THE EFFECTS OF STATIC VERSUS DYNAMIC STRETCHING ON FALL RISK, BALANCE AND MUSCLE FUNCTION IN OLDER ADULTS: IS STRETCHING A BENEFICIAL INTERVENTION?

A dissertation submitted to the Kent State University College of Education, Health and Human Services in partial fulfillment of requirements for the degree of Doctor of Philosophy

By

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With aging, fall risk increases due to a degeneration in the systems that control balance. As sway levels increase in older adults the ankle muscles act to maintain midline postural control. Stretching of the ankle musculature is a commonly prescribed intervention for older adults. Static stretching (SS) is known to diminish muscle activity, while dynamic stretching (DS) has been reported to enhance muscle activation levels in the younger population. It is of question to how these stretching types may affect muscle activity and balance in older adults. To assess balance, muscle response and ROM post-SS versus DS in older adults. Thirteen healthy females (60-75 yo) completed a static and dynamic stretching intervention at the gastrocnemius and soleus. Pre-post-testing included: fall risk, ankle ROM, and activation of the gastrocnemius, soleus and tibialis anterior during balance. SS increased soleus muscle activity during all balance activities \((p < 0.05)\). DS increased sway with eyes closed soft surface \((p < 0.05)\). Fall risk approached a significant interaction between SS and DS \((p = 0.07)\), with observed increase in fall risk post-DS and reduced fall risk post-SS. This study is the first to report that SS can immediately improve muscle activity within the stretched muscle, and refutes previous claims of the deleterious effects of SS in terms of reducing muscle function and inhibiting activation. The current study promotes the use of SS held for 135 seconds at
the gastrocnemius/soleus to allow for improved soleus activation, reduced fall risk and improved balance in older adults.
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CHAPTER I
INTRODUCTION

Background

Human balance is the ability of the body to maintain its center of gravity (COG) within its base of support (BOS) in order to preserve upright control in standing (D.A. Winter, 1995). It involves a complex integration of peripheral sensory signals from three sensory systems including the vestibular, visual and somatosensory systems (D.A. Winter, 1995). Each system works in conjunction to provide appropriate balance response in quiet standing in order to keep to reduce amount of sway or teetering while the feet are firmly planted on the ground (D.A. Winter, 1995).

During quiet standing, proprioceptive inputs provide the most sensitive means of perceiving postural sway (Fitzpatrick & McCloskey, 1994; Sturneiks, 2008). The stretch reflexes in the lower extremity muscles provide feedback regarding sway activity about the ankles, and allow for appropriate reaction/motor output to activate muscles for maintenance of upright posture (Fitzpatrick & McCloskey, 1994). With the feet planted firmly on the ground there is an inherent angular acceleration of the body in the anterior-posterior direction over the BOS. In response, the ankle plantar-flexors and dorsi-flexors are activated to keep sway levels low (Gage, Winter, Frank, & Adkin, 2004; D. A. Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998). Due to the positioning of the body in a slight anterior direction during quiet stance, the plantar-flexors are the most active muscle in quiet standing, and act as the main agonist for maintaining balance and control (Di Giulio, Maganaris, Baltzopoulos, & Loram, 2009).
With aging, balance ability diminishes, fall risk increases as a result of a structural decline within the somatosensory system, especially at the level of the muscle receptors (Sturnieks, 2008). As sway increases in quiet standing, an inherent stretch reflex is activated at the ankle muscles via the muscle spindles, then there is a concurrent activation of these muscles to counter the sway to return to midline (Sturnieks, 2008). Structural degeneration at the level of the muscle receptors within this feedback control loop is seen as older individuals, and a resultant increase in sway can occur (Hageman, Leibowitz, & Blanke, 1995). With this reduction in sensory feedback, and increase in sway, older individuals have an even greater reliance on ankle muscle activation with more presence of muscle co-contractions (Benjuya, Melzer, & Kaplanski, 2004; Shaffer & Harrison, 2007). This reveals the important role of the ankle muscles, including the agonists gastrocnemius/soleus and antagonist tibialis anterior, and the high reliance on these structures as age increases (Benjuya et al., 2004; Kouzaki & Shinohara, 2010).

Several intervention strategies have been developed to counteract balance dysfunction resulting from the aging somatosensory system (Carter, Kannus, & Khan, 2001). Exercise has been reported as a useful intervention, and encompasses many modes, such as strengthening, endurance training, balance training and stretching. Multimodal exercise based intervention models have been shown to improve balance capabilities in the older adult population (Carter et al., 2001), but variable reports of one being superior to the other has been reported. Flexibility training and strength training have been compared in some studies, with one study citing that balance improvements were seen in both a strength training only versus a flexibility training only program (Bird,
Hill, Ball, & Williams, 2009), while another study reported that strength training demonstrated greater improvement in balance versus flexibility training (Barrett & Smerdely, 2002). It is still of question to which interventions may be superior to the other.

Static stretching, as a main component of a flexibility program, is designed to work on lengthening a muscle and improving joint range of motion (Decoster, Cleland, Altieri, & Russell, 2005). Stretches are typically held for 30-60 seconds, and the longer the stretch is held, the greater the immediate joint range of motion gains (Radford, Burns, Buchbinder, Landorf, & Cook, 2006). In older adults range of motion has been reported to be diminished leading to increased difficulty with everyday tasks (Bergstrom et al., 1985). Stretches that are usually prescribed about the ankle joint look to target increase in range of motion into dorsiflexion, inversion and eversion. Range of motion about the ankle has been reported as significant predictor of balance capabilities, and the range of motion of all three have been reported as significant predictors of balance and functional abilities (Menz, Morris, & Lord, 2005; Spink et al., 2011). While range of motion is a significant predictor, and is modifiable via stretching, it is still of question on how it may affect balance capabilities immediately after performing the intervention.

When a muscle is stretched or lengthened for a period of time, there is a lengthening to its components at the muscle belly, tendon or other surrounding connective tissues. The prolonged lengthening that occurs as the muscle will activate receptors within the muscle tissues that will enact a subsequent relaxation, which is defined as autogenic inhibition, therefore dampening the ability for the muscle to activate
immediately post-stretch (Behm & Chaouachi, 2011). After repeated and prolonged passive muscle stretching at the gastrocnemius/soleus complex there is a reported alteration is reflex sensitivity and overall reduced force output post stretch that can last up to 60 minutes (Avela, Kyrolainen, & Komi, 1999). In the older adult population, who is at risk for falling, it remains unknown whether static flexibility training to improve joint range of motion could be putting this population more at risk for falls immediate post-static stretching.

If stretching is prescribed to an older adult, it is important to consider other stretching techniques outside of the typically utilized static stretching protocol. Dynamic stretching may be an option, and this technique is defined as controlled repetitive movements through an active range of motion in a respective joint (Behm & Chaouachi, 2011). This stretch technique have been reported to increase muscle activity via increased post-activation nerve potentiation, which occurs via increasing the rate of muscle cross bridge cycling as one quickly moves through the joint range of motion (Behm & Chaouachi, 2011). Dynamic stretching techniques do not result in decrease maximal strength or muscular activation when compared to static stretching (Bacurau et al., 2009), but have also been reported to increase joint range of motion (Covert, Alexander, Petronis, & Davis, 2010). No known studies to date have examined the effects of dynamic stretching in the older adult population in terms of muscle activation as related to balance and function. However, one study examined shorter stretch durations and the effects on balance in a young healthy population. Costa and colleagues compared balance performance, as a product of sway index, after 15 second and 45
second of static stretching in a young healthy population (Costa, Graves, Whitehurst, & Jacobs, 2009). They reported a reduction in sway index or improved balance control after 15 seconds of stretching (Costa et al., 2009). These results, along with the reports of dynamic stretching increasing muscle function, could lead to questioning the utilization of dynamic stretching to improve balance in the older population. Dynamic stretching may be a better option when prescribing a stretching program to the older adult population at risk for falling, and may even enhance balance capabilities while still improving range of motion.

**Rationale for Current Study**

Flexibility training using static stretching is commonly used as an intervention for older fallers, but previous literature suggests that this technique may increase the immediate risk of falling due to decreased muscle force production. In contrast, dynamic stretching may improve balance and muscle function in older adults without reduced muscle force output.

**Objective/Hypothesis**

The objective of the current study is to assess the differences between balance and muscle response to long duration static stretching and quick short duration dynamic stretching in the older adult population. Static stretching typically reduces force production, while quicker dynamic stretching has no effect on or may augmenting muscle activation (Costa et al., 2009; Costa et al., 2010). The primary aim of this study will be to assess the difference between static versus dynamic stretching on fall risk, balance and muscle function in older adults. We hypothesize that:
1. Sway and fall risk will decrease post-dynamic stretch

2. Muscle activity (EMG) will increase in the gastrocnemius and soleus post-ballistic stretch

A secondary aim will look to assess the difference of static versus dynamic stretching on range of motion. We hypothesize that:

3. Both static and dynamic stretching will increase range of motion

These results will provide information for the development of stretching interventions for the older population to maximize safety and reduce risks that may be associated with a static stretching recommendation. Finally, a third aim will assess health related quality of life as related to fall risk, balance muscle function and range of motion in older adults. Based on previous literature, we hypothesize that:

4. Stability index scores (fall risk) and proprioceptive balance capabilities will be significantly associated with one’s health related quality of life (SF36v2 scores)
CHAPTER II
REVIEW OF THE LITERATURE

Postural Maintenance and Balance

Posture is defined as the orientation of a body segment relative to the gravitational vector, and balance is a more generalizable term that describes the body’s ability to maintain posture to prevent falling (D.A. Winter, 1995). To maintain upright posture, an individual must be able to maintain the body’s center of mass (COM) over its base of support (BOS). The center of mass is defined as the point equivalent of the total body mass in the global reference system, and is the weighted average of the COM of each body segment within space, while the BOS is the area or supporting surface where the feet come in contact with ground (D.A. Winter, 1995). The vertical projection of the COM onto the ground is considered the center of gravity (COG) (D.A. Winter, 1995). In quiet standing, many intrinsic factors work to maintain the COM over the BOS, and reduce the amount of sway over the BOS. The center of pressure (COP) is the point or location of the vertical ground reaction force vector or the point on the ground where the foot is in contact (D.A. Winter, 1995). COP is directly related to the neural control at the ankle muscles as the body sways in relation to gravity about this contact point (D.A. Winter, 1995). COP is the primary variable used to quantify postural balance in quiet and perturbed standing, as it is the net neuromuscular response to the control of passive COM movements (D. A. Winter, Prince, Frank, Powell, & Zabjek, 1996).

The human inverted pendulum model acts to provide a better understanding of balance control in quiet standing. In quiet standing, the COP tracks the movement of
one’s COM in order to correct the inherent sway the body has in relation to gravity (D. A. Winter et al., 1998). With the feet firmly planted on the ground, the body will experience angular accelerations either anteriorly to posteriorly (A/P) or medially to laterally (M/L), and act at the ankles or hips to attain midline posture (D.A. Winter, 1995). These reactions are mechanically defined respectively as the “ankle strategy” and “hip strategy,” which will combine or act alone to pull the body back to midline stance (D. A. Winter et al., 1996). The hip strategy is most active with large perturbations, while in quiet standing the ankle strategy is most readily utilized. The ankle plantar-flexors and dorsi-flexors act in the A/P direction to control the inverted pendulum to maintain upright midline standing posture; while in the frontal plane (M/L) the hip abductors/adductors are active via loading/unloading activity (D.A. Winter, 1995). The calculated difference between COP and COM (COP-COM) has been compared to the acceleration of the whole-body COM in the A/P and M/L direction during quiet standing (Winter, Patla, Prince 1998; Gage 2004). The COP-COM and COM acceleration was highly correlated with A/P direction, and slightly lower in the M/L direction (Gage et al., 2004; D. A. Winter et al., 1998). Thus, revealing the importance of A/P balance reaction, and ankle muscle activity for balance in quiet standing. As an example, with anterior body movement or acceleration the plantar-flexors will become more active to move the body posteriorly (Gage et al., 2004; D. A. Winter, Patla, Ishac, & Gage, 2003). The body’s COM at absolute rest has been found to be approximately 5 cm anterior to the ankle, thus calling on plantar flexor activity at an even greater rate in quiet standing (Gage et al., 2004; D. A. Winter et al., 2003).
These external components of balance control in quiet standing are made possible by a sensory feedback system, which allows for appropriate activation of these muscles of postural control.

**Sensorimotor Integration in Human Postural Control**

Sensorimotor control refers to the afferent input, integration and efferent output within the central nervous system that allow for maintenance of posture and balance control. Three major sensory systems combine to allow for balance to be maintained: visual, vestibular and somatosensory/proprioceptive system (Sturnieks, 2008). Neuromuscular control and joint stabilization are achieved via multisite sensory input received from each system, where it is processed by the brain for appropriate motor output and response (Lephart, Pincivero, & Rozzi, 1998). The received information either can provide conscious awareness and reaction, or unconscious reflexive responses for overall stability and balance (Lephart et al., 1998). Each sensory system contributes to the overall function of balance, but not all equal are in the amount of input for balance control. In a normal environmental setting the visual system accounts for 10%, vestibular 20% and proprioceptive 70%, of the overall input for balance control (Peterka, 2002). These contributions and balance responses are usually developed at a level of automaticity, allowing one to maintain the COM over the BOS. For there to be appropriate motor output, and muscle function to counteract the amount of sway that occurs in the inverted pendulum model, input needs to be provided about the body’s orientation in space to give a sense of when it is out of midline.
The visual system allows for adequate spatial organization within the respective environment (Sturnieks, 2008). Visual sensors can detect the orientation of the head relative to the visual world, and provide that input for the bodily adjustment (Peterka, 2002). The visual system permits the brain to create a spatial map of the environment, and allows one to better assess the respective surroundings that require balance reactions or control (Sturnieks, 2008). It also allows for visual acuity, contrast sensitivity, glare sensitivity, dark adaptation and depth perception (Sturnieks, 2008). As the body sways about the ankles, the visual field consequently shifts and provides feedback regarding motion to the allow for postural adjustment (Wade & Jones, 1997). By eliminating vision during standing one can better understand the role it plays in balance control. Visual input is necessary for maximal stability because sway increases when the eyes are shut (Fitzpatrick & McCloskey, 1994; Paulus, Straube, & Brandt, 1984). Fitz and McClosky (1994) reported that visual perceptions of postural sway are increasingly realized as sway velocity escalates, but this perceptual input is not readily activated at lower sway velocities (Fitzpatrick & McCloskey, 1994). Despite the higher velocity findings, this information signifies the importance of the visual system in recognizing one’s own sway from midline (Fitzpatrick & McCloskey, 1994). In terms of outside movement of the visual field or outside stimulus motion, when all three systems are available the visual system has been found to have what is called a “saturation effect” (Bles, Kapteyn, Brandt, & Arnold, 1980; Peterka & Benolken, 1995). This is the point where an increase in the amplitude of the visual field will cause little to no addition in postural sway in relation to the visual motion amplitude imposed on the system (Bles et al., 1980; Peterka
This saturation effect depends also on the contribution of the other systems, as when proprioceptive input is disrupted, then there is an increase in visually induced sway via visual surrounding feedback (Bles et al., 1980), leading to an increase in balance response to visually induced motion. The body typically moves in the direction of the visual stimulus, where there are larger magnitude head and trunk motions but smaller phasic motions about the ankle (Sasaki et al., 2002). The body will act to stabilize around the ankles as to not give in to the surrounding visual stimulus (Sasaki et al., 2002). Therefore, visual input is an important component to maximal balance control in standing, and sway is reduced when the eyes are open, but the overall contribution is less when the other systems are available (Asslander, Hettich, Gollhofer, & Mergner, 2013; Fitzpatrick & McCloskey, 1994).

The vestibular system accounts 20% of input needed for balance control. It allows for detection of position and motion of the head (Sturnieks, 2008). Corrective movements occur via reflexive activity of the vestibulo-ocular reflex, allowing for visual fixation during head movements. In addition, via the vestibulo-spinal reflexive pathways, which activate neck, trunk and extremity muscles for maintaining upright stance (Sturnieks, 2008). The vestibular apparatus also contributes to balance control, and contains semi-circular canals that relay information about angular acceleration (Fitzpatrick & McCloskey, 1994; Kristjansson & Treleaven, 2009; Sturnieks, 2008). Linear acceleration and tilt of the head is sensed by the utricle and secular organs of the otolithic system, which are more sensitive to static positioning in relation to the gravitational field (Fitzpatrick & McCloskey, 1994; Kristjansson & Treleaven, 2009;
The vestibular perception of sway depends on the velocity of the imposed movement, and is more sensitive to larger disturbances in posture (Fitzpatrick & McCloskey, 1994). The vestibular contribution to balance correction can be best explained by examining those with bilateral vestibular loss. In these individuals when increasing visual motion/stimulus occurs there is an overall increase in sway to the point of falling, even when there is still somatosensory system is available (Peterka & Benolken, 1995). In those without vestibular loss who are subjected to visually induced sway, there is a critical point or maximal point of sway where the vestibular system will act to return to midline, the vestibular motion will act to attenuate the visually induced sway response (Peterka & Benolken, 1995). While the vestibular system does have a large roll in balance capabilities, it plays much less of a role in perception of sway in quiet standing. However, during normal standing it does not contribute much to modulate motor output at the lower extremity muscles to assist in overall stability (Fitzpatrick, Rogers, & McClosky 1994).

The somatosensory or proprioceptive system accounts for 70% of the input, and depends on receptors in the muscles, tendons and joints for feedback on joint position sense, movement and touch (Sturnieks, 2008). Different sensory organs are responsible for playing a part in proprioception. Muscle spindles found within the muscle belly relay information regarding muscle length and velocity of contraction to allow for correct joint position sense and kinesthesia (Sturnieks, 2008). Golgi tendon organs that are found at the muscle-tendon interface are sensitive to change in tension of the muscle that occurs by active contraction or passive stretch mechanoreceptors in and around the joint space.
will relay information about distortion of the joint capsule or alteration in the ligament (Sturnieks, 2008). Finally, cutaneous and subcutaneous receptors are part of the proprioceptive system that send feedback from the skin about pressure and stretch as a supplement to joint position sense and movement detection (Sturnieks, 2008).

