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Differences in Balance and Muscle Activation Strategies during Gait Initiation at Different Speeds between Young and Middle-Aged Adults

Lynn Curtis-Vinegra
Lynn.Curtis-Vinegra@shu.edu

DIFFERENCES IN BALANCE AND MUSCLE ACTIVATION STRATEGIES DURING GAIT INITIATION AT DIFFERENT SPEEDS BETWEEN YOUNG AND MIDDLE-AGED ADULTS

BY

Lynn Curtis-Vinegra

Dissertation Committee:

Dr. Doreen Stiskal, Chair
Dr. Lee Cabell
Dr. Genevieve Pinto Zipp

Approved by the Dissertation Committee:

______________ Date 5/13/2015
Genevieve Zipp Date 5/13/15
______________ Date 5/14/15

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DEDICATION

This work is dedicated to Warren H. Curtis, my father, and Dr.Arthur Nelson, a researcher and a teacher. Both of these men spent their lives dedicated to the art and science of Physical Therapy. One of my father's greatest joys was helping children with limitations reach their full potential. He loved to sing and do magic tricks while he treated to make it more fun for the children as well as for himself. Dr. Nelson, a physical therapist who believed in the healing effects of Physical Therapy treatment, spent his life researching and designing ways in which Physical Therapy could be substantiated. These two men contributed so much to the world and we are forever grateful. Thank you!

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ABSTRACT

DIFFERENCES IN BALANCE AND MUSCLE ACTIVATION STRATEGIES DURING GAIT INITIATION AT DIFFERENT SPEEDS BETWEEN YOUNG AND MIDDLE-AGED ADULTS

Lynn Curtis-Vinegra, PT, MS

Seton Hall University
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Chair, Dr. Doreen Stiskal

Middle-age adults' (MA) self-report of falls are greater compared to younger adults (YA) during ambulation. A previous study found that MA compared to YA use different strategies taking one-step forward at a fast speed. No other studies have compared the effect of two different speeds on balance variables and muscle activity during gait initiation in the MA compared to YA using an instrumented walkway. The objectives of this study were to assess the effects of age and speed on balance by measuring a) the Center of Pressure (COP) in two planes: COPx (sagittal) and COPy (frontal) and the Center of Mass-Center of Pressure (COM-COP) distances, and b) activation of lower extremity muscles (onset/offset, average amplitudes) during gait initiation. Thirteen healthy MA (M_{age} = 54.0 years, age range: 52-61 years) and nine healthy YA (M_{age} = 25.5 years, age range: 19-35 years) had surface electromyography (EMG) signals of the gluteus medius (GM), adductors (ADD), tibialis anterior (TA) and medial gastrocnemius (MG) recorded while initiating three steps forward while walking on a GAITRite® platinum mat at a normal self-selected and fast walking speed for 10 trials each. COP and COM-COP distances were measured using ProtoKinectics Movement Analysis Software-PKMAS. Rectified surface EMG signals were normalized using Maximum Voluntary Contractions (MVCs). Post hoc analysis used a Two-Way Mixed Design ANOVA. TA on the swing leg shuts off significantly later in the MA when compared to YA when taking a faster step (p = .04). MG on the stance leg activates significantly earlier

in the MA when compared to YA when taking a faster step (p = .04). Middle-age adults activate the MG earlier in response to the greater amount of COM displacement at a faster speed. As a result the efficiency of the TA activation, which is used to generate velocity, is compromised in order to maintain balance. The changes in timing in the MA may be precursors to age-related spatial and temporal changes. This study highlights the impact of speed on initiating gait and the importance of incorporating it into the evaluation of MA.

Chapter I

INTRODUCTION

Background of the problem

Walking is a skill necessary for independence and may become problematic as adults age. As the oldest of the baby boomers approach retirement age it is expected that the U.S. population aged 65 and older is going to increase from 43 million to 76 million in the next two decades (Wise, 2014). The growth of the middle-age adults into older adults over the next two decades will create a greater challenge in managing healthcare (Walker, 2002). It is imperative that this emerging group of baby boomers is evaluated closely for identifying areas where age-related changes are developing.

