THE RELATIONSHIP BETWEEN POSTURE DISTORTION PATTERNS
AND STATIC/DYNAMIC BALANCE ABILITY

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DEDICATION

This thesis is dedicated to the field of Personal Training, through which I first developed my interest in posture and rehabilitation. It is also dedicated to Bryan College in Sacramento, CA, where I was provided the opportunity to put these interests into practice, and vowed to make a difference in the lives of those in need of postural correction for improved quality of life.
For me, I am driven by two main philosophies: know more today about the world than I knew yesterday, and lessen the suffering of others. You’d be surprised how far that gets you.

--Neil deGrasse Tyson
ABSTRACT OF THE THESIS

The Relationship between Posture Distortion Patterns and Static/Dynamic Balance Ability

by

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Master of Arts in Kinesiology
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Study Rationale:

Disequilibrium while standing increases an individual’s risk of injury, especially in the elderly population. To maintain upright posture, the body’s center of mass must be stabilized in a central, equilibrium location over the feet, which act as the base of support (BOS) during standing. Segmental postural impairments such as forward head position, thoracic and lumbar kyphosis, misalignment of the knees, and foot/ankle abnormalities are all implicated in the literature as disrupting this relationship, subsequently contributing to instability and increased fall risk. These findings are equivocal, however, and certain individuals are better able to compensate for these imbalances than others. This suggests that a global approach to assessing postural alignment, accounting for any compensatory joint position changes, may provide a more accurate way to distinguish alignment imbalances that may lead to falls. To objectively identify and rehabilitate instability in patients and clients, health practitioners such as Physical Therapists and Personal Trainers require quantitative measures to determine how far these individuals have migrated from equilibrium positions.

Purposes and hypotheses:

The present study suggests a method for calculating global posture offset measures, using computerized posture analysis software, from coronal and sagittal view photographs of individuals during quiet standing. It was expected that these measures would accurately predict deviations of the line of gravity (LOG) (i.e., the ground projection of the body’s center of mass measured with a force plate) away from an equilibrium position within the BOS. It was also expected that postural alignment abnormalities and/or deviations of the LOG would decrease the size of an individual’s stability limits during a multi-directional leaning task, the NeuroCom Balance Master’s Limits of Stability (LOS) test. To assess how physical activity behaviors may have affected the posture and balance relationship, participants responded to items on the Behavioral Risk Factor Surveillance System (BRFSS) questionnaire regarding physical activity and leisure time behaviors. It was expected that individuals who failed to meet the American College of Sports Medicine’s 2011 minimum physical activity recommendations, and/or spent greater amounts of time watching television, would have greater deviations from ideal postural alignment and lesser balance control than those who reported meeting these recommendations and watched less television.

Major findings:

Healthy, adult participants (N=98, age range 18-75 years) with greater global coronal and sagittal posture offsets had greater deviations of the LOG away from an equilibrium position. These global posture offset measures predicted the location of the LOG (as
estimated by center of pressure (COP) position) within 0.57 cm in the medial/lateral direction and 1.33 cm in the anterior/posterior direction. The resulting regression equations successfully predicted COP positions in an additional cross validation sample (N=20) of healthy adults with similar demographics. Postural offsets and COP positions were not significantly related to maximum excursions on the LOS test; however, postural offsets were inversely correlated with directional control scores, and both postural offsets and COP positions were positively correlated with movement velocity on this test. Demographic variables and BRFSS responses to neuromotor physical activity participation and TV-watching time were able to explain 42.8% of the maximum excursions participants attained on the LOS test. No relationships between physical activity behaviors or television-watching time and postural alignment were discovered.

**Conclusions:**

Overall, the findings in the present study suggest that postural alignment deviations are capable of influencing the location of the LOG during quiet standing. Global posture offset measures, provided by computerized posture analysis software, may offer health practitioners an objective, reliable method for identifying disequilibrium in their patients and clients. While the LOG location during quiet standing was not directly related to the maximum excursions participants achieved on the LOS test, it was related to the movement strategies participants employed when leaning toward targets, indicating that postural alignment may indirectly influence one’s stability limits. Finally, physical activity and sedentary behaviors were poor predictors of postural alignment and balance performance. It is possible that no direct relationship exists between these measures, or, that self-reported physical activity behaviors are not the best measure to use when investigating the relationships between postural alignment, balance control, and fitness level.
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CHAPTER 1

INTRODUCTION

Practitioners in health, fitness, and related fields are aware of an inactivity epidemic in both the United States and abroad. Over the last twenty years, developments in “Information Age” technology have decreased the need for physically demanding tasks and encouraged time spent quiescent (Hamilton, Healy, Dunstan, Zderic, & Owen, 2008). Among habitual exercisers, the percentage of total daily activity has declined (Owen, Healy, Matthews, & Dunstan, 2010). The availability of technology in the workplace and in leisure time activities has promoted both sedentary static (e.g., watching television) and sedentary repetitive (e.g., typing at a computer) behaviors (Hamilton et al., 2008). These sedentary behaviors are associated with a rise in morbidity and mortality due to preventable, chronic conditions such as cardiovascular disease and obesity (Matthews et al., 2008). While not yet recognized as a chronic disease, poor posture is another critical consequence of sedentary behavior (Hutchful, 2009).

Kendall, McCreary, Provance, Rodgers, and Romani (2005) defined poor posture eloquently, stating, “Poor posture is a faulty relationship of the various parts of the body that produces increased strain on the supporting structures, and in which there is less efficient balance of the body over its base of support” (p. 51). Postural impairments, due to poor ergonomics and lifestyle habits, have a direct impact on an individual’s ability to perform activities of daily living and sport/leisure avocations with the same ease as our more active predecessors (Katzman et al., 2012). Although the merits of good posture have been broadcast for centuries, the detrimental effects of neglecting proper posture have not been confirmed in the literature. Increased load on the joints, perceived chronic pain, muscular fatigue, and reduced balance ability are acknowledged as potential complications (Roussouly, Gollogly, Berthonnaud, & Dimnet, 2005). Research describing the specific consequences of poor postural alignment on balance control, and successful training strategies to restore equilibrium, would be advantageous to therapists and trainers in both identifying and rehabilitating instability, ultimately reducing injury and/or fall risk.
Injurious falls are a leading cause of death for older adults and were the number one cause of non-fatal injuries in the U.S. for all ages in 2010 (Centers for Disease Control and Prevention [CDC], 2012a). By 2020, the annual direct and indirect cost of fall injuries is expected to reach $54.9 billion. Screening for potential causes of instability has been a focus of copious research studies (for recent e.g., see Fraix, 2012; Pardasaney et al., 2012). The majority of this research has focused on the sensory (i.e., visual, vestibular, and somatosensory) contributions to declining balance ability. Too little has focused on the biomechanical contributions (i.e., musculoskeletal alignment), even though a primary component of balance is known to be control of the center of the body’s mass over the feet, which act as the base of support (BOS) for upright standing (Horak, 2006).

As individuals engage in larger amounts of quiescent time, a simultaneous increase in postural distortions has been noted at younger ages (Hutchful, 2009). Health practitioners such as Physical Therapists and Personal Trainers are perhaps best equipped to identify the biomechanical risk factors for falls, including postural impairments, and preventative screening may identify these risk factors at an early stage. With aging it becomes progressively more challenging to alter behaviors and correct posture, as evidenced by young women (\(n=25; \bar{M}=29.2\) years) exhibiting superior ability to actively correct excessive spinal flexion (i.e., achieve a 28% reduction) during standing as compared to elderly women (\(n=26; \bar{M}=72.3\) years) who could only achieve a 9.6% reduction when asked to stand as straight as possible (Hinman, 2004). Thus, proper postural habits should be inculcated early in life when an individual is best able to improve his/her postural alignment. Indeed, postural changes left unchecked as one ages may lead to a less economical standing position and subsequent balance instability that may lead to falls (Balzini et al., 2003; Britnell et al., 2005; Horak, Shupert, & Mirka, 1989).

**Ideal Posture and Balance**

It is generally accepted that ideal posture is desirable for successful maintenance of balance (Lafage et al., 2008). Ideal posture involves the proper alignment of body segments such that the least amount of energy is required to maintain upright standing, and minimal stress is placed on body tissues (Danis, Krebs, Gill-Body, & Sahrmann, 1998). It allows the center of gravity (COG), the point where gravitational force acts on the body’s mass, to be
positioned directly over the BOS (i.e., feet). The generally accepted standard for “ideal” alignment includes comparisons to a plumb line, a vertical line that should symmetrically divide the body in the coronal (i.e., front or back) view, and bisect the ear, cervical vertebral bodies, lumbar vertebral bodies, and terminally the tarsals of the foot in the sagittal (i.e., side) view (Figure 1) (Kendall et al., 2005).

![Figure 1. Ideal posture in the sagittal (left panel) and coronal (right panel) views.](image)

The term plumb line is often used interchangeably with the line of gravity (LOG), but this extrapolation is misleading. The LOG is actually the external reflection of the COG projected over the BOS, which rarely corresponds with reference plumb lines (Schwab, Lafage, Boyce, Skalli, & Farcy, 2006). For example, existing evidence comparing the location of the C7 plumb line (i.e., a line dropped from the body of the 7th cervical vertebra) with the location of the LOG, has established these lines as being disparate measures, with over 3.5cm separating their positions within the BOS (Roussouly, Gollogly, Berthonnaud, & Dimnet, 2006). These findings are unsurprising, however, because these segmental plumb lines do not account for the positions or relationships between all of the major joints in the body. To fully appreciate the effects of joint position changes on the location of the LOG during quiet standing, global posture offset measures, which assess the relationships between each major body segment, would be advantageous. No study to date has compared such measures to the location of the LOG.
Control of the COG within the BOS is necessary for adroit balance; however, direct measurement of the COG is difficult to obtain (Peterka, 2009). The most common estimation of the horizontal COG location is the center of pressure (COP) position, a measure of the resultant forces an individual exerts on his/her supporting surface while standing (Benda, Riley, & Krebs, 1994). COP position is commonly used to estimate the LOG location in the literature. It is measured with a force plate and has been reported to be a valid estimation of the LOG location during quiet standing (Benda et al., 1994). Mean COPx and COPy positions provide Cartesian coordinates for the location of the COP (i.e., LOG) within the BOS. In ideal posture, where the center of mass of each major body segment is aligned over the feet, the COP should be projected on a force plate in a position of postural equilibrium. This location is mid-way between the feet, and approximately 4-5cm anterior to the ankle joint axis (Hellebrandt, Tepper, Braun, & Elliot, 1938; Woodhull, Maltrud, & Mello, 1985), ultimately bisecting the tarsals through the calcaneocuboid joint (Kendall et al., 2005). Deviations from this central location place the COP closer to one’s stability limits (Figure 2a) (Woodhull et al., 1985). The functional limits of stability (LOS) are the distances toward (or past) the perimeter of the BOS in all directions that can be traveled before a loss of balance occurs (Horak, 2006). While standing, if an individual’s LOG migrates outside his/her BOS he/she will be forced to use corrective strategies to maintain balance (Blaszcyk, Lowe, & Hanson, 1994). An individual demonstrating a COP position close to the border of the LOS in any direction may suffer from a decreased functional LOS and thus be at an increased risk for loss of balance (Figure 2b) (Horak, 2006; Melzer, Benjuya, & Kaplanski, 2004).

Most falls do not occur during quiet stance conditions; therefore, assessments involving dynamic postural control may provide a more functional evaluation of balance ability (Shimada et al., 2003). The addition of a LOS test when investigating balance control provides important insight into an individual’s directional stability, and indicates how well the static posture of an individual prepared him/her for movement (Maeda, Tanaka, Miyasaka, & Shimizu, 2011). LOS performance is evaluated using excursions (i.e., distances attained when leaning toward stability limits with no changes in the BOS), directional control (i.e., accuracy of movement toward stability limits), and movement velocity (i.e., speed of movement toward stability limits) (Pickerill & Harter, 2011). Excursion scores are assigned as a percentage (out of 120%) of the theoretical stability limits attained based on age range.
Figure 2. (a) COP position during quiet standing for an individual with theoretically high risk (red) and low risk (green) postural alignment. The x-axis represents the ankle joint axis, thus, an individual with ideal posture will maintain a COP position midway between the feet along this axis, and 4-5cm anterior to this location along the y-axis. (b) Hypothetical size comparison of the functional LOS in the high risk (red) and low risk (green) posture respectively.

and height, directional control as an accuracy score out of 100%, and movement velocity in degrees/second. Higher scores on all three measures indicate superior performance. A few studies have investigated LOS tests for reliability and fall prediction capability (Forth, Fiedler, & Paloski, 2011; Hof, Gazendam, & Sinke, 2005; Jbabdi, Boissy, & Hamel, 2008); however, none have assessed whether the location of the LOG during quiet standing impacts LOS performance. Further investigations are necessary, to clarify the importance of maintaining a LOG equilibrium position within the BOS, and to determine how essential this position is in maximizing the size of an individual’s functional LOS.

Additional COP variables used to assess static and dynamic balance ability are excursions and velocity (Collins & DeLuca, 1993). The amount of body sway (i.e., total distance or area traveled) during quiet standing is expressed as COP path length or sway area, while distances traveled along the x (medial-lateral) and y (anterior/posterior) axes are termed COPx and COPy excursions. COP movement during upright standing is greater than COG movement, and occurs to modulate the LOG, keeping it within the constraints of the BOS (Lafond, Duarte, & Prince, 2004). Smaller measures of COP are typically indicative of superior, controlled balance ability and reduced risk of falling (Rogind, Lykkegaard, Bliddal, & Danneskiold-Samsoe, 2003). The COP is a better predictor of the horizontal COG location when excursions are small (Lafond et al., 2004). Increased COP velocity during quiet stance.
and decreased COP velocity during dynamic activities also represent instability, and may predict elderly individuals at increased risk for falling (Melzer et al., 2004).

**Effects of Poor Postural Alignment on the Musculoskeletal and Somatosensory Systems**

Deviations from ideal postural alignment also lead to muscle imbalances on opposing sides of the major joints, disrupting optimal length-tension relationships (Comerford & Mottram, 2001). Typically, individuals are pulled in the direction of gravity such that muscles on the anterior sides of the joints shorten and muscles on the posterior sides of the joints are forced to lengthen (Page, 2006). The short muscles are considered “tight” and the lengthened muscles “weak”. These altered length-tension relationships may disrupt the normal functioning of the muscle synergies necessary for postural control (Clark, Lucett, & Sutton, 2012). For example, two muscles necessary for optimal hip and ankle strategies used to maintain balance, gluteus maximus and tibialis anterior, are implicated as being weak or “underactive” in several common postural distortions (Daubney & Culham, 1999; Page, 2006). If these muscles are too weak to adequately respond to external perturbations, by making necessary corrective movements, balance may be affected.