During quiet standing, proprioceptive inputs provide the most sensitive means of perceiving postural sway (Fitzpatrick & McCloskey, 1994; Fitzpatrick, Rogers, & McCloskey, 1994; Sturnieks, 2008). The stretch reflexes in the lower extremity muscles provide input regarding sway activity about the ankles, to allow for appropriate reaction/motor output to maintain upright posture (Fitzpatrick & McCloskey, 1994; Fitzpatrick et al., 1994). Fitzpatrick and colleagues showed that when the feet are anesthetized and one component of proprioceptive feedback (cutaneous) is missing, balance is still adequately maintained in standing (Fitzpatrick et al., 1994). This indicates that the muscle receptors are the primary information source for balance in quiet standing, as stability can be maintained when the stretch receptors from the muscles are the only source of afferent feedback (Fitzpatrick et al., 1994). This afferent feedback is owed to the sway-dependent elongation at the calf muscles that occurs via passive forward sway with the heels on the ground (Lakie, Caplan, & Loram, 2003). This creates a spring like activation to increase muscle force to pull the body back into midline standing (Lakie et al., 2003). The gastrocnemius/soleus complex provide the greatest proprioceptive information during standing. The muscle spindles and Golgi tendon organ receptors within this complex respond to the length changes as sway occurs around the ankle and send afferent information to alter motor response or muscle activation resulting
in corrective balance reactions (Lakie et al., 2003). It has been shown that calf muscles shorten (concentrically) as the body sways forward and lengthen (release) as it sways backward (Lakie et al., 2003).

Proprioceptive information relayed from the ankle plays a central role in activating and ensuring appropriate muscle synergistic reactions for balance control (Allum, Bloem, Carpenter, Hulliger, & Hadders-Algra, 1998). This takes one back to the idea of the “ankle strategy,” as visualized by the inverted pendulum model being at the forefront of balance control in quiet standing (Fitzpatrick et al., 1994; Lephart et al., 1998). The central nervous system’s control and maintenance of balance control relies on feedback from what has been called the “stiffness model,” where the inherent stiffness in the muscles act as springs to allow the COP to move in phase with the COM (D. A. Winter et al., 1998). Sway has been reported to be proportional to effective “stiffness,” where the muscles act as springs around the ankle joint (D. A. Winter et al., 1998). The muscle tone appears to be set in the plantar-flexors to allow for the spring constant to be large enough to overcome the gravitational load, and allow the COP to move more than the COM (D. A. Winter et al., 1998). This is where the 5 centimeter (cm) anterior postural displacement around the ankle joint is maintained, and the COP is set to oscillate around 5 cm causing a continued plantar-flexor moment to occur (D. A. Winter et al., 1998). This stiffness model allows for the feedforward and feedback loop to be maintained, as the plantar-flexors can maintain sufficient tone to generate a stiffness to allow COP to move more than COM (D. A. Winter et al., 1998). It has been reported by Loram et al. (2005) that sway size will increase as spring stiffness decreases, and with
greater intrinsic stiffness (versus the pendulum load, or in the case of balance, gravitational load) the overall system is passively stable (Loram, Maganaris, & Lakie, 2005). With a lower spring stiffness versus pendulum load, the sway increases, and further active movements from the upper extremities are required to restore balance (Lakie et al., 2003; Loram et al., 2005). It can be deducted that the correct amount of intrinsic stiffness within the calf muscles allows for maintenance of the pendulum-like model of balance control in quiet standing.

Quiet standing balance requires internal planning, anticipation and pre-set models for accomplishing overall bodily control (Loram et al., 2005). The act of quiet standing is made possible by constant activation of the gastrocnemius/soleus, with continued length changes in this muscle complex, leading to a loop system of feedback and control (Loram et al., 2005). Ultrasound imaging has revealed that with any unidirectional sway there is on average 2.8 unidirectional adjustments to length in the gastrocnemius/soleus, and without this proactive control mechanism at the calf muscles the body will ultimately fall forward (Loram et al., 2005). This model suggests that the muscles act as springs to allow the COP to move in phase with the COM, revealing the continued importance of the calf muscle activity in quiet standing.

Muscles that cross the ankle joint, gastrocnemius, soleus and tibialis anterior, each play a role in proprioceptive feedback and motor output when standing. The gastrocnemius and soleus play the role of active agonists, while the tibialis anterior is the antagonist (Giulio, Maganarus 2009). Generally, it has been accepted that the calf muscles are continuously modulated and active, while the tibialis anterior is mostly
un-modulated or showing no real change in activity levels (Giulio, Maganarus 2009). The soleus, in fact, has been confirmed as the main agonist to regulate quiet standing with high density of muscle spindles present (Di Giulio et al., 2009; Levy, 1963). Despite it being the main antagonist, the tibialis anterior takes on an agonistic role while the COG is near the ankle, and can play a role in active balance control in standing as well (Di Giulio et al., 2009). The gastrocnemius, while usually taken with soleus as the main agonist, has demonstrated fluctuations in activity levels, and does not always act as an agonist (Di Giulio et al., 2009). This demonstrates the importance of the push/pull relationship these muscles play in quiet standing as a result of the proprioceptive receptors contained (Di Giulio et al., 2009).

**Balance Control in the Elderly**

Within the aging population, frequent falling can become very debilitating, causing secondary injuries and reduction in quality of life (Trombetti et al., 2016). Degeneration of each sensory system, and reduction in balance capabilities can lead to falls, and ultimately death within the elderly. The Center for Disease Control and Prevention (CDC) has reported that falls are the leading cause of injury among adults greater than 65 years of age in the US with the primary injuries reported as head traumas and hip fractures, and in 2012 direct medical costs of falls was just over $30 billion (CDC, 2014). Falls or simply fear of falling among elderly have been reported to be highly associated with reduced quality of life, reduction in muscle mass and reduced physical performance (Trombetti et al., 2016). More specifically, degeneration in the sensory, motor and central processing systems that contribute to stability in the aging
population can lead to balance dysfunction and an increased risk of falls. How to combat this aging, degenerative system can become of lead importance in preventing falls and improving quality of life in older adults.

Lack of postural stability occurs as sway increases, and sway stabilization becomes increasingly difficult with age. Older individuals demonstrate larger areas of sway versus younger individuals (Hageman et al., 1995). Older fallers have been found to have an increase in sway in the A/P direction, along with an increase in gastrocnemius, soleus and tibialis anterior activity versus younger individuals (Laughton et al., 2003). In addition, older non-fallers show an increase in muscle activation levels versus younger which results in greater sway and greater risk of falls.

**Sensorimotor Integration in the Aging Population**

Due to the degenerative nature of the visual, vestibular and somatosensory system with aging, ability to maintain stability can become a difficult task. Vision can become progressively worse as one ages, leading to reduced visual field feedback and information about one’s sway for stability reaction (Sturnieks, 2008). All products of vision that are important to balance reaction, such as contrast sensitivity, acuity and depth perception worsen, leading to inability to judge the environment or correct loss of balance when sway reaches a point outside the limits of stability (Sturnieks, 2008). Despite age-related changes in the visual system, Benjuya et al. (2004) report that visual input was more important for balance control in a younger population than in an older population, with a 36.5% increase in COP with eyes closed compared to eyes open in the younger versus 19% in the older (Benjuya et al., 2004). This is important information to consider, as
vision may not play as much of a roll in balance correction in quiet standing in older adults.

Vestibular deficits are also present in the aging population, and play a role in reduced balance reaction to imposed perturbations (Sturnieks, 2008). As one ages, there is a reduction in neural input from the vestibular system, and general loss of vestibular sensory receptors (Sturnieks, 2008). With degenerative or pathological changes in the vestibular system in the elderly, balance loss may become more apparent during gait and other functional activity, and not as apparent in quiet standing (Sturnieks, 2008). There is no relationship between older people with vestibular dysfunction and falls, and it has been suggested that vision and somatosensory input can compensate for this vestibular loss (Baloh, Enrietto, Jacobson, & Lin, 2001; Sturnieks, 2008).

The peripheral somatosensory system is the most important system in postural maintenance in younger and older individuals (Benjuya et al., 2004). Structural degeneration within the somatosensory system is most associated to age related balance dysfunction in the older population. With aging the responsiveness of the muscle spindle (stretch sensitive receptors) is decreased with a reported increase capsular thickness and reduced intra-fusal fiber presence in the distal muscles, affecting balance strategies around the ankle (Kararizou, Manta, Kalfakis, & Vassilopoulos, 2005; Miwa, Miwa, & Kanda, 1995; Swash & Fox, 1972). Intra-fusal fibers are the fibers that transmit afferent information about dynamic and static muscle states, and with the loss of these fibers there is less muscles stretch reflex capabilities. The Golgi tendon organs could possibly be affected with aging, as several studies have reported a general decline in the GTO
receptors in ligaments (Aydog, Korkusuz, Doral, Tetik, & Demirel, 2006; Morisawa, 1998). However, it is not known how the muscle/GTO complex is altered with increasing age, but may be assumed the same could occur in the muscle as in the ligament structures.

There are several types of somatosensory receptors that are required to provide appropriate proprioceptive feedback, and joint position sense (JPS) testing can be used to determine integrity of the somatosensory system (Shaffer & Harrison, 2007). JPS utilizes joint and muscle receptors to convey feedback of limb angular position and velocity (Madhavan & Shields, 2005). Maldavan and Shields showed that proprioceptive decline resulted in altered joint position sense and reduced balance (measured via a reduction in single leg stance time) (Madhavan & Shields, 2005). In older adults, there was a strong co-contraction in both the plantar flexors and dorsi-flexors during the passive proprioceptive positional testing, suggesting that older adults utilize this co-contraction to increase muscle spindle sensitivity (Madhavan & Shields, 2005).

As previously stated, typical balance reactions in healthy individuals includes high activation levels of the gastrocnemius/soleus in quiet standing (agonist), and little activation of the tibialis anterior (antagonist). In the aging population, co-contractions occur about the ankle to assist in compensatory strategies for standing balance (Benjuya et al., 2004; Shaffer & Harrison, 2007). Electromyogram (EMG) data collected during quiet balance in older adults revealed a significant increase in tibialis anterior (TA) activity during quiet stance versus younger (Benjuya et al., 2004; Kouzaki & Shinohara, 2010), while soleus activity revealed no significant difference in activation levels.
This suggests the importance of the soleus, but also the increased need for tibialis activity to counter the increase in sway in the A/P direction in the older population. When eyes are closed, though, the soleus and tibialis activity rises significantly in older adults when compared to younger (Benjuya et al., 2004). These age-related changes in the postural control system, with resultant in increase in muscle activation, may serve as a strategy to reduce increased sway and represent compensatory adjustments in muscle activity to counter the declining abilities of the proprioceptive system. This decline may also occur at a greater rate in the distal joints versus proximal, whereas hips may be less affected proprioceptively versus knee, ankle and foot (Shaffer & Harrison, 2007). Therefore, it can be said the ankle muscles act as the main component and most important control system in quiet standing in older adults, and with degenerative changes there is even more reliance on the ankle muscles in the aging population.

**Current Intervention Strategies**

Due to the degenerative processes that occurs within the aging proprioceptive system, it is important to consider ways this can be counteracted, improved upon or halted from further deterioration. Many intervention strategies have been developed to combat balance disorder in the elderly (Carter et al., 2001). Exercise has been reported as a useful intervention, and encompasses many modes, such as strengthening, balance training and stretching. Carter et al. reviewed generalized intervention strategies such as Tai Chi, lower limb strengthening, balance exercises, walking endurance training and flexibility training to combat balance dysfunction and falls in the elderly (Carter et al.,
In the meta-analysis of 7 trials there was a reduced fall incidence ratio for balance intervention, resistance training and flexibility training above that seen in endurance training (Carter et al., 2001). However, these studies still do not suggest that one intervention is superior to the other to improve balance.

While multi-modal exercise based intervention models have been shown to improve balance capabilities in the older adult population (Carter et al., 2001), there are variable reports of one being superior to the other. Flexibility training and strength training have been compared in some studies, with one study citing balance improvements in both a strength training only versus a flexibility training only program (Bird et al., 2009), while another study reported that strength training demonstrated greater improvement in balance versus flexibility training (Barrett & Smerdely, 2002). Bird et al. reported that there was a reduction in sway after in both a 16 weeks flexibility program and resistance training program, but there was no difference between the two interventions (Bird et al., 2009). The authors proposed that a decline in strength that occurs with aging may contribute to a reduced neural processing and sensory detection in balance reaction as a support to the strength training intervention to improve balance in older people (Bird et al., 2009). However, it was not clear how flexibility training via static stretching contributes to improvements in balance and neural function (Bird et al., 2009). They did, however, conclude that the improvement after the stretching intervention may be attributed to performing the stretching a single leg stance position which had a balance training component (Bird et al., 2009). On the other hand, a study performed by Barrett and Smerdely reported that a 10-week resistance program
demonstrated greater improvements in balance measures versus a flexibility program (Barrett & Smerdely, 2002). However, the flexibility group was reported to do some “light strength training” as part of their intervention (Barrett & Smerdely, 2002). Considering these results it is still not clear how static stretching alone affects balance and the neural properties of the muscles active for balance in older adults.

**Static Stretching Principles**

Passive static stretching involves lengthening a muscle group to its maximal range, and then holding that position for a time period (Guissard & Duchateau, 2006). When a muscle is stretched for a period of time, the components at the muscle belly, tendon or other surrounding connective tissues are lengthened (Behm & Chaouachi, 2011). Static stretching within a flexibility program for older adults is typically prescribed to improve range of motion. In older adults range of motion has been reported to be diminished, and has been reported to cause for increase functional difficulty with everyday tasks (Bergstrom et al., 1985). Stretches that are usually prescribed about the ankle joint look to target increase in range of motion into dorsiflexion, inversion and eversion. Range of motion about the ankle has been reported as significant predictor of balance capabilities, and the range of motion of all three motions have been reported as significant predictors of balance and functional abilities (Menz et al., 2005; Spink et al., 2011). While range of motion is a significant predictor of balance and function, it is still of question on how interventions like static stretching may affect immediate balance capabilities.
Static stretching, as a main component of a flexibility program, is designed to work on lengthening a muscle and improving joint range of motion (Decoster et al., 2005). Stretches are typically held for 30-60 seconds, and the longer the stretch is held, the greater the immediate joint range of motion gains (Radford et al., 2006). Radford et al. analyzed several articles that assessed the dorsiflexion range of motions effects of stretching the gastrocnemius/soleus complex, and reported an increase of 2.1-3.0 (significant change) degrees with measurements taken from 5 to 60 minutes after completing the static stretch versus no stretching (Radford et al., 2006). The longer the stretch hold, the greater the gains in immediate range of motion (Radford et al., 2006).

The neuro-physiological affects at the level of the muscle when it is put on prolonged stretch can be attributed to autogenic inhibition. The prolonged lengthening that occurs at the muscle will activate receptors within the muscle tissues to cause for a subsequent relaxation (Behm & Chaouachi, 2011). This inhibitory effect of the stretched muscle will reduce its activation ability, but also is in part the process by which range of motion could be improved upon. While range of motion can be improved upon with static stretching, it is important to also consider the stretch induced strength loss that can occur due to the inhibitory properties of a statically stretched muscles. Stretch durations within the literature have ranged from short duration of 15 seconds up to 60 seconds duration, and with any duration there has been reported reduction in isometric strength, force production, velocity and torque production (Behm & Chaouachi, 2011). With a reduction in strength and force production the question can be raised, is stretching a safe
intervention for an elderly falling population, where muscle activity is known to be of utmost importance to balance capabilities in quiet stance?

Reduction in strength after passive stretching has been shown to occur immediately and for some time after a stretch is applied to a muscle of interest. Fowles et al. reported a 28% decrease in plantar-flexor maximal isometric voluntary contraction immediately post static stretch of the gastrocnemius soleus complex, and a 9% reduction in force remained up to 60 minutes-post stretch (Fowles, Sale, & MacDougall, 2000). Furthermore, Behm et al. showed that after 20 minutes of quadriceps stretch there was a reduced MVIC force and reduced EMG activity post-stretch (Behm, Bambury, Cahill, & Power, 2004). These studies however stretched the muscle for a period of 20-30 minutes, which is beyond the normal prescribed stretching intervention, but these findings do show that there is stretch induced strength loss at any stretch duration.

Muscle spindle activity is reduced after a bout of static stretching, leading to a dampening of the afferent-efferent feedback loop, as previously described, required at the ankle in standing balance. Avela et al. reported an altered reflex sensitivity after repeated and prolonged passive muscle stretching at the gastrocnemius/soleus complex after repetitive passive stretches to a relaxed muscle, and reported reduced force output post stretch (Avela et al., 1999). They propose that a reduction in afferent neural propagation and a reduction in reflex sensitivity of the muscle spindles may be mechanical in nature due to modification of the extra-fusal or intra-fusal fibers during stretching (Avela et al., 1999).
Peripheral factors outside the actual muscle also play a role in this strength reduction post static stretching. Studies in animal models have shown that long duration passive stretch can increase intracellular calcium concentration via a “stretch-activated chancel activation” to disrupt calcium homeostasis (Trajano, Seitz, Nosaka, & Blazevich, 2013). This could impair the excitation-contraction coupling mechanism of muscle contraction, and reduce force production (Trajano et al., 2013). Stretch induced force loss in the plantar flexors was reported after five minutes of sustained dorsi-flexion stretching, and central factors were strongly correlated with torque reduction immediately after stretch and during recovery (Trajano et al., 2013).

In a recent review by Behm et al. (2011), there was a reported reduction in overall functional performance after static stretching, and longer duration of static stretching resulted in greater impairment in performance (such as, jumping, sprinting, etc.) (Behm & Chaouachi, 2011). Static stretch times of as low as 30 seconds, which is more clinically relevant, has also shown post- performance reduction (Behm & Chaouachi, 2011; Cornwell, Nelson, & Sidaway, 2002). After stretching the gastrocnemius/soleus complex for 3 sets of 30 seconds there was a reduction in countermovement jump height and EMG activity at the level of the muscle (Cornwell et al., 2002). While these studies report performance reduction post static stretching in activities that require high levels of muscle recruitment and power, it may be related to reduced abilities of the muscle to be activated or recruited with the act of balancing. One study reported a significant decrease in balance scores on the wobble board test in a younger population after stretches held for 45 seconds at the plantar-flexors, quadriceps and hamstrings (Behm et al., 2004). While
this study utilized a younger subject population, it gives rise to questioning how stretching may affect balance in older individuals.

Considering the already known reduction in balance abilities in the older population, as well as the decreased force production after static stretching, it is of interest to examine how static stretching may alter balance and possibly increase the risk of falls in the older population. Because the ankle musculature plays an important role in balance, it is likely that this commonly stretched group may be inhibited after static stretching and may increase the risk of falls in older adults. A recent paper found a significant decline in balance capabilities via an increase in sway in quiet standing, but no reduction in measures of dynamic balance after 5 minutes of static stretching on the gastrocnemius/soleus complex in a population of older individuals (>65 years) (Han, Yuk, Gak, Suh, & Kim, 2014). This suggests that temporary inhibition of the ankle muscles leading to decreased balance in quiet standing after static stretching. While stretching is a commonly utilized intervention for improving range of motion, it is possible that it increases fall risk and balance dysfunction in older adults. Therefore, possible alternative interventions for improving balance need to be examined.

