well due to fatigue. Previous research on the free-weight barbell squat has indicated that fatigue does not cause an increase to WBAs (Hodges et al., 2011). These authors postulated that asymmetries may not have increased due to the need to maintain balance and limit the risk for falling. This may be the case here as well. There's also a possibility that the length of time for the PS trial was not long enough to induce enough fatigue in this population. Several PS studies required subjects to stand for 2 hours (Gallagher et al., 2011, Gregory & Callaghan, 2008, Nelson-Wong et al., 2008, Nelson-Wong et al., 2010), so perhaps 30 minutes of standing wasn't long enough to cause the changes that were expected. Additionally, we recruited from a healthy subject population. All subjects were required to be free of any back ailment, and confirmed that they were able to stand for 30 minutes comfortably without needing to sit down. It's possible that having individuals this healthy wouldn't allow for these suspected changes to occur. During the PS trial, they were allowed to shift and sway to stay comfortable, which could suggest that this is a mechanism adopted by healthy individuals to keep comfortable and prevent LBP. A major difference between the studies that found changes to WBAs due to PS exposure and this study, is that the previous works have noted the changes occurring over time during the actual PS trial, while this study only analyzed the effect it had on QS. It's possible that WBA changes occur during the actual PS trial, but aren't reflected during QS for a healthy population. Future analysis of the PS trial could help confirm whether or not this is true. Additionally, individuals with LBP have been noted to have higher WBA than healthy subjects during QS, and greater WBAs are reflected in higher levels of LBP (Childs et al., 2003). Over time, LBP levels have also been seen to increase in PD during PS (Gregory & Callaghan, 2008, Nelson-Wong et al., 2010), so it's possible that an increase in WBAs could occur in a LBP population rather than with a healthy population. When comparing our recorded levels of WBAs to that of the healthy individuals in Childs et al. (2003), asymmetry values were similar, and in fact, our subject population may have been more symmetric than their control group. This further confirms that a healthy population may need more time to exhibit major asymmetry changes.

While fatigue wasn't reflected in changes to the asymmetries, there were signs of it occurring in CoP movements. Thus, the fatigue hypothesis related to CoP can be accepted. However, there wasn't an increase in all of the net CoP variables. The PS trial caused an increase in only the AP sway, ML maxV, and both AP and ML PL during QS. The increase in PL is most likely primarily due to the increase in AP sway, along with the faster movements (maxV) in the ML direction. Previous research has shown that fatigue causes an increase in sway, maxV, and mean velocity (which suggests an increase in PL), which is consistent with our findings (Bermejo et al., 2015, Corbeil et al., 2003, Gribble & Hertel, 2004). With these observed changes, it could be suggested that after 30 minutes of PS, balance is being compromised and may put an individual at a slightly increased risk of falling.

When looking at the effects of PS on pooled muscle activity, it was seen that the ES in men had a decrease from the pre to the post-PS trials. Although there wasn't a hypothesis specific to muscle activity changes, these results help further solidify the conclusion that only minimal fatigue is occurring. Within the lumbar ES, men typically have a higher relative percentage of fatigable Type II fibers (Mannion et al., 1997). Due to this, men have shorter times to task failure during submaximal fatiguing contractions (Clark et al., 2005, Hunter et al., 2006). It's possible that the recorded decrease in ES activity is a result of the men essentially reaching fatigue, and thus using other muscles or passive structures to maintain posture. It's also possible that the men reduced ES activity to minimize spinal compression. Men have more mass in their upper body compared to women (Janssen et al., 2000) which would contribute to greater amounts of passive compressive loading in the lumbar spine. Individually or in combination, these two differences could explain why the same decrease in activity was not recorded in the women. Additionally, the increase in AP sway could result in postural changes that would in return affect the ES activity. However, the decrease in ES activity was relatively low, which brings up the concern how meaningful the decrease really is.