In addition to muscular impairments, postural distortions can cause altered arthrokinematics (i.e., joint motion). Faulty positioning and movement of the major joints may have a negative impact on body proprioception, which is one’s ability to know one’s body position in space (Gaerlen, Alpert, Cross, Louis, & Kowalski, 2012). The alignment of certain joints may have a greater impact on proprioception than others. Janda and VaVrova (1996) emphasized the crucial role that the alignment and positioning of the feet, sacroiliac joint, and cervical spine play in supporting adequate proprioceptive feedback to the brain.

Reduced balance control, as evidenced by increased COP excursions during eyes closed, double stance conditions on a force plate ($F_{(4,136)}=2.55, p<0.05$), was observed in healthy adults following five-minutes of fatiguing contractions for the neck extensor muscles (Schieppati, Nardone, & Schmid, 2003). The cervical musculature is rich in sensory afferents (i.e., muscle spindles), and fatigue of this muscle group, due to prolonged periods of neck hyperextension as seen in cases of poor posture, may similarly impair balance control. Without proper posture, sensorimotor integration and control over the body suffers (Page, 2006). Quality sensory feedback relayed to the brain, from the mechanoreceptors underlying
proprioception, is necessary for optimal movement (Comerford & Mottram, 2001). In individuals with poor posture, the musculoskeletal and somatosensory systems may both require attention to prevent progressive instability.

**REVIEW OF THE LITERATURE EXAMINING POSTURE AND BALANCE**

While deviations from ideal posture have not been conclusively implicated in balance impairments, there is evidence to suggest that postural abnormalities may hinder balance control. Sagittal segmental deviations occur in the anterior/posterior direction (i.e., seen from a side view) and may negatively affect balance by causing a forward or backward shift of the LOG away from a position of postural equilibrium. Coronal segmental deviations occur in the medial/lateral direction (i.e., visible from a front or back view) and may cause migration away from postural equilibrium toward the right or left lower limb. However, research findings examining the effects of segmental deviations (i.e., deviations of only one major body segment such as the head) on balance control are equivocal, suggesting that perhaps a global approach may be necessary to elucidate the consequences of sagittal and coronal alignment deviations on balance control. In fact, compensatory joint position changes are known to occur in the body in response to segmental deviations (Roussouly et al., 2006). For example, a strong correlation \((r=0.889, p<0.001)\) between the angle formed by the spine and sacrum and the degree of low back curvature was observed in healthy adults \((N=153;\) age range 18 to 48 years) during standing, indicating that changes in the position of the spine relative to the pelvis affected the degree of lumbar curvature. Based on the knowledge that compensatory postural adjustments are unique to the individual, other authors are beginning to acknowledge the paucity of global postural alignment information and the need for alignment reference values (Ferreira, Duarte, Maldonado, Burke, & Marques, 2010). Such values would assist in characterizing “normal” versus “risky” postures and in identifying outcome goals for the rehabilitation process.

**Segmental Deviations of the Head**

The head is a prominent body segment that weighs roughly 8% of the body’s mass (De Leva, 1996). The significant weight of this structure, coupled with the large supply of sensory nerves in the cervical musculature, has led to investigations of the effects of head
alignment deviations on balance control. Changes in head position are indeed purported to affect balance in healthy, young men (n=11; M=29 years, SD=5) and women (n=13; M=24 years, SD=3) during dynamic sit to stand movements (Johnson, Richard, & Emmerik, 2011). Specifically, extended neck positions and forward head positions caused significantly greater (p<0.01 to 0.04) COP excursions during sit to stand trials as compared to flexed and neutral neck positions. Forward head posture, the term for anterior migration of the tragus away from vertical alignment with the acromion process, is the most common postural impairment involving the head and neck, and is shown to impact balance control in additional studies (Kang et al., 2012; Nemmers & Miller, 2008).

Workers with computer-based jobs and forward head posture (n=30; M=34.9 years, SD=2.1) demonstrated a significant (p<0.05) forward shift in COP positions during standing, when compared with neutral alignment individuals (n=30; M=35.2 years, SD=2.1) (Kang et al., 2012). Static and dynamic balance were also negatively affected in the computer workers, as evidenced by significantly lower (p<0.05) Equilibrium Scores on the most challenging conditions (i.e., 5 & 6) of the NeuroCom Sensory Organization Test, and inferior movement velocity, endpoint excursion, and maximum excursion scores on the LOS Test. Furthermore, forward head posture was inversely correlated (r=-0.62, p<0.05 & r=-0.42, p<0.05) with overall static balance and dynamic balance. Functional balance control in the elderly also appears to be affected by the severity of forward head posture, as indicated by an inverse correlation (r=-0.514, p<0.0001) with performance on the Berg Balance Scale in elderly women (n=203; M=77.33 years, SD=7.59) (Nemmers & Miller, 2008). These correlations, while not strong, do suggest that the position of the head may impact balance control. Other studies, however, have refuted these findings.

Hyouk and Hyun (2012) investigated the effects of forward head posture on balance control and ankle joint range of motion in a sample of healthy, young adults (N=51; M=21.8 years, SD=2.1). No significant increases were found in COP excursions for individuals with forward head posture; however, available range in ankle plantarflexion motion was reduced in these individuals. These authors concluded that while balance control may not be affected by forward head posture in young, healthy adults, the connection between the head and ankle joints via the superficial back line (i.e., fascia) may contribute to balance problems as individuals age, by causing ankle joint dysfunctions. Two other studies attempted to induce
forward head posture in young adults (both \(N=25; M=20.76\) years, \(SD=2.19\) & \(M=25.1\) years, \(SD=3.4\)) with normal alignment, and reached similar conclusions that voluntarily adopted forward head posture does not cause balance to suffer in young individuals with normal alignment (Silva & Johnson, 2012; Sivayogam, Johnson, & Skinner, 2011). The evidence implicating forward head posture in impaired balance control is clearly equivocal. This supports the rationale that assessing only alignment of the head is not sufficient to determine the impact of this postural deviation on balance control. The detrimental effects of forward head posture may be countered by alterations in spinal curvature, which allow the head to remain balanced over the pelvis through compensatory joint position changes (Lafage et al., 2008).

**Segmental Deviations of the Spine**

Thoracic hyper-kyphosis (i.e., excessive flexion of the upper back) is a common postural deviation in the elderly population, often observed along with forward head posture (Sinaki, Brey, Hughes, Larson, & Kaufman, 2005). One potential reason for the observed instability in individuals with hyper-kyphosis may be the inefficient standing position they must combat to stay upright, which likely induces fatigue (Richmond, 2012). Increasing degrees of thoracic hyper-kyphosis are associated with higher multi-segmental spinal loads \((r=0.85\) to \(0.93, p<0.0001\)) and trunk muscle forces \((r=0.7\) to \(0.82, p<0.01\)) during upright standing, which may lead to muscle fatigue and dysfunction (Briggs et al., 2007). Hyper-kyphosis may also shift the COP away from a position of equilibrium within the BOS, toward the anterior perimeter of the LOS (Bot, Caspers, Van Royan, Toussaint, & Kingma, 1999). Anterior displacement of the COP position has successfully discriminated between cognitively able, elderly fallers \((n=45; M=79\) years, \(SD=6\)) and non-fallers \((n=67; M=79\) years, \(SD=5\)) (Merlo et al., 2012), indicating that COP positions deviating from equilibrium in this direction are not conducive to successful balance control. Hyper-kyphosis was also significantly correlated \((r=0.29, p<0.05)\) with recent fall history in elderly women with Osteoporosis \((n=73; M=68.9\) years, \(SD=5.7\)) (Arnold, Busch, Schachter, Harrison, & Olyszynski, 2005). These findings were confirmed in other groups of elderly women with Osteoporosis and hyper-kyphosis \((n=12; M=76.5\) years, \(SD=5\)) who had significantly higher \((p<0.001)\) falls-efficacy scores \((M=34.4\) vs. \(M=10)\), indicating increased likelihood of falling
as compared to asymptomatic controls ($n=13; \bar{M}=71$ years, $SD=4.6$) (Sinaki et al., 2005). The Osteoporosis and hyper-kyphosis group also had significantly lower ($p=0.002$) Equilibrium Scores than controls ($\bar{M}=58.8$ vs. $\bar{M}=73.0$), as measured by computerized dynamic posturography, indicating inferior balance ability.

Hyper-kyphosis, in the absence of Osteoporosis, also appears to elevate fall risk in elderly women. Scores on functional tests of balance control, the Berg Balance Scale and Functional Reach, were negatively correlated ($r=-0.439, p<0.01$ & $r=-0.311, p<0.05$ respectively) with degrees of upper thoracic slope in elderly women ($n=36; \text{age} > 65$ years) (O’Brien, Culham, & Pickles, 1997). Thoracic slope was also positively correlated ($r=0.347, p<0.05$) with Timed Get up and Go Test scores, indicating reduced performance on these functional measures as degrees of hyper-kyphosis increased. An additional study of elderly women ($n=3,108; \bar{M}=68.2$ years, $R=55$ to 81) confirmed associations between slower ($p<0.02$) Timed Get Up and Go Test scores and greater hyper-kyphosis (Katzman, Vittinghoff, & Kado, 2011). Challenging balance tasks that alter the BOS (e.g., single leg standing) also appear to be more difficult for individuals affected by hyper-kyphosis. The ability to maintain single leg standing was significantly decreased ($p<0.05$) in two groups of elderly women ($n=8; \bar{M}=81.9$ years, $SD=3.8$ & $n=9; \bar{M}=81.0$ years, $SD=3.8$ respectively) with hands-on-knees and flexion type postures (based on Nakata’s classification of postural deformations), when compared to normal posture individuals ($n=16; \bar{M}=79.2$ years, $SD=6.1$) (Maejima et al., 2004).

Elderly men with hyper-kyphotic posture are also purported to be at an increased risk of falling. Hyper-kyphotic posture, defined by $\geq 2, 1.7$cm thick, wooden blocks (i.e., the number necessary to bring participants’ line of sight perpendicular to the plane of their body), placed elderly males ($n=752; \bar{M}=73.6$ years, $SD=8.9$) at a significantly increased odds of experiencing injurious falls, even after adjusting for age ($odds ratio=1.59, 95\% CI 1.0$ to $2.54, p=0.05$) (Kado, Huang, Nguyen, Barrett-Connor, & Greendale, 2007). Both men and women with hyper-kyphosis exhibit impaired gait performance. Elderly hyper-kyphotic participants ($n=127; \bar{M}=80.8$ years, $R=70.84$ to 90.85) had significantly shorter ($p<0.0001$ to 0.022) stride length, step length, and step width, and significantly longer ($p<0.0001$ to 0.007) time of stride, single stance, double stance, and gait speed than normal posture participants ($n=110; \bar{M}=78.4$ years, $R=68.9$ to 87.8) (Hirose, Ishida, Nagano, Takahashi, & Yamamoto,
2004). These findings were supported by Maejima et al. (2004) with both hands-on-knees and flexion type participants demonstrating significantly shorter ($p<0.001$ & $p<0.05$ respectively) stride length, and significantly longer ($p<0.001$ & $p<0.05$ respectively) 10-m gait time when compared to normal posture participants. As thoracic hyper-kyphosis worsens, the body becomes unable to adequately compensate for the forward shift in COP position through joint position changes, and states of disability, including static and dynamic balance impairments, may ensue (Balzini et al., 2003).

However, not all of the evidence regarding hyper-kyphosis and balance control suggests that this postural impairment causes instability. COP measurements, recorded from elderly populations with and without Osteoporosis, suggest that thoracic hyper-kyphosis does not impair balance control, or, that observed balance impairments are due to vertebral fractures rather than hyper-kyphosis (Greig, Bennell, Briggs, Wark, & Hodges, 2007; Ishikawa, Miyakoshi, Kasukawa, Hongo, & Shimada, 2009; Kasukawa et al., 2010). Efforts to acutely reduce the degrees of kyphosis, through postural taping of the thoracic spine in elderly women ($N=15$; $M=67.2$ years, $SD=2.5$), did not improve COP measures (i.e., excursions, velocity, & positions) despite immediate, positive reductions in the angle of kyphosis (Greig, Bennell, Briggs, & Hodges, 2008).

There have also been attempts to model kyphosis deformity in young adults with normal alignment ($N=14$; $M=25.6$ years, $SD=2.6$ & $N=50$; $M=27.5$ years, $R=23$ to 33) to determine the acute effects of hyper-kyphosis on balance control (Choi et al., 2001; Saha, Gard, Fatone, & Ondra, 2007). These studies were unable to demonstrate lesser static balance control in individuals with hyper-kyphotic postures; however, it is likely that these healthy, young adults were able to successfully compensate for voluntarily adopted postural abnormalities, much like in the studies involving induced forward head posture. Even so, a large increase in oxygen consumption was observed in one of these studies, when the young adults adopted the most severe hyper-kyphotic postures (Saha et al., 2007). Over time, it is likely that maintaining an energy-demanding postural alignment may lead to fatigue and indirectly affect balance control through this mechanism.

Thoracic hyper-kyphosis was inconsistently measured across these studies, with each study quantifying degrees of kyphosis with a different tool. This large variety in measurement techniques could account for the inconsistent findings among studies. Another
potential reason for the equivocal nature of these results, is that screening for thoracic hyper-
kyphosis in isolation does not describe or consider compensatory joint positions elsewhere in
the body, specifically in the lumbar spine, pelvis, and knees (Le Huec, Saddiki, Franke,
Rigal, & Aunoble, 2011). For example, thoracic hyper-kyphosis without increased lordosis of
the lumbar spine (i.e., lower back curvature) appears to yield an uncompensated posture that
greatly increases fall risk in the elderly (Kasukawa et al., 2010).

When lumbar kyphosis (i.e., flattening of the lumbar spine) is present with thoracic
hyper-kyphosis, it prevents the body from maintaining an equilibrium COP position, instead
allowing a forward shift of the body’s mass toward the anterior border of the LOS (Le Huec
et al., 2011). Ishikawa et al. (2009) and Kasukawa et al. (2010) found that the combination of
thoracic hyper-kyphosis and lumbar kyphosis placed elderly individuals at a higher risk for
falls, based on self-reported fall history and measures of postural sway, than individuals with
only thoracic hyper-kyphosis. COP path length, sway area, and excursions were positively
correlated ($r=0.243$ to $0.350$, $p<0.05$ to $0.001$) with degrees of lumbar kyphosis in these
elderly participants ($n=93; M=70$ years) (Ishikawa et al., 2009). Lumbar kyphosis angle was
also significantly larger ($p\leq 0.0001$ & $p=0.003$ respectively) in a self-reported falls group
($n=16; M=77.3$ years, $SD=6.5$) than a non-falls group ($n=40; M=72.9$ years, $SD=8.1$) and a
fear of falls group ($n=36; M=74.2$ years, $SD=9.4$) (Kasukawa et al., 2010). These findings
highlight the importance of assessing lumbar curvature in the screening process for fall risk.
Identifying the combinations of postural distortions an individual presents, and their resulting
impact on the LOG location, is necessary to determine the overall threat to balance control.
Certain postures with adapted, compensatory joint motions may preserve the LOG within the
BOS while others may force migration toward or past the boundaries of the LOS (Le Huec et
al., 2011).