**Dynamic Stretching Principles**

A possible alternative stretching technique is dynamic stretching, and this technique is defined as controlled repetitive movements through an active range of motion in a respective joint (Behm & Chaouachi, 2011). This stretch technique has been reported to increase muscle activity via increased post-activation nerve potentiation, which occurs via increasing the rate of muscle cross bridge cycling as one quickly moves
through the joint range of motion (Behm & Chaouachi, 2011). In a review by Behm et al. (2011), dynamic stretching was shown to improve power, sprint, and jump performance (Behm & Chaouachi, 2011). These performance improvements may be attributed to activation of the muscle spindle, and the storage of elastic energy (Behm & Chaouachi, 2011).

Since range of motion is the primary goal of a flexibility program, it is important to see if dynamic stretching may be able to achieve similar range of motion results as static stretching. Covert et al. (2010) showed that static stretching increased hamstring muscle length greater than dynamic stretching, but dynamic stretching did increase range of motion more than a no-stretching group (Covert et al., 2010). In contrast, Mahieu et al. reported a significant increase in range of motion after both dynamic (continuous, 1 second holds) and static stretching (20 second static holds) on the gastrocnemius/soleus complex (Mahieu et al., 2007). These findings present conflicting results of one method of stretching over the other on range of motions gains, but it can be said that both do increase range of motion is some capacity.

Although static stretching may have negative effects on muscle activation and balance, it is commonly prescribed within an elderly balance rehabilitation program. Dynamic stretching does not decrease maximal strength or muscular activation when compared to static stretching (Bacurau et al., 2009), so dynamic stretching may be a better option. However, no known studies to date have examined the effects of dynamic stretching in the older adult population in terms of muscle activation as related to balance and function. Furthermore, the optimal duration of a stretch to optimize balance
improvements is not known in an older population. Costa et al. reported a greater
reduction in sway index or improved balance control after 15 seconds of stretching when
compared with a 45 second stretch in a young population (Costa et al., 2009). These
results of short duration stretching allowing for balance improvements in young adults,
along with the reports of dynamic stretching increasing muscle function, could lead to
questioning the utilization of dynamic stretching to improve balance in the older
population. Dynamic stretching may be a better option when prescribing a stretching
program to the older adult population at risk for falling, and may even enhance balance
capabilities while still improving range of motion.
CHAPTER III

METHODOLOGY

Subject Population

The study design was a within-subject two condition design comparing two stretching protocols: static versus dynamic.

Inclusion Criteria

Inclusion criteria was community dwelling healthy older adults ages 60-75 years that could ambulate independently (Bullock-Saxton, Wong, & Hogan, 2001). Healthy older adults were defined as having no outstanding health issues, and leading a normal active lifestyle within the normal aging process. Older individuals who exercise regularly or competitive athletes also qualified.

Exclusion Criteria

Individuals were excluded if they had any disease processes or signs and symptoms that affected balance abilities. Specifically, exclusion criteria included history of a neurological diagnosis, general lower extremity numbness or tingling affecting the cutaneous receptors of the lower extremity, any disease that can affect the cutaneous and subcutaneous receptors in the lower extremities, such as, diabetes (diagnosis of 10 years or greater) and peripheral arterial disease (PAD). In addition, those with a recent major surgery or hospitalization that that rendered the individual unable to participate in usual daily activity in the last month and anyone that requires use of assistive device (AD) for ambulation were excluded (Appendix A) (Bullock-Saxton et al., 2001; West, Bhat, Stevens, & Bergen, 2015). These exclusion criteria were chosen based on the role that
they play in balance, more specifically the proprioceptive system. The proprioceptive system plays a very large role in balance capabilities, and diseases or surgical history that can affect this system outside of the normal aging process. Also, any subject with history of dementia was excluded, as this may play a role in safety and ability to follow instructions.

Individuals with any neurological diseases or diagnoses (Table 1) that can affect balance or mobility status were excluded, as they could not be generalized as part of the healthy older adult population. Diseases that affect the neurological system could have a profound effect on balance. Those with Cerebral Vascular Accident (CVA)/Stroke along with any other neurological diagnosis (Table 1) could have reduced sensation as previously discussed, as well as, reduce muscle function, control and coordination, all important factors to baseline balance function. Common diagnoses were screened as listed in table 1 and were listed on the intake form (Appendix A).

Individuals with a history of Diabetes of 10 years or greater diagnosis were excluded. Cutaneous and subcutaneous receptors in the periphery play a large role in proprioceptive feedback and balance reaction (Sturnieks, 2008), so any subject with reported general lower extremity numbness and tingling was eliminated. Diabetes, which can lead to loss of peripheral sensation in the lower extremity, was screened and eliminated. It has been reported that those with diabetes mellitus have peripheral nerve damage in up to 25% of people after 10 years of being diagnosed (Pirart, 1977). After 20 years or more the incidence of nerve damage can increase up to 50% (Pirart, 1977).
Table 1

List of Excluded Neurological Diagnoses

- CVA/Stroke
- Cerebral Palsy
- Dementia
- Traumatic Brain Injury
- Huntington’s Disease
- Amyotrophic Lateral Sclerosis (ALS)
- Lower Extremity Complex Regional Pain Syndrome (CPRPS)
- Foot Drop
- Guillain-Barre Syndrome
- Parkinson’s Disease
- Multiple Sclerosis (MS)
- Muscular Dystrophy
- Myasthenia Gravis
- Myopathy
- Post-Polio Syndrome
- Spina Bifida
- Spinal Cord Injury
- Spinal Muscular Atrophy (SMA)

(NIH, 2005)

Additional diseases that could impair lower extremity sensory function include peripheral arterial disease (PAD). Lower extremity PAD is an atherosclerotic syndrome that causes obstruction of blood supply and flow to and through the lower extremity, therefore impeding nerve conductivity (Schainfeld, 2001). Common symptoms include pain, numbness, weakness or muscle fatigue in the legs (Schainfeld, 2001). It has been reported that those diagnosed with PAD, may be asymptomatic, but have poor standing balance and walking speed (McDermott, Fried, Simonsick, Ling, & Guralnik, 2000).

Individuals with a recent major surgery or hospitalization that makes them unable to participate in usual daily activity in the last month were excluded, as this could cause impairment that affects the individual’s baseline balance and functional levels. Older
individuals who are hospitalized or require any period of rest from normal activity have been reported to experience decline and disability (Gill, Allore, & Guo, 2004). Furthermore, surgery or hospitalization will require periods of immobility, possibly leading to overall functional decline.

Any individual using an assistive device (AD) was excluded. Those who required use of AD are more likely to report a recent fall versus non-users (West et al., 2015). In addition, use of AD use has been associated with limited ability to walk outside due to fear of falling and inability to ambulate more than 10 minutes without need for rest (West et al., 2015).

**Sample Size Analysis**

A power analysis was completed utilizing data results from a previous, similar study by Costa et al. (2009), looking at the acute effects of different durations of stretching on dynamic balance on the Biodex Balance System (BBS). The protocol included a 15 second stretch time versus a 45 second stretch time, and then reported the immediate sway score on the BBS. The authors reported that the longer stretch protocol reduced the overall stability index score, although this change was not statistically significant (Costa et al., 2009). However, the shorter 15 second stretch time significantly improved balance scores (Costa et al., 2009). They reported overall stability index scores with standard error of the mean (SEM) pre to post stretch (Costa et al., 2009). The reporting of SEM required a calculation to be run to obtain standard deviation. The change scores from pre-to post stretch stability index, with the respective standard deviation (Std) was calculated utilizing the equation: 
\[ \text{Std} = \text{SEM} \times (\text{sqrt (n)}) \]

Table 2 depicts the method of transformation of SEM to Std for power analysis. Table 3 demonstrates how the change score was obtained from the 15 second and 45 second stretch group pre-to post stretch for stability index with the newly calculated standard deviation, which were the final numbers used for the power analysis.

Table 2

\textit{Method of Conversion SEM to Standard Deviation}

<table>
<thead>
<tr>
<th></th>
<th>Pre-SEM</th>
<th>Pre-Std</th>
<th>Pre-SEM</th>
<th>Pre-Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 seconds stretch</td>
<td>0.35</td>
<td>0.35 * 5.3 = 1.86</td>
<td>0.28</td>
<td>0.28 * 5.3 = 1.86</td>
</tr>
<tr>
<td>45 second stretch</td>
<td>0.28</td>
<td>0.28 * 5.3 = 1.48</td>
<td>0.48</td>
<td>0.48 * 5.3 = 2.54</td>
</tr>
</tbody>
</table>

**sqrt (n) = sqrt (28) = 5.3**

Table 3

\textit{Calculated Change Score for Stability Index on the BBS Pre- to Post Stretching for 15 Seconds Versus 45 Seconds}

<table>
<thead>
<tr>
<th></th>
<th>15 seconds stretch (stability index)</th>
<th>45 seconds stretch (stability index)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-score (mean +/- std)</td>
<td>3.73 +/- 1.86</td>
<td>3.40 +/- 1.48</td>
</tr>
<tr>
<td>Post-score (mean +/- std)</td>
<td>3.06 +/- 1.48</td>
<td>3.71 +/- 2.54</td>
</tr>
<tr>
<td>Change score</td>
<td>0.67 +/- 0.38</td>
<td>-0.31 +/- 1.06</td>
</tr>
</tbody>
</table>

(Costa et al., 2009)

Sample size was determined using the G*Power calculator (Faul, Erdfelder, Lang, & Buchner, 2007) based on the previously reported data with parameters set at a 2-tailed
test, effect size at 1.0, power at 0.80 and alpha error probability at 0.05. A sample size of 10 was recommended based on this data. In the current study, we planned for a sample size of at least 12 for significant results.

**Recruitment, Screening and Self-Reported Measures**

Subjects were recruited via flyers (Appendix B) and word of mouth. Pre-screening and assessment for inclusion/exclusion was completed over the phone or in person (Appendix A). Once the subject was cleared for inclusion, they were scheduled to come into the lab and asked to read and sign the study consent form that was approved by the KSU IRB (IRB #16-688) (Appendix D).

After complete understandings and signing of the consent, individuals completed a demographic questionnaire (Appendix E) and the SF-36v2 (Appendix C) via computer based assessment. Each SF-36v2 was saved and scored on one computer, where the tool’s scoring system was downloaded and saved. This computer was secured and the data was de-identified.

**SF-36v2**

Health related quality of life has been known to be linked to many factors, such as disability risk, fall history/risk, levels of physical activity, strength and gait speed in older individuals (Sartor-Glittenberg et al., 2014). The Short Form Health Survey 36 (SF-36) was utilized in the current study to allow for a better assessment of the health-related quality of life of each subject. The SF-36 is a well-validated self-reported measure that allows for overall quantification of one’s health status and can be used to measure health related quality of life. The survey was utilized to identify a composite score of each
subject’s physical and mental health, which helped to identify any differences in the subject population.

The 36 item measure is divided into 8 subscale with 2 composite summary measures (Ware & Sherbourne, 1992). The 8-scale profile includes: physical functioning, role limitations due to physical problems, general health perceptions, vitality, social functioning, role limitations due to emotional problems, general mental health and bodily pain (Appendix C) (Ware & Sherbourne, 1992). Subjects answer the 36 questions in regards to the last 4 weeks of life, and the scoring system is based on a weighted Likert scale (Appendix C) (Ware & Sherbourne, 1992). Each item in the subscale is totaled to provided individualized and a summed score within each dimension. All but one of the items are used to score the eight scales, that being question 2, which is a single measure of health transition (Ware et al., 1995). Each subscale is linearly transformed onto a scale 0-100 to give a score for each subscale to allow each subscale to be reported independently (Ware et al., 1995). The scores obtained on the 100 scale will also be transformed into z-scores based on normative data, and those numbers will be used for final analysis. Version 2.0 of the SF-36, which was created to correct some deficiencies in the original version, will be utilized, and scored on a computer (Turner-Bowker, Saris-Baglama, & Derosa, 2013).

The reliability of the 8 scales and 2 summary measures has been well established, and has been evaluated using internal consistency and test-retest measures. Reliability studies ranged from 0.70 to 0.80, even exceeding these reliability measures for the 8 scales (McHorney, Ware, Lu, & Sherbourne, 1994; Ware & Sherbourne, 1992).
Reliability of the two summary measures of physical and mental health also have been reported as exceeding 0.90 (Gandek, Sinclair, Kosinski, & Ware, 2004).

Protocol

Subjects came in on 2 testing days. Each time the subject completed baseline testing including maximal isometric voluntary contraction (MVIC) with EMGs, fall risk on the Biodex Balance System (BBS), modified clinical test of sensory organization and balance (m-CTSIB) with surface electromyographic (EMG) recordings on the BBS and passive range of motion measurements (ROM). Subjects were alternatively assigned via a counterbalancing randomization technique to start with static stretching or dynamic stretching intervention, then immediately after each respective intervention post-testing occurred (Figure 1). A minimum of 24 hours wash out was required between testing days, then the subject came back to complete the protocol again, performing the second intervention.

Intervention

Once baseline testing was completed the subject started with static or dynamic stretching. The starting condition will be randomized via a counterbalancing technique, meaning when subject one started with static, then subject two started with dynamic and so on. This allowed for controlling the starting intervention, to ensure subjects performed each intervention in a different order while allowing for equal number of participants in each group.
Prior to engaging in the stretching protocol, each subject performed a two minute warm up on the cycle ergometer before engaging in their respective first intervention with use of RPE (Appendix F) to allow for consistency in warm up intensity (maintained RPE of 12) (Covert et al., 2010). Immediately after each stretching protocol was completed outcomes were recorded including: fall risk on the BBS, m-CTSIB with EMG recordings on the BBS and passive range of motion (ROM) with the goniometer.

Between each stretching protocol the subjects required a minimum of 24 hour wash out, then returned on another planned testing day where they engaged in baseline, intervention and post testing again.

The static stretches for this study were based on previous work, and each stretch selected was considered appropriate for the older adults (Behm et al., 2004;
Chatzopoulos, Galazoulas, Patikas, & Kotzamanidis, 2014; Jaggers, Swank, Frost, & Lee, 2008). The static stretch protocol included passive stretching of the ankle plantar-flexors (gastrocnemius and soleus) (Table 4). Each stretch was held 45 seconds with a 10 second break and repeated three times (Behm et al., 2004; Costa et al., 2009). The stretching was passively performed by the subject, and they were instructed to push the limb into its limits of ROM where they feel resistance or slight discomfort (Behm et al., 2004). Both lower limbs were stretched starting with gastrocnemius, then the soleus next.

The dynamic stretch protocol included two stretches, adapted/modified from Jagger 2008 study, that will target the soleus and gastrocnemius (Table 4) (Jaggers et al., 2008). The stretches were performed a total of 15 times, with the first five performed at a slow rate and speed increased throughout the next 10 up to maximum velocity (will be instructed to not “bounce” at end range, but rather smoother movements). Each subject performed the stretches in a reciprocating fashion, totaling 30 repetitions and were given a max time of 45 seconds to complete the task. Stretches were performed alternating right first, left next until the protocol intervention was completed.

Each static and dynamic stretch was verbally and visually instructed prior to starting the stretching routine, and feedback was be given by a licensed Physical Therapist to ensure proper performance. Verbal instructions were written out and verbalized by the researcher Physical Therapist to allow for control over how the stretches were instructed to reduce variation (Appendix G). Visual instruction was completed via demonstration by the researcher Physical Therapist, along with a picture (Appendix H). The subject was instructed to not perform the stretches from the initial
Table 4

Static and Ballistic Stretching Positions

<table>
<thead>
<tr>
<th>Target muscle</th>
<th>Static Stretch (3 sets, 45 second holds), performed bilaterally</th>
<th>Dynamic Stretch (15 reps, 5 slow, 10 quick), performed bilaterally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrocnemius</td>
<td>Subjects faced the wall in standing were instructed to place hands on the wall at chest level with one foot placed slightly behind with the knee fully extended while keeping the heel on the floor, they leaned forward while bending the forward knee and keeping back leg straight with the heel on floor. (Behm et al., 2004; Chatzopoulos et al., 2014)</td>
<td>Calf Raise: Subjects stood on a step with feet side by side. The subject then pushed one heel toward the ground while bending the contralateral leg, and keeping the ipsilateral knee extended, then repeated this to the other side. This stretch was performed bilaterally in a reciprocating fashion (Jaggers et al., 2008)</td>
</tr>
<tr>
<td>Soleus</td>
<td>Subjects faced the wall in standing and were instructed to place hands on the wall at chest level with one foot placed slightly behind with the knee slightly bent while keeping the heel on the floor, they leaned forward while bending the forward knee and keeping back leg slightly bent with heel on floor (Behm et al., 2004; Chatzopoulos et al., 2014)</td>
<td>Calf Raise: Subjects stood on a step with feet side by side. The subject then pushed one heel toward the ground while bending the contralateral leg, and keeping the ipsilateral knee bent as well, then repeated to the other side. This stretch was performed bilaterally in a reciprocating fashion (Jaggers et al., 2008)</td>
</tr>
</tbody>
</table>

(intervention group in between sessions, resume normal daily activity and await completion of the full study and data collection prior to performing any of the learned stretches.