A recent survey included a wider span of age groups to better understand the impact of aging on falls during functional activities, such as walking. The results of the study show higher incidence of falls in healthy older (35 %) and middle-age adults (21 %) compared to younger adults (18 %) (Talbot, Musiol, Witham, & Metter, 2005). This rise in falls in the middle-age adults parallels the advent of the oldest of the baby boomers approach to retirement. Similarly, the middle-age adults and older adults report falls related to balance/gait impairments in comparison to the younger adults who associate their falls with accidents or environmental situations. Detection of functional decline during walking is pivotal in rehabilitation in order to implement a program to reverse the effects of aging.

There is a growing interest in using walking speed, particularly fast walking, in detecting declines with ageing due in part because it has been shown to decline more rapidly as we age (Jahn, Zwergal, & Schiepp, 2010; Ko, Hausdoff, Ferrucci, 2010; Tanaka et al., 1995). Previous studies involving older adults have found that age-related changes in neuromuscular control of the gastrocnemius, decrease timing and force production, alter gait strategies and as a result limit the ability to walk at a faster speed (Clark, Manini, Fielding & Patten, 2013). Similarly, middle-age adults were found to have decreased plantar flexion isokinetic strength at 30, 60 and 120 °/sec compared to younger adults (Kim, Lockhart, & Nam, 2010). However, the effects on walking due to the altered plantarflexor activity in the middle-age adults have not been documented.

The plantarflexor muscles, both the gastrocnemius and soleus, play a pivotal role during initiating gait; a time period during initial walking that moves the body from a static standing state into the dynamic state of walking. The role of the gastrocnemius (GA) and the soleus (SOL) of the stance leg is to control the vertical fall of the Center of Mass (COM) once the swing leg lifts off the ground (Honeine, Schieppati, Gagey, & Do, 2013). It is through its modulation of the COM during gait initiation that the plantarflexors indirectly controls our first step length and velocity (Honeine, Schieppati, Gagey, & Do, 2014).

During initiation of gait, the body uses a motor program to generate the muscle activity for taking a step before the COM moves forward on its base of support (BOS) (Polcyn, Lipsitz, Kerrigan, & Collins, 1998). The COM is a reflection of body position (Chang & Kregs, 1999) and when the COM stays within its BOS balance is maximized. However, balance is decreased in order to make the necessary weight shifts to generate velocity to take a step forward. These weight shifts are controlled by muscle activity and are reflected through a ground reaction force vector called the Center of Pressure (COP). Thus, the COP reflects an individual's neuromuscular control during weight shifting. Previous studies have shown that older adults during gait initiation have significantly decreased displacement of COP posteriorly at a normal self-selected gait speed compared to younger adults resulting in a slower velocity of the COM forward (Halliday, Winter, Frank, Patla, & Prince, 1998). Similarly, the middle-age adults showed a trend of smaller COP distances posteriorly compared to younger adults while taking one fast step forward yet no differences in velocity between the groups (Chu, Tang, Chen, & Cheng, 2009).

In order to produce displacement of COP posteriorly, the GA bilaterally must be inhibited, as the Tibialis Anterior (TA) muscles are bilaterally activated (Polcyn et al., 1998). This inverse relationship between anterior and posterior musculature at the calf allows for affective shifting of the COP primarily in the posterior direction at the start of gait initiation. Earlier activation of the GAs might compromise the effectiveness of the TAs to displace the COP posteriorly.

In healthy older adults, the GA muscles continue to fire throughout gait initiation (Polcyn et al., 1998) and results in inefficient TA activity as reflected in decrease velocity forward of the COM as the swing leg lifts off the ground (Halliday et al., 1998). Unlike the older adults in Polcyn et al. (1998), the middle-age adults, in a different study, did not show earlier activation in the medial gastrocnemius (MG) (Chu et al., 2009). The procedures, varying within both studies, had the older adults taking more than one step compared to the middle-age adults that were asked to take only one step forward. Previous researchers found the role of the SOL, functioning similarly to the GA during gait initiation (Honeine et al., 2014), reduces its activity when one step versus two or more steps is required (Chastan et al., 2010). Therefore, it is unknown if the GA activates earlier bilaterally while taking two or more steps forward in the middle-age adults compared with younger adults.