There are a considerable number of studies examining the relationships between
coronal (i.e., frontal plane) spinal postural aberrations and balance control in children and
adolescents. Scoliosis (i.e., lateral deviation of the thoracic spine, lumbar spine, or both) is
linked to inferior balance control in these populations. Adolescent girls ($n=21; M=11.7$ years,
$SD=3.1$; Cobb angle=$13.5^\circ$, $SD=5.5$) with idiopathic scoliosis exhibited 45% greater
($p<0.01$) COPy excursions, 29% greater ($p=0.02$) COPx excursions, 16% faster ($p<0.01$)
COPy velocity, and 29% faster ($p<0.01$) COPx velocity than able-bodied girls ($n=20;$
$M=12.5$ years, $SD=1.3$) during quiet stance, indicating instability (Dalleau et al., 2011). COPx excursions and velocity were also correlated ($r=0.542$ & $r=0.589$ respectively) with anterior/posterior center of mass offset (i.e., the difference between the center of mass of the head and trunk and that of the whole body) for the scoliotic girls. These findings supported the observations of Nault et al. (2002) where scoliotic girls ($n=43; M=12.5$ years, $SD=1.7$; Cobb angle=29°, $SD=12$) had a 44% larger ($p<0.01$) COP sway area than able-bodied girls ($n=38; M=12.9$ years, $SD=2$) during quiet stance. The type of scoliosis and location of the major curve appear to be indicators of instability severity in adolescent idiopathic scoliosis. Increasing lateral disequilibrium ($p<0.01$ to 0.001) is observed in adolescents ($N=102; M=14$ years, $SD=2$) with double major curve, thoracic curve, thoracolumbar curve, and most significantly, lumbar curve scoliosis during static balance tests (Gauchard, Lascombes, Kuhnast, & Perrin, 2001).

Little research exists regarding the adult population and scoliosis deformity. Scoliosis, as defined by a Cobb angle of $\geq10^\circ$ in the coronal plane, had a 35.5% prevalence in a group of elderly men and women ($N=1,347; M=73.3$ years, $R=60$ to 94) (Hong et al., 2010); yet, research examining its effects, particularly in degenerative cases, on balance control in the elderly is scarce. If balance impairments exist in adolescents with scoliosis, it is likely that the elderly may also be negatively affected by this coronal postural distortion. Further research exploring the detrimental impacts of scoliosis on balance ability is necessary, especially since increased medial/lateral sway is consistently found to be a distinguishing characteristic of increased fall risk in the elderly (Bergland & Wyller, 2004; Liu, Y. T., Liu, K. T., & Yang, 2012; Melzer et al., 2004).

Spinal inclination, the angle between the sagittal vertical axis (i.e., straight line from the 1st thoracic vertebra to the 1st sacral vertebra) and a vertical plumb line, assesses the spine as a whole, and may be a superior predictor of increased fall risk in the elderly (Ishikawa et al., 2009; Kasukawa et al., 2010). Elderly men and women fallers ($n=16; M=77.3$ years, $SD=6.5$) had significantly larger ($p=0.001$) spinal inclination angles than non-fallers ($n=40; M=72.9$ years, $SD=8.1$) and exhibited 56% longer ($p=0.002$) COP path length and 111% larger ($p=0.0007$) COP sway area than non-fallers (Kasukawa et al., 2010), indicating that larger spinal inclination angles predispose elderly individuals to falls through reduced balance control. Ishikawa et al. (2009) also demonstrated that spinal inclination angles were
significantly correlated ($r=0.416$ to $0.550$, $p<0.001$) with parameters of postural sway (i.e., COP path length, sway area, & excursions). While spinal inclination may be a superior balance risk factor to evaluate than thoracic hyper-kyphosis or lumbar kyphosis, it is still limited to the region of the spine and does not include salient structures such as the head and knees in the evaluation of postural alignment. Without these joints, the accuracy of the sagittal vertical axis in describing the global posture of an individual diminishes. In fact, small changes in the positions of the lower extremity joints were shown to drastically alter the distance (varying from -4.5 to 14.9cm) between the sagittal vertical axis and the anterior superior corner of the first sacral vertebra. When these distances were compared with the lower extremity joint angles, significant correlations (all $p<0.01$) were discovered between these distances and the hip ($r=-0.959$), knee ($r=-0.936$), and ankle ($r=0.755$) joints (Van Royen et al., 1998), indicating that the positions of these joints greatly affect the sagittal vertical axis. These findings make the importance of including lower extremity joints in the overall postural alignment assessment explicitly clear. An assessment failing to include all of the major joints and segments of the body (i.e., segmental vs. global assessment) may provide inadequate information to therapists regarding the resulting location of the LOG within the BOS and consequential threats to balance control.

**Segmental Deviations of the Knees**

The evidence linking knee joint deviations to impaired balance control is more consistent, which is somewhat unsurprising considering knee joint position is suggested to be the best predictor ($R^2=0.71$) of an individual’s COP position during standing (Woodhull et al., 1985). Knee joint position in both the sagittal and coronal planes has been postulated to affect balance control. Potential instability risk factors involving this joint include excessive knee flexion or hyperextension in the sagittal plane, and valgus (i.e., knock-kneed) or varus (i.e., bow-legged) alignment in the coronal plane. In the sagittal plane, hyper-extended knee position reportedly causes increased COP velocity during static balance tasks (Siqueria et al., 2011). Participants with hyper-extended knees ($>180^\circ$) had significantly higher ($p<0.001$) movement velocity than participants with aligned knees ($<180^\circ$) during eyes open, quiet standing on a force plate, indicating less precise modulation of their LOG. Hyper-extended knee participants also demonstrated increased knee flexion during challenging balance
conditions (i.e., eyes closed, foam surface), suggesting that hyper-extended positions are not conducive for balance maintenance.

Excessive knee flexion during standing appears to be a protective strategy adopted by elderly individuals ($n=13; M=76$ years, $SD=6.7$) classified as fallers (O’Brien et al., 1997). Fallers who experienced one or more fall incidents in the prior year had significantly greater ($p=0.01$) knee flexion angles ($M=4.5^\circ$, $SD=5.2$ vs. $M=1.3^\circ$, $SD=2.5$), as measured by a universal goniometer during quiet standing, than non-fallers ($n=23; M=73.8$ years, $SD=4.1$). Balance scores were also significantly associated with knee flexion angles on the Berg Balance Scale ($r=-0.382$, $p<0.01$) and the modified Timed Get up and Go Test ($r=0.380$, $p<0.01$), indicating that elderly individuals who adopted greater knee flexion angles during standing had reduced performance on these functional balance tests as compared to elderly individuals who stood with less knee flexion.

Coronal plane varus and valgus alignment of the knees may hinder balance control through impaired quadriceps function and associated foot deformations (i.e., pronated & supinated positions) (Nyland, Smith, Beickman, Armsey, & Caborn, 2002). Adolescent male and female athletes ($N=56; M=15.4$ years, $SD=2$), video analyzed for coronal plane tibiofemoral joint angulation during single leg stance with $20^\circ$ knee flexion, were placed into three groups: neutral angulation (genu varus or valgus $<5^\circ$), genu varus angulation ($\geq 5^\circ$), or genu valgus angulation ($\leq 5^\circ$). While mean COPx location did not differ between groups, mean COPy position was significantly different ($p=0.003$), with both the varus and valgus aligned groups displaying a posterior shift in COPy position toward the heels as compared to the neutral aligned group. Plantar pressure also differed significantly ($p=0.008$) between groups, with larger mean plantar force magnitude in the varus and valgus aligned groups, indicating greater amounts of plantarflexor muscular force were necessary to generate the ankle moments required to maintain balance in those with varus or valgus knee alignments.

Young adults ($N=90; M=21.8$ years, $SD=1.75$) may also be affected by varus and valgus angulation of the knees, as measured by visual observation of distance between the medial malleoli ($>3$cm for genu valgum) and distance between the femoral medial epicondyles ($>3$cm for genu varum) (Samaei, Bakhtiary, Elham, & Rezasoltani, 2012). A higher medial-lateral stability index, indicating worse balance, was observed in the genu valgum group ($n=30$) as compared to the aligned knee group ($n=30$) during static balance...
trials on a stable force plate, and a significantly higher ($p=0.036$) medial-lateral stability index was observed in the genu varum group ($n=30$) as compared to the aligned group. Medial-lateral stability index was also significantly higher ($p=0.031$) for the genu varum group during balance trials on a moving platform. Consequently, a significant increase ($p=0.03$) was seen in the normalized falling risk index for the genu varum group as compared to the aligned group. Knee alignment in older individuals with osteoarthritic knees may also contribute to instability. Varus alignment was a significant predictor ($\beta=-2.73$, 95% CI -4.74 to 0.72, $p<0.01$) of COP path length in a group of adults with osteoarthritic knees ($N=57$; $M=63.7$ years, $SD=8.2$), suggesting that this modifiable risk factor could reduce instability if properly rehabilitated (Hunt, McManus, Hinman, & Bennell, 2010).

### Segmental Deviations of the Ankles and Feet

The feet act as the BOS for upright posture. The alignment of the feet must, therefore, provide a solid foundation for more proximal joints during standing. While some degree of foot deformation, including pronation and supination, is necessary for balance control (Wright, Ivanenko, & Gurfinkel, 2012), excessive amounts may contribute to balance impairments. Research findings in this area, much like the other major joints/segments, are equivocal. Pes planus (i.e., a low arched or pronated foot type) appears to be related to increased COPy (spearman’s $\rho = 0.670$, $p = 0.006$) and COPx (spearman’s $\rho = 0.880$, $p = 0.01$) excursion measures in healthy adults ($N=15$; $R=18$ to 33 years) during single stance balance trials (Harrison & Littlewood, 2010). Tsai, Yu, Mercer, and Gross (2006) reported similar findings of significantly reduced ($p<0.05$) balance control, as evidenced by greater normalized COP standard deviation and maximum displacement in the anterior/posterior direction, in young adults ($n=15$; $M=21.9$ years, $SD=3.5$) with pronated foot posture as compared to young adults ($n=15$; $M=26.1$ years, $SD=3.6$) with neutral foot posture. These authors also suggested that supinated foot posture (i.e., a high arch foot type) might decrease young adults’ ($n=15$; $M=23.9$ years, $SD=3.2$) balance due to significantly greater ($p<0.05$) COP excursions during single stance trials. Hertel, Gay, and Denegar (2002) did not confirm greater overall COP excursions in supinated foot postures, but did find a significant main effect of foot type ($F_{2,57}= 3.55$, $p=0.035$) in their investigation of young adults ($N=30$; $M=21.9$ years, $SD=2.0$), which revealed that individuals with pronated foot posture had
significantly greater ($p=0.031$) COP sway area than other (i.e., neutral and supinated) foot postures. Pronated foot posture is also associated with greater postural sway in elderly individuals ($N=305; M=73.9$ years, $SD=5.9$) during eyes open, quiet standing trials on the floor ($r=0.123, p<0.05$) and on a medium-density, foam mat ($r=0.172, p<0.01$) (Spink et al., 2011).

Forefoot varus (i.e., elevation of the medial forefoot) is another foot posture related to over-pronation that is implicated in poor balance control. Healthy adults ($n=20; M=29.0$ years, $SD=8.4$) with greater than or equal to $7^\circ$ of bilateral forefoot varus exhibited significantly greater ($F_{(1,30)}=5.956, p=0.021, \eta^2=0.166$) COPy excursions as compared to a neutral foot group ($n=12; M=25.8$ years, $SD=6.0$) (Cobb, Tis, Johnson, & Higbie, 2004). While COPx excursions were also greater for the forefoot varus group, the difference was not statistically significant. Dynamic measures of balance may also be affected by pronated and supinated foot postures. Dabholkar, Shah, and Yardi (2012) demonstrated that young adults ($n=60; M=21.36$ years, $SD=1.43$) with pronated foot posture had significantly shorter ($p<0.0001$ to $0.0008$) reaching distance on all directions of the Star Excursion Balance Test as compared to young adults with neutral foot posture ($n=60; M=21.4$ years, $SD=1.33$).

There is also evidence to suggest that pronated and supinated foot postures do not impair balance control. Cote, Brunet, Gansneder, and Shultz (2005) found that individuals with pronated ($n=16; M=20.7$ years, $SD=2.2$; navicular drop=$13.0$mm, $SD=3.7$) and supinated ($n=16; M=20.4$ years, $SD=1.3$; navicular drop=$2.2$mm, $SD=1.7$) foot postures did not have greater COP sway or excursions than those with neutral foot posture ($n=16; M=20.7$ years, $SD=2.2$; navicular drop=$6.2$mm, $SD=1.1$) during single leg balance tests with eyes open and closed. They did find a significant main effect of foot type ($F_{(14,315)}=3.176, p < .001$) for dynamic reach distance during the Star Excursion Balance Test; however, no one foot type performed best in all directions. Pronators and supinators both outperformed neutral foot type individuals in several directions. Elderly individuals are also inconsistently affected by pronated and supinated foot postures. Postural sway, measured during eyes open conditions on the floor and a foam mat, was not significantly different in an elderly sample ($N=176; M=80.1$ years, $SD=6.4$) regardless of foot posture type (Menz, Morris, & Lord, 2005). Investigating foot posture alone, like most other individual body segments, does not
appear to accurately categorize those at increased risk for loss of balance due to biomechanical constraints.

**Statement of the Problem**

A relationship clearly exists in the literature surrounding posture and balance; yet, the best way to assess posture remains unclear due to the multitude of different approaches utilized and the lack of a global measurement tool. An important question for the future is: how can therapists better use static posture analysis in the risk screening process to identify biomechanical balance impairments? Fowler and Kravitz (2011) stated that impaired posture is related to increased risk of falling in the elderly, and that postural screening may reveal necessary training emphases to improve balance control. If static postural assessments can indeed identify biomechanical risk factors related to impaired balance, and provide guidance for appropriate training strategies to ameliorate balance ability, their merit in the screening process would be clear.

Many health practitioners, like Physical Therapists and Personal Trainers, use postural analyses due to the non-invasive nature of the assessments and their feasibility of use in field settings. Currently, there is little compelling data to indicate that global reference plumb lines, used to analyze front and side view postural alignment, are actually indicative of the LOG location. In fact, therapists and trainers should be discouraged from using these simple plumb lines (e.g., the 7th cervical vertebra plumb line) to predict the LOG location, because they have been established as being disparate measures (Roussouly et al., 2006). Research focusing on the global alignment of the body, accounting for compensatory position changes of the joints, would improve the understanding of how body alignment relates to the position of the LOG within the BOS. A global alignment approach should consider the positions of all major joints (i.e., the head, spine, pelvis, knees, and ankles), offer a quantitative measure to indicate how severe an individual’s alignment deviates from ideal posture, and indicate the associated consequences on the location of the LOG. This knowledge would allow health practitioners to use posture analyses to assist in screening for disequilibrium.