**Biodex Balance System (Balance)**

The BBS allowed for assessment of neuromuscular control and balance via a closed chain, multi-plane testing structure. The system specifications included a moveable platform that is 55 centimeters in diameter where subjects stood in double stance without shoes. Static testing measured the angular excursion of the subject’s center
of gravity (COG). The testing formats that were utilized in the current study were the fall risk and Modified Clinical Test of Sensory Interaction and Balance (m-CTSIB) tests. (Biodex, 2010)

The BBS works via a series of “strain gauges” that determines the variation in the subject’s center of pressure (COP), and COP is a product of the subject’s COG projection with a resultant sway angle as related to the height of the subject. Data was collected at a rate of 20Hz, and each of the recorded samples over this time consisted of an (X,Y) coordinate. The display was the actual sway angle across these coordinates, and was derived from the COG from the zero point and the height of the subject’s COG taken as 0.55 times the subject’s height. Over the duration of the test the standard deviation of the subject’s position was defined as the absolute vector length deviation from the mean vector end-point. All of the vectors were a product of the (X,Y) coordinates, and were averaged to allow for a position “mean” to be determined. (Biodex, 2010)

The fall risk testing on the BBS identified individuals who may be at risk for falls with daily functional mobility. Testing results were compared to pre-determined age dependent normative data. Subjects performed double leg stance on the round platform without upper extremity support, and the overall stability index score along with a standard deviation score based on subject performance was recorded. The higher the score from the normative data the greater risk for falling. Normative data has previously been reported in a group of men and women between the ages of 54-7 (N = 50) as an average stability index (SI) score of 2.3 with an average standard deviation of 1.4 (Biodex, 2010; Finn, 1999).
The clinical test of sensory integration and balance (CTSIB) is a standard balance assessment tool that is performed on a static surface (A. Shumway-Cook & Horak, 1986; A; Shumway-Cook & Woollacott, 2001). The BBS was utilized to perform the CTSIB balance assessment as a means to assess how well one can integrate the three sensory systems (vestibular, vision, somatosensory) that play the essential role in balance function, and how each system works alone or in conjunction with the others (Biodex, 2010; A. Shumway-Cook & Horak, 1986; A; Shumway-Cook & Woollacott, 2001). The CTSIB test has a total of 6 conditions, but the current study utilized the modified CTSIB (m-CTSIB), which has 4 conditions. The 4 conditions, will give adequate of evaluation and outcome information about each balance system, as each is defined by how it uses the visual, vestibular and somatosensory systems for balance (Table 5; Biodex, 2010; A. Shumway-Cook & Horak, 1986; A; Shumway-Cook & Woollacott, 2001).

Table 5

*Description of Each Condition Within the BBS CTSIB, Defining Which Balance System is Being Tested/Utilized Under Each Condition*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Test Set Up</th>
<th>Sensory System Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eyes Open, Firm Surface (EOFS)</td>
<td>Visual, Vestibular and Somatosensory</td>
</tr>
<tr>
<td>2</td>
<td>Eyes Closed, Firm Surface (ECFS)</td>
<td>Eliminates visual, evaluates vestibular and somatosensory input</td>
</tr>
<tr>
<td>3</td>
<td>Eyes Open, Dynamic or Soft Surface (EOSS)</td>
<td>Evaluation of somatosensory interaction with visual input</td>
</tr>
<tr>
<td>4</td>
<td>Eyes Closed, Dynamic or Soft Surface (ECSS)</td>
<td>Evaluation of somatosensory interaction with vestibular input.</td>
</tr>
</tbody>
</table>

Biodex, 2010; A. Shumway-Cook & Horak, 1986; A; Shumway-Cook & Woollacott, 2001)
Sway index (SwI) and stability index (SI) were measured during the m-CTSIB test. While SI has already been introduced in the fall risk scoring structure, and is the average position of deviation from the center, the SwI is the standard deviation of the SI. The SwI was main outcome measure that was analyzed from this assessment. The higher the SwI, the more unsteady the subject performed on the test. If the condition was unable to be completed by the subject it was noted as a “fall” without a score associated. (Biodex, 2010) The SwI score was the quantitative description of how well the subject could maintain a stable vertical posture while positioned on the stationary platform. The sway information was collected via the static force plate, and it recorded the amount of movement under each of the four conditions.

CTSIB normative SwI ranges and overall reliability of testing has been determined via data collected by the Biodex Medical System Inc. on 100 healthy, active working adults with ages ranging from 17 to 72 years (Biodex, 2010) The subjects in this study performed the CTSIB testing with well valid and reliable measures of balance and function, the timed up and go (TUG) and gait speed analysis (GS). The TUG and GS where utilized to strengthen the CTSIB reliability measures via correlating these tests with the CTSIB results. The resultant interclass correlation coefficient was reported as 0.81 (acceptable), and CTSIB normative ranges for conditions 1, 2, 3 and 4 are reported in the table below (Table 6). Knowing normative data ranges, and having this available will allow for comparative analysis subject outcomes within the current study. However, with such large age ranges the comparison will be modest and not hold much reliability
within the current study due to age ranges of the included subject population (Biodex, 2010).

Table 6

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sway Index score ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOFS</td>
<td>0.21-0.48</td>
</tr>
<tr>
<td>ECFS</td>
<td>0.48-0.99</td>
</tr>
<tr>
<td>EOSS</td>
<td>0.38-0.71</td>
</tr>
<tr>
<td>ECSS</td>
<td>0.84-1.47</td>
</tr>
</tbody>
</table>

(Biodex, 2010)

Where the subject stood on the platform was written down, as the BBS surface contained markers to allow for replicating the standing position. The subject were placed and instructed “to try to maintain a stable vertical posture.” Testing time for the fall risk test, as well as the m-CTSIB, was set at 15 seconds, and the subjects performed one recorded trial of each test with 10 seconds of rest between trials. To ensure safety each subject had a harness placed and loosely connected to overhanding bar to prevent falling if were to occur. Surface EMG recorded medial gastrocnemius, medial soleus and tibialis anterior muscle firing frequency throughout the m-CTSIB testing.

EMG (Muscle Function)

Surface electromyographic measurements (EMG) were used to assess muscle function during the balance testing. Surface EMG method allows for access to the physiological process that causes a muscle of interest to generate force and produce
movement (Kollmitzer, Ebenbichler, & Kopf, 1999). EMG signals were analyzed by amplitude and frequency variables, and the surface electrodes were placed at the muscle belly between a motor point (innervation zone) and the tendon insertion along the midline of the muscle (Florimond, 2008). The electrodes picked up electrical signals via the number of muscle action potentials that occurred underneath the electrode surface (Reaz, Hussain, & Mohd-Yasin, 2006). The action potentials occurred at random intervals based on activation/relaxation waves, yielding positive or negative voltage. For this study the two pads were positioned parallel to the muscle fibers of interest with inter-electrode distance of two centimeters center to center, and were placed on the medial gastrocnemius, medial soleus and tibialis anterior on the individual’s right leg, along with a reference electrode located at the medial malleolus (De Luca, 2002; Peter & Durding, 1979). To correctly choose the electrode sites, the subjects performed a resisted isometric contraction to produce maximum activity of the muscle for the greatest area of muscle bulk to be assessed and chosen for pad placement (Gilmore & Meyers, 1983). The skin was prepped with alcohol pads to allow them to adequately adhere to the skin surface.

Once the EMG pads were in place over each muscle belly of interest the subjects performed maximal isometric voluntary contraction (MVIC) against resistance provided by the tester (~5 seconds) while the EMGs recorded the muscle activity. This allowed for normalizing the EMG activity during balance testing. Each testing position was based on traditional MVIC testing positions for obtaining maximal contractions for the muscle of
interest (Table 7), and was held against a non-moveable surface and reaching maximal force over 3-5 seconds (Hsu, Krishnamoorthy, & Scholz, 2006).

Table 7

*MVIC Testing Positions*

<table>
<thead>
<tr>
<th>Muscle</th>
<th>MVIC testing position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibialis Anterior</td>
<td>Supine with hips, knees and ankle in neutral</td>
</tr>
<tr>
<td>Soleus</td>
<td>Quadruped position with hips and knees in 90 degrees of flexion and the ankle in neutral</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Prone with hips, knees and ankles in neutral</td>
</tr>
</tbody>
</table>

(Hsu et al., 2006)

While subjects completed the four balance conditions the surface electrodes recorded muscle firing frequency at the medial soleus, medial gastrocnemius and tibialis anterior. The raw EMG signal for each muscle during each balance task was smoothed and converted to a positive signal (Florimond, 2008). Average amplitude for the 3-5 second MVIC and 15 second balance task was obtained, and each test was normalized with respect to MVIC at each muscle for final comparative analysis.

*Universal Goniometer (Range of Motion)*

Range of motion was measured via use of the universal goniometric measurements at each joint of interest. The most widely accepted method of recording range of motion is the 0-180-degree system. The system is based on anatomical position, where the neutral or extended position of each joint is denoted as 0 degrees and as the joint flexes the axis will progress toward 180 degrees (Reese & Bandy, 2002). The
goniometer consisted of a full circle protractor with a stationary arm, a moving arm and an axis (Figure 2). The measurement obtained was in degrees of movement. The stationary arm was in line with the non-moveable limb or point specified on the body, while the moving arm moved in line with the location on the limb that was being mobilized.

![Universal Goniometer with description of parts.](Image taken by Liz Narducci)

*Figure 2.* Universal Goniometer with description of parts. (Image taken by Liz Narducci)

The goniometric procedure for measuring muscle length is called the “direct measurement” method. In the current study the gastrocnemius and soleus being stretched statically and dynamically were measured subsequently via the goniometer. The muscles will be measured in certain positions to maximize or target the correct muscle length, while controlling for compensatory patterns as well as other muscles that are involved or cross the same joint.
After the m-CTSIB with EMG is completed active ROM measures will be taken to determine muscle length. ROM measurements will be measured at each joint of interest by a Physical Therapist researcher. The gastrocnemius crosses at the knee and the posterior ankle, and acts slightly in knee flexion, but acts mostly to plantar flex the ankle. This was measured in long sitting with the knee fully extended and hip in neutral. The soleus crosses only at the posterior ankle joint, and acts to plantar flex the ankle as well. This was measured in long sitting with a bolster under the knee to allow for approximately 45 degrees of knee flexion. The knee flexion ensured elimination of the gastrocnemius muscle for pure measurement of the soleus muscle length when measuring dorsiflexion. All testing positions were set with clearly defined procedures for each goniometric measure (Table 8).
Table 8

Range of Motion Measurement Protocol With Reported Reliability

<table>
<thead>
<tr>
<th>Joint Motion</th>
<th>Reliability</th>
<th>Muscle Length Tested</th>
<th>Goniometric procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsiflexion</td>
<td>Intra-tester reliability = 0.97 (Elveru, Rothstein, &amp; Lamb, 1988)</td>
<td>Gastrocnemius</td>
<td>Seated dorsiflexion with fully extended (Reese &amp; Bandy, 2002)</td>
</tr>
<tr>
<td></td>
<td>Intertester reliability = 0.50 (Elveru et al., 1988)</td>
<td></td>
<td>• Goniometer Landmarks - Axis at lateral malleolus, proximal arm: Fibular head, distal arm: parallel to 5th metatarsal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Patient Position - Supine with hip in neutral and knees fully extended</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Examiner Action - While maintaining knee extended knee flexion, dorsiflex the ankle through full ROM</td>
</tr>
<tr>
<td>Dorsiflexion</td>
<td>Intra-tester reliability = 0.97 (Elveru et al., 1988)</td>
<td>Soleus</td>
<td>Seated dorsiflexion with knee bent (Reese &amp; Bandy, 2002)</td>
</tr>
<tr>
<td></td>
<td>Intertester reliability = 0.50 (Elveru et al., 1988)</td>
<td></td>
<td>• Goniometer Landmarks - Axis at lateral malleolus, proximal arm: Fibular head, distal arm: parallel to 5th metatarsal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Patient Position - Supine with hip and knee flexed 45 degrees. Opposite leg has knee fully extended</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Examiner Action - While maintaining hip and knee flexion, dorsiflex the ankle through full ROM</td>
</tr>
</tbody>
</table>

Data Storage and Analysis

All demographic information, SF-36v2 score, outcome measure scores/results were written onto a data sheet with the subject ID number (Appendix I), then this information was transferred onto an excel document as de-identified data. Data was downloaded from Excel and analyzed using SPSS software.

2x2 ANOVA With Repeated Measures

A 2x2 ANOVA with repeated measures was run for conditions (Static and Dynamic) by time (Pre-Post scores). Pre-post scores included: SwI (EOFS, ECFS,
EOSS, ECSS), fall risk score (SI), EMG activity (tibialis anterior, medial soleus and medial gastrocnemius within each condition 1-4) and ROM measurements (dorsiflexion knee extended and knee bent). If significant interaction is discovered, post analysis included paired sample t-tests to find where any of these differences lied. Post analysis was also run if significance for time only was discovered, any trending interactions or near significance was found. Significance is defined as a value of p ≤0.05.

**Correlation Analysis**

A secondary analysis was run including a correlation analysis SF-36v2 scores for both composite scores (Mental and Physical) and all 8 domains versus baseline variables including: SwI (EOFS, ECFS, EOSS and ECSS), SI (fall risk), EMG (anterior tibialis, medial gastrocnemius and medial soleus for each condition 1-4) and range of motion (ankle dorsiflexion with knee bent and knee extended). A Pearson-product correlation coefficient > 0.50 with an associated significance of p ≤0.05 along was considered significantly correlated.
CHAPTER IV
THE EFFECTS OF DYNAMIC AND STATIC STRECHING ON BALANCE, MUSCLE FUNCTION AND RANGE OF MOTION IN OLDER ADULTS

Falling, as a result of balance dysfunction, is a very common occurrence in the aging population (Robitaille et al., 2005). In the aging adult, fall related injuries are projected to reach $54.9 billion in healthcare costs by the year 2020 (Englander, Hodson, & Terregrossa, 1997). Fall related injuries account for increased risk of prolonged disability, nursing home admissions and possibly even death (Patel et al., 2014). With aging, the ability to balance declines leading to this increased risk for falls (Sturnieks, 2008). When balance dysfunction occurs in the elderly, there is a reduced ability to maintain postural control with a gradual loss of the ability to maintain the center of mass (COM) over the base of support (BOS), and a resultant increase in levels of bodily sway (D. A. Winter et al., 1998). This reduction is a product of the diminishing properties of the neurological systems that control balance, those being the visual, vestibular and proprioceptive systems. Each system has unique receptor properties that allow for appropriate body orientation and muscle activation to counteract increased sway and provide maintenance of midline balance control in quiet standing (Sturnieks, 2008).

While each of the three systems plays an important role in postural control, the proprioceptive system contributes 70% of the overall input (Peterka & Benolken, 1995). The proprioceptive system contains receptors in the muscles, tendons and joints that give appropriate feedback on joint position and overall body orientation (Sturnieks, 2008). Sensory organs most responsible for proprioceptive input are the muscle spindles within
the muscle belly, and Golgi tendon organs found at the muscle-tendon junction (Sturnieks, 2008). Muscle spindles relay information about muscles length and velocity of contraction that allow for correction of point position and overall kinesthetic sense (Sturnieks, 2008). Golgi tendon organs are sensitive to change in tension of the muscle, and are activated via mechanoreceptors in and around the joint space. They relay information about distortion of the joint capsule or alteration in the ligamentous structures (Sturnieks, 2008).

During quiet standing the proprioceptive receptors provide the most sensitive means of perceiving postural sway (Fitzpatrick & Mclosky 1994). While cutaneous input from the skin does play a role, the muscle receptors provide the primary sensory feedback (Fitzpatrick & McCloskey, 1994). In quiet standing, where the feet are placed side by side, the body will move in an anterior-posterior (AP) direction, and to counter this movement the ankle musculature will activate and correct to midline, better defined as the ankle strategy of balance (Winter, DA 1994). There is a sway-dependent elongation of the calf muscles (gastrocnemius and soleus) as passive forward sway occurs with the heels on the ground, and this creates spring like activation of these muscles to pull the body back to midline standing (Lakie et al., 2003). The gastrocnemius/soleus complex provides the greatest proprioceptive input in quiet standing, and provides a certain amount of spring stiffness to allow for control (Lakie et al., 2003; Loram et al., 2005). While these two muscles about the ankle are constantly activated, the third muscle surrounding the ankle, the tibialis anterior, acts as the primary agonist (Di Giulio et al., 2009). These three muscles act together to regulate balance in quiet standing, with the
soleus as the most active agonist, and the tibialis anterior showing little to no activity (Di Giulio et al., 2009; Levy, 1963).

The proprioceptive system’s role in muscle activation and balance control can rapidly decline in older adults, leading to reduced quality of life and frequent falls. The responsiveness of the muscle spindles diminishes, and there is an increased capsular thickness with reduced intra-fusal fiber density in the ankle muscles (Kararizou et al., 2005; Miwa et al., 1995). There is also a significant reduction in the amount of GTO receptors in the aging muscle, which affects ligament and stretch receptor activity (Aydog et al., 2006; Morisawa, 1998). In the elderly, there is a significant increase in overall co-contraction of the tibialis anterior and the soleus (Benjuya et al., 2004; Shaffer & Harrison, 2007). This muscle activity rises even further when visual input is not available, suggesting the increased reliance on ankle muscle activity in the older population (Benjuya et al., 2004).

Therefore, it is important to develop intervention strategies that could lead to improvement in balance and reduction in falls. With the high reliance of ankle muscle activity in aging population in balance control, interventions geared toward these distal muscles seem most appropriate. Previous studies have mostly focused on balance exercises, tai chi, endurance training, strengthening and flexibility (Carter et al., 2001). When comparing strength training and flexibility training, studies report improvement in balance with both strength and flexibility training (Barrett & Smerdely, 2002; Bird et al., 2009). These studies incorporated a more generalized strengthening and stretching protocol and did not focus on one muscle group alone (Barrett & Smerdely, 2002; Bird et
al., 2009). Although it has been shown that increased strength can improve balance via improved neural function, there is little consensus on how the flexibility training may contribute to improved balance control. In addition, with interventions for balance control in the elderly population being generally multi-modal (Carter et al., 2001), it is difficult to determine the superiority of one type and how stretching alone may affect balance control in older adults.

Stretching allows for components of the muscle belly, tendon and other surrounding connective tissue to be lengthened (Behm & Chaouachi, 2011). This length allows for an improved range of motion (ROM) and can be achieved by either static or dynamic stretching methods. Static stretching, or passive stretching, includes taking a muscle group to its maximal range and holding for a period of time (Guissard & Duchateau, 2006), which allows for an increase in range of motion about the joint of interest (Decoster et al., 2005). In older adults, ROM about the ankles is diminished due to muscle stiffness in the gastrocnemius/soleus complex, leading to a reduction in dorsiflexion ROM (Bergstrom et al., 1985). ROM in dorsiflexion has been reported as a significant predictor of balance capabilities (Menz et al., 2005; Spink et al., 2011). Static stretches to increase ROM are typically held between 30-60 seconds, and allow for immediate ROM gains with an increase in 2.1 to 3.0 degrees 5-60 minutes after stretching (Radford et al., 2006). This increased ROM after prolonged stretch can be attributed to autogenic inhibition of the muscle or subsequent relaxation of the muscle being stretched (Behm & Chaouachi, 2011). With this relaxation, there is a subsequent reduction in isometric strength, force and torque production (Behm & Chaouachi, 2011; Fowles et al.,
2000). With the high reliance on ankle muscle activation in the elderly the question can be raised as to whether static stretching to increase ROM is a beneficial or safe intervention, as a dampening in muscle activity may occur post-stretch.