The role of the GA and TA in initiating gait in the sagittal plane has been well documented yet the controversy over the frontal plane muscle(s) involved in gait initiation continues. The COP moves in a posterior direction, as previously discussed, as well as in a lateral direction in the frontal plane toward the swing leg. Interestingly, as the COP shifts laterally towards the swing leg it causes the COM to move towards the stance leg preparing for single-leg stance (SLS) (Elble, Moody, Leffler, & Sinha, 1994). One study with stroke subjects (M_{age} = 54 years) and control subjects (M_{age} = 46 years) found the abductors on the swing leg and adductors on the stance leg caused the COP to shift toward the swing leg during gait initiation (Kirker, Simpson, Jenner, & Wing, 2000). In contrast, another study has shown abductor muscle activity to be absent in a quarter of the healthy older adults ($M_{age} =$ 70.77 years) during this phase; unfortunately, the study did not have a younger control group to identify any age related influences found in the surface EMG data (Mickelborough, van der Linden, Tallis, & Ennos, 2004). Another researcher suggests that the medial gastrocnemius (MG) and the hip and knee flexion on the swing leg might contribute to the lateral movement of the COP toward the swing leg in both younger (M_{age} = 29 years) and older adults (M_{age} = 74 years) (Elble et al., 1994). To date specific contributions of the lower extremity musculature involved in the salient lateral movement of the COP remains unclear for older adults and unknown in the middle-age adults.

Surprisingly, in spite of the functional importance of frontal plane musculature and its role in balance (MacKinnon & Winter, 1993) and fall prevention (Sato, Inoso, Higuchi & Kondo, 2002) there is a scarcity of research in relationship to gait initiation. During dynamic gait, SLS creates a destabilizing force in the frontal plane due to the gravitational load created by the head, arms and trunk and the swing leg (MacKinnon & Winter, 1993). This load during the swing phase is countered by the active ipsilateral stance leg hip abductor/adductors moments and passively by the medial acceleration of the supporting hip center. The hip abductor/adductor moments of the stance leg during swing determines mediolateral foot position relative to the COM at foot contact. This mediolateral foot position is the most important factor affecting frontal whole body balance due to its affect on the COM displacement in the frontal plane. The impact of frontal plane muscles: the hip abductors/adductors, and its relationship to balance variables: COM and COP, in the middle-age adults during gait initiation has not been sufficiently explored.

Understanding the relationship of the COP with the COM is central to evaluating the events that occur during gait initiation. To maintain balance, a person produces muscular forces to continually control the position of the COM, which in turn changes the distance between the COP and COM. The COM-COP distances reflect how far a subject allows the COM and COP to separate; that is, how well they can control or allow that excursion to occur and remain balanced. To change from static standing to active walking by taking a step, the distance between COM and COP increases. Therefore, the individual is less stable and is required to utilize more muscle activation as they begin to walk (Martin et al., 2002). The separation in these distances is fundamental to the generation of forward velocity during initiation of gait (Honeine et al., 2014). Delays or declines in velocity seem momentary or minute yet can translate into the inability to move forward efficiently or more importantly safely.

Age-related declines in the COM-COP distances could be found. Research shows that older adults demonstrate smaller COM-COP distances during initiation of gait at a normal velocity compared to younger adults (Martin et al., 2002). One reason for a smaller COM-COP distance that was not measured in the study by Martin et al. (2002) may be related to the TA amplitudes bilaterally, which are responsible for the displacement of the COP posteriorly. Data show a strong correlation between amplitude of the TA bilaterally and the degree of posterior displacement of COP during slow, normal and fast initiation of gait in younger adults (n = 6, M_{age} = 22.5 years) (Crenna & Frigo, 1991). Additionally, Elble et al. (1994) found the younger adults (n= 5, M_{age} = 29 years, age range: 22-47 years) demonstrated stronger ankle dorsiflexion moments during fast initiation of gait compared to older adults (n = 6, M_{age} = 74 years, age range 64-82 years). As a result, older adults moved their COP behind their ankles significantly less compared to younger adults. The reduction in posterior movement of the COP would ultimately decrease the ability of the older adults to generate appropriate velocity forward. Similarly, the middle-aged adults (n = 9, M_{age} = 52.3 years) tended to show a trend of smaller COP displacement posteriorly compared to younger adults (n = 9, M_{age} = 22.1 years) (Chu et al., 2009). A previous researcher documented age-related declines in isometric and isokinetic

TA strength in the middle-age adults (Kim et al., 2010). However, Chu et al. (2009) did not quantify muscle amplitudes of the TAs in the study. Therefore it is unknown if middle-age adults need to increase TAs activity to accomplish similar displacements.