Limb Dominance

There's been suggestion that humans primarily use their right leg for motor control (categorized as the D limb), while the left leg (ND limb) is used for balance control (Sadeghi et al., 2000). Due to this, it was hypothesized that the ND foot would have more postural movement than the D foot during QS. In general, this hypothesis can be accepted. Twenty one of the 24 subjects reported their right leg as being their preferred kicking leg, which supports the previous mention of most individuals using their right limb for motor control (Sadeghi et al., 2000). While maxV and PL had higher values in both the AP and ML directions for the ND limb compared with the D limb during the pre-PS trial, there was no significant difference between the two limbs for sway. Additionally, during the post-PS trial, there were significant differences related to limb dominance for the PL in both the AP and ML directions (similar to the pre-PS trial), and for the AP maxV. This could also give suggestion of fatigue, due to the difference between the ND and D limbs not being significant for the ML maxV during the post-PS trial, while it existed for the pre-PS trial. With the lack of differences related to sway, it can be seen that while the two feet move with similar magnitudes, the ND foot has to move more and with greater speed to help maintain balance and stability. As previously discussed, the net CoP movements increased from the pre-PS to post-PS trials. With the additional changes of which variables have significant differences between the D and ND limbs, it suggests that neither foot is doing quite the same thing as it was prior to PS. This could potentially increase the risk for falls even more than what was indicated by the increase in net CoP movements.

Correlations

It was hypothesized that there would be a correlation between the WBAs and MAAs, and this can be partially accepted. It really only held for the correlation involving the GM MAA for women during the pre-PS trial only. Logically, it makes sense that this correlation would exist. As an individual puts more weight onto one limb, the GM on that side of the body would need to activate to help pull them into this position and stabilize. With this correlation not being significant for the post-PS trial, it brings up the concern that something may be occurring during PS to decrease the strength of this relationship. This correlation is also not occurring at a significant level for the men in either of the QS trials. A possible reason for this could be related to the musculoskeletal differences that exist between men and women, primarily at the hip, with women typically having a wider pelvis (Smith & Smith, 2002). Since there wasn't a change in WBAs or GM activity levels from pre-PS to post-PS, but there were changes to the correlations between these two variables, it suggests that different strategies were being used to deal with the fatigue. Women could be using different muscles, besides the GM, to stabilize weight distribution during the post-PS trial as compared to the pre-PS trial. However, due the constraint of only being able to record 4 sets of core muscles, this can't be confirmed with the current data.

Due to the several significant correlations found between the WBAs and CoPAs, the hypothesis pertaining to those correlations can be accepted. However, there was a great amount of inconsistency for which variables were significant. More specifically, some CoPA variables were significantly correlated with WBAs in one direction (ML or AP) but not the other, some had significant correlations during the pre-PS trial but not the post-PS trial, and some were significantly correlated for the women but not the men. This suggests that, again, fatigue may be occurring to cause changes to the magnitude of the correlations from pre-PS to post-PS and multiple response mechanisms might exist. All of the correlations found were negative, which indicates that the unloaded foot had higher CoP movements. This supports previous findings where it was found that as more weight was applied to a limb, the opposite (unloaded) limb contributed more to the CoP movements (Genthon & Rougier, 2005). However, this conflicts with other findings that have indicated the loaded foot plays a larger role in CoP movements (Anker et al., 2008, Rougier & Genthon, 2009). These contradictory results between the loaded and unloaded foot's role could be related to the way the WBAs were applied. With the mentioned previous research, individuals were specifically told to apply more weight to one limb than the other, thus causing drastic WBA (Anker et al., 2008, Genthon & Rougier, 2005, Rougier & Genthon, 2009), while the subjects in our study had smaller, more naturally occurring WBAs. It is possible that during typical (quiet) standing conditions, the unloaded foot contributes more to CoP movements, and that during a forced asymmetrical stance, there is more variance with the limb contributions.