A possibly alternative to static stretching is dynamic stretching which is defined as controlled repeated movements through an active ROM of a respective joint (Behm & Chaouachi, 2011). Dynamic stretching increases muscle activity, while still increasing ROM in young adults (Behm & Chaouachi, 2011; Mahieu et al., 2007). The storage of elastic energy and increased activity of the muscle spindle may contribute to this increased muscle activation (Behm & Chaouachi, 2011). Dynamic stretching and dynamic warm ups have been the recommended intervention for pre-performance warm up, as dynamic stretching has been deemed more advantageous in the younger athletic population, increasing balance agility and movement time (Chatzopoulos et al., 2014). With the similar improvements in ROM, and the increase in muscle activity post-dynamic stretch reported in the younger athletic population, it is not clear whether this stretching technique improves immediate balance while still achieving the primary goal of increased ROM in older adults.

Stretching intervention studies in the younger, healthy population (18-35 years), have reported that there was a greater reduction in sway after 15 seconds of stretching versus 45 seconds (Costa et al, 2009). While 15 second hold times are not defined as dynamic, it can be deducted that the greater the stretch hold the more balance capabilities are compromised. Therefore, this study examined how long duration static stretch and quicker short duration dynamic stretch at the gastrocnemius and soleus affect muscle
function, balance control and ROM in older adults. While both stretching techniques are likely to increase ROM, it is hypothesized that: 1) sway and fall risk will be reduced post-dynamic stretch via increase a gastrocnemius and soleus activity and 2) static stretch will increase sway and fall risk via inhibition of the gastrocnemius and soleus, with a subsequent increase in tibialis anterior activity to counter the increase in sway.

Methods: Subject Population

Inclusion criteria were older adults between 60-75, community dwelling, healthy and able to ambulate independently (Bullock-Saxton et al., 2001). Healthy older adults were defined as having no outstanding health issues, and leading a normal active lifestyle within the normal aging process. Exclusion criteria included individuals with neurological disease or diagnosis specified on the NIH 2005 list of neurological diagnoses (NIH, 2005), general lower extremity numbness, history of any disease affecting the lower extremity subcutaneous and cutaneous receptors, specifically, peripheral artery disease and diabetes, recent major surgery or hospitalization that rendered one unable to participate in daily activity over the last month, and any use of assistive device for ambulation. Participants were screened via a screening question form, and after inclusion each were asked to read and sign the consent form. Each subject was asked to maintain their current daily regimen, and to not perform any intervention learned in the study between testing sessions. Subjects also completed a health-related quality of life questionnaire (SF-36) once they were consented to participate in the study.
Sample Size Analysis

Sample size was determined using the G*Power calculator (Faul et al., 2007) based on previously reported data from Costa et al. 2009, where a significant difference in balance was discovered between long duration versus short duration stretching. Parameters were set at a 2-tailed test, effect size at 1.0, power at 0.80 and alpha error probability at 0.05. A sample size of 10 was recommended based on this data. In the current study, we planned for a sample size of at least 12 for significant results.

Study Protocol

Subjects came to the research lab on two separate testing days. Each test day included baseline measurements, the intervention (static or dynamic stretching) and post-intervention assessments. Baseline testing including MVIC with EMGs, fall risk on the BBS, m-CTSIB with EMG recordings on the BBS and ROM measurements. Subjects were alternatively assigned one of the two interventions via a counterbalancing randomization technique to either start with static stretching or dynamic stretching, and prior to stretching subjects performed a 2-minute warm up on the cycle ergometer at a level of 12 RPE. Then immediately after each respective intervention post-testing occurred (Chapter 3, Figure: 1). Testing days were separated by a minimum of 24 hours, but no more than a total of two weeks where the subject will come back and complete the protocol again performing the second intervention.

Static Stretching

Static stretches were based on previously reported stretching techniques for the gastrocnemius and soleus (Behm et al., 2004; Chatzopoulos et al., 2014; Jaggers et al.,
The static stretching protocol included passive stretches at the ankle plantar-flexors, and each subject was instructed in proper stretching technique via verbal and visual (pictures) instruction. Subjects were instructed to face the wall in standing, place the hands on the wall at chest level with one foot placed slightly behind with the knee fully extended or straight while keeping the heel on the floor. They were then asked to lean forward while bending the forward knee and keeping back leg straight for the gastrocnemius stretch and with the back-leg slight bent for the soleus stretch, while maintaining the heel on floor. They were instructed to push enough into the limits of ROM where they felt a slight resistance or discomfort (Behm et al., 2004). Each stretch was performed 3 times on the left and the right leg, and each stretch was held for 45 seconds. Subjects completed the gastrocnemius first, then soleus.

**Dynamic Stretching**

Dynamic stretches were adapted from Jagger and targeted the gastrocnemius and soleus (Jaggers et al., 2008). The dynamic stretching protocol included quick, ballistic type movements targeting the ankle plantar-flexors, and each subject was instructed in proper stretching technique via verbal and visual (pictures) instruction. Subjects were instructed to stand on a step with feet side by side. The subject then pushed one heel toward the ground while bending the contralateral leg, while keeping the ipsilateral knee extended for the gastrocnemius stretch and the ipsilateral leg bent for the soleus stretch. This stretch was performed bilaterally in a reciprocating fashion. They were instructed to push enough into the limits of ROM where they felt a slight resistance or discomfort (Behm et al., 2004). Each stretch was performed a total of
15 times per leg, with the first five performed at a slow rate and speed increased throughout the next 10 up to maximum velocity. Each subject performed the stretches in a reciprocating fashion, starting with the right leg, for a total of 30 repetitions and a max time of 45 seconds.

**Biodex Balance System (BBS)**

The BBS was utilized to test balance and fall risk. Subjects performed both the fall risk test and Modified Clinical Test of Sensory Interaction and Balance (m-CTSIB). Fall risk testing on the BBS was performed on the platform without upper extremity support, and overall stability index (SI) score was the primary outcome measure. SI is the variance of the platform displacement in degrees from level as the subject attempted to balance as the platform loosened. A higher score indicated greater sway and increased fall risk as compared to normative age-related data. Subjects performed the fall risk test once.

M-CTSIB testing was used to assess the three sensory systems (vestibular, vision, somatosensory) that play the essential role in balance function, and how each system works alone or in conjunction with the others (A. Shumway-Cook & Horak, 1986). A total of 4 conditions were utilized, eyes open firm surface (EOFS), eyes closed firm surface (ECFS), eyes open soft surface (EOSS) and eyes closed soft surface (ECSS). The soft surface utilized covers the normally hard platform when those conditions are tested. Sway index (SwI) was calculated for each condition, and is the standard deviation or amount of variability in values attained from the average position of the participant on the
platform during the test. Participant performed each condition for 15 seconds with a 5-8 second rest break between each.

**EMG**

Surface electromyography measurements (EMG) were used to assess muscle function during the balance testing (m-CTSIB). Pre-amplified gel bipolar surface electrodes with a fixed center-to-center 10 cm distance were adhered to the right leg’s medial gastrocnemius, medial soleus and tibialis anterior of the right leg, along with a reference electrode located at the medial malleolus. The skin was prepped with alcohol to allow pads to adequately adhere to the skin surface. Once the EMG pads were in place over each muscle belly of interest, the subjects performed a maximal isometric voluntary contraction (MVIC) against resistance provided by the tester (~5 seconds). This recording allowed for normalizing the EMG activity during as a percent activation of muscle activity during balance testing. Each testing position was based on traditional MVIC testing positions for obtaining maximal contractions for the muscle of interest (Chapter 3; Table 7), and was held against a non-moveable surface and reaching maximal force for 3-5 seconds.

EMG recordings were also obtained while subjects completed each of the 4 balance tasks. EMG sampling rate was set at 500 Hz. The raw EMG signal was amplified, full wave rectified, and smoothed via low pass filtering set at 100 Hz over the recording time. The average firing amplitude (microvolts) was obtained for the MVIC and balance data for each muscle of interest.
Range of Motion

Range of motion at the ankle was measured via a universal goniometer. Dorsiflexion ROM measures were taken to determine gastrocnemius and soleus muscle length. The gastrocnemius was measured in long sitting with the knee fully extended and hip in neutral. While the soleus was measured in long sitting with the knee bent using a bolster or pillow to 45 degrees of knee flexion. Each ROM measurement was taken after the balance testing was completed, and measurements were performed pre-post stretching.

Statistical Analysis

A 2x2 (intervention x time) repeated-measures ANOVA was utilized to analyze the results of the balance testing, muscle function/activation levels, fall risk and ROM. Significance level was p<0.05 was considered statistically significant. When justified via significant interaction, trending interaction or significance for time alone a paired t-test was performed for pre-post testing to confirm changes within each condition. All statistical analysis was performed using IBM SPSS statistical software version 23.

Participant Demographics

Thirteen healthy women (age: 63.15 ± 2.67; height 64.77 ± 2.00 inches; weight 149.77 ± 26.06 pounds; average exercise per week 4.54 ± 1.20 days) completed the study. There were no subject drop-outs and all completed all measures within the study.

Balance and Fall Risk

A significant interaction was present for ECSS for time x condition (Table 9), but there were non-significant interactions for EOFS, ECFS and EOSS for static versus
dynamic stretch (Figure 3). Within the static stretch group, there were only 12 data points analyzed due to equipment malfunction during post-testing with subject 13. Due to a significant interaction for ECSS a post-hoc analysis was run for change in sway in static versus dynamic group. There was an increase in sway post-dynamic stretch and a reduction in sway post-static stretch (Figure 4). A paired sample t-test was run for pre-post static and pre-post dynamic stretching (Table 9). Pre-post static stretch scores were not significant for reduced sway during ECSS ($p = 0.12; t = 1.67$) for static stretching, but pre-post dynamic stretch was approaching a significant increase in sway during ECSS ($p = 0.08; t = -1.88$) (Figure 3).

Table 9

*Static Versus Dynamic Stretch 2x2 ANOVA Interaction Results for Each Balance Task*

<table>
<thead>
<tr>
<th>Balance Task</th>
<th>Static Sway Index (mean ± std; n=12)</th>
<th>Dynamic Sway Index (mean ± std; n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOFS</td>
<td>Pre: 0.39 ± 0.16</td>
<td>Pre: 0.36 ± 0.15</td>
</tr>
<tr>
<td></td>
<td>Post: 0.39 ± 0.27</td>
<td>Post: 0.43 ± 0.27</td>
</tr>
<tr>
<td></td>
<td>Pre: 0.75 ± 0.52</td>
<td>Pre: 0.70 ± 0.62</td>
</tr>
<tr>
<td></td>
<td>Post: 0.89 ± 0.90</td>
<td>Post: 0.65 ± 0.38</td>
</tr>
<tr>
<td>ECFS</td>
<td>Pre: 0.79 ± 0.26</td>
<td>Pre: 0.77 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>Post: 0.74 ± 0.28</td>
<td>Post: 0.73 ± 0.23</td>
</tr>
<tr>
<td>EOSS</td>
<td>Pre: 3.14 ± 1.74</td>
<td>Pre: 2.32 ± 0.92</td>
</tr>
<tr>
<td></td>
<td>Post: 2.67 ± 1.00</td>
<td>Post: 2.84 ± 1.04</td>
</tr>
</tbody>
</table>

*significant interaction*
Figure 3. A significant interaction between change in static versus dynamic stretch ($p = 0.02; F = 6.29$). Pre-post static stretch scores were not significant for reduced sway during ECSS ($p = 0.12; t = 1.67$) for static stretching, but pre-post dynamic stretch was approaching a significant increase in sway during ECSS ($p = 0.08; t = -1.88$). (Error Bars = Std)

There was no significant interaction time x condition for fall risk scores pre-post static versus dynamic ($p = 0.07; F = 3.50$; Stability Index (mean ± std) Static Pre: 1.12 ± 0.66 Post: 1.06 ± 0.45; Dynamic Pre: 0.95 ± 0.57 Post: 1.35 ± 0.50). There was a reduced (but non-significant) fall risk post-static stretch, and an increase in fall risk post-dynamic stretch (Figure 4). Since this interaction is approaching significance, a paired sample t-test was run for pre-post static and pre-post dynamic stretching. Pre-post static stretch was not significant for reduced fall risk ($p = 0.80; t = 0.26$), but pre-post dynamic stretch did reveal a significant increase in fall risk ($p = 0.01; t = -3.185$) (Figure 4).
Figure 4. The interaction of time x condition between change in static versus dynamic stretch approached significance ($p = 0.07; F = 3.50$). Paired sample t-test revealed a significant increase in falls risk post-dynamic stretching ($p = 0.01; t = -3.185$). (Error Bars = Std)

**Muscle Function**

EMG output (average amplitude, µV) for each muscle of interest (Gastrocnemius, Soleus and Tibialis Anterior) was analyzed during each balance task (EOFS, ECFS, EOSS, ECSS), independently. Only 12 subjects could be analyzed in the static stretch group secondary to equipment malfunction during testing on subject 13. EMG activity for each muscle during each balance task was taken as a percent of the MVIC (µV).

Significant interactions for time x condition (Table 10) were found in the soleus during EOFS (Figure 5) and ECFS (Figure 6). Within each balance condition (EOFS and ECFS), soleus activity increased at a greater rate post-static stretch and at a lesser rate post dynamic stretch. There was not a significant interaction for soleus muscle activity
during EOSS (Figure 7) or ECSS (Figure 8), although both data points were significant for time alone, with both stretch conditions demonstrating increase in soleus activity (Table 10). There was no significant interaction found for gastrocnemius or tibialis anterior during any of the balance conditions (Table 10), and neither muscle was significant for time alone. Post-hoc comparisons were analyzed via paired sample t-tests for the soleus where a significant interaction was discovered (EOFS and ECFS). A paired-sample t-test was run in the EOSS and ECSS conditions for soleus, as time was significant, and a trending increase in soleus activity was observed. Soleus activity significantly increased post-static stretch in all four balance conditions, while there was no significant change in soleus activity post-dynamic stretch in any of the balance conditions (Table 11).
Table 10

*Static Versus Dynamic Stretch 2x2 ANOVA Interaction Results for Muscle Activity During Each Balance Task*

<table>
<thead>
<tr>
<th>Muscle of Interest</th>
<th>Balance Condition</th>
<th>Average Amplitude (µV) (mean ± std) Static Stretch (n=12)</th>
<th>Average Amplitude (µV) (mean ± std) Dynamic Stretch (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soleus</strong></td>
<td><em>EOFS</em></td>
<td>Pre: 0.24 ± 0.17</td>
<td>Pre: 0.24 ± 0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.36 ± 0.19</td>
<td>Post: 0.27 ± 0.10</td>
</tr>
<tr>
<td></td>
<td><em>ECFS</em></td>
<td>Pre: 0.24 ± 0.16</td>
<td>Pre: 0.25 ± 0.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.38 ± 0.21</td>
<td>Post: 0.28 ± 0.12</td>
</tr>
<tr>
<td></td>
<td><strong>EOSS</strong></td>
<td>Pre: 0.27 ± 0.13</td>
<td>Pre: 0.28 ± 0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.39 ± 0.22</td>
<td>Post: 0.35 ± 0.17</td>
</tr>
<tr>
<td></td>
<td><strong>ECSS</strong></td>
<td>Pre: 0.33 ± 0.17</td>
<td>Pre: 0.34 ± 0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.40 ± 0.24</td>
<td>Post: 0.37 ± 0.18</td>
</tr>
<tr>
<td><strong>Gastrocnemius</strong></td>
<td>EOFS</td>
<td>Pre: 0.17 ± 0.14</td>
<td>Pre: 0.16 ± 0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.22 ± 0.20</td>
<td>Post: 0.18 ± 0.12</td>
</tr>
<tr>
<td></td>
<td>ECFS</td>
<td>Pre: 0.17 ± 0.10</td>
<td>Pre: 0.21 ± 0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.20 ± 0.10</td>
<td>Post: 0.20 ± 0.14</td>
</tr>
<tr>
<td></td>
<td>EOSS</td>
<td>Pre: 0.19 ± 0.11</td>
<td>Pre: 0.22 ± 0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.23 ± 0.11</td>
<td>Post: 0.23 ± 0.13</td>
</tr>
<tr>
<td></td>
<td>ECSS</td>
<td>Pre: 0.33 ± 0.19</td>
<td>Pre: 0.33 ± 0.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.37 ± 0.20</td>
<td>Post: 0.35 ± 0.21</td>
</tr>
<tr>
<td><strong>Tibialis Anterior</strong></td>
<td>EOFS</td>
<td>Pre: 0.10 ± 0.09</td>
<td>Pre: 0.07 ± 0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.10 ± 0.10</td>
<td>Post: 2.67 ± 1.00</td>
</tr>
<tr>
<td></td>
<td>ECFS</td>
<td>Pre: 0.13 ± 0.10</td>
<td>Pre: 0.09 ± 0.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.12 ± 0.10</td>
<td>Post: 0.08 ± 0.08</td>
</tr>
<tr>
<td></td>
<td>EOSS</td>
<td>Pre: 0.12 ± 0.07</td>
<td>Pre: 0.08 ± 0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.09 ± 0.06</td>
<td>Post: 0.09 ± 0.08</td>
</tr>
<tr>
<td></td>
<td>ECSS</td>
<td>Pre: 0.25 ± 0.16</td>
<td>Pre: 0.16 ± 0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post: 0.19 ± 0.11</td>
<td>Post: 0.22 ± 0.23</td>
</tr>
</tbody>
</table>

(*significant interaction; **significant for time).
<table>
<thead>
<tr>
<th>Balance Task</th>
<th>Soleus muscle activity</th>
<th>Soleus muscle activity</th>
<th>Significance</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Post Static Stretch</td>
<td>Pre-Post Dynamic Stretch</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta$ Mean (pre-post) (mean ($\mu$V) ± std)</td>
<td>$\Delta$ Mean (pre-post) (mean ($\mu$V) ± std)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOFS</td>
<td>0.12 ± 0.09</td>
<td>*$p = 0.00; t = 4.74$</td>
<td>0.03 ± 0.07</td>
<td>*$p = 0.11; t = 1.70$</td>
</tr>
<tr>
<td>ECFS</td>
<td>0.14 ± 0.12</td>
<td>*$p = 0.00; t = 4.07$</td>
<td>0.03 ± 0.09</td>
<td>*$p = 0.30; t = 1.17$</td>
</tr>
<tr>
<td>EOSS</td>
<td>0.11 ± 0.12</td>
<td>*$p = 0.01; t = 3.23$</td>
<td>0.07 ± 0.13</td>
<td>*$p = 0.09; t = 1.86$</td>
</tr>
<tr>
<td>ECSS</td>
<td>0.07 ± 0.11</td>
<td>*$p = 0.04; t = 2.27$</td>
<td>0.03 ± 0.11</td>
<td>*$p = 0.30; t = 1.09$</td>
</tr>
</tbody>
</table>

(*significance)
Figure 5. There was a significant interaction of time x condition between change in static versus dynamic stretch \((p = 0.01; F = 7.53)\). Paired sample t-test revealed a significant increase in soleus activity post-static stretching \((p = 0.00; t = 4.74)\). Soleus activity increased at a greater rate post-static stretch. Dynamic stretch was not significant. (Error Bars = Std)
Figure 6. There was a significant interaction of time x condition between change in static versus dynamic stretch ($p = 0.02; F = 6.66$). Paired sample t-test revealed a significant increase in soleus activity risk post-static stretching ($p = 0.00; t = 4.07$). Soleus activity increased at a greater rate post-static stretch. Dynamic stretch was not-significant. (Error Bars = Std)
Figure 7. There was not a significant interaction of time x condition between change in static versus dynamic stretch ($p = 0.40; F = 0.80$). There was, however, significance found for time alone ($p = 0.03; F = 12.67$) with both static and dynamic stretch increasing soleus activity. Even though an interaction was not found, the paired sample t-test revealed a significant increase in soleus activity post-static stretching ($p = 0.01; t = 3.23$), while dynamic stretch was not-significant. (Error Bars = Std)
Figure 8. There was not a significant interaction of time x condition between change in static versus dynamic stretch ($p = 0.40; F = 0.71$). There was, however, significance found for time alone ($p = 0.03; F = 5.64$) with both static and dynamic stretch increasing soleus activity. Even though an interaction was not found, the paired sample t-test revealed a significant increase in soleus activity post-static stretching ($p = 0.04; t = 2.27$), while dynamic stretch was not-significant. (Error Bars = Std)

**Range of Motion**

There was no significant interaction for change in ROM within the soleus post-static versus dynamic stretch ($p = 0.316; F = 1.05$), although there was a main effect of time ($p = 0.00; F = 171.38$). Both stretch conditions increased ROM at the same rate (Figure 9). Due to significant findings for time, a post-hoc analysis was run to see level of significant for difference in ROM within each stretch condition. Post-hoc comparisons via two sample paired t-test revealed a significant increase in soleus ROM in both the static stretch (mean ± std: pre: $9.15 \pm 3.63$, post: $13.92 \pm 3.47$; $p = 0.00; t = 10.48$) and...
dynamic stretch (mean ± std: pre: 10.20 ± 3.25, post: 14.31 ± 2.21; \( p = 0.00; t = 8.81 \)).