As oppose to the MG at the ankle activating earlier, absence of activation of the hip abductors on the swing leg can also alter COM displacement laterally towards the stance leg. Kirker et al. (2000) found that the COM displacement toward the stance leg is caused by simultaneous contraction of the ipsilateral swing leg abductor and contralateral stance leg adductor. Previous studies with older adults show a decrease in activation of the hip abductors during gait initiation at a normal self-selected speed (Mickelborough et al., 2004). Similarly, middle-age adults show a significant decrease in the abductors on the swing during a fast step forward (Chu et al., 2009). Although not measure in the older adults, the COP displacement was not reduced in the middle-age adults. The relationship between the timing and amplitude of the stance leg adductors and swing leg abductors and how the COM may be affected by the muscle activity has yet to be determined in the middle-age adults.

A pilot study was conducted to evaluate the key balance variables: COP and COM-COP distances, and muscle activity: timing and amplitudes, related to gait initiation in younger and middle-age adults at a normal self-selected speed compared to a fast speed (Curtis-Vinegra, Stiskal, Cabell, & Pinto-Zipp, 2013). The results indicate that the middle-age adults activated the MG significantly earlier and with greater amplitudes in both the TA and MG of the stance leg regardless of speed. The middle-age adults needed significantly more TA muscle activity to achieve equal displacement of COP posteriorly compared to the younger adults. As a result, the earlier MG activation in response to greater TA amplitudes may interfere with the middle-age adults' displacement of the COM forward. The reduction in TA efficiency in developing velocity may reflect the middle-age adults' compromise between generating velocity and maintaining balance.

The timing and amplitudes changes in the middle-age adults in the pilot may be related to the self-reports of balance and gait impairments related to falls as reported in a previous survey (Talbot et al., 2005). Based on research, age-related declines occur as early as 50 years of age in strength, both isometric and isokinetic, in the lower extremities and in dynamic balance compared to younger adults (Cahalan, Johnson, Liu, & Chao, 1989; Gajdosik, Vander Linden, & Williams, 1999; Kim et al., 2010; Liaw, Chen, Pei, Leong & Lau, 2009; Murray & Sepic, 1968; Trudelle-Jackson, Ferro & Morrow, 2011). However, very little is known on how that these factors affect the middle-age adults' ability to step forward. Aging impairments in the ability to generate timely and appropriately controlled muscular forces and biomechanical weight shifts during gait initiation may compromise stability during fast stepping to get across a street when the light changes or recovering from tripping. From a preventive perspective, identifying deficits earlier in the middle-age adults and establishing a measure to reflect evidence based practice may contribute in keeping the percentage of falls from rising to the levels of the older adults as found in Talbot et al. (2005). The information gathered from this study will assist in identifying and quantifying age-related changes in balance and muscle activity in order to characterize the typical patterns seen in younger and middle-age adults. By documenting the baseline characteristics inherent in healthy subjects of both age groups, future research will be able to help predict clinically relevant strategies for rehabilitation of atypical patients; for example identification and rehabilitation to reducing future fall risks or recovery from lower extremity surgeries that are becoming prevalent in the active baby boomer patient.

Statement of the Problem

While biomechanical and surface EMG activity data exists for the older adults during gait initiation, a scarcity of data exists for middle-age adults. The relationship between neuromuscular timing and the effect of speed is of great interest due to its functional implications and as how it relates to identifying functional decline. In light of a recent survey reporting increase falls in middle-age adults combined with studies showing physiological declines related to aging, research into how middle-age adults execute gait initiation is warranted.