A potential solution to the need for quantitative, global measures of postural alignment is computerized posture screening software. These types of software products
analyze and report deviations from ideal alignment using 2D digitized photographs of a client in the coronal (i.e., front) and sagittal (i.e., side) views (Normand et al., 2007). These analyses are often used as a substitute for costly and invasive radiographic imaging (Kuo, Tully, & Galea, 2009). They employ many of the same anatomical landmarks used in radiographic analyses, emphasizing superficial bony landmarks that can be palpated and identified with reflective markers. Coronal and sagittal measurements agree with radiographic images ($r=0.804$, $p<0.001$; $r=0.81$ to $0.91$, $p<0.01$) for accuracy in classifying postural abnormalities (Fortin, Feldman, Cheriet, & Labelle, 2010; Furlanetto, Candotti, Comerlato, & Loss, 2012), and have high (i.e., 0.75 to 0.99) test-retest, intra-class correlation coefficients indicating excellent reliability (Ferreira et al., 2010; Fortin et al., 2010; Santos, Silva, Sanada, & Alves, 2009).

When analyzing the 2D photographic images of the anterior view, deviations from symmetrical alignment can be assessed either globally with a reference plumb line, or segmentally with right or left offsets and tilts calculated using the eyes, acromion processes (i.e., shoulders), episternal notch, the 8th ribs, the anterior superior iliac spines (i.e., hips), and the tali (i.e., ankles) as landmarks (Normand et al., 2007). To assess alignment deviations from a side view, a global plumb line may again be used, or segmental deviations may be reported for each major joint using the ear, acromion process, greater trochanter of the femur (i.e., the center of the hip), lateral condyle of the knee, and lateral aspect of the talus (i.e., just anterior to the ankle axis) as landmarks. Unfortunately, while these segmental offsets are accurate and reliable measures, the global reference plumb lines provided by these software products still fail to supply a quantitative global alignment measure. However, a simple solution to evaluating the global alignment of an individual may be to sum each segmental deviation to yield global offset scores for both the coronal and sagittal views. If these scores could accurately express the overall alignment of the individual, and predict the location of the LOG, they would provide therapists and trainers with a way to evaluate the global balance of a patient/client during upright standing, and assess any deviations from a position of postural equilibrium without the need for expensive force plates.
PURPOSES OF THE PRESENT STUDY

No conclusive statements can yet be made regarding the effectiveness of using static posture screening, with state of the art posture analysis software, as a tool to identify risk factors for either static or dynamic balance impairments. Therefore, the aims of the present study were (1) to determine if global coronal and sagittal offset measures, computed from 2D photographic images using the Posture Screen Mobile computerized posture analysis software (PostureCo Inc., Trinity, FL), can successfully predict the location of the LOG, as estimated by mean COP position on a force plate, and if so, to develop a regression equation to predict COP position using these measures, (2) to identify relationships between global posture offsets, mean COP positions, and dynamic balance control on a LOS test, and (3) to determine if the total amounts of time spent in physical activity and sedentary behaviors (as measured by responses to the Behavioral Risk Factors Surveillance System (BRFSS) exercise and leisure time questions) are related to postural alignment and/or balance ability.

With respect to the first study aim, it was hypothesized that coronal and sagittal offset measures would successfully predict COP positions, with left or right-shifted coronal offsets corresponding to left or right COPx positions respectively. Similarly, higher values of sagittal offsets were expected to correspond with more forward-displaced COPy positions. Regarding the second study aim, it was hypothesized that the overall size of the functional LOS would be reduced in individuals with greater postural deviations and/or COP positions located further from equilibrium. Concerning the third study aim, it was hypothesized that individuals who do not meet physical activity requirements, as outlined by the American College of Sports Medicine’s 2011 position stand, and/or who spend greater amounts of time in sedentary behaviors (i.e., TV-watching), would have more severe postural alignment deviations, as evidenced by larger global posture offsets, significantly different COP positions, and respectively lower balance scores on the LOS test, as compared to individuals who do meet the physical activity requirements and accumulate less TV-watching time.

PRACTICAL IMPLICATIONS

As Physical Therapists and Personal Trainers continue to work with the deconditioned, sedentary population now living to older ages, it is likely that postural abnormalities will only increase in prevalence. Biomechanics, including postural alignment,
clearly play a role in adroit balance, especially with age. Determining the best way to accurately identify risky versus compensated postures in field settings is necessary to provide health practitioners a uniform, feasible way to approach posture screening and evaluate fall risk. Ultimately, if therapists and trainers were able to use a simple tool like computerized posture analysis software, to obtain global postural alignment measures that accurately predict the location of the LOG and subsequent balance performance, they would be able to identify disequilibrium in their clientele and structure relevant training programs to restore equilibrium and improve balance control. This approach would provide an alternative to expensive equipment like clinical grade force plates to read COP data, or computerized dynamic posturography to administer a LOS test, while still providing segmental offset information to practitioners regarding which joints or body segments require attention to restore an equilibrium standing position.
CHAPTER 2

METHODS

Predictive validity and explanatory correlational designs were used to address the hypotheses in the present study. The former was used to determine how accurately global posture offset measures could predict the line of gravity (LOG) location (i.e., COP position) during quiet standing. Explanatory design was used to explore the relationships between the posture offset measures, the location of the LOG, and dynamic balance ability on a limit of stability (LOS) test, with participant demographics, physical activity, and sedentary behaviors investigated as additional explanatory variables. Finally, univariate and bivariate analyses were used to determine if differences existed in the severity of postural deviations (i.e., global posture offsets) between groups split by physical activity behaviors, and if relationships existed between these postural offsets and time spent in sedentary behaviors (i.e., TV-watching time).

PARTICIPANTS

Participants (Table 1 for demographics) were recruited from the greater San Diego area (i.e., fitness centers, SDSU & UCSD campuses, and local businesses) via flyers, word of mouth, and email. Participants were generally healthy, with no known musculoskeletal or nervous system diseases, no current medications that interfere with the normal functioning of these systems, and no major musculoskeletal injuries within the last 6 months. Ethical approval for this study was obtained from the Institutional Review Board (IRB) of San Diego State University. No compensation was offered to participants as incentive to take part in this study, and no grants or external funding supported this study. All subjects signed informed consent documents prior to testing.

INSTRUMENTS AND APPARATUS

Photographs for the posture analysis were taken with an iPhone 4 (Apple Inc., Cupertino, CA). The Posture Screen Mobile (PostureCo, Trinity, FL) posture analysis software was used to analyze global coronal and sagittal offsets on an iPad 2 (Apple Inc.,
Table 1. Participant Demographics Expressed as Mean (Standard Deviation)

<table>
<thead>
<tr>
<th>Category</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>BMI (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males, n=51</td>
<td>34.4 (14.0)</td>
<td>83.7 (12.5)</td>
<td>178.45 (6.13)</td>
<td>26.3 (3.6)</td>
</tr>
<tr>
<td>Females, n=47</td>
<td>33.8 (14.7)</td>
<td>61.2 (9.4)</td>
<td>165.70 (7.43)</td>
<td>22.2 (2.7)</td>
</tr>
<tr>
<td>Total sample, N=98</td>
<td>34.1 (14.3)</td>
<td>72.9 (15.8)</td>
<td>172.40 (9.29)</td>
<td>24.3 (3.8)</td>
</tr>
<tr>
<td>CV males, n=12</td>
<td>28.0 (8.6)</td>
<td>86.4 (13.6)</td>
<td>179.29 (6.14)</td>
<td>26.8 (2.8)</td>
</tr>
<tr>
<td>CV females, n=8</td>
<td>33.1 (12.2)</td>
<td>63.5 (12.6)</td>
<td>164.81 (5.99)</td>
<td>23.3 (4.1)</td>
</tr>
<tr>
<td>CV total sample, N=20</td>
<td>30.1 (10.2)</td>
<td>77.3 (17.3)</td>
<td>173.50 (9.38)</td>
<td>25.4 (3.7)</td>
</tr>
</tbody>
</table>

Note: CV=cross validation

Cupertino, CA). Mean COP positions were calculated from raw ground reaction force data collected with the dual force plates of the NeuroCom Balance Master (NeuroCom®, Clackamas, OR). Dynamic balance scores (i.e., composite maximum excursions, directional control, and movement velocity) were obtained from the Limits of Stability (LOS) test summary reports provided by the NeuroCom.

DATA COLLECTION

All participants reported to the SMARTlab in the ENS annex building for a single, 60-minute, data collection session. During this session, participants underwent five phases of testing as outlined in the sections below.

Phase 1 – Participant Characterization

After completing informed consent documentation (Appendix A), participants filled out the AHA-ACSM Health Fitness Facility Pre-participation Screening Questionnaire (Balady et al., 1998) (Appendix B) and answered additional inclusion/exclusion questions approved by the IRB (Appendix C) to ensure “generally healthy” status. Participant demographics were then collected, including weight and height measurements.

Phase 2 – Subject Physical Activity Habits

Following characterization, participants responded to items on the Behavioral Risk Factor Surveillance System (BRFSS; Yore et al., 2007) questionnaire to provide information regarding recent physical activity behaviors as well as time spent in sedentary activities (Appendix D).
Phase 3 – Posture Assessment

A static posture analysis was conducted for each participant in minimal clothing, to allow visibility of the anatomical landmarks used to calculate global coronal and sagittal posture offsets. Anatomical landmarks were marked with colored stickers to improve accuracy when identifying alignment deviations in the posture analysis software. Anatomical landmarks (Figure 3) identified with stickers were as follows: acromion processes (i.e., shoulders), episternal notch, 8th ribs at anterior axillary line, anterior superior iliac spines (i.e., hips), and anterior aspects of the tali (i.e., ankles) in the coronal view; and right acromion process, right greater trochanter (i.e., center of hip), right lateral condyle of the knee, and right lateral aspect of the talus (i.e., just anterior to the ankle joint axis) in the sagittal view. Photographs were taken from these views with an iPhone 4 using the Posture Screen Mobile application that has a built in level and plumb line to improve the integrity and consistency of the pictures. Pictures were taken three times each to later allow internal consistency reliability calculations for the posture measures. Participants were asked to walk around for one-minute between pictures. During picture taking, participants were asked to relax their body and adopt a comfortable stance width with their heels on a strip of tape, standing in their habitual, not best, upright posture. They were asked to face directly forward and keep their gaze eye level on the wall straight in front of them. The distance between the investigator and participant was a standard 10 feet, as recommended in the literature (Mota, Mochizuchi, & Carvalho, 2011), even though this step was most likely unnecessary due to the sizing function provided by the Posture Screen Mobile application.

Phase 4 – Static Balance Testing

Each participant performed three, twenty-second, quiet-standing trials on the NeuroCom Balance Master dual force plates, harnessed for safety purposes (Figure 4a). The mean COP position data averaged from the three trials was used to estimate the LOG location as a measure of static balance. Participants’ feet were aligned on the dual force plates at a standardized width based on height, and centrally such that the medial malleoli crossed a designated line to ensure consistency of the COP position data (Figure 4b). The instructions provided to each participant were to stand as still as possible, but to stay relaxed, keeping their feet in the designated location at all times. They were asked to not lift their
Figure 3. Sample photographs of the (a) sagittal view, with landmarks used to identify shifts of the head, shoulder, hip, and knee, summed to yield global sagittal offset, and (b) coronal view, with landmarks used to identify shifts of the head, shoulders, ribs, and hips, summed to yield global coronal offset.

Figure 4. The Neurocom Balance Master indicating (a) participant set-up with support harness and (b) dual force plate with the thick, horizontal black line designating medial malleoli alignment. Source: Natus. (2011). Smart balance master. Retrieved from http://www.onbalance.com/products/Balance-Master/detail.php#smart.
heels or toes, keep their arms at their sides, and if they needed to move, please do so between the twenty-second trials.

**Phase 5 - Dynamic Balance Testing**

Participants performed the LOS test following the static balance testing. Their feet were aligned in the same manner as that of the static trials. Each participant was allowed one practice attempt moving to each of the eight targets prior to the start of the test. Participants then performed three separate LOS tests, and composite maximum excursions, directional control, and movement velocity scores, provided by the LOS summary report, were used in data analyses. Instructions to participants during each LOS test were to maintain their cursor figure (Figure 5) in the center box on the screen until they heard an auditory tone. Upon hearing the tone, they were instructed to move as quickly and accurately as possible to the highlighted target on the screen, using their ankles instead of their hips (i.e., ankle strategy vs. hip strategy), and keeping their feet flat at all times. They were asked to pause and hold their position when they reached the target, or the furthest distance they could attain, until they heard a second tone. All targets were completed in order, moving clockwise around the screen.

![Figure 5. LOS test display screen showing the cursor figure in the center target and each of the eight goal targets.](image)

**DATA ANALYSIS**

All statistical analyses were performed with IBM SPSS Statistics software version 20. A priori alpha of 0.05 was set for all analyses.
Posture Variables

Photographs were uploaded onto the iPad 2 for calculation of global posture offset measures. In the coronal view, the eyes, philtrum (i.e., the upper lip depression below the nose), acromion processes, episternal notch, 8th ribs along the anterior axillary line, anterior superior iliac spines, and anterior aspects of the tali, were the landmarks used to calculate left or right shifts of the head, shoulders, ribcage, and hips. These segmental offsets were then converted from inches to centimeters (for expression in SI units) and summed to yield a variable called global coronal offset. In the sagittal view, the right external auditory meatus (i.e., ear), acromion process, greater trochanter of the femur, lateral condyle of the knee, and lateral aspect of the talus were used to calculate forward or backward shifts of the head, shoulder, hip, and knee. These segmental offsets were again converted to centimeters and summed to yield a variable called global sagittal offset.

LOG Location Variables

Mean COP positions were used to represent the location of the LOG. Customized LabVIEW 2011 software (National Instruments Corporation, Austin, TX) was used to calculate the average x and y positions from the raw COP data collected during the three, twenty-second, static balance trials. These average values were used as the variables mean COPx and COPy positions in analyses. Descriptive COP data, including average COPx and COPy excursions (i.e., total movement during each trial) and average root mean square error (i.e., variability in movement), were also computed using LabView in order to demonstrate that participants indeed maintained quiet standing during all static balance trials.

LOS Dynamic Balance Variables

Composite LOS maximum excursions were used to reflect dynamic balance in analyses. Maximum excursions were defined as the maximum distance traveled by the center of gravity toward each target, expressed as a percent out of a possible 120% (Figure 6). The 120% represents possible over-shooting of the LOS targets. Two separate measures provided by the LOS summary report were used as independent variables to explain excursion scores, directional control and movement velocity. Directional control represents a comparison between the amount of movement in the intended direction toward each target and the amount of extraneous movement (i.e., (amount of intended movement - amount of
extraneous movement) / (amount of intended movement)), and movement velocity represents the average speed of the center of gravity movement in degrees/second between 5% and 95% of the endpoint excursion (all measurements by Neurocom Inc.). Each of these measures was obtained from the LOS summary reports provided by the NeuroCom.