There was also a significant increase in Gastrocnemius ROM in both the static stretch (mean ± std: pre: 4.62 ± 3.55, post: 10.38 ± 3.12; \( p = 0.00; t = 10.16 \)) and dynamic stretch (mean ± std: pre: 6.38 ± 3.55, post: 10.85 ± 3.44; \( p = 0.00; t = 8.04 \)).

![Figure 9](image)

*Figure 9. Change in Soleus and Gastrocnemius muscle length pre-post static versus dynamic stretch. There was not a significant interaction of time x condition between change in static versus dynamic stretch (\( p = 0.316; F = 1.05 \)), although there was a significance for time (\( p = 0.00; F = 171.38 \)). Even though an interaction was not found, the paired sample t-test revealed a significant increase in ROM in both muscles within both stretch conditions (Soleus static stretch: \( p = 0.00; t = 10.48 \); Soleus dynamic stretch: \( p = 0.00; t = 8.81 \); Gastrocnemius static stretch: \( p = 0.00; t = 10.16 \) Gastrocnemius dynamic stretch: \( p = 0.00; t = 8.04 \)). (Error Bars = SEM)*
Discussion

The goal of the current study was to describe how static and dynamic stretching of the ankle plantar-flexors affects fall risk, balance, muscle activity and ROM. It was hypothesized that dynamic stretching would improve balance, reduce fall risk and increase muscle activity in the stretched muscles, while static stretching would do just the opposite, and both interventions would increase ROM equally. The results of this study demonstrated the opposite of what was hypothesized, and generally dynamic stretching increased sway and fall risk, while static stretching reduced fall risk and increased soleus muscle activity. Both stretching protocols increased ROM at the same rate.

The results of the current study conflict with the reports that dynamic stretching can allow for neural augmentation, or increased activation in the muscle being stretched, subsequently increasing performance in the younger athletic population (Behm & Chaouachi, 2011). In the older adult population, this does not appear to be the case, as sway index significantly increased during ECSS balance and fall risk increased post-dynamic stretching. The ECSS and fall risk test are the most challenging of all testing, as the soft surface with eyes closed challenges the individual’s reliance on proprioceptive input, requiring the most ankle muscle activity of all four conditions. The fall risk task also is challenging, as the platform loosens, requiring increased postural stability and balance reaction. With this call on increased need for muscle activity in these cases, it would be predicted that dynamic stretching would improve abilities during these tasks.
Dynamic stretching has not been studied in the older adult population, so comparative analysis with other studies is difficult, but, overall, the findings within this study suggest that balance abilities diminish. Possible explanations for this phenomenon may be due to the dynamic stretching protocol chosen, and may be linked to muscle fatigue ability or reduced ability of the muscle to generate force. While the dynamic stretching protocol was shorter, and quicker than the static, it did require active muscle contraction during the cycling or alternating from plantar-flexion to dorsi-flexion phases while on the step. Older individuals may be more susceptible to muscle fatigue during dynamic contractions compared to younger healthier adults who are active and athletic, and have trained muscle structure (Kent-Braun, 2009). While these subjects could be deemed as “active,” most reported the primary means of activity as walking, yoga or water aerobics, which are low to moderate type of activity.

While static standing and balance may not require a high level of muscle force, in older individuals it may require more force than anticipated, especially when related to the difficulty imposed during ECSS and fall risk testing environment as the surface stability reduces (Madhavan & Shields, 2005). It has been reported in older adults that submaximal exercises of the gastrocnemius muscle (40% MVC) to fatigue resulted in an increase in COP (AP deviation) and increased sway in single leg standing balance (Nam et al., 2013). This may explain what occurred post-dynamic step stretch, where subjects were performing muscle contractions concentrically to plantar-flex their body weight on the step, then eccentrically dorsi-flexing to lower their body weight into the stretch. When an aging muscle that is not trained in that capacity to called upon to perform that
type of exercise, muscle fatigue or even generalized body fatigue could result
(Kent-Braun, 2009). When muscle fatigue occurs, the proprioceptive afferent feedback
to the plantar flexors, that plays a role in pulling the body posteriorly from an anteriorly
displaced location, could be attenuated. This attenuation is likely attributed to peripheral
muscle fatigue factors include a build-up of localized metabolites and muscle contraction
by-products that impede the contractile process required for balance (Kent-Braun, 1999).
This is further supported by the EMG data, which showed that soleus muscle activity in
the dynamic stretching group demonstrated little to no increase in activation after
dynamic stretching. While this does not represent an attenuation of the muscle activity, it
may represent diminishing activity that would normally be heightened after an
intervention that is known to increase activation.

Static stretching, however, reduced sway during ECSS and significantly increased
soleus activity in all four balance conditions. In the EOSS and ECSS, an interaction was
not discovered, which is likely attributed to high variability, but there was a significance
main effect for time (pre-post). When breaking down dynamic versus static, the static
stretch pre-post soleus activity significantly increased, while pre-post dynamic soleus
activity was not. While the increased soleus activity was found in each balance condition,
it was only associated with a significant reduction in sway in the ECSS condition
post-static stretch. With this reduction in sway and increase in soleus activity post-static
stretch it is of question to what physiological process may be responsible.

Although prolonged stretching can reduce muscle strength and function in
younger adults (Behm et al., 2004), this was not the case in the older adult population.
Reduction in strength after passive stretching has been shown to occur immediately, and for some time after a stretch is applied to a muscle of interest (Fowles et al., 2000). Fowles and colleagues reported a 28% decrease in plantar-flexor maximal isometric voluntary contraction immediately post static stretch of the gastrocnemius soleus complex, and a 9% reduction in force remained up to 60 minutes-post stretch (Fowles et al., 2000). However, in the current study muscle function increases (soleus) or remains unchanged (gastrocnemius) after 135 second of static stretching at the gastrocnemius and soleus.

It is not clear as to why soleus activity increased, and gastrocnemius did not, as both were stretched equally. One explanation could be that the soleus has been confirmed as the main agonist to regulate postural control with high density of muscle spindles (Di Giulio et al., 2009; Levy, 1963). The gastrocnemius, while working in conjunction with the soleus, has a lower level of activity and does not always act as a main agonist (Di Giulio et al., 2009). In the aging population muscle spindles thicken, and become less sensitive, but the soleus remains highly active (Benjuya et al., 2004). Therefore, the increase in soleus activity post-static stretch could be attributed to increased receptor sensitivity. This increase could be due to the prolonged stretch that impact both tendon and muscle belly, while dynamic stretch may only be affecting tendinous properties. The muscle spindle, housed in the muscle belly may then become more sensitive or available, subsequently allowing for increased muscle activation within the proprioceptive efferent-afferent loop.
While static stretching is typically used for increasing ROM, and increased ROM could be important for balance control, it is difficult to defend that as the primary reason for the outcomes in the current study since ROM increased at the same rate in both static and dynamic stretching. While it can be argued that ROM increased in both static and dynamic stretching, the static stretching protocol did not promote any muscle fatigue as previously described within the dynamic stretching protocol. Static stretching included a gentle passive stretch with the subject resting against the wall. As the static stretch is held, ROM increases via a reduction in muscle/tendon stiffness (Handrakas et al., 2010). While younger adults may have diminished muscle activation post-static stretching, in older adults, the inherent muscle and tendon stiffness reduction can allow for a more optimal length/tension relationship for improved muscle cross bridge cycling to occur. The static stretching performing in this study may have allowed for improved ROM in both the gastrocnemius and soleus, but since the soleus is the more “needed” or highly activated muscle of static balance, the newly lengthened muscle properties allowed for it to perform at a greater capacity when the proprioceptive system was called upon for immediate balance control.

In conclusion, this study suggests that static stretching is a more beneficial intervention for older adults to improve balance and increase soleus muscle function. Limitations to the current study include the small sample size and having women only as subjects. Future research should include a larger the sample size, incorporate and compare men and should reduce the difficulty of the dynamic stretch protocol to minimize the effects of muscle fatigue.
CHAPTER V
THE RELATIONSHIP BETWEEN BALANCE, MUSCLE FUNCTION, ROM, AND FALL RISK WITH HEALTH-RELATED QUALITY OF LIFE IN THE AGING POPULATION

Falls and balance dysfunction are a common problem among the aging population, and fall related injury is known to cause prolonged disability ultimately impacting one’s quality of life (QoL) (Suzuki, Ohyama, Yamada, & Kanamori, 2002). Falls and balance loss can lead to loss of independence further leading to physical and emotional issues, and there is a significant relationship between increased fear of falls and a reduction in self-reported QoL (Fuzhong et al., 2002; Suzuki et al., 2002). Increase in falls can be related to reduced balance abilities, and the ability to balance is within the control of the lower extremity muscle activity in response to increase in sway. The ability to control balance and reduce falls is a product of being able to maintain COM over BOS, and in the older individual this can become increasingly difficult (D. A. Winter et al., 2003). Older individuals demonstrate larger areas of sway versus younger individuals (Hageman et al., 1995), and older fallers show an increase in sway in the anterior/posterior (A/P) direction (Laughton et al., 2003). With an increase in A/P sway, there is a subsequent increase in activity of muscles of the ankle joint such as the gastrocnemius, soleus and tibialis anterior (Loram et al., 2005). Stiffness and activation ability of these muscles are both important components for balance and postural control (D. A. Winter et al., 1998). During quiet standing, the stretch reflexes in the lower extremity muscles provide input regarding sway activity about the ankles, to allow for
appropriate reaction/motor output to maintain upright posture (Fitzpatrick & McCloskey, 1994; Fitzpatrick et al., 1994). As the body sways over the ankles, the inherent stiffness of the ankle muscles act like springs and relay afferent information about amount of sway activity allowing for subsequent muscle activation (D. A. Winter et al., 1998). Typical balance reactions in young adults include high activation levels of the gastrocnemius/soleus in quiet standing (agonist), and little activation of the tibialis anterior (antagonist) (Lakie et al., 2003). In the aging population, there is an increase in sway during balance tasks which results in higher activation of the gastrocnemius, soleus and tibialis anterior (Benjuya et al., 2004; Shaffer & Harrison, 2007).

It is not known how the amount of sway, tendon stiffness and muscle activation about the ankle individually contribute to overall QoL in older adults, and how these variables may be associated with health-related QoL. The aim of the current study is to explore the relationship between the physical and mental components of QoL, balance performance, muscle activation of the ankle musculature (tibialis anterior, gastrocnemius and soleus) and range of motion at the ankle. It is hypothesized that stability index scores (fall risk) and proprioceptive balance capabilities will be significantly associated with one’s health related quality of life as measured on the SF36v2.

**Methods: Subject Population**

Inclusion criteria were older adults between 60-75, community dwelling, healthy and able to ambulate independently (Bullock-Saxton et al., 2001). Healthy older adults were defined as having no outstanding health issues, and leading a normal active lifestyle within the normal aging process. Exclusion criteria included individuals with
neurological disease or diagnosis specified on the NIH 2005 list of neurological
diagnoses (NIH, 2005), general lower extremity numbness, history of any disease
affecting the lower extremity subcutaneous and cutaneous receptors, specifically,
peripheral artery disease and diabetes, recent major surgery or hospitalization that
rendered one unable to participate in daily activity over the last month, and any use of
assistive device for ambulation. Participants were screened via a screening question
form, and after inclusion each were asked to read and sign the consent form.

**Protocol**

All measures were completed on one testing day. Subjects completed the
subjective SF-36v2 and the other objective measures including: fall risk (SI) on the
Biodex Balance System (BBS), sway index (SwI) during the modified clinical test of
sensory integration and balance (m-CTSIB: EOFS, ECFS, EOSS ECSS) on the BBS,
muscle activity via EMG in the gastrocnemius, soleus and tibialis anterior during
m-CTSIB (EOFS, ECFS, EOSS ECSS), ROM in the gastrocnemius and soleus, fall risk
and sway index scores during EOFS, ECFS, EOSS and ECSS on the BBS.

The SF-36v2 was completed by each subject on a computer in a room without any
distraction prior to functional testing. The outcome tool was provided from Quality
Metrics with a one year licensing agreement. V4.5 of the desktop scoring solution was
utilized to obtain raw and normalized z-scores for each of the 8 domains and 2 composite
scores.

Once the SF-36 was completed subjects completed maximal voluntary contraction
at the medial gastrocnemius, medial soleus and tibialis anterior of the right leg, fall risk
on the BBS, m-CTSIB on the BBS with EMG recordings of the medial gastrocnemius, medial soleus and tibialis anterior of the right leg and ROM measurements within that specific order.

**SF-36v2**

The Short Form Health Survey 36 (SF-36) was utilized to allow for a better assessment of the health-related quality of life of each subject. The SF-36 is a well-validated self-reported measure that allows for overall quantification of one’s health status, and can be used to measure health related quality of life. The 36 item measure is divided into 8-subscale with 2 composite summary measures (Ware & Sherbourne, 1992). The 8-scale profile includes: physical functioning, role limitations due to physical problems, general health perceptions, vitality, social functioning, role limitations due to emotional problems, general mental health and bodily pain (Ware & Sherbourne, 1992). Subjects answered the 36 questions in regards to the last 4 weeks, and the scoring system is based on a weighted Likert scale (Ware & Sherbourne, 1992). The items in the subscales were totaled to provide individualized, then summed scores within each summary measure. The raw scores were obtained on a 100-point scale and were transformed into z-scores based on normative data. Version 2.0 of the SF-36, which was created to correct some deficiencies in the original version, was utilized, and scored automatically on the computer (Turner-Bowker et al., 2013).

**Biodex Balance System (BBS)**

The BBS was utilized to test balance and fall risk. The BBS contains a moveable platform that is 55 centimeters in diameter where subjects stood in double stance without
shoes. Balance testing measures the angular excursion of the subject’s center of gravity (COG). The testing formats that will be utilized in the current study will be the fall risk and Modified Clinical Test of Sensory Interaction and Balance (m-CTSIB).

Fall risk testing on the BBS was performed on the platform without upper extremity support, and provided an overall stability index (SI) score based on subject performance. SI is the variance of the platform displacement in degrees from level as the subject attempted to balance as the platform loosened. The higher the score indicated the higher level of movement and increased fall risk as compared to stored normative age-related data within the system. Subjects performed the fall risk test once, and it last for 15 seconds where the platform reduced stability levels as time progresses. In both testing sessions subjects were asked to “maintain upright posture” by the tester.

M-CTSIB testing was used to assess the three sensory systems (vestibular, vision, somatosensory). A total of 4 conditions were utilized, eyes open firm surface (EOFS), eyes closed firm surface (ECFS), eyes open soft surface (EOSS) and eyes closed soft surface (ECSS). The soft surface utilized covers the normally hard platform when those conditions are tested. Sway index (SwI) was calculated for each condition, and is the standard deviation or amount of variability in values attained from the average position of the participant on the platform during the test. Participant performed each condition for 15 seconds with a 5-8 second rest break between each.

**EMG**

Surface electromyography measurements (EMG) were used to assess muscle function during the balance testing (m-CTSIB). Pre-amplified gel bipolar surface
electrodes with a fixed center to center distance were adhered to the right leg’s medial gastrocnemius, medial soleus and tibialis anterior of the right leg, along with a reference electrode located at the medial malleolus. The skin was prepped with alcohol to allow pads to adequately adhere to the skin surface. Once the EMG pads were in place over each muscle belly of interest, the subjects performed a maximal isometric voluntary contraction (MVIC) against resistance provided by the tester (~5 seconds). This recording allowed for normalizing the EMG activity during as a percent activation of muscle activity during balance testing. Each testing position was based on traditional MVIC testing positions for obtaining maximal contractions for the muscle of interest (Chapter 3; Table 7), and will held against a non-moveable surface and reaching maximal force, then holding that for 3-5 seconds.