While there were significant correlations present between the WBAs and CoPAs, as discussed previously, there were no significant correlations between the absolute WBAs and net CoP movements. The lack of a significant relationship found could be due to the removal of the individual limb element. Absolute WBAs and net CoP movements are calculated without regard to one limb contributing more than the other (they assess overall asymmetry and movement), and as seen with some of the previously discussed findings, both limb dominance and the unloaded limb's contribution appear to play an important role in overall movement and asymmetries. So perhaps the removal of that aspect is related to the lack of significant correlations present. It may also be due to the existence of multiple response mechanisms existing for maintenance of posture and balance.

Sex Differences

There were several differences between men and women found, shedding light onto the diversity that exists between the sexes for muscle use and postural stability during QS. Due to all of the differences present, our final hypothesis can be accepted.

Overall, women had higher GM activity than the men in both of the QS trials. As mentioned with the discussion of the GM MAA and WBA correlation, these findings are likely due to the musculoskeletal differences at the hip between the sexes. Women have wider hips, which has been previously suspected of playing a role in GM muscle activation differences that are present between men and women (Nelson-Wong et al., 2012, Smith & Smith, 2002). This muscle activation difference was noted during trunk flexion-extension, with women activating their hip muscles prior to trunk muscles (Nelson-Wong et al., 2012). Due to our muscle activity findings, it could be suggested that these same activation strategies are also used during the minimal movements in QS.

As discussed previously in the fatigue section, men had a decrease in ES activity from the pre-PS to post-PS trials, while women did not experience a change in ES activity. Previous research has suggested a shift in activity to the more laterally oriented spinal muscles when fatigue occurs among men (they did not study women), however, they did not note a decrease in ES activity, but rather a slight increase with greater increases occurring in the more lateral muscles (vanDieën, 1996). Due to the limitations on the number of muscles that activity could be recorded, we do not have the data to see if the men had an increase in the more lateral muscles alongside this decrease in ES activity. These slight differences could be related to the type of fatigue that is occurring. It is possible that when less extreme fatigue begins to occur, like with PS, the ES muscles have a decrease in activity to help relieve spinal compression and prevent more fatigue from happening. The reasoning behind why these changes were only found in the men and not the women could be related to the musculoskeletal differences of the spine between the two above and beyond just carrying more load in the upper body than women. Men typically have thicker ES muscles, larger cross-sectional areas of the lumbar vertebrae (Marras et al., 2001), and less oblique fiber orientation (relative to the spine) in the multifidus muscle (lies deep relative to the ES) (Biedermann et al., 1991). Perhaps these differences are significant enough to cause men and women to have the altered responses to low level fatigue that are being observed in this study.

There were several differences between men and women present for the CoP movements. Overall, women had higher values for PL (in both AP and ML) and ML maxV during the pre-PS trial. During the post-PS trial, similar differences were found alongside the addition of AP maxV. With the net CoP, women had greater PL and ML maxV. There were also several correlation differences found between men and women. During the pre-PS trial, significant correlations that were present for one sex and not the other were that the women had a significant correlation between WBA and ML sway asymmetry, while men had a significant correlation between WBA and ML maxV asymmetry. For the post PS trial, correlations that existed for one sex and not the other were WBA/ML sway asymmetry and WBA/AP PL asymmetry for the women, and WBA/ML maxV asymmetry for the men. All of these differences related to CoP movements suggest that men and women have noticeable differences in their standing styles and the potential for multiple ways of responding to fatigue within each sex. It appears that during QS, while women have similar sway magnitudes as men, they're moving more and with greater speed. This doesn't necessarily infer that men have better balance than women, which has been suggested by previous research (Mechling, 1986), because one sex isn't swaying with greater magnitude than the other, which is what typically constitutes as being less stable. It does, however, suggest that men and women have different strategies for maintaining postural stability (Ekdahl et al., 1989, Mechling, 1986).