**Physical Activity Variables**

BRFSS survey responses to physical activity questions were condensed into four categories supplied by the American College of Sports Medicine’s 2011 position stand: cardiorespiratory, resistance, flexibility, and neuromotor exercise training (Garber et al., 2011). The requirements for cardiorespiratory exercise involve engaging in moderate to vigorous cardiovascular-based activities on minimally 3 to 5 days per week, accumulating 150 minutes or more weekly. For resistance exercise, 2 to 3 days a week of strength training involving the major muscle groups is advocated. Flexibility recommendations involve performing stretches focused on each major muscle-tendon unit on greater than or equal to 2 to 3 days per week. Finally, to meet the recommendations for neuromotor exercise, minimally 2 to 3 days per week of exercises involving motor skills, proprioceptive exercise training, and multifaceted activities (e.g., tai chi) are recommended. A value of 0 was assigned to individuals who did not meet the requirements outlined by this position stand, and a value of 1 was assigned to individuals meeting these requirements, for each of the four physical activity categories. BRFSS responses to sedentary behavior questions regarding TV-
watching time were quantified in minutes/average weekday and minutes/average weekend day and summed to yield total TV-watching time.

**Internal Consistency Reliability**

The internal consistency reliability of trials averaged to compute global posture offsets, mean COP positions, and LOS scores were examined, with significant departure from reliability resulting in trial exclusion from mean calculation, as needed. ICCs above 0.75 for posture measures were considered to be excellent, based on comparisons to previously reported reliability measures for computerized posture analysis software (Ferreira et al., 2010; Fortin et al., 2010; Santos et al., 2009). Previous reports of COP position reliability are also high, with ICCs of 0.86 to 0.91 for COPy positions and 0.75 to 0.84 for COPx positions (Carpenter, Frank, Winter, & Peysar, 2001). Composite LOS scores are shown to demonstrate higher test-retest reliability than directional measures (i.e., movement toward each separate target) with excursion ICCs of 0.88, movement velocity ICCs of 0.80, and directional control ICCs of 0.69 (Pickerill & Harter, 2011).

**ANALYSES ADDRESSING STUDY AIM 1**

In order to assess the relationship between global posture offsets in the coronal and sagittal views and mean COP positions, two linear regressions were performed with the initial sample \( N=98 \) to determine if the predictors, coronal and sagittal offsets, could forecast the positions of COPx and COPy respectively. Additional predictor variables including age, gender, and body mass index (BMI) were also examined, due to previous reports of relationships between these demographic variables and balance ability (Anker et al., 2008; Blaszcyk et al., 1994; Vereeck, Wuyts, Truijen, & Van de Heyning, 2008). For cross validation of the predictor equations, a further sample \( N=20 \) of healthy adults was used to detect and prevent over-fitting of the resulting regression equations. Two-tailed, paired t-tests were used to determine if the predicted COP positions were significantly different from the actual COP positions for the cross validation sample.

**ANALYSES ADDRESSING STUDY AIM 2**

To create a model for explaining composite LOS maximum excursion scores, the potential explanatory variables, global posture offsets, mean COPx and COPy, LOS
composite directional control and movement velocity scores, age, BMI, gender, physical activity, and TV watching time were investigated. Posture offsets and COP positions were converted to single independent variables using the Pythagorean Theorem, coronal offset$^2 +$ sagittal offset$^2 = \text{posture offset}^2$ and COPx$^2 + \text{COPy}^2 = \text{COP}^2$ respectively, to create linear variables. Prior to inclusion in the regression model, univariate (i.e., one-way ANOVA) and bivariate (i.e., correlational) analyses were used to determine whether significant differences existed between genders and physical activity measures in LOS excursions, and whether significant relationships existed between posture offsets, COP positions, directional control, movement velocity, age, BMI, TV-watching time, and LOS scores. Due to little existing research regarding this collection of explanatory variables and these criterions, explanatory variables that were significant at the $p=0.10$ level in preliminary analyses were included in regression model to predict LOS maximum excursions.

**ANALYSES ADDRESSING STUDY AIM 3**

To examine the influence of physical activity behaviors on global postural alignment, participants were split into two groups: (1) does not meet requirements and (2) meets requirements for each of the four physical activity categories outlined by the American College of Sports Medicine. One-way ANOVAs were used to determine if significant differences existed in severity of global posture offsets (i.e., using the single linear posture offset variable) or COP positions (i.e., using the single linear COP variable) between groups. In order to evaluate the effects of sedentary behaviors on the severity of global posture offsets and COP positions, correlations were investigated between these variables and total minutes spent watching TV. Bonferroni corrections were used to protect for multiple comparison inflation when interpreting significance levels for each family of statistical tests. A family of statistical tests was considered to be the global posture measure and COP position for each category of physical activity. The adjusted $p$-value for interpretation of significance was $p<0.025$ (i.e., $0.05/2$).
CHAPTER 3

RESULTS

All participants in the initial study sample (N=98) completed data collection and were included in analyses. In the following sections, internal consistency reliability measurements are reported for each posture measure, mean center of pressure (COP) positions, and limits of stability (LOS) scores. Descriptive information including the sample means, standard deviations, and ranges are reported for all measures. Regression equations are proposed to predict mean COP positions from posture measures (i.e., global coronal and sagittal offsets), and variables capable of explaining performance on the LOS test are presented. The effects of physical activity and sedentary activities on postural alignment and COP positions are also reported.

INTRACLASS CORRELATION COEFFICIENTS (ICCs)

Results of the intra-rater internal consistency reliability indicated that all measures used in this study have substantial to excellent reliability (Table 2).

DESCRIPTIVE DATA FOR THE POSTURE MEASURES, COP POSITIONS, AND LOS SCORES

The sample means, standard deviations, and ranges for each segmental posture measure and global coronal and sagittal offsets are displayed in Table 3. One-way analyses of variance (ANOVA) revealed no significant differences between segmental or global posture measures for men and women (all p>0.05); therefore, values are expressed for the total sample (N=98). For coronal measures, negative signs denote left shifts and/or global offsets. For sagittal measures, negative signs denote backward shifts and/or offsets relative to the calcaneocuboid joint.

One-way ANOVAs revealed no significant differences between genders in COP positions (both p>0.05). The mean COPx position for the initial sample (N=98) was located 0.13cm (SD=0.66) to the right, with a range of -1.99 to 1.43cm. Negative signs once again denote left-shifted positions. Mean COPx excursions were 0.52cm (SD=0.22) and average
Table 2. Average ICCs (i.e., Three Trials) for the Posture Measures, COP Positions, and LOS Scores for the Initial Sample N=98

<table>
<thead>
<tr>
<th>Measure</th>
<th>Average ICC</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>0.90</td>
<td>0.87 to 0.93</td>
</tr>
<tr>
<td>Head</td>
<td>0.96</td>
<td>0.95 to 0.97</td>
</tr>
<tr>
<td>Sagittal offsets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>0.95</td>
<td>0.94 to 0.97</td>
</tr>
<tr>
<td>Hip</td>
<td>0.97</td>
<td>0.95 to 0.97</td>
</tr>
<tr>
<td>Knee</td>
<td>0.97</td>
<td>0.95 to 0.98</td>
</tr>
<tr>
<td>Coronal offsets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>0.89</td>
<td>0.84 to 0.92</td>
</tr>
<tr>
<td>Head</td>
<td>0.89</td>
<td>0.85 to 0.93</td>
</tr>
<tr>
<td>Coronal offsets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulders</td>
<td>0.91</td>
<td>0.87 to 0.93</td>
</tr>
<tr>
<td>Ribs</td>
<td>0.86</td>
<td>0.80 to 0.90</td>
</tr>
<tr>
<td>Hips</td>
<td>0.88</td>
<td>0.83 to 0.92</td>
</tr>
<tr>
<td>COP Positions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COPx</td>
<td>0.98</td>
<td>0.98 to 0.99</td>
</tr>
<tr>
<td>COPy</td>
<td>0.99</td>
<td>0.98 to 0.99</td>
</tr>
<tr>
<td>LOS Scores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Excursion</td>
<td>0.94</td>
<td>0.92 to 0.96</td>
</tr>
<tr>
<td>Directional Control</td>
<td>0.93</td>
<td>0.90 to 0.95</td>
</tr>
<tr>
<td>Movement Velocity</td>
<td>0.96</td>
<td>0.95 to 0.97</td>
</tr>
</tbody>
</table>

Root mean square error was 0.10 (SD=0.04) indicating low variability of movement in the medial-lateral direction during the static balance trials. The mean COPy position was located 3.69cm (SD=1.52) anterior to the ankle joint axis with a range of 1.08 to 7.88cm. Mean COPy excursions were 1.15cm (SD=0.33) and average root mean square error was 0.24 (SD=0.07) indicating low variability of movement in the anterior-posterior direction.

Significant differences did exist between genders for LOS maximum excursions, with females achieving higher ($F_{(1.96)}=18.99, p<0.001$) composite maximum excursion scores than males. Mean scores are, therefore, reported separately for each gender for the LOS performance measures (Table 4).
Table 3. Means, Standard Deviations, and Ranges in Centimeters for Each Segmental and Global Posture Measure

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>2.53 (2.46)</td>
<td>-2.46 to 9.50</td>
</tr>
<tr>
<td>Head</td>
<td>1.61 (1.55)</td>
<td>-1.51 to 6.00</td>
</tr>
<tr>
<td>Shoulder</td>
<td>-2.80 (2.11)</td>
<td>-7.52 to 1.24</td>
</tr>
<tr>
<td>Hip</td>
<td>1.94 (2.32)</td>
<td>-4.61 to 8.46</td>
</tr>
<tr>
<td>Knee</td>
<td>1.78 (2.16)</td>
<td>-2.75 to 6.85</td>
</tr>
<tr>
<td>Overall</td>
<td>0.53 (1.40)</td>
<td>-4.11 to 3.83</td>
</tr>
<tr>
<td>Head</td>
<td>0.11 (0.58)</td>
<td>-1.24 to 1.30</td>
</tr>
<tr>
<td>Shoulders</td>
<td>0.35 (0.58)</td>
<td>-1.09 to 1.79</td>
</tr>
<tr>
<td>Ribs</td>
<td>-0.26 (0.48)</td>
<td>-1.55 to 1.05</td>
</tr>
<tr>
<td>Hips</td>
<td>0.32 (0.91)</td>
<td>-2.42 to 2.69</td>
</tr>
</tbody>
</table>

Table 4. Means, Standard Deviations, and 95% CIs for Each LOS Performance Score. Excursions as % Out of 120%; Directional Control as (Amount of Intended Movement - Amount of Extraneous Movement) / (Amount of Intended Movement); and Movement Velocity in Degrees/Second

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females n=47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Excursion</td>
<td>95 (5)</td>
<td>93 to 96</td>
</tr>
<tr>
<td>Directional Control</td>
<td>86 (4)</td>
<td>85 to 88</td>
</tr>
<tr>
<td>Movement Velocity</td>
<td>4.3 (1.4)</td>
<td>4 to 5</td>
</tr>
<tr>
<td>Males n=51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Excursion</td>
<td>90 (5)</td>
<td>89 to 92</td>
</tr>
<tr>
<td>Directional Control</td>
<td>86 (4)</td>
<td>85 to 87</td>
</tr>
<tr>
<td>Movement Velocity</td>
<td>4.4 (1.7)</td>
<td>4 to 5</td>
</tr>
</tbody>
</table>

**PREDICTION OF THE LOG LOCATION**

Linear regression analyses were used with the initial sample (N=98) to develop models for predicting the location of the LOG (i.e., mean COP positions) from the posture measures, global coronal and sagittal offsets. Data were normally distributed, with no violations of independence or homoscedasticity. The results of the COPx regression indicated
that coronal offset explained a significant portion of the variance in COPx position $R^2=0.26$, $F_{(1,96)} = 34.12, p<0.001, \beta=0.51, \text{SEE}=0.57$ (Figure 7). Age, body mass index (BMI), and gender were also investigated as potential predictors, and due to low, non-significant correlations ($r=-0.10$ to $0.15, p>0.05$) were excluded from the final regression model.

Figure 7. Scatter plot with regression equation for predicting COPx position from global coronal offset.

The results of the COPy regression indicated that sagittal offset explained a significant portion of the variance in COPy position $R^2=0.27$, $F_{(1,96)} = 35.76, p<0.001, \beta=0.52, \text{SEE}=1.31$ (Figure 8). Demographic variables age, BMI, and gender were investigated as potential predictors, and excluded from the regression model due to low, non-significant correlations ($r=-0.09$ to $0.10, p>0.05$). These regressions were cross-validated with an additional sample of participants ($N=20$), and two-tailed, paired t-tests revealed no significant differences between predicted and actual COPx and COPy positions, $t_{(19)} = 1.91, p=0.07, 95\% \text{ CI}_\Delta -0.02$ to $0.53$ and $t_{(19)} = -0.13, p=0.90, 95\% \text{ CI}_\Delta -0.80$ to $0.70$ respectively.

LIMITS OF STABILITY

Multiple linear regression analysis was used with the initial sample ($N=98$) to develop a model for explaining composite LOS maximum excursion scores. Data were normally distributed, with no violations of independence, homoscedasticity, or multicollinearity. Preliminary one-way ANOVAs revealed that groups split by gender and neuromotor physical
activity were significantly different in maximum excursion scores, with women achieving significantly farther ($F_{(1,96)}=18.99$, $p<.001$) maximum excursions than men, and participants who met the American College of Sports Medicine’s guidelines for neuromotor physical activity traveling significantly farther ($F_{(1,96)}=14.37$, $p<0.001$) than those who did not. Directional control, movement velocity, age, BMI, and TV-watching time also met inclusion criteria for the regression model, with zero-order correlations of $r=-0.187$ to $-0.386$, $p<0.001$ to 0.06. Groups split by the other physical activity measures (i.e., cardio, resistance, and flexibility training) did not reflect significant differences ($p=0.653$ to 0.984) in maximum excursion scores. COP positions and posture offsets were also not significantly correlated ($r=-0.104$, $p=0.307$ & $r=-0.074$, $p=0.470$ respectively) with maximum excursion scores. Significant correlations were noted, however, between COP positions and movement velocity ($r=0.286$, $p=0.004$), total posture offset and movement velocity ($r=0.306$, $p=0.002$), and total posture offset and directional control ($r=-0.243$, $p=0.016$), indicating that while posture and COP positions may not have significant effects on the maximum excursions reached by the participants in this study, they did influence the movement strategies these individuals used to reach the targets. The final model to explain LOS maximum excursion scores was significant ($F_{(7,90)}=9.63$, $p<0.001$), and explained 42.8% of the variability in maximum LOS.

**Figure 8. Scatter plot with regression equation for predicting COPy position from global sagittal offset.**
excursion scores. Explanatory variables and coefficients for the model are presented in Table 5.

**Physical Activity**

The effects of self-reported physical activity behaviors for cardiorespiratory, resistance, flexibility, and neuromotor exercise on both global posture offsets and COP positions were investigated with the initial sample (N=98) using one-way ANOVAs. In general, the majority of participants met the guidelines outlined by the American College of Sports Medicine’s 2011 position stand for cardiorespiratory, resistance, and flexibility exercise, but did not meet the criteria for neuromotor. The Bonferroni adjusted p-value for significance interpretation was $p<0.025$ (i.e., 0.05/2) for each physical activity category (i.e., family of statistical tests).