EMG recordings were also obtained while subjects completed each of the 4 balance tasks. The surface electrodes recorded muscle firing frequency at the medial soleus, medial gastrocnemius and tibialis anterior. EMG sampling rate was set at 500 Hz. The raw EMG signal was amplified, full wave rectified, and smoothed via low pass filtering set at 100 Hz over the recording time. Then, the average amplitude was obtained for the MVIC and balance data for each muscle of interest.

**Range of Motion**

Range of motion at the ankle was measured via a universal goniometer. Dorsiflexion ROM measures were taken to determine gastrocnemius and soleus muscle length. The gastrocnemius was measured in long sitting with the knee fully extended and hip in neutral. While the soleus was measured in long sitting with the knee bent using a
bolster or pillow to 45 degrees of knee flexion. Each ROM measurement was taken after the balance testing was completed, and measurements were performed pre-post stretching.

**Data Analysis**

A correlation analysis was utilized to assess the association between the SF-36v2 scores for both composite scores (Mental and Physical) and all 8 domains versus variables: SwI (EOFS, ECFS, EOSS and ECSS), SI (fall risk), EMG (anterior tibialis, medial gastrocnemius and medial soleus for each condition 1-4) and range of motion (ankle dorsiflexion with knee bent and knee extended). A Pearson-product correlation coefficient > 0.50 with an associated significance of $p \leq 0.05$ along was considered significantly correlated. SF-36 z-scores were divided by 100 to allow for appropriate scaling when comparing to the muscle activity EMG and fall risk data.

**Results**

A correlation analysis was run to find any significant association between baseline variables, including muscle activity in the gastrocnemius, soleus and tibialis anterior during balance tasks (EOFS, ECFS, EOSS and ECSS), ROM in the gastrocnemius and soleus, fall risk and sway index scores during EOFS, ECFS, EOSS and ECSS. All SF-36 domains and composite scores were analyzed. For graphing purposes SF-36 z-scores were divided by 100 to allow for appropriate scaling when comparing to the muscle activity EMG and fall risk data.

Muscle activity in the tibialis anterior during EOFS and ECFS and the gastrocnemius EOFS were significantly correlated with SF-36 physical composite, role
limitation due to physical problems and bodily pain scores (Figures 10, 11, 12). A higher level of muscle activity in the tibialis anterior during ECFS and ECFS and gastrocnemius during EOFS was associated with a reduction in scores for the physical composite (Figure 10), role limitations due to physical problems (Figure 11) and bodily pain (Figure 12) on the SF-36. As muscle activity increased in these conditions, physical functioning was reduced.

Muscle activity in the tibialis anterior during EOFS and ECFS was significantly associated with role limitation due to emotional problems scores (Figure 13), while muscle activity in the tibialis anterior during EOFS and the gastrocnemius during EOFS was associated with general health scores (Figure 14). As muscle activity increased in these conditions, there was a decrease in self-reported health and role limitation due to emotional problems. Fall risk was moderately associated with social functioning \((r=-0.56; p = 0.05)\), but once graphically analyzed data appeared to be largely weak relationship, so this relationship was not considered statistically significant.
Figure 10. Correlation between SF-36 physical composite score (y-axis) and tibialis anterior muscle activity during EOFS and ECFS (x-axis) and gastrocnemius activity during EOFS (x-axis). A significantly negative correlation exists between SF-36 physical composite score and tibialis anterior activity during EOFS (r= -0.71, p = 0.01), tibialis anterior activity during ECFS (r= -0.57, p = 0.04) and gastrocnemius activity during EOFS (r= -0.64, p = 0.02).
Figure 11. Correlation between SF-36 role limitation due to physical problems (y-axis) and tibialis anterior muscle activity during EOFS and ECFS (x-axis) and gastrocnemius activity during EOFS x-axis). A significantly negative correlation exists between SF-36 physical composite score and tibialis anterior activity during EOFS ($r = -0.92, p = 0.00$), tibialis anterior activity during ECFS ($r = -0.83, p = 0.00$) and gastrocnemius activity during EOFS ($r = -0.68, p = 0.01$).
Figure 12. Correlation between SF-36 bodily pain (y-axis) and tibialis anterior muscle activity during EOFS and ECFS (x-axis) and gastrocnemius activity during EOFS (x-axis). A significantly negative correlation exists between SF-36 physical composite score and tibialis anterior activity during EOFS ($r = -0.72, p = 0.01$), tibialis anterior activity during ECFS ($r = -0.70, p = 0.01$) and gastrocnemius activity during EOFS ($r = -0.63, p = 0.02$).
Figure 13. Correlation between role limitations due to emotional problems (y-axis) and tibialis anterior muscle activity during EOFS and ECFS (x-axis). A significantly negative correlation exists between SF-36 role limitations due to emotional problems score and tibialis anterior activity during EOFS \((r = -0.76, \ p = 0.00)\) and tibialis anterior activity during ECFS \((r = -0.81, \ p = 0.00)\).
Figure 14. Correlation between general health (y-axis) and tibialis anterior muscle activity during EOFS (x-axis) and gastrocnemius activity during EOFS (x-axis). A significantly negative correlation exists between SF-36 general health scores and tibialis anterior activity during EOFS ($r = -0.71, p = 0.01$) and gastrocnemius activity during EOFS ($r = -0.65, p = 0.02$).
Not all baseline variables were significantly associated with SF-36 outcomes, and those are outlined in the table below (Table 12).

Table 12

*Variables That Were Not Significantly Correlated*

<table>
<thead>
<tr>
<th>SF-36 Variable</th>
<th>Functional Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Composite</td>
<td>Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius ECFS, EOSS, ECSS</td>
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<tr>
<td></td>
<td>Tibialis Anterior EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
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<tr>
<td></td>
<td>Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
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<tr>
<td></td>
<td>Fall Risk (SI)</td>
</tr>
<tr>
<td>Mental Composite</td>
<td>Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Tibialis Anterior EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
</tr>
<tr>
<td></td>
<td>Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
</tr>
<tr>
<td></td>
<td>Fall Risk (SI)</td>
</tr>
<tr>
<td>Role Limitation Due to Physical Problems</td>
<td>Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Tibialis Anterior EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
</tr>
<tr>
<td></td>
<td>Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
</tr>
<tr>
<td></td>
<td>Fall Risk (SI)</td>
</tr>
<tr>
<td>Bodily Pain</td>
<td>Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius ECFS, EOSS, ECSS</td>
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<tr>
<td></td>
<td>Tibialis Anterior EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>ROM</td>
</tr>
<tr>
<td></td>
<td>Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
</tr>
<tr>
<td></td>
<td>Fall Risk (SI)</td>
</tr>
<tr>
<td>General Health</td>
<td>Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Gastrocnemius ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>Tibialis Anterior ECFS, EOSS, ECSS</td>
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<tr>
<td></td>
<td>ROM</td>
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<tr>
<td></td>
<td>Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
</tr>
<tr>
<td></td>
<td>Fall Risk (SI)</td>
</tr>
</tbody>
</table>

*table continues*
Table 12 (continued)

Variables That Were Not Significantly Correlated

<table>
<thead>
<tr>
<th>SF-36 Variable</th>
<th>Functional Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vitality</strong></td>
<td>• Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>• Gastrocnemius EOFS, ECFS, EOSS, ECSS</td>
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<tr>
<td></td>
<td>• Tibialis Anterior EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>• ROM</td>
</tr>
<tr>
<td></td>
<td>• Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
</tr>
<tr>
<td></td>
<td>• Fall Risk (SI)</td>
</tr>
<tr>
<td><strong>Social Functioning</strong></td>
<td>• Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>• Gastrocnemius EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>• Tibialis Anterior EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>• ROM</td>
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<tr>
<td></td>
<td>• Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
</tr>
<tr>
<td></td>
<td>• Fall Risk (SI)</td>
</tr>
<tr>
<td><strong>Role Limitation Due to Emotional Problems</strong></td>
<td>• Soleus EOFS, ECFS, EOSS, ECSS</td>
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<tr>
<td></td>
<td>• Gastrocnemius EOFS, ECFS, EOSS, ECSS</td>
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<tr>
<td></td>
<td>• Tibialis Anterior EOFS, ECSS</td>
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<tr>
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<td>• ROM</td>
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<tr>
<td></td>
<td>• Fall Risk (SI)</td>
</tr>
<tr>
<td><strong>Mental Health</strong></td>
<td>• Soleus EOFS, ECFS, EOSS, ECSS</td>
</tr>
<tr>
<td></td>
<td>• Gastrocnemius EOFS, ECFS, EOSS, ECSS</td>
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<tr>
<td></td>
<td>• Tibialis Anterior EOFS, ECFS, EOSS, ECSS</td>
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<td></td>
<td>• ROM</td>
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<tr>
<td></td>
<td>• Sway Index (EOFS, ECFS, EOSS, ECSS)</td>
</tr>
<tr>
<td></td>
<td>• Fall Risk (SI)</td>
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</tbody>
</table>

(r > 0.50; p > 0.05)

**Discussion**

The current study examined quality of life measures as reported on the SF-36 and its association to balance, muscle function at the ankle during balance, fall risk and range of motion in older adults. Results indicate an inversely associated relationship between physical and mental quality of life measures and muscle activity at the tibialis anterior.
and gastrocnemius during some of the balance tasks performed on the BBS. While falls have been significantly reported as associated with reduced scores on the SF-36 indicating poor quality of life (Huang, Lytle, Miller, Smith, & Fredrickson, 2014; Ozcan, Donat, Gelecek, Ozdirenc, & Karadibak, 2005; Suzuki et al., 2002), the current study did not find any significant correlations with any of the SF-36 measures and sway index (balance), fall risk and ROM.

A significant correlation was found between the physical composite, role limitations due to physical problems and bodily pain decreased the muscle activity in the tibialis anterior (EOFS, ECFS) and gastrocnemius (ECFS) increased during two of the four balance conditions. As scores on the SF-36v2 decreased for general health, muscle activity in the tibialis anterior and gastrocnemius increased during ECFS. In addition, scores in the domain of role limitation due to emotional problems decreased the muscle activity in the tibialis anterior increased during EOFS and ECFS.

The tibialis anterior had increase activity in those who reported a reduction in QoL within the physical composite and in four of the eight SF-36 domains. EMG studies have reported that older adults rely increasingly on tibialis anterior when compared to younger, especially with eyes closed (Benjuya et al., 2004). Muscle co-contraction about the ankle has been reported as a more reliable means of balance control in the older population (Benjuya et al., 2004), and this high reliance may be attributed to the general age-related decrease in muscle strength in older adults (Faulkner, Larkin, Claflin, & Brooks, 2007). Typically, in quiet standing, the gastrocnemius/soleus complex is the main agonist, constantly activated to modulate balance control and reducing sway (Loram
et al., 2005). A reduced sway, is indicative of good balance control, so when the tibialis anterior becomes more active it may be an indicator of reduced balance control to counteract an increase in sway, calling for a more co-contracted muscle environment. This increased activation is indicative of a poorer QoL, suggesting the possibility that the compensatory muscle activation pattern around the ankle could have great physical and mental impact on the aging individual.

Soleus did not have a significant association with the QoL measures. Studies have reported that soleus activity is an important for balance control in the aging adult, and activates at a similar level of as young adults during quiet standing (Benjuya et al., 2004). In the current study the soleus was not associate directly with QoL. One may assume that activation levels in the soleus may be related to a higher quality of life, but that was not the case in this study. When sway occurs, elongation of the ankle muscles occurs and muscle spindle (stretch sensitive receptors) are activated, and those muscles are subsequently activated to pull the body back to midline (Lakie et al., 2003). The soleus is very rich and dense in mechanoreceptors responsible for this balance control (Kararizou et al., 2005). With aging, there is a reduction in the ability for these receptors to function correctly due to thickening and reduced fiber presence, which could affect the normal activity levels of the soleus in response to sway (Kararizou et al., 2005; Miwa et al., 1995; Swash & Fox, 1972). This suggests that typical soleus activity required for static standing was unable to be achieved due reduced muscle compliance and increased capsular thickness reducing the sensitivity of the soleus mechanoreceptors. Other surrounding muscles must come into play to correct upright balance control via reliance
on gastrocnemius and tibialis anterior for balance control. Those who must rely on these muscles could have a poorer reported QoL due to inability to call upon the much-needed soleus.

The current study allows for a better understanding that age related changes in muscle structure and function could be at the core factor in assessing QoL in the aging individual. This discovery may have many clinical implications, and change how rehabilitation specialists approach interventions aimed at improving balance, and in turn improving quality of life in older individuals. Several intervention strategies have been developed to counteract balance dysfunction resulting from the aging somatosensory system (Carter et al., 2001), including endurance training, balance training, strengthening and stretching. These multi-modal exercise based intervention models have been shown to improve balance capabilities in the older adult population (Carter et al., 2001), and strength training has demonstrated significant improvement in balance (Barrett & Smerdely, 2002). By demonstrating how muscle activity around the ankle may impact quality of life it may be beneficial to incorporate more specific interventions aimed at reducing the reliance on the typical antagonist tibialis anterior, while maximizing soleus activation for postural control to improve physical well-being. Older adults generally utilize compensatory strategy for balance control, relying on antagonistic activation when sway increases or perturbations occur (Tang & Woollacott, 1998). Therefore, a generalized balance intervention may reinforce this type of reaction and muscle activation pattern with continued reliance on the antagonist muscle structures, which may
reduce QoL. Future studies should test interventions that reduce this reliance with increased focus on structure and function of the ankle musculature to improve QoL.

Limitations within the current study could include homogeneity or similarity between subjects in all baseline measures within the subject population. Also, the small sample size may have not allowed for an appropriate detection of relationships between functional measures and self-reported QoL measures. Large sample sizes are recommended in a correlation type, and a sample size of \( \geq 25 \) is what is recommended when utilizing a Pearson type correlational analysis (Bonett & Wright, 2000). So, continued work on obtaining more data for a more definitive relationship assessment is indicated moving forward in future study.
CHAPTER VI
SUMMARY AND FUTURE DIRECTIONS

This study suggests that older individuals should perform static stretching at the gastrocnemius/soleus complex to increase soleus muscle activity, reduce fall risk, and reduce sway during static balance activities. This is the first study to investigate the effects of static versus dynamic stretching in the aging population, and to refute the idea that prolonged stretches can cause immediate reduction in muscle activation (Fowles et al., 2000). The gastrocnemius/soleus complex, being the main agonist of static standing balance, responded with increased activation, especially at the level of the soleus after static stretching. The current study demonstrated that dynamic stretches, while usually performed to increase performance and balance ability in younger adults (Behm & Chaouachi, 2011), caused for a reduction in balance capabilities in older adults.

This is also the first study to report how QoL may be affected by muscle activation and performance during static balance in older adults. Quality of life is known to be associated with fall risk and balance, where quality of life diminishes as fall risk increases and balance capabilities decrease (Fuzhong et al., 2002; Suzuki et al., 2002). The current study demonstrated as older adults report a reduction in QoL on a physical and mental level, then there is also an increase in gastrocnemius and tibialis anterior activation during static balance tasks. As the need for tibialis anterior and gastrocnemius increases, leading to the overall reduction in general well-being as aging occurs. These two muscles, while important for balance, could act as a barrier and indicate a reduced QoL in those who require high level of activation when static standing. It was interesting
that tibialis anterior and gastrocnemius seemed to trend as the main correlated variable with QoL measures, indicating the possible importance of their activation levels with balance control and implication on QoL in older adults. It reveals the possibility of less coincidence, as these two muscles seemed to relate to a reduced quality of life with many of the SF-36 variables.

Future work should increase subject numbers to reduce variability and continue to trend toward more significant results within each outcome. A power analysis via G*Power calculator utilizing means from the fall risk data within the current study shows that a total of 16 subjects will reveal a significant interaction (Faul et al., 2007). Additional study may allow for a better or more definitive assessment of how static and dynamic stretching are truly differentiating in how they affect fall risk, sway and muscle activation. The data for fall risk was close to statistical significance.

Future studies could also expand on the current protocol may look at lower extremity stretching at multiple joints. While the ankle joint and muscle structures are very important to balance, so are the muscles that cross the knee, hip and spine. Older adults not only experience sway in the A/P direction, but also in the medial to lateral (M/L) direction in the frontal plane. Older adults have a high level of EMG activity at the hip musculature along with increased level of sway in the M/L directions (Amiridis, Hatzitaki, & Arabatzi, 2003). It would be of interest to add stretches to musculature up the lower extremity chain to examine how muscle activation and balance abilities are affected. Lastly, future studies should assess the same intervention but additional outcome measures, such as added perturbations to standing balance, gait speed, sit to
stand or other functional tasks. While static standing balance is very important, perturbed balance and functional balance abilities are just as important, as they mimic what older adults encounter in everyday life. Falls often do occur when older adults are performing functional tasks, and it would be of great interest on how stretching interventions may act to improve upon or reduce abilities in these tasks.

Overall, the results of the current studies fill a gap in the literature by examining how different stretching types affects balance and muscle function in older adults. This gives rise to a better understanding of how the commonly prescribed intervention of static stretching can affect balance and fall risk, while also adding how dynamic stretching may affect balance in older adults. In relating the two studies, it can be implied that static stretching of the soleus improves its activity during balance may reduce tibialis anterior activity or need for its activation in older adults, thus reducing reports of a poor QoL.
APPENDIX A

SCREENING FORM
Appendix A

Screening Form

Name: _________________________________

Answer Each Question:

1.) Are you between 60-75 years old?  Yes ____  No_____ if yes, proceed to next question

2.) Do you use an assistive device for ambulation? Yes ____  No_____ if no, proceed to next question

3.) Have you had any recent major surgery requiring anesthesia within the last 4 weeks that had rendered you unable to engage in regular activity?  Yes____  No ____ if no proceed to next question

4.) Do you have a chronic history of thigh, lower leg or foot numbness and tingling?  Yes____  No ____ if no proceed to next question

5.) Have you been diagnosed with Diabetes? Yes ____  No ____ If yes, proceed to next question
   a. What year were you diagnosed? ________ if diagnosis was between 2006 to 2016 proceed to next question

6.) Have you been diagnosed with dementia? Yes _____ No _____

7.) Please answer yes or no to the following list of neurological diagnoses:
<table>
<thead>
<tr>
<th>Condition</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVA/Stroke</td>
<td></td>
</tr>
<tr>
<td>Cerebral Palsy</td>
<td></td>
</tr>
<tr>
<td>Dementia</td>
<td></td>
</tr>
<tr>
<td>Traumatic Brain Injury</td>
<td></td>
</tr>
<tr>
<td>Huntington’s Disease</td>
<td></td>
</tr>
<tr>
<td>Amyotrophic Lateral Sclerosis (ALS)</td>
<td></td>
</tr>
<tr>
<td>Lower Extremity Complex Regional Pain Syndrome (CPRPS or RSD)</td>
<td></td>
</tr>
<tr>
<td>Foot Drop</td>
<td></td>
</tr>
<tr>
<td>Guillain-Barre Syndrome</td>
<td></td>
</tr>
<tr>
<td>Parkinson’s Disease</td>
<td></td>
</tr>
<tr>
<td>Multiple Sclerosis (MS)</td>
<td></td>
</tr>
<tr>
<td>Muscular Dystrophy</td>
<td></td>
</tr>
<tr>
<td>Myasthenia Gravis</td>
<td></td>
</tr>
<tr>
<td>Myopathy</td>
<td></td>
</tr>
<tr>
<td>Post-Polio Syndrome</td>
<td></td>
</tr>
<tr>
<td>Spina Bifida</td>
<td></td>
</tr>
<tr>
<td>Spinal Cord Injury</td>
<td></td>
</tr>
<tr>
<td>Spinal Muscular Atrophy (SMA)</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

RECRUITMENT FLYER
Appendix B

Recruitment Flyer

Let’s Get Flexible!