Limitations

As with any study, there were limitations to the research. As discussed previously within the fatigue section, there's a possibility that 30 minutes was not long enough to induce the changes that were hypothesized to occur. This is an issue that could easily be addressed with a longer PS trial, such as one lasting 1 to 2 hours. However, 30 minutes of PS is more realistic for most people compared to the longer durations that might be experienced by shift workers. The subject population was also very healthy and able to comfortably stand for 30 minutes, which could limit the changes occurring during the PS trial. While we did not specifically select NPD for this study, our inclusion criteria most likely limited our population to NPD. Further, we did not survey everyone at the end of the 30 minute PS trial, though no subject commented on the presence of pain. A longer PS trial could also shed light on the multiple response mechanisms that appear to be present within each sex. It may be that one type of response might lead to pain development that could not be elucidated in only 30 minutes. Conducting research on individuals who suffer from LBP or have significant known asymmetries could also prove to be a valuable future direction to address these concerns, and allow for comparison to the results from healthy individuals. In addition to not verifying that the subjects were NPD at the end of the study, there wasn't a test conducted to assess for fatigue. While these findings are suggestive of fatigue occurring, we didn't directly measure fatigue. Another restraint put on the research was that there was a limitation on the number of muscles that could be recorded. Due to the sEMG system used, only 4 pairs of muscles could be recorded. The findings pertaining to the changes in muscle use in the back suggests a need for different muscles to be recorded, to verify if there's an increase in muscle use elsewhere while the ES has a decrease in use. During a clinical assessment, sEMG may be difficult to use, however, if the relationships between muscle activity and other variables (such as WBAs and CoP movements) are understood, then sEMG may not be needed. If the relationship is understood, and the WBAs are calculated, then it can be understood what would be occurring with the muscle activity during this time. The use of two separate force platforms during the PS is a potential limitation, due to subjects then being restricted to keep one foot per force platform. During PS, some individuals may place one foot on top of the other while standing, and by not allowing that to be an option, their natural standing styles may have then been affected. Another lower-limb limitation was that subjects were required to have a stance width of 10% of their standing height. With women having wider hips (Smith & Smith, 2002), this stance width may have been narrower for them than it was for the men. A future study could take this into account by having individuals select a comfortable stance width, with that same width being used for both of the QS trials. In addition to the constraints put on foot placement, there was also restriction put on their hand placement during the study. Subjects couldn't have their hands or arms placed over any of the sEMG electrodes, which could be normal placement for some individuals. Another upper-extremity related limitation was that individuals could not lean on the safety bars that were around the force platforms. This made for a slightly different standing scenario than what could be recorded if the individuals were allowed to lean against the bars or a table while standing, which is a common action during PS. Due to these restrictions placed on the hands and feet, it potentially brings into question how representative this study is of how people really stand during extended periods of time. The repeatability levels that were able to be assessed weren't as high as would be needed for a clinical test. However, this doesn't disregard the relationships that were still found to be present within the research. The lower levels of repeatability could be potentially related to the force platform malfunction, which only allowed for calculation of the variables under one foot. This prevented calculation of any of the asymmetries and net CoP movements, which restricted the number of variables that could be tested for repeatability.

Conclusions

In conclusion, 30 minutes of PS appears to cause fatigue, though minimal, among muscle activity, muscle use, and CoP movements in young healthy adults. It does not, however, appear to cause changes to the asymmetries. The GM MAA is significantly correlated to WBAs before PS, but no longer exists post-PS which is suggestive of fatigue as well. In general, the ND limb contributes more to CoP movements than the D limb. There are several correlations present between the WBA and CoPA, suggesting a strong relationship between weight distribution and CoP movements, with the unloaded limb having the greater contribution to these movements. Lastly, the significant number of differences between men and women indicates that while weight distribution patterns are similar, they have different movements and muscle use during QS. Finally, the change in some of the correlation levels pre-PS to post-

PS without changes in average level indicate that multiple response mechanisms might be present. Further research should be performed with known PD to verify if the observed responses are pain protective or potentially pain promoting, or use slightly longer trials. Regardless, these findings shed light on how PS affects QS in both men and women.