Purpose of the Study

The purpose of the study was to examine potential differences between younger and middle-age adults during gait initiation at two different speeds: normal self-selected and fast. Specifically, this study examined adults taking three alternating steps from a quiet standing position measuring: a.) How the Center of Pressure (COP) moved in both a posterior and lateral direction and the distances between of the Center of Mass and the Center of Pressure (COM-COP distance) using a computerized gait mat; and b.) How ankle and hip muscles were activated in terms of onset, offset and amplitudes using surface EMG.

Hypotheses

H1: Younger adults, when compared with middle-aged adults, will display farther COP distances during gait initiation at fast speeds more than at normal self-selected speeds.

H2: Younger adults, when compared with middle-aged adults, will display farther COM-COP distances during gait initiation at fast speeds more than at normal self-selected speeds.

H3: Middle-aged adults, when compared with younger adults, will display higher amplitudes and earlier timing in muscle activity for both lower extremities during gait initiation at fast speeds more than at normal self-selected speeds.

Chapter II

REVIEW OF THE LITERATURE

Population

In the next two decades, the U.S. population aged 65 and older is projected to increase from 43 million to 76 million people as a result of the baby boomers (Wise, 2014). Born between 1946 and 1964, these post World War II babies are expected to live longer and place greater demands on the healthcare system (Walker, 2002). Amid the growth of the middle-age adults of today and the older adults of the next two decades there lies an opportunity to advance strategies for promoting health in later life. The advent of the Affordable Care Act, is found by some, to show a shift from an emphasis on lengthening life to optimizing higher levels of physical and cognitive function (Ory, Smith & Resnick, 2012). This call to arms is for bridging research and clinical practice in order to design effective interventions that can maintain positive functional benefits. It is critical to managing health care cost that deficits in the middle-age adults are identified earlier so that preventive measures can be implemented.

In 2004 the cost of fall-related injuries in the United States was at 20 billion and it is estimated to rise to 32.4 billion by 2020 (Center for Disease Control and Prevention, 2004). In accordance with this estimate, a rise in self-reported falls in the middle-age adults (21 %) compared to younger adults (18 %) parallel this occurrence as the oldest of the baby boomers are starting to approach retirement age. Similarly, the middle-age and older adults in the survey reported falls related to balance/gait impairments compared to the younger adults who’s falls were related more to environmental/accident related situations (Talbot et al., 2005). Across all groups, walking was reported as the most common activity prior to a fall (Li at al., 2006). There is a plethora of evidence-based guidelines suggesting that physical activity is associated with improving health for the middle age and older adults (Robert Wood Johnson Foundation, 2001) and reducing the risk of falls for the OA (American Geriatrics Society, British Geriatrics Society, American Academy of Orthopedic Surgeons Panel on Falls Prevention, 2001) yet very little empirical evidence exist for middle-age adults in regards to balance and reducing the risk of falls during functional activities such as walking.

Physiological Changes

A great deal of research has identified age-related risk factors for falling. Areas of interest are the somatosensory (visual, vestibular and proprioceptive) and the musculoskeletal system related to its role in keeping the body's COM within its BOS in order to maintain balance. Unfortunately, the effects of aging compromise these systems and increase the risk of falls as seen in older adults (Judge, Lindsey, Underwood, & Winsemius, 1993; Nevitt, Cummings, Kidd, & Black, 1989; Tinetti, Liu, & Claus, 1993; Tinetti, Speechley & Ginter, 1988). In the last decade, similar physiological changes have been found in middle-age adults yet their link to falls has not been studied.

In order to step quickly or respond to slipping or tripping it is necessary to move at an appropriate speed. Muscles fibers, specifically type II fibers, are involved in assisting in this quickly needed muscle response. Unfortunately, type II fibers showed a trend of decreasing in male middle-age adults (n = 12, M_{age} = 54.5 (*SD*) 0.6 years, type II fibers = 2,802 (*SD*) 125) compared to male younger adults (*n* = 11, M_{age} = 26.1 (*SD*) 0.8 years, type II fibers = 3,663 (*SD*) 224) as found in study looking at a sample from the quadriceps muscle (Larsson, Grimby, & Karlsson, 1979). Another study found a trend in the reduction in the overall proportions of type I and type II in the middle-age adults. Although the older adults (*n* = 8, M_{age} = 77 years, age range: 71-81 years, type I + type II = 387,000 (*SD*) 80,000) showed a greater reduction compared to the younger adults (*n* = 10, $M_{age =}$ 24 years, age range: 15-35 years, type I + type II = 614,000 (*SD*) 137,000), the middle-age adults (*n* = 6, M_{age} = 52 years, age range: 49-56 years, type I + type II = 582,000 (*SD*) 202,000) also shows signs of declines in fibers (Lexell, Downham, & Sjostrom, 1986). Stalberg and Fawcett (1982) found that a reduction in fibers is accompanied by reduction in the number of motor units and an increase in the size of the surviving motor units. The loss of type II motor units in the middle-age adults would impede responses needing speed and may explain differences in muscle timing and amplitude if present.