• Are you between the ages of 60 and 75?
• Do you want to learn how static and dynamic stretching can affect performance?

If you answered yes to both of these questions, you may be eligible to participate in a research project that is designed to compare the effectiveness of different stretching types on balance, muscle function and range of motion.
You will be asked to participate in static and dynamic stretches, then look at your balance, muscle function and range of motions measurements to see how the different stretches effect these outcomes.

Benefits include the opportunity to learn different stretching interventions, and create a better understanding of how stretching can affect your balance and muscle activity.

If you would like to learn more, please contact Elizabeth Narducci at 330-620-4779 or enarducc@kent.edu or Angela Ridgel at 330-672-7495 or aridgel@kent.edu
APPENDIX C

SF-36V2
### Question: In general, would you say your health is:

<table>
<thead>
<tr>
<th>Item Responses:</th>
<th>Sub-scale being measured</th>
<th>Summary Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>General health perceptions</td>
<td>Physical Health</td>
</tr>
<tr>
<td>Very Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Question: Compared to one year ago, how would you rate your health in general now?

<table>
<thead>
<tr>
<th>Item Responses:</th>
<th>Sub-scale being measured</th>
<th>Summary Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Much better now than one year ago</td>
<td>Health Transition</td>
<td>None</td>
</tr>
<tr>
<td>Somewhat better now than one year ago</td>
<td></td>
<td></td>
</tr>
<tr>
<td>About the same as one year ago</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Somewhat worse now than one year ago</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Much worse now than one year ago</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Question: The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

<table>
<thead>
<tr>
<th>Item Responses:</th>
<th>Sub-scale being measured</th>
<th>Summary Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, Limited a lot</td>
<td>Physical functioning</td>
<td>Physical Health</td>
</tr>
<tr>
<td>Yes, limited a little</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No, not limited at all</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Vigorous activities**, such as running, lifting heavy objects, participating in strenuous sports
- **Moderate activities**, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf
- Lifting or carrying groceries
- Climbing several flights of stairs
- Climbing one flight of stairs
- Bending, kneeling, or stooping
<table>
<thead>
<tr>
<th></th>
<th>Walking more than a mile</th>
<th>All of the time</th>
<th>Role limitations due to physical problems</th>
<th>Physical Health</th>
</tr>
</thead>
<tbody>
<tr>
<td>g.</td>
<td>Walking several hundred yards</td>
<td>Most of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
<tr>
<td>h.</td>
<td>Walking one hundred yards</td>
<td>Some of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
<tr>
<td>i.</td>
<td>Bathing or dressing yourself</td>
<td>A little of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
<tr>
<td>j.</td>
<td>Bathing or dressing yourself</td>
<td>None of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
</tbody>
</table>

4.) During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health?
   
a. Cut down on the amount of time you spent on work or other activities
   
b. Accomplished less than you would like
   
c. Were limited in the kind of work or other activities
   
d. Had difficulty performing the work or other activities (for example, it took extra effort)

<table>
<thead>
<tr>
<th></th>
<th>All of the time</th>
<th>Role limitations due to physical problems</th>
<th>Physical Health</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Most of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Some of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A little of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
<tr>
<td></td>
<td>None of the time</td>
<td>Physical Health</td>
<td></td>
</tr>
</tbody>
</table>

5.) During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?
   
a. Cut down on the amount of time you spent on work or other activities
   
b. Accomplished less than you would like
   
c. Did work or activities less carefully than usual

<table>
<thead>
<tr>
<th></th>
<th>All of the time</th>
<th>Role limitations due to emotional problems</th>
<th>Mental Health</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Most of the time</td>
<td>Mental Health</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Some of the time</td>
<td>Mental Health</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A little of the time</td>
<td>Mental Health</td>
<td></td>
</tr>
<tr>
<td></td>
<td>None of the time</td>
<td>Mental Health</td>
<td></td>
</tr>
<tr>
<td>6.) During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?</td>
<td>• Not at all • Slightly • Moderately • Quite a bit • Extremely</td>
<td>• Social functioning</td>
<td>• Mental Health</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>7.) How much bodily pain have you had during the past 4 weeks?</td>
<td>• None • Very mild • Mild • Moderate • Severe • Very severe</td>
<td>• Bodily pain</td>
<td>• Physical Health</td>
</tr>
<tr>
<td>8.) During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?</td>
<td>• Not at all • A little bit • Moderately • Quite a bit • Extremely</td>
<td>• Bodily pain</td>
<td>• Physical Health</td>
</tr>
<tr>
<td>9.) These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling. (How much of the time during the past 4 weeks...)</td>
<td>• All of the time • Most of the time • Some of the time • A little of the time • None of the time</td>
<td>• Vitality (a, e, g, i) • General mental health (b, c, d, f, h)</td>
<td>• Mental Health</td>
</tr>
<tr>
<td>a. Did you feel full of life?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Have you been very nervous?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Have you felt so down in the dumps that nothing could cheer you up?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Have you felt calm and peaceful?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Did you have a lot of energy?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. Have you felt downhearted and depressed?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. Did you feel worn out?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. Have you been happy?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. Did you feel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10.) During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?

<table>
<thead>
<tr>
<th>All of the time</th>
<th>Most of the time</th>
<th>Some of the time</th>
<th>A little of the time</th>
<th>None of the time</th>
</tr>
</thead>
</table>

11.) How TRUE or FALSE is each of the following statements for you?

<table>
<thead>
<tr>
<th>Definitely true</th>
<th>Mostly true</th>
<th>Don’t know</th>
<th>Mostly false</th>
<th>Definitely false</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>General health perceptions</th>
<th>Physical Health</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D

Consent Form

Informed Consent to Participate in a Research Study

Study Title: The Effects of Static Versus Dynamic Stretching on Fall Risk, Balance and Muscle Function in Older Adults: Is Stretching a Beneficial Intervention?

Principal Investigator: Angela Ridgel, PhD
Co-Investigator: Elizabeth Narducci, PT, DPT

You are being invited to participate in a research study. This consent form will provide you with information on the research project, what you will need to do, and the associated risks and benefits of the research. Your participation is voluntary. Please read this form carefully. It is important that you ask questions and fully understand the research in order to make an informed decision. You will receive a copy of this document to take with you.

**Purpose:**

The purpose of this study is to determine the immediate effects of static versus dynamic stretching in healthy individuals ages 60-75 in terms of balance, muscle function and range of motion.

**Procedures:**

If you choose to participate in this study then you will be asked to visit Kent State University’s Laboratory for 2 sessions separated by at least 24 hours. You will perform 2 stretching protocols that will be instructed and monitored by a licensed physical therapist.

Below is a description of the information and tests that will be recorded:

- **Health Related Quality of Life Questionnaire (SF-36v2):** Computer based questionnaire to determine overall physical and mental well-being.
- **Joint Range of Motion:** Measurements will be taken at the ankle joint using a device to help determine the amount of motion or muscle tightness in the ankle.
- **Muscle function:** Surface electromyogram pads will be placed on your skin over three leg muscles of the lower right leg. This will include cleaning and removing
hair/dead skin to allow for the pads to stick (like a bandaid). We will mark your skin with a permanent marker and we ask that you do not remove the mark until after the last session.

- **Fall Risk Testing:** To test fall risk, a piece of equipment will be used that is called the Biodex Balance system. This system measures and records your ability to stabilize your body during movement, and a number will be given to show your level of “fall risk.” **Balance Testing (m-CTSIB):** The Biodex Balance System will be utilized for to test balance. Your balance will be tested with eyes open and closed, on soft and solid surface. Safety will be ensured with use of harness system.

- Each participant will engage in both stretching groups and testing of balance, surface EMG and range of motion will occur once prior to stretching, and immediately after each stretching session. You will be asked to not perform stretches learned in session one at any time until after the second stretching session and full testing is completed.

**Benefits** Your participation may provide you with learning certain stretch techniques that could be done as a form of daily exercise, as well as, knowing your own balance capabilities and risk of falls based on your scores obtained on the balance system. Your participation in this study will help us to better understand how stretching techniques could prevent or increase risk of falls in the older adult community.

**Risks and Discomforts**
Falls are possibly with balance testing, although you will be protected via a harness to prevent any fall if loss of balance occurs. You may experience some muscle soreness in the stretches muscles, but this is should usually resolve within 48 hours after activity. If the stretching intensity is too hard you will be permitted to stop at any time during the session. Emergency services will be called for injuries or any other circumstances. Your medical insurance will be billed for any emergency services that are performed by medical staff. The research personnel are trained in basic cardiac life support and there is an Automatic External Defibrillator (AED) in the laboratory.
Privacy and Confidentiality
All results will be kept confidential. Any identifying information will be kept in a secure location and only the researchers will have access to this information. Individuals who participate in this study will not be identified in any publication or presentation of research results. Your personal information, such as your name and date of birth, will be removed as soon as possible. Only information you have disclosed to the researchers will be collected, such as your healthy history. Your research information may, in certain circumstances, be disclosed to the Institutional Review Board (IRB), which oversees research at Kent State University, or to certain federal agencies. Confidentiality may not be maintained if you indicate that you may do harm to yourself or others.

Voluntary Participation
Taking part in this research study is entirely up to you. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. You will be informed of any new, relevant information that may affect your health, welfare, or willingness to continue your study participation.

Contact Information
If you have any questions or concerns about this research, you may contact Dr. Angela Ridgel at 330.672.7495 or Elizabeth Narducci at 330.620.4779. This project has been approved by the Kent State University Institutional Review Board. If you have any questions about your rights as a research participant or complaints about the research, you may call the IRB at 330.672.2704.

Consent Statement and Signature
I have read this consent form and have had the opportunity to have my questions answered to my satisfaction. I voluntarily agree to participate in this study. I understand that a copy of this consent will be provided to me for future reference.

Participant Signature ___________________________ Date ___________________________
APPENDIX E

DEMOGRAPHIC INFORMATION
Appendix E

Demographic Information

Name: ____________________________

Study ID: ________________________ (to be filled out by researcher)

Age: ____________________________

Sex: ____________________________

Height: __________________________

Weight: __________________________

Occupation: ________________________

How many days a week do you exercise? __________________________

What are your main modes of exercise? __________________________

Do you train for any competitive events? __________________________

  If yes, please specify: ________________________________________

Have you experienced any falls in the last 6 months? __________________________

  If yes, how many? __________________________

Do you wear glasses or contacts? __________________________

  If yes, please specify when (reading, at all times, etc.) __________________________

Have you ever been treated for dizziness or vestibular disorders? __________________________

  If yes, please specify diagnosis, when and has it resolved: __________________________
APPENDIX F

RPE SCALE
Appendix F

**RPE Scale**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>No exertion at all</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Very Light</td>
</tr>
<tr>
<td>10</td>
<td>Light</td>
</tr>
<tr>
<td>11</td>
<td>Somewhat Hard</td>
</tr>
<tr>
<td>12</td>
<td>Hard (Heavy)</td>
</tr>
<tr>
<td>15</td>
<td>Very Heard</td>
</tr>
<tr>
<td>19</td>
<td>Extremely Hard</td>
</tr>
<tr>
<td>20</td>
<td>Maximal Exertion</td>
</tr>
</tbody>
</table>
APPENDIX G

VERBAL INSTRUCTION OF STRETCHES
Appendix G

Verbal Instruction of Stretches

Static:

“You will be complete 2 static stretch techniques. Each stretch will be completed a total of 3 times, and be held for 45 total second, which I will keep time. You will start with the right leg, then perform on the left and repeat this sequence until all sets are completed.”

Gastrocnemius: “Please face the wall in standing, place hands on the wall at chest level with one foot placed slightly behind with the knee fully extended or straight while keeping the heel on the floor, lean forward while bending the forward knee and keeping back leg straight with the heel on floor. Lean forward to the point of slight discomfort or stretch in the back leg, but you should not feel pain.”

Soleus: “Please face the wall in standing, place hands on the wall at chest level with one foot placed slightly behind with the knee slightly bent while keeping the heel on the floor, lean forward while bending the forward knee and keeping back leg slightly bent with the heel on floor. Lean forward to the point of slight discomfort or stretch in the back leg, but you should not feel pain.”

Dynamic:

“You will be complete 2 dynamic stretch techniques. Each stretch will be completed a total of 15 times, and be held for 1-2 seconds. The first 5 reps will be completed slowly, then the last 10 reps will build to become much quicker based on self-selected speed without bouncing at end range (controlled movements). You will have a max of 45 seconds to complete the 15 reps, as both legs will be completed within the same set in an alternating fashion.”

Gastrocnemius: “Please stand with both feet on the step, balls of feet in contact with the step and heels hanging off. You may hold on with one or two hands. Please push one heel toward the ground while keeping the knee straight, and bending the opposite knee, then repeat to the other side. This stretch will be performed in a reciprocating fashion.”

Soleus: “Please stand with both feet on the step, balls of feet in contact with the step and heels hanging off. You may hold on with one or two hands. Please push one heel toward the ground while keeping the knee bent, and bending the opposite knee, then repeat to the other side (knees remain bent while performing side to side). This stretch will be performed in a reciprocating fashion.”
APPENDIX H

VISUAL AID OF STRETCHES
Appendix H

Visual Aid of Stretches

Static Soleus:
Static Gastrocnemius:
Dynamic Soleus:
Dynamic Gastrocnemius:
APPENDIX I

DATA SHEET
Appendix I

Data Sheet

Subject ID: ______________________

SF-36 Score:

(1) physical functioning ________
(2) role limitations due to physical problems ________
(3) general health perceptions ________
(4) vitality ________
(5) social functioning ________
(6) role limitations due to emotional problems ________
(7) general mental health and bodily pain ________

e. Composite scores: Physical ___________ Mental ___________

Baseline 1: (Pre)

Biodex:
Fall Risk (SI): __________________________
Condition 1 (EOFs):
   SwI: ____________
   EMG:
   Gastrocnemius: _________ (μV)
   Soleus: ___________ (μV)
   Tibialis Anterior: ___________ (μV)
Condition 2 (ECFS):
   SwI: ____________
   EMG:
   Gastrocnemius: _________ (μV)
   Soleus: ___________ (μV)
   Tibialis Anterior: ___________ (μV)
Condition 3 (EOSS):
   SwI: ____________
   EMG:
   Gastrocnemius: _________ (μV)
   Soleus: ___________ (μV)
   Tibialis Anterior: ___________ (μV)
Condition 4 (ECSS):
   SwI: ______________
   EMG:
   Gastrocnemius: ____________ (µV)
   Soleus: ____________ (µV)
   Tibialis Anterior: ____________ (µV)
Range of Motion:
Gastrocnemius: ____________ degrees
Soleus: ____________ degrees

Post- Stretch 1: ____________ (state dynamic or static)
Biodex:
Fall Risk (SI):

Condition 1 (EOFS):
   SwI: ______________
   EMG:
   Gastrocnemius: ____________ (µV)
   Soleus: ____________ (µV)
   Tibialis Anterior: ____________ (µV)
Condition 2 (ECFS):
   SwI: ______________
   EMG:
   Gastrocnemius: ____________ (µV)
   Soleus: ____________ (µV)
   Tibialis Anterior: ____________ (µV)
Condition 3 (EOSS):
   SwI: ______________
   EMG:
   Gastrocnemius: ____________ (µV)
   Soleus: ____________ (µV)
   Tibialis Anterior: ____________ (µV)
Condition 4 (ECSS):
   SwI: ______________
   EMG:
   Gastrocnemius: ____________ (µV)
   Soleus: ____________ (µV)
   Tibialis Anterior: ____________ (µV)
Range of Motion:
Gastrocnemius: ____________ degrees
Soleus: ____________ degrees
Baseline 2: (Pre)
Biodex:
Fall Risk (SI): __________________________
Condition 1 (EOFS):
  SwI: ___________
  EMG:
    Gastrocnemius: ___________ (μV)
    Soleus: ___________ (μV)
    Tibialis Anterior: ___________ (μV)
Condition 2 (ECFS):
  SwI: ___________
  EMG:
    Gastrocnemius: ___________ (μV)
    Soleus: ___________ (μV)
    Tibialis Anterior: ___________ (μV)
Condition 3 (EOSS):
  SwI: ___________
  EMG:
    Gastrocnemius: ___________ (μV)
    Soleus: ___________ (μV)
    Tibialis Anterior: ___________ (μV)
Condition 4 (ECSS):
  SwI: ___________
  EMG:
    Gastrocnemius: ___________ (μV)
    Soleus: ___________ (μV)
    Tibialis Anterior: ___________ (μV)

Range of Motion:
Gastrocnemius: ___________ degrees
Soleus: ___________ degrees

Post-Stretch 2: (state dynamic or static)
Biodex:
Fall Risk (SI): __________________________
Condition 1 (EOFS):
  SwI: ___________
  EMG:
    Gastrocnemius: ___________ (μV)
    Soleus: ___________ (μV)
    Tibialis Anterior: ___________ (μV)
Condition 2 (ECFS):
  SwI: ___________
EMG:
Gastrocnemius: ___________ (µV)
Soleus: ___________ (µV)
Tibialis Anterior: ___________ (µV)

Condition 3 (EOSS):
SwI: ___________
EMG:
Gastrocnemius: ___________ (µV)
Soleus: ___________ (µV)
Tibialis Anterior: ___________ (µV)

Condition 4 (ECSS):
SwI: ___________
EMG:
Gastrocnemius: ___________ (µV)
Soleus: ___________ (µV)
Tibialis Anterior: ___________ (µV)

Range of Motion:
Gastrocnemius: ___________ degrees
Soleus: ___________ degrees
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