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APPENDICES

Appendix A

Subject ID: ___________

Clinical Biomechanics Lab Health Screening - Coded Cover Sheet

(Separate from the coded screening form, store separately)

Project Title: ***Effects of Prolonged Standing on Weight-Bearing and Muscle Activation Asymmetries***

Name (Last, First): ________________________

Address: _______________________
____

Phone number: __________________

Email: __________________________

Screened by:________________________

Acceptable Subject: Yes or No

Willing to be contacted in the future for other studies? Yes or No

Notes____

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- Phone Screening Section-

Screener's initials:_________ Screening date:___________ Approved: Y or N

Subject ID:______________ Sex: O **M** O **F**

DOB:___________Age:_______

Females only: Are you pregnant? O Yes O No

Height:______________ Weight:____________ → BMI:___________________

Are you healthy (pain, soreness, and injury free)? O Yes O No

Have previous injuries healed at least 4 weeks ago? O Yes O No

Do you have now, or ever had, chronic low-back pain or scoliosis? O Yes O No

Do you have any orthopedic or arthritic problems? O Yes O No

Do you have any prior injuries or conditions that would cause you to favor one side of the body while performing otherwise symmetric tasks (broken bones, torn muscles and ligaments, a leg-length differential, etc.)?

O Yes O No

____

Do you use any bilateral corrective devices (heel lift, brace, etc.)? O Yes O No

Do you have a balance disorder or are you taking any medications that affect balance? O Yes O No

Are you involved in an occupation or activity that requires you to stand still for 4+ hours? O Yes O No

Are you able to stand for 30 minutes without needing to sit down? O Yes O No

Are you willing to let us shave hair from small areas in the hip/abdominal/back area? O Yes O No

Are you willing to have a DEXA scan performed, exposing you to low doses of X-rays? O Yes O No

Are you willing to abstain from rigorous physical activity for the 24 hours prior to a lab visit? O Yes O No

Do you have any conditions that we should be aware of in the chance that an adverse event were to occur during your visit? We want to be able to act quickly and correctly if something were to happen to you.

(heart, asthma, allergies, epilepsy, medications, etc.)?____

____

____

…based on your answers, you are a good match for this project. Can we schedule a 2hr block of time for you to come in to the lab? O Yes O No _________________________

-Need to be well rested (no major physical activity prior to lab visit)
-Need to wear comfortable clothing that does not restrict motion (t-shirt, shorts, walking shoes)
-Need to consume a 'normal' amount of caffeine that day (ie, if you don't normally drink caffeine, don't drink any that morning, or if you usually have 2 cups of coffee, then drink 2 cups)

…unfortunately, it does not look like you are a good match for this project. Can we keep your name and contact information on file for future studies? O Yes O No

Notes____

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Appendix B

Consent to Participate in a Research Study
Colorado State University

TITLE OF STUDY: **Effects of Prolonged Standing on Weight-Bearing and Muscle Activation Asymmetries**

PRINCIPAL INVESTIGATOR: Raoul F. Reiser II, PhD. Department of Health and Exercise Science. Director of the Clinical Biomechanics Laboratory. Contact at (970) 491-6958 or Raoul.Reiser@Colostate.edu

CO-PRINCIPAL INVESTIGATOR: Kylie Soliday. Graduate Student, School of Biomedical Engineering. Contact at (303) 249-2401 or KSoliday@rams.colostate.edu

WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH? *You are being asked to volunteer for this research because you are a healthy adult between the ages of 18-30 years with no current injuries (pain free for the last month). You must also be free of any medical condition that affects balance or medication affecting balance, free of current or chronic low-back pain, scoliosis, or other condition, such as a prior injury, that would cause you to favor a leg while standing and have a BMI < 30 kg/m^2 (i.e., not obese). Furthermore, you must not be employed or participate in activities that require extended bouts of static standing. Note: many medications list the possible side effect of reduced balance, though you might not experience a problem and you would be fine to participate. If the medication causes you to feel dizzy, light-headed, unsteady, woozy, or like you are floating or spinning you should not participate. Typical medications you might encounter that affect balance are certain antibiotics and painkillers.*