**Cardiorespiratory Exercise**

Seventy-nine participants (i.e., 81% of the sample) reported performing moderate to vigorous cardiovascular-based activities on minimally 3 to 5 days per week, accumulating minimally 150 minutes weekly, which met the criteria for cardiorespiratory exercise. Means and standard deviations for global posture measures and COP positions for each group are presented in Table 6. There were no significant differences between groups in global posture offsets ($p=0.553$) or COP positions ($p=0.751$).

**Resistance Exercise**

Eighty-four participants (i.e., 86% of the sample) reported performing 2 to 3 days per week of resistance exercise involving the major muscle groups, which met the criteria for resistance exercise. Means and standard deviations for global posture measures and COP positions are presented in Table 7. There were no significant differences between groups in global posture offsets ($p=0.210$) or COP positions ($p=0.114$).

**Flexibility Exercise**

Seventy participants (i.e., 71% of the sample) reported performing minimally 2 to 3 days per week of flexibility exercises designed to improve range of motion of the major muscle groups, which met the criteria for flexibility exercise. Means and standard deviations for global posture measures and COP positions are presented in Table 8. There were no
Table 5. Summary of the Multiple Regression Analysis for Variables Explaining LOS Maximum Excursion Scores

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1 β</th>
<th>SE 1</th>
<th>Model 2 β</th>
<th>SE 2</th>
<th>Model 3 β</th>
<th>SE 3</th>
<th>Model 4 β</th>
<th>SE 4</th>
<th>Model 5 β</th>
<th>SE 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.406***</td>
<td>1.016</td>
<td>0.292**</td>
<td>1.148</td>
<td>0.325**</td>
<td>1.062</td>
<td>0.272**</td>
<td>1.080</td>
<td>0.255*</td>
<td>1.079</td>
</tr>
<tr>
<td>BMI</td>
<td>-0.202</td>
<td>0.153</td>
<td>-0.121</td>
<td>0.145</td>
<td>-0.126</td>
<td>0.143</td>
<td>-0.118</td>
<td>0.142</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.248**</td>
<td>0.034</td>
<td>-0.058</td>
<td>0.036</td>
<td>-0.049</td>
<td>0.035</td>
<td>-0.040</td>
<td>0.035</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC</td>
<td></td>
<td></td>
<td>0.386***</td>
<td>0.140</td>
<td>0.356**</td>
<td>0.139</td>
<td>0.354**</td>
<td>0.138</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MV</td>
<td></td>
<td></td>
<td>0.343**</td>
<td>0.336</td>
<td>0.319**</td>
<td>0.332</td>
<td>0.315**</td>
<td>0.330</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.178*</td>
<td>0.995</td>
<td>0.192*</td>
<td>0.994</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.124</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.165</td>
<td></td>
<td>0.261</td>
<td></td>
<td>0.386</td>
<td></td>
<td>0.413</td>
<td></td>
<td>0.428</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Body mass index (BMI); directional control (DC); movement velocity (MV); neuromotor physical activity (NM)
*p<0.05, **p<0.01, ***p<0.001.
Table 6. Means, Standard Deviations, and 95% CIs in Centimeters for Global Posture Offsets and COP Positions Between Groups Split by Self-Reported Cardiorespiratory Exercise

<table>
<thead>
<tr>
<th>Group</th>
<th>Measure</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met requirements</td>
<td>COP position</td>
<td>3.74 (1.44)</td>
<td>3.40 to 4.08</td>
</tr>
<tr>
<td>n=79</td>
<td>Posture offset</td>
<td>3.25 (1.76)</td>
<td>2.82 to 3.68</td>
</tr>
<tr>
<td>Did not meet requirements</td>
<td>COP position</td>
<td>3.86 (1.76)</td>
<td>3.18 to 4.55</td>
</tr>
<tr>
<td>n=19</td>
<td>Posture offset</td>
<td>3.54 (2.53)</td>
<td>2.67 to 4.42</td>
</tr>
</tbody>
</table>

Table 7. Means, Standard Deviations, and 95% CIs in Centimeters for Global Posture Offsets and COP Positions Between Groups Split by Self-Reported Resistance Exercise

<table>
<thead>
<tr>
<th>Group</th>
<th>Measure</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met requirements</td>
<td>COP position</td>
<td>3.67 (1.39)</td>
<td>3.34 to 3.99</td>
</tr>
<tr>
<td>n=84</td>
<td>Posture offset</td>
<td>3.21 (1.81)</td>
<td>2.79 to 3.62</td>
</tr>
<tr>
<td>Did not meet requirements</td>
<td>COP position</td>
<td>4.34 (1.99)</td>
<td>3.56 to 5.14</td>
</tr>
<tr>
<td>n=14</td>
<td>Posture offset</td>
<td>3.91 (2.47)</td>
<td>2.89 to 4.92</td>
</tr>
</tbody>
</table>

Table 8. Means, Standard Deviations, and 95% CIs in Centimeters for Global Posture Offsets and COP Positions Between Groups Split by Self-Reported Flexibility Exercise

<table>
<thead>
<tr>
<th>Group</th>
<th>Measure</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met requirements</td>
<td>COP position</td>
<td>3.59 (1.43)</td>
<td>3.24 to 3.94</td>
</tr>
<tr>
<td>n=70</td>
<td>Posture offset</td>
<td>3.13 (1.67)</td>
<td>2.67 to 3.58</td>
</tr>
<tr>
<td>Did not meet requirements</td>
<td>COP position</td>
<td>4.20 (1.60)</td>
<td>3.65 to 4.76</td>
</tr>
<tr>
<td>n=28</td>
<td>Posture offset</td>
<td>3.76 (2.42)</td>
<td>3.05 to 4.48</td>
</tr>
</tbody>
</table>
significant differences between groups in global posture offsets \((p=0.138)\) or COP positions \((p=0.064)\).

**Neuromotor Exercise**

Thirty-two participants (i.e., 33% of the sample) reported performing 2 to 3 days per week of exercises involving motor skills (e.g., balance, agility, coordination, and gait), proprioceptive exercise training, and multifaceted activities (e.g., tai chi), which met the criteria for neuromotor exercise. Means and standard deviations for global posture measures and COP positions are presented in Table 9. There were no significant differences between groups in global posture offsets \((p=0.285)\) or COP positions \((p=0.356)\).

<table>
<thead>
<tr>
<th>Group</th>
<th>Measure</th>
<th>Mean (SD)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met requirements</td>
<td>COP position</td>
<td>3.56 (1.66)</td>
<td>3.04 to 4.09</td>
</tr>
<tr>
<td>(n=32)</td>
<td>Posture offset</td>
<td>3.01 (1.56)</td>
<td>2.33 to 3.68</td>
</tr>
<tr>
<td>Did not meet requirements</td>
<td>COP position</td>
<td>3.86 (1.41)</td>
<td>3.49 to 4.23</td>
</tr>
<tr>
<td>(n=66)</td>
<td>Posture offset</td>
<td>3.45 (2.07)</td>
<td>2.98 to 3.92</td>
</tr>
</tbody>
</table>

**Television-Watching Time**

The effects of self-reported, average TV-watching time per week on global posture offsets and COP positions were investigated using simple Pearson’s correlations. There were no significant relationships between TV-watching time and global posture offsets \((r=0.049, p=0.630)\) or COP positions \((r=-0.122, p=0.232)\).
CHAPTER 4

DISCUSSION

The primary objective of this thesis was to determine whether global measures of postural alignment could accurately predict the location of the line of gravity (LOG) during upright standing. Additionally, a secondary aim was to elucidate the relationship between postural deviations and impaired balance control. In order to maintain upright standing, the alignment of the body’s major joints must position the center of gravity (COG) over the base of support (BOS) (i.e., feet) (Horak, 2006). The findings in this study indicate that global posture offsets do indeed influence the location of the LOG, and can be used to estimate its resulting location within the BOS during quiet, upright standing. This suggests that performing a posture analysis may be an important step toward identifying instability in a patient or client.

The development of computerized posture analysis software, such as the Posture Screen Mobile, has transformed previously subjective static posture analysis into an objective, reliable, clinical tool (Ferreira et al., 2010; Fortin et al., 2010; Santos et al., 2009). Its advent offers a comparable alternative to invasive radiographic imaging of individuals suspected of having postural abnormalities (Kuo et al., 2009). Prior to the work done in this thesis, these software products were primarily used to describe segmental deviations from ideal postural alignment. Much like radiographic imaging, they are not coupled with force plate analyses, and therefore the location of the LOG remained unknown (Schwab et al., 2006). Until now, this approach has rendered them ineffective in screening for impaired balance control risk factors, since segmental deviations in posture alone appear to be insufficient to identify inferior balance control or increased fall risk, as demonstrated by the large body of equivocal research presented in the review of literature section in this thesis.

Using Global Posture Measures to Predict the LOG Location

When analyzing posture, it is necessary for therapists and trainers to observe global alignment in addition to segmental, in order to fully appreciate any compensatory position changes of the major joints and the resulting location of the LOG (Le Huec et al., 2011).
Therefore, this study highlighted the need for quantitative, global posture offset measures to be available to health practitioners, and suggested calculating these global measures from the segmental deviations provided by the Posture Screen Mobile computerized posture analysis software. The hypothesis that these global offsets would allow the prediction of the LOG location was supported. The global posture measures were highly reliable, with average ICCs having close to perfect agreement, and they predicted the location of the LOG (i.e., mean COP position) with little error. The resulting regression equations for calculating COP positions from global posture offsets accurately predicted COP positions in an additional sample of 20 individuals with similar demographics, indicating the robust nature of these prediction equations.

The global posture offset measures were positively related to COP position shifts away from equilibrium (i.e., the symmetrical location in the medial/lateral direction and approximately 4 to 5cm anterior to the ankle joint axis in the anterior/posterior direction) (Hellebrandt et al., 1938; Woodhull et al., 1985). Greater global posture offsets in the coronal view corresponded to more severe left or right shifts in COP positions, and offsets in the sagittal view corresponded to forward or backward shifted COP positions. These findings demonstrate that larger joint deviations from ideal postural alignment are capable of displacing the COP toward the edges of the BOS, and that these COP displacements can be reliably predicted with quantitative measures of global postural alignment.

An estimation of the LOG location is useful to therapists and trainers for several reasons. To optimize balance control, patients/clients should be instructed to adopt the most energy efficient position during upright standing, without the need for excessive corrective movements (Horak, 2006). Understanding where an individual’s LOG is positioned during his/her habitual, quiet standing provides necessary information to improve rehabilitation or exercise instruction. Stability increases with a larger BOS (e.g., wider and or staggered stance), a lower COG, or a COG located more centrally within the BOS (Pollock, Durward, Rowe, & Paul, 2000). In many clinical or pathological cases (e.g., pregnancy, morbid central obesity, progressive thoracic hyper-kyphosis) the COG migrates too far forward for the body to correct through compensatory joint position adjustments (Le Huec et al., 2011). These cases often require an external form of support (e.g., cane or other assisted device) to increase the size of the BOS and maintain upright standing (Van Hook, Demonbreun, & Weiss, 2003). Individuals suffering from these conditions may even require these external supports prior to the COG migrating past the stability limits due
to musculoskeletal complications. In an effort to maintain upright standing, the body may employ painful, dysfunctional compensations such as excessive contraction of the paraspinal muscles, retroversion of the pelvis, and flexion of the knees (Sugrue et al., 2013). A general shift toward forward inclination is also commonly observed in the elderly, even in the absence of pathological states, and these forward-shifted COP positions are significantly associated with fall risk (Merlo et al., 2012).

Forward-shifted COP positions during quiet, upright standing are shown to be less stable than equilibrium positions, as evidenced by backward shifts of the COP toward the ankle joints of individuals exposed to situations deemed threatening to postural control (e.g., standing on an elevated surface or closing the eyes) (Carpenter et al., 2001; Nichols, Glen, & Hutchinson, 1995). This makes logical sense, as deviations from vertical standing positions, like forward inclinations, are shown to create a gravitational torque about the joints (Hue et al., 2007). This torque causes acceleration of the body further away from a stable, upright position, making maintenance of balance more difficult. Right or left shifts from equilibrium, where one limb supports more than 50% of the body’s weight, are also shown to be less stable than perfectly symmetrical weight distributions, as evidenced by increased COP velocity during asymmetrical standing (Anker et al., 2008). These findings highlight the benefits of adopting a standing position close to equilibrium, with symmetrical distribution of the body’s weight supported just anterior to the ankle joint axis.

As one ages, the size of the functional BOS purportedly decreases (Blaszcyk et al., 1994). This decrease in turn limits the amount of COG movement that may be tolerated prior to a loss of balance. The LOS within the BOS is much smaller in the elderly as compared to the young (i.e., approximately 50% of their BOS in the anterior/posterior direction vs. 80% in the young, and 68% of their BOS in the medial/lateral direction vs. 80% in the young) (Blaszcyk et al., 1994). The elderly may benefit from maintaining a centrally located COP, further from the edges of the BOS, so that they have a wider margin available for making any necessary corrective movements. Instructing individuals in the practice of maintaining this equilibrium position throughout their lifespan seems reasonable, to ensure good habits are instilled prior to advancing age. Identifying shifts away from postural equilibrium is the first step for therapists and trainers to identify instability in their patients and clients, and structure appropriate training programs to restore a position of equilibrium and maximize the use of the BOS. The global and segmental
offset measures provided by the Posture Screen Mobile software will indicate to practitioners
how far a patient/client has migrated from equilibrium, and which joints or body segments
require the most attention during rehabilitation or exercise training to correct the observed
imbalance. The findings in this study are an important first step in demonstrating that this simple
field tool may be used for this purpose.

The COPx regression model explained 26% and the COPy model 27% of the variance in
COP position. Demographic variables including age, body mass index (BMI), and gender did not
explain any additional variance in position. There was a trend toward more individuals exhibiting
right-shifted global posture offsets and subsequent right-shifted mean COP positions. While it is
possible that the right-shifted, coronal COP positions reflected some limb dominance, this is
unlikely, based on previous reports of limb dominance having no relationship with COP position
during standing (Anker et al., 2008). Another study reported an average left-shifted COP
position, also with no suggestion of the shift reflecting limb dominance, but did not assess
postural alignment (Nichols et al., 1995). The fact that limb dominance does not seem to explain
coronal COP position suggests that deviations in postural alignment may be the bigger
contributing factor to asymmetrical standing. The COPy position ($M=3.69\text{cm}$, $SD=1.52$) was
slightly closer to the ankle joint axis in the present study than in previously reported equilibrium
positions ($M=4.95\text{cm} \pm 1.34$) (Woodhull et al., 1985) but still within a reasonable range.

To the author’s knowledge, this was the first attempt to use global posture offset
measures, provided by computerized posture analysis software, to predict the location of the
LOG. While the explained variance may seem low, the sample population investigated in this
study had a small range in posture offsets and mean COP positions, with no participants
exhibiting gross deviations from ideal alignment or postural equilibrium. It is impressive that the
small range in posture offsets was still capable of predicting COPx positions within 0.57cm and
COPy positions within 1.31cm. The larger standard error in COPy position is likely due to the
larger range in anterior/posterior positions observed in this study. The explained variance in COP
positions would conceivably increase if individuals with greater postural deviations were
investigated.