WHO IS DOING THE STUDY? *This research is being performed by Raoul F. Reiser II, Ph.D. of the Health and Exercise Science Department. Dr. Reiser is interested in musculoskeletal biomechanics. Kylie Soliday is a graduate student interested in spine biomechanics.*

WHAT IS THE PURPOSE OF THIS STUDY? *Most people have an uneven distribution of their weight on their lower limbs when standing. A significant asymmetry in the lower limbs is linked to falls in the elderly, reduced sports performance, and low back pain. This study will see if there's a correlation between weight bearing asymmetries and the muscles of the hip/abdomen during prolonged standing. Results will help understand how weight bearing when standing potentially relates to back pain.*

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST? *This research project will take place in the Human Performance Clinical/Research Laboratory located on the first floor of Moby Arena (B wing) on the CSU main campus. Your involvement will last roughly 2 hours. While not required, we would like to have you return on a second day (within two weeks of your first visit) to repeat the study. This will help us determine the day-to-day repeatability of our measures. It would increase your involvement by another 2 hours.*

WHAT WILL I BE ASKED TO DO? *If you agree to participate you will be required to do a single trial consisting of standing continuously for 30 minutes, along with two 1 minute standing trials. During each of the trials you will stand while the forces under your feet are measured. You will also have electrodes attached to your skin so that the muscle activations of your hip, stomach, and back muscles can be measured. To attach these electrodes we will need to clean the skin with alcohol and may need to shave hair to ensure contact with the skin. Additionally, you will receive a DEXA scan that will accurately measure your body composition and bone mineral density. The DEXA is a machine that will use x-rays to determine your body composition and bone mineral content. The DEXA scan requires you to lie quietly on a padded table while a small probe gives off low-level x-rays and sends them over your entire body. If you return for a second visit an additional DEXA will not be performed.*

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY? *You should not volunteer for this study if you do not meet the criteria outlined above. Additionally, if you are a woman, you should not participate if you are pregnant. Regardless of gender, you should also not participate if you are uncomfortable with what you will be asked to do.*

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS? *The risks associated with the DEXA are very low. The maximum radiation dose you will receive per scan is less than 1/3000th of the federal and state occupational whole body dose limit allowed to radiation workers. Put another way, you will receive less than 1.3 mrem from this scan and you already receive approximately 450 mrem per year from normal background radiation doses in Colorado. However, the more radiation you receive over the course of your life, the more the risk increases of developing a fatal cancer or inducing changes in genes. The radiation dose you receive from this scan is not expected to significantly increase these risks, but the exact increase in such risks is not known.*

Other possible risks include fatigue, muscle soreness, dry/irritated skin, boredom and very minimally a risk for falling. Light contractions of the muscles measured with the electrodes will be needed as a reference. The skin under/around the electrodes may become dry. You will be given a documentary to watch during the 30 minute standing trial. A handrail is available in the case you lose balance. You will be able to move your feet and adjust your posture during the trial. However, you should not "lock" your knees during the trials. A research assistant with be close by. It is not possible to identify all potential risks in research procedures, but the researchers have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

WILL I BENEFIT FROM TAKING PART IN THIS STUDY? *While this study should provide useful information that may in the future provide useful information in understanding lower limb asymmetries, there are no current benefits to participation in this study. You may find the results of the DEXA scan useful. It will provide you with body composition and bone density information.*

DO I HAVE TO TAKE PART IN THE STUDY? *Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.*

WHAT WILL IT COST ME TO PARTICIPATE? *There are no costs to participate in this study. However, if you are injured during the course of involvement, you will be responsible for medical costs beyond the emergency treatment. You must provide your own transportation to and from the laboratory.*

WHO WILL SEE THE INFORMATION THAT I GIVE? *We will keep private all research records that identify you, to the extent allowed by law.*

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key. You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court. . We may be asked to share the research files for audit purposes with the CSU Institutional Review Board ethics committee, if necessary. The files containing information about you will be identified with a code, such as "PS01", where PS is short for Prolonged Standing and 01 is a subject number. Upon completion of data collection and verification of results, the list linking your name to the code will be destroyed.