An additional explanation for the low explained variance may be that the mean COP
positions used to estimate the location of the LOG in this study are not entirely reflective of the
exact COG location (Zatsiorsky & King, 1997). The true definition of the LOG is the ground
projection of the center of the body’s mass (i.e., COG) along the direction of gravitational force; it is represented mathematically by the double integration of the horizontal anterior/posterior and medial/lateral elements of the COP (Ihlen, Skjæret, & Vereijken, 2012). COP, the resulting application of forces on the supporting surface during upright standing, is usually referred to as a central nervous system response for controlling movement of the COG (Duarte & Freitas, 2010). The COP thus varies about the COG, and the two are only theoretically equal when horizontal forces acting upon the body equal zero (Lafond et al., 2004). While these concepts must be considered, it is unlikely that using mean COP positions to predict the LOG location introduced too much error in the present study, because participants were asked to stand as still as possible during the collection of COP position data. Observed COP excursions (i.e., body sway) during these quiet standing trials were very small, as were root mean square errors, indicating that very little COP corrective movements were necessary to modulate the LOG. Another COG-related explanation for the low explained variance is that the mass of each body segment was not accounted for in the global posture measures used to predict COP positions. Weighting each segmental deviation, based on anthropometric data regarding the mass of each segment, may more appropriately represent the resulting position of the COP within the BOS (Dempster & Gaughran, 1967; McConville, Clauser, Churchill, Cuzzi, & Kaleps, 1980). It is likely that deviations of heavier segments cause greater displacement of the COG, and therefore have a greater influence on the resulting COP positions.

It must also be noted, that the photographs used to calculate global posture offsets were not taken simultaneously with the collection of COP position data. In fact, several minutes, as well as a change in environment (i.e., quiet standing on the floor near a blank wall vs. in the NeuroCom Balance Master apparatus), separated the capture of participants’ postures and the collection of their COP position data. The likelihood that the passing time, transition, and repositioning within the NeuroCom apparatus led to small changes in participants’ postures is considerable. This methodology was selected purposely in the present study, however, because in order to be a useful tool to practitioners interested in estimating deviations from equilibrium in their clientele, the global posture offsets’ ability to predict COP positions must hold true beyond the application of just one assumed, short-term, standing position.
**Dynamic Balance Performance**

An important functional purpose for learning to control the COG in a position of equilibrium is the necessary transition from equilibrium maintenance during static tasks to those requiring movement during daily activities. Dynamic balance control is essential for the performance of activities of daily living and sport/leisure avocations (Huxham, Goldie, & Patla, 2001). Most falls occur during movement; therefore, dynamic postural control tests may provide a more functional evaluation of balance ability than static tests (Shimada et al., 2003). There is currently no gold standard, however, for evaluating dynamic balance (Pickerill & Harter, 2011). The NeuroCom Balance Master LOS test was used in the present study to quantify dynamic balance performance. There is some discrepancy in the literature regarding whether this test is measuring components of static or dynamic balance, since it requires volitional movement of the COG but maintains a stationary BOS (Huxham et al., 2001; Maeda et al., 2011). A reasonable solution is that it should be referred to as a hybrid test, reflecting the transition from static to dynamic states (Blaszcyk et al., 1994). This rationale makes it an ideal test to reflect how well an individual’s static posture prepared him/her for subsequent movement.

The present study sought to explain performance on the LOS test, as quantified by composite maximum excursions, in part through the self-selected COP positions participants adopted during the static balance trials and/or the severity in global posture offsets. These positions and offsets were not significantly related to LOS performance. It must be noted, however, that participants did not commence movement toward each target on the LOS test from the self-selected COP positions they adopted during the static trials. The LOS test instructions required every test participant to begin each trial in a standard, equilibrium location within the BOS. This artificially controlled testing condition may not be truly representative of an individual’s LOS during normal daily activities (e.g., reaching for a cupboard or picking up an object). It may be that the generally healthy adults observed in this study were able to perform at their theoretical LOS when visually coached to adopt an equilibrium position prior to commencing movement. Postural alignment may also have been improved in order to achieve this starting position. It would be interesting to observe whether LOS performance differences would emerge when individuals are allowed to begin from their self-selected COP positions with no visual assistance.
Additional possibilities for the lack of relationships between COP positions, posture offsets, and LOS performance are the movement strategies participants used to reach the targets. Since COP positions and posture offsets are intimately related to the alignment and positioning of the major joints, they have the greatest potential to impact the movement strategies an individual adopts (e.g., ankle strategy vs. hip strategy) when challenging their stability limits. Particularly, individuals with lesser balance control are shown to depend more on hip strategies to maintain balance when moving toward stability limits (Horak, 2006). Participants were instructed to move using ankle strategies in the present study; however, with no descriptive strategy measure provided by the LOS summary report, it is difficult to determine whether deviations from these instructions were in part responsible for participants’ excursion scores.

In addition to hip and ankle strategy differences among participants, electromyography (i.e., muscular activity) was an unknown in the present study during the static balance trials and the LOS test. Greater muscular activity in the spinal erectors is reported in individuals with poor posture during upright standing (Briggs et al., 2007). Elderly individuals with poor balance exhibit abnormal co-contraction of antagonist muscle groups to maintain their balance ability (Kemoun, Thoumie, Boisson, & Guieu, 2002). It may be that while participants with greater postural deviations in the present study were able to achieve similar excursions toward the LOS targets as those with aligned postures, they required more muscular effort to do so, or used abnormal muscular synergies, thus expending more energy to accomplish these distances. Since postural equilibrium is defined as joint alignment and positions that allow minimal muscular activity and minimal energy to be expended during standing (Danis et al., 1998), electromyography may reflect the negative consequences of poor posture on balance control more successfully than postural alignment constraints alone.

While COP positions and posture offsets did not significantly explain the maximum distance participants’ attained when moving toward the LOS targets, they were related to the directional control and movement velocity strategies participants employed to arrive at these destinations. Participants with greater global posture offsets exhibited reduced accuracy (i.e., directional control) when moving toward targets. Since ideal posture is associated with optimal muscle length-tension relationships, and the resulting best force production potential (Clark et al., 2012), deviations from ideal alignment may have negatively affected the muscle synergies responsible for orchestrating movement toward each target. Movement velocity, however, was
positively correlated with posture offsets and COP positions. These findings are somewhat counterintuitive and thus more challenging to explain. Faster velocities during the LOS test are generally reported in healthy, young adults as compared to the elderly, indicating that faster velocities reflect superior performance on this test (Maeda et al., 2011). The faster velocities associated with greater posture offsets and COP positions in the present study may simply be due to chance. The correlations, while significant, were quite low ($r=0.306$ & 0.286 respectively). It is also possible that the increased movement velocity, coupled with decreased directional control, represents dysfunctional coordination of the muscle synergies required to accomplish leaning tasks. It is suggested that postural deviations negatively affect proprioception (Page, 2006); therefore, participants with greater postural deviations may have overestimated their ability to move toward the targets due to altered neural feedback.

While COP positions and posture offsets were unable to explain any variance in LOS maximum excursions, several other explanatory variables did account for 42.8% of the participants’ scores. Gender, body mass index (BMI), age, directional control and movement velocity, neuromotor physical exercise, and TV-watching time were all included in this explanatory model. While some of these findings are previously reported in the literature, the combination of these explanatory variables has not been investigated. Women attained significantly larger composite maximum excursions than men during the LOS test in the present study. Balance control is known to be task-specific (Horak, 2006) and previously reported LOS tests in the elderly have shown no differences in excursions between genders (Musselman & Brouwer, 2005). The fact that women outperformed men on this dynamic balance task is interesting, because when gender differences do surface on other balance measures, they are usually in favor of men having superior balance control or reduced fall risk as compared to women (Vereeck et al., 2008). These differences are generally observed in the elderly population, however, so it may be that the relatively young sample investigated in the present study does not adhere to these trends. Women typically have a lower COG than men (Kendall et al., 2005); thus, the enhanced stability provided by a lower COG may have allowed women to achieve further distances toward each target.

Age and BMI are often reported as having inverse relationships with postural stability (Anker et al., 2008; Blaszcyk et al., 1994; Hue et al., 2007; Rogind et al., 2003). Increased postural sway, lower balance confidence ratings, and smaller LOS are all acknowledged as
complications associated with increasing age (Blaszcyk et al., 1994; Rogind et al., 2003). Higher BMI is purported to increase COP velocity during quiet standing and reduce the size of the functional LOS due to the increased inertia of body segments in obese individuals (Blaszczzyk, Cieslinska-Swider, Plewa, Zahorska-Markiewicz, & Markiewicz, 2009; Hue et al., 2007). Age and BMI were significantly, inversely correlated with composite maximum excursions in this study; however, this relationship disappeared when directional control and movement velocity were accounted for in the LOS regression model. This suggests that with increasing age and BMI a decline in movement quality occurs, which in turn reduces LOS performance.

To combat the decline in movement quality with age, physical activity that emphasizes body control and joint position sense (e.g., Tai Chi) is recommended for older adults (CDC, 2012b). In fact, individuals participating in these activities exhibit superior directional control during LOS tests as compared to individuals of the same age who do not engage in these activities (Tsang & Hui-Chan, 2003). Aside from the specific transfer of multi-faceted exercises like Tai Chi to balance control, these types of exercise may also serve to improve balance-related confidence of individuals who perform them regularly. Balance performance is related to past experiences and beliefs regarding balance ability (Myers et al., 1996), so encouraging individuals to partake in these forms of exercise may improve balance performance through psychological mechanisms.

Coupled with increasing age, high BMI becomes an even greater risk factor for impaired balance control (Manckoundia et al., 2008). To restore optimal movement quality in obese individuals, weight loss is recommended (Teasdale et al., 2007). A reduction in body weight (i.e., lower BMI) is shown to be successful in improving postural stability, as quantified by reduced COP velocity during quiet standing. It is likely that weight loss would similarly improve variables such as directional control and movement velocity on the NeuroCom LOS test, leading to improved performance in excursions.

To further support the argument for superior movement strategies being in part responsible for LOS performance, neuromotor physical activity was also significantly related to LOS excursion scores in the present study. Individuals who met the requirements established by the American College of Sports Medicine for this category of physical activity outperformed those who did not. While this relationship was not strong, it remained significant in the final LOS regression model. The majority of the sample in the present study was very active, based on
self-reported physical activity measures. The neuromotor exercise category was the only one of
the four physical activity categories where the majority of participants did not report meeting the
American College of Sports Medicine’s requirements. While group sizes in this category were
uneven, this finding still implies that all exercise modalities may not be equal when training to
improve balance control. Neuromotor exercise is focused on balance, coordination, and
proprioception (Garber et al., 2011). In the elderly, individuals participating in exercise programs
involving this style of training have demonstrated superior balance improvements, as determined
by LOS performance, when compared to individuals participating in regular resistance training
programs, despite similar increases in lower body strength in both groups (De Bruin & Murer,
2007). This suggests that specificity of training is important to consider when designing a
program to improve balance control. The present study confirms that exercise modalities that are
not directly related to balance control (i.e., cardiorespiratory, resistance, and flexibility exercise)
did not seem to have an effect on balance performance.

The last variable to be included in the final regression model for LOS performance was
TV-watching time. While weakly, inversely correlated with LOS max excursions, it was only
able to explain an additional 1.5% of the variability in scores. Evidence suggests that TV time
may be related to overall time spent in sedentary behaviors (Sugiyama, Healy, Dunstan, Salmon,
& Owen, 2008). Large amounts of TV time are implicated in increased cardio-metabolic risk
factors and adverse metabolic biomarkers, even in individuals who meet the minimum 150
minutes per week of moderate-vigorous physical exercise (Owen et al., 2010). These individuals,
deemed “active couch potatoes”, seem to be at risk for a multitude of health consequences
despite meeting physical activity guidelines. While the types of exercise best suited to improve
balance control are still debatable, it is well established that physically active individuals have
superior balance control than their inactive peers (Perrin, Gauchard, Perrot, & Jeandel, 1999). No
study to date has directly compared the effects of TV-watching time on balance control. The
findings in the present study suggest that TV time, irrespective of physical exercise, may have a
deleterious effect on balance control, since the majority of the sample population was physically
active. It would be interesting to conduct further examinations, with more detailed questions
reflecting cumulative sedentary behaviors, to establish whether accumulated sedentary activity
has the ability to offset the beneficial, protective benefits of exercise on balance control.
PHYSICAL ACTIVITY AND POSTURE

While some research indicates that structured exercise may improve existing postural alignment deviations (Katzman, Sellmeyer, Stewart, Wanek, & Hamel, 2007), there is no evidence directly linking poor posture to physical inactivity. Regardless, professionals specializing in posture and musculoskeletal health continually describe the detrimental effects of lifestyles including more sedentary behaviors than physical activity on postural alignment and musculoskeletal integrity (Sahrman, 2002). Individuals with office-based, sedentary jobs commonly report musculoskeletal discomforts that may be associated with poor posture (Janwantanakul, Pensri, Jiamjarasrangsri, & Sinsongsook, 2008). For these reasons, the present study sought to link self-reported physical inactivity and TV-watching time with global posture offsets and COP positions. No major differences were discovered in these variables for any of the four physical activity categories. This is likely due to the largely active sample investigated in the present study. While a small percentage of participants did not meet the physical activity requirements for each of the four activity categories, most met the criteria in at least one of the categories. Assessing groups of individuals exhibiting greater differences in physical activity behaviors is probably necessary to establish any link between postural alignment and physical inactivity. Such investigations may be worthwhile to determine whether the protective benefits of regular exercise include maintenance of good postural alignment, and if certain types of exercise are more effective than others for these purposes.

TV time was also not related to posture offsets in this study. While TV time has been reported to estimate total time spent in sedentary behaviors (Sugiyama et al., 2008) it may not have adequately captured these behaviors in the present sample. Additional questions reflecting job type, driving time, and other sedentary behaviors like reading and Internet usage, would likely improve the validity of estimating sedentary behavior. It is also possible that participants underreported TV time or over-reported physical activity behaviors in the present study, which is a commonly encountered problem when administering physical activity behavior questionnaires (Rzewnicki, Auweele, & De Bourdeaudhuij, 2003).

STUDY LIMITATIONS

There were several limitations in the present study. A convenience sample, recruited from the greater San Diego area, was used to reflect generally healthy adults 18 to 75 years of age;
however, no efforts were made to recruit equally from each decade within this age span. The mean age was skewed toward the younger end of the range (i.e., 34 years); thus, these findings may not accurately reflect the characteristics of the elderly population. The recruited participants also had a fairly small range in posture offsets. A more diverse sample, reflecting larger variations in postural deviations, would be desirable to create regression equations to predict mean COP positions with less standard error. Nevertheless, this study demonstrated that even in individuals with fairly mild postural deviations, such equations are effective in estimating the LOG location. Caution should be taken, however, when applying these findings to the adult population due to the above delimitations imposed by the sample in this study.

The NeuroCom Balance Master, while ideal for standardizing participants’ positions and foot placement, imposed restrictions during the LOS test that may have blurred the relationship between COP positions and LOS maximum excursions. A standard force plate, with no requirements regarding initial COP positions, may provide a more accurate representation of how well the static posture of an individual prepares him/her for subsequent movement. Additionally, no measure examining balance confidence was used in the present study. While likely unnecessary for the younger end of the sample, past experiences with activities requiring balance control and/or beliefs about balance ability may have influenced the older participants’ balance scores on the LOS test.

The use of self-reported physical activity measures may have prevented stronger relationships from emerging between exercise habits and both posture and balance. Aside from reporting errors, frequency of participation in physical activity does not necessarily correspond to physical fitness level (Tager, Hollenberg, & Statariano, 1998). For example, the elderly participants in this study may have reported engaging in frequent physical activity; however, they were still unlikely to have the cardiorespiratory endurance, strength, flexibility, and balance control of the younger participants. A more accurate way to determine the role physical activity has on postural alignment and balance control would be to obtain direct measures of physical ability (e.g., maximal oxygen consumption, resistance repetition maximums, sit & reach) in each of these categories, and compare them to postural alignment and balance performance.
**STUDY CONCLUSIONS AND FUTURE EXPLORATION**

In conclusion, this thesis successfully used a non-invasive, inexpensive, accessible device to create regression equations capable of predicting the LOG location during quiet, upright standing. Health practitioners, such as Physical Therapists and Personal Trainers, can feasibly use the Posture Screen Mobile application in field settings to screen patients and clients for the biomechanical risk factors contributing to poor balance. Postural alignment does appear to have a relationship with COP positions adopted during quiet standing. The explained variance in position was lower than desirable, so additional research using a more diverse sample is warranted to improve the goodness of fit of the prediction equations. The next step will be to determine how successfully a rehabilitation or physical activity program is in instructing individuals with poor posture to correct these imbalances and adopt a habitual standing position in equilibrium.

While close to half of the variance in LOS scores was accounted for in this thesis, the remaining variability in scores remains elusive. Since LOS tests are ideal for reflecting the transition from static to dynamic states, continued research examining the physical attributes responsible for this aspect of balance performance is warranted. Studies including direct measures of physical fitness would likely be important additions to the explanatory regression model. The types of physical activity an individual chooses to engage in seem to play a role in balance performance. Since neuromotor physical exercise was the only category that accounted for balance control scores, this suggests that this style of training may be the most successful in improving balance performance.

Finally, general physical activity participation does not seem to prevent individuals from having postural deviations and subsequent COP position displacements. This suggests that specific instructions regarding how to achieve an equilibrium standing position are necessary, and individuals with severe offsets may require the assistance of a therapist or trainer to improve this aspect of their standing balance, and eliminate this biomechanical risk factor for instability and/or falls.
REFERENCES


APPENDIX A

CONSENT FORM
Study Title:
The relationship between posture distortion patterns and static/dynamic balance ability.

Investigators:
Sarah Kirtland, B.S., School of Exercise and Nutritional Sciences, SDSU
Daniel J Goble, Ph.D., School of Exercise and Nutritional Sciences, SDSU

Purpose of the Study:
Poor posture is increasingly prevalent in today’s sedentary society. The popularity of performing a posture screen with clientele is growing in the health and fitness profession, yet little is known about its direct application to creating a training program to fit the specific needs of each client. The present study aims to shed light on the relationship between posture and static/dynamic balance ability. Understanding the changes that occur in an individual who possesses poor posture in regards to their ability to manipulate their center of gravity will support the use of posture analysis as a preliminary screening tool and assist in the design of appropriate fitness programs.

Study Description:
To determine if you are eligible to participate you will be asked to give your birth date, indicate your sex, and tell us about your current health status. If your responses indicate you are eligible, you will then be asked to participate in the posture screening and balance tasks associated with this study. If you are not eligible to participate, the information obtained from you will be omitted from this study and destroyed to protect your privacy.

Posture Screening
The first component of this study involves a posture analysis using posture screening
software (Posture Pro 8). The posture screen requires you to wear minimal clothing (i.e. a bathing suit or tank top and shorts). The principle investigator for this study, Sarah Kirtland, will take a digital photograph of you from the front, side and back views. The posture screen should take no more than 5-10 minutes. These images will be uploaded to the posture software for analysis. Deviations from ideal alignment will be identified from each view. This portion of the study is entirely optional and if at any time you feel uncomfortable with the posture analysis, you may choose to terminate the screen.

Balance Tests

Following your posture analysis, your balance ability will be assessed. Balance is known to involve three main sensory systems: vision, your sense of ankle position (proprioception), your sense of head movement (vestibular) and lower body muscle competence. All of these systems will be assessed using a series of tasks on a piece of standardized equipment known as the Neurocom Balance Master.

The Neurocom Balance Master consists of a balance plate that you will stand on, some surrounding walls and a harness for your safety. In the balance tests you will experience things like a moving plate below your feet and moving walls. Some trials of the tasks will be performed with your eyes closed and some with them open. These tasks will take approximately 30 minutes to complete. You will be given short breaks after each balance task.

Experimental Aspects:

No procedure or questionnaire used in this study is experimental in nature. The only experimental aspect of this study is the gathering of information for the purpose of analysis.
Risks, Discomforts, and Risk Management:

As a participant in this study you may experience minor muscle fatigue from the balance tests. Should you feel uncomfortable you should temporarily or permanently discontinue your participation.

There is also a risk of falling during the balance tasks in this study, however; this risk is being managed by having 100% supervision by the principle investigator, Sarah Kirtland, and by providing a safety harness to fully support body weight if necessary.

Benefits:

The posture analysis portion of this study will provide you with some non-clinical information about areas of your body that appear to deviate from neutral alignment. Postural awareness is the first step toward fixing any imbalances.

Beyond the personal, this work will likely have benefits for adults in general. A greater understanding of the ways in which postural abnormalities affect balance ability will allow for future studies and rehabilitation programs to be specifically tailored to reduce the known consequences of poor balance. Identifying risks associated with poor posture early in life will allow these intervention strategies to be implemented at a young enough age to successfully see improvements and reduce the likelihood of falls and associated morbidities later in life.

Defining the use of screening tools like posture analysis will benefit all individuals seeking to participate in a physical activity program. Health and Fitness professionals will be better able to choose appropriate pre-screening tests and effectively use the results to create a more individualized program for their clients.

Confidentiality/Privacy:

Confidentiality will be maintained to the extent allowed by law. Research files
including the posture images will be password protected and stored on Laboratory computers without personal information from the participant. Subjects will be identified by unique alphanumeric codes and only the primary investigator (Sarah Kirtland) and her supervising faculty member (Dr. Goble) will have access to the data. This consent form will be stored for up to 3 years in a locked cabinet in a locked office in the Motor Control Laboratory. Federal regulations require that the Institutional Review Board (IRB) periodically review all approved and continuing projects that involve human subjects. To ensure that your rights as a subject are being protected in this study, it is possible that representatives of the Institutional Review Board may come to this research site to inspect study records.

Incentives to Participate:

There is no financial compensation for participation in this study. The principle investigator, Sarah Kirtland and supervising faculty member Dr. Goble greatly appreciate your willingness to participate.

Costs:

Participants are responsible for their own transportation to and from the Motor Control Laboratory. If you are a visitor to the SDSU campus and you elect to park in the on campus garages, parking is $1 per hour. Street parking is available free of cost.

If any complications arise as a direct result of participation in this study, we will assist you in obtaining appropriate attention. If you need treatment or hospitalization as a result of being in this study, you are responsible for payment of the cost for that care. If you have insurance, you may bill your insurance company. You will have to pay any costs not covered by your insurance. San Diego State University will not pay for any care, lost wages, or provide other financial compensation [include San Diego State University Foundation if this research is
funded]. However, if you feel you have a claim that you wish to file against the State [or the Foundation], please contact Graduate and Research Affairs - Division of Research Affairs at (619) 594-6622 to obtain the appropriate claim forms.

**Voluntary Participation:**

Participation in this study is voluntary. Your choice of whether or not to participate will not influence your future relations with San Diego State University or the San Diego State University Research Foundation. If you decide to participate, you are free to withdraw your consent and to stop your participation at any time without penalty or loss of benefits to which you are allowed.

**Contact Information:**

If you have any questions about your rights as a participant in this study, you may contact Sarah Kirtland directly via email: skirtland1@gmail.com or her supervising faculty member Dr Goble (tel: 619-594-7272; email: dgoble@mail.sdsu.edu). You may also contact an IRB representative in the Division of Research Affairs at San Diego State University (tel: 619-594-6622; email: irb@mail.sdsu.edu).

**Consent to Participate/Rights of the Participant:**

The San Diego State University Institutional Review Board has approved this consent form, as signified by the Board's stamp. The consent form must be reviewed annually and expires on the date indicated on the stamp.

Your signature below indicates that you have read the information in this document and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. You have been given a copy of this consent
form. You have been told that by signing this consent form you are not giving up any of your legal rights.

**Signatures:**

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<tr>
<th>Participant Name (Printed)</th>
<th>Date</th>
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APPENDIX B

AHA/ACSM HEALTH/FITNESS FACILITY PRE-PARTICIPATION SCREENING QUESTIONNAIRE
AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire

Assess your health needs by marking all true statements.

**History**
You have had:
___ A heart attack
___ Heart surgery
___ Cardiac catheterization
___ Coronary angioplasty (PTCA)
___ Pacemaker/implantable cardiac defibrillator/rhythm disturbance
___ Heart valve disease

**Other health issues**
___ Heart failure
___ You have diabetes
___ Heart transplantation
___ You have or asthma other lung disease.
___ Congenital heart disease
___ You have burning or cramping in your lower legs when walking short distances.

**Symptoms**
___ You have musculoskeletal problems that limit your physical activity.
___ You experience chest discomfort with exertion.
___ You experience unreasonable breathlessness.
___ You have concerns about the safety of exercise.
___ You experience dizziness, fainting, blackouts.
___ You take prescription medication(s).
___ You take heart medications.
___ You are pregnant.

**Cardiovascular risk factors**
___ You are a man older than 45 years.
___ You are a woman older than 55 years, you have had a hysterectomy, or you are postmenopausal.
___ You smoke, or quite within the previous 6 mo.
___ Your BP is greater than 140/90.
___ You don't know your BP.
___ You take BP medication.
___ Your blood cholesterol level is >200 mg/dL.
___ You don't know your cholesterol level.
___ You have a close blood relative who had a heart attack

If you marked any of the statements in this section, consult your physician or other appropriate healthcare provider before engaging in exercise. You may need to use a facility with medically qualified staff.

If you marked two or more of the statements in this section, you should consult your physician or other appropriate healthcare provider before engaging in exercise. You might benefit from using a facility with professionally qualified exercise staff.
before age 55 (father or brother) or age 65 (mother or sister).

___You are physically inactive
(i.e., you get less than 30 min. of physical activity on at least 3 days per week).
___You are more than 20 pounds overweight.

___None of the above is true.

You should be able to exercise safely without consulting your physician or other healthcare provider in a self-guided program or almost any facility that meets your exercise program needs.

www.acsm-msse.org/pt/pt-core/template-journal/msse/media/0698c.htm
APPENDIX C

ADDITIONAL PRE-SCREENING QUESTIONS
1. AGE

What is your birthday? ______________________________________________________

*Participants must be between 18-75 years.*

2. SEX

What is your sex? ___________________________________________________________

*Attempt will be made to match the number of women and men in both the normal and poor posture groups.*

3. NEUROMUSCULAR STATUS

Do you currently have any known neurological or muscle-related illness that impacts your ability to do physical activities?

___________________________________________________________________

*Goal is to have “healthy” individuals participate in the study*

4. VISUAL and VESTIBULAR STATUS

Do you currently have any known visual or vestibular (inner ear) impairments that impact your ability to do physical activities?

__________________________________________________________________

*Goal is to have “healthy” individuals participate in the study*

5. MUSCULOSKELETAL INJURIES

Have you sustained any musculoskeletal injuries in the last six months that affected your ability to perform typical activities of daily living?

__________________________________________________________________

*Goal is to have injury-free individuals participate in the study*
APPENDIX D

BEHAVIORAL RISK FACTOR SURVEILLANCE SYSTEM (BFRSS) – TV AND PHYSICAL ACTIVITY QUESTIONS
FOR MONDAY – FRIDAY:

1. On average, how many minutes or hours do you spend watching TV or videos (streaming or renting movies, etc.) on a typical day Monday through Friday? (Please circle hours OR minutes for your answer)

<table>
<thead>
<tr>
<th>Hours OR Minutes on one typical day M - F</th>
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FOR SATURDAY or SUNDAY:

2. On average, how many minutes or hours do you spend watching TV or videos (streaming or renting movies, etc.) on either Saturday or Sunday? (Please circle hours OR minutes for your answer)

<table>
<thead>
<tr>
<th>Hours OR Minutes on either Sat or Sun</th>
</tr>
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</table>

3. In the last 30 days, other than activities you did for work, did you participate in any physical activities or exercises like running, walking for exercise, or gardening?

☐ YES

☐ NO \( \Rightarrow \) SKIP TO Q4

☐ I am not sure/I do not remember \( \Rightarrow \) SKIP TO Q4

3a. On average, how many days a week did you exercise/do physical activity? __

☐ I am not sure/I do not remember \( \Rightarrow \) SKIP TO Q4
3b. On average, **how much time** did you usually spend exercising/doing physical activity on one of those days?

<table>
<thead>
<tr>
<th>Hours OR Minutes on one day</th>
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</thead>
</table>

☐ I am not sure/I do not remember  SKIP TO Q4

4. In a **usual week** in the **past month**, did you do any activities designed to increase muscle strength or tone, such as lifting weights, pull-ups, push-ups, or sit-ups?

☐ YES

☐ NO  SKIP TO Q5

☐ I am not sure/I do not remember  SKIP TO Q5

4a. On average, how many **days a week** did you do these activities?  ____

☐ I am not sure/I do not remember  SKIP TO Q5

5. In a **usual week** in the **past month**, did you do any activities designed to increase flexibility, such as stretching or yoga?

☐ YES

☐ NO  SKIP TO Q6

☐ I am not sure/I do not remember  SKIP TO Q6

5a. On average, how many **days a week** did you do these activities?  ____

☐ I am not sure/I do not remember  SKIP TO Q6
In a usual week in the past month, did you regularly perform any activities such as martial arts, gymnastics, or tai chi?

☐ YES

☐ NO → SKIP TO Q7

☐ I am not sure/I do not remember → SKIP TO Q7

6a. On average, how many days a week did you do these activities? ____

☐ I am not sure/I do not remember → SKIP TO Q7

In a usual week in the past month, did you regularly perform any exercises using balance-training implements such as a stability ball, bosu ball, balance board, or other similar pieces of equipment?

☐ YES

☐ NO

☐ I am not sure/I do not remember

7a. On average, how many days a week did you do these activities? ____

☐ I am not sure/I do not remember