CAN MY TAKING PART IN THE STUDY END EARLY? *Your participation in the study may end early if you are unable to perform the tasks required of the study. Most notably, you must be able to stand for 30 minutes without sitting.*

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY? *There is no monetary compensation for your involvement in the study.*

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH? *The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury.*

In light of these laws, you are encouraged to evaluate your own health and disability insurance to determine whether you are covered for any physical injuries or emotional distresses you might sustain by participating in this research, since it may be necessary for you to rely on your *individual coverage for any such injuries. Some health care coverages will not cover research-related expenses. If you sustain injuries, which you believe were caused by Colorado State University or its employees, we advise you to consult an attorney.*

WHAT IF I HAVE QUESTIONS? *Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigators, Raoul F. Reiser II, Ph.D. at 970-491-6958 or Kylie Soliday at (303) 249-2401. If you have any questions about your rights as a volunteer in this research, contact the CSU IRB at: RICRO_IRB@mail.colostate.edu ; 970-491-1553. We will give you a copy of this consent form to take with you.*

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 3 pages.

____ _____________________

Signature of person agreeing to take part in the study Date

____

Printed name of person agreeing to take part in the study

____ _____________________

Name of person providing information to participant Date

____

Signature of Research Staff

Appendix C

Colorado State University
Knowledge to Go Places

Research Integrity & Compliance Review Office
Office of the Vice President for Research
321 General Services Building - Campus Delivery 2011 Fort Collins, CO
TEL: (970) 491-1553
FAX: (970) 491-2293

NOTICE OF APPROVAL FOR HUMAN RESEARCH

DATE:	May 30, 2014	
TO:	Reiser, Raoul, Health & Exercise Science	
	Israel, Richard, Health & Exercise Science, Soliday, Kylie	
FROM:	Barker, Janell, Coordinator, CSU IRB 2	
PROTOCOL TITLE:	Effects of Prolonged Standing on Weight-Bearing and Muscle Activation Asymmetries	
FUNDING SOURCE:	NONE	
PROTOCOL NUMBER:	14-4989H	
APPROVAL PERIOD:	Approval Date: May 27, 2014	Expiration Date: May 15, 2015

The CSU Institutional Review Board (IRB) for the protection of human subjects has reviewed the protocol entitled: Effects of Prolonged Standing on Weight-Bearing and Muscle Activation Asymmetries. The project has been approved for the procedures and subjects described in the protocol. This protocol must be reviewed for renewal on a yearly basis for as long as the research remains active. Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed.

If approval did not accompany a proposal when it was submitted to a sponsor, it is the PI's responsibility to provide the sponsor with the approval notice.

This approval is issued under Colorado State University's Federal Wide Assurance 00000647 with the Office for Human Research Protections (OHRP). If you have any questions regarding your obligations under CSU's Assurance, please do not hesitate to contact us.

Please direct any questions about the IRB's actions on this project to:

Janell Barker, Senior IRB Coordinator - (970) 491-1655 Janell.Barker@Colostate.edu
Evelyn Swiss, IRB Coordinator - (970) 491-1381 Evelyn.Swiss@Colostate.edu

Barker, Janell

Barker, Janell

Approval is to recruit up to 24 participants with the approved recruitment and consent. The above-referenced project was approved by the Institutional Review Board with the condition that the approved consent form is signed by the subjects and each subject is given a copy of the form. NO changes may be made to this document without first obtaining the approval of the IRB.

Approval Period:	May 27, 2014 through May 15, 2015
Review Type:	EXPEDITED
IRB Number:	00000202

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