The gastrocnemius (medial & lateral head), which has both type II and type I fibers, plays a pivotal role during initiating both a normal self-selected and fast step forward. Its role is to generate adequate muscle activity to control the fall of the COM forward as a step is initiated (Honeine et al., 2013, 2014). The gastrocnemius increases activity at faster walking speeds compared to normal walking speed due to the COM having a greater vertical displacement.

Gajdosik et al. (1999) were interested in the ability of female younger, middle-age and older adults in generating torques at different speeds using the plantarflexors (PF). The middle age (M_{age} = 50.21 years, age range: 40-59) and older adults (M_{age} =

72.94 years, age range: 60-84 years) compared to younger adults (M_{age} = 29.67 years, age range: 20-39 years) had less PF peak torque and mean torque at 30, 60, 120 and 180 deg/s. ($p < .042$). In a study using both men and women, the middle-age adults (7 males, 7 females, M_{age} = 41.1 years, age range: 35-54 years) had decreased PF isometric and isokinetic strength at 30, 60, and 120 deg/sec compared to younger adults (7 males, 7 females, M_{age} = 25.34 years, age range: 18-34 years, $p < .05$) (Kim et al., 2010). Interestingly in Gajdosik et al. (1999), it was only at the highest speed (180 deg/s) of testing peak torque that the middle-age adults compared to the younger adults showed significantly lower angles of displacement, the angle at which peak torque occurred. Whereas, the older adults showed lower angles of displacement at all speeds. Researchers speculate that the lower angles of peak torque may suggest slower contractile properties and possible loss of Type II fibers (Vandervoort & McComas, 1986; Vandervoort & Hayes, 1989). A faster speed appears to challenge the middle-age adults' ability to generate torque and could reveal age-related differences that may not be evident at normal self-selected or slower speeds.

Other muscles of the ankle, such as the dorsiflexors, have shown age-related declines in isometric and isokinetic strength in the middle-age adults. In a study with both men and women, the middle-age adults (7 males, 7 females, M_{age} = 41.1 years, age range: 35-54 years) were found to have decreased isometric and isokinetic dorsiflexion strength at 30, 60, and 120 deg/s compared to younger adults (7 males, 7 females, M_{age} = 25.3 years, age range: 18-34 years, $p < .05$) (Kim et al., 2010). In contrast, Vandervoort and McComas (1986) found the female middle-age adults (10 males, 10 females, age range: 40-52 years) and female younger adults (11 males, 11 females, age range: 20-32 years) had similar dorsiflexion isometric torques with only dorsiflexion torques in male middle-age adults showing a significant decrease compared to the male younger adults. Previous studies in older adults (n = 24, female M_{age} = 74.2 years, male M_{age} = 69.6 years, age range: 65-86 years) compared to younger adults (n = 24, female and male, M_{age} = 23.4 years, age range: 19-29 years) found that isokinetic strength testing at all speeds for dorsiflexion (30, 60, 120, 180, and 240 deg/s) showed greater declines in comparison to isometric strength testing in the OA (Thelen, Schultz, Alexander, & Ashton-Miller, 1996). The disparity in findings between the middle-age adults' studies may suggest that increasing speed may be more challenging to recruitment of motor units and a better determinant of age-related decline in strength of the dorsiflexors of the ankle.

Changes in muscles strength in the middle-age adults occur not only in the sagittal plane but in the frontal plane as well as seen in the hip abductors and adductors. Surprisingly, in spite of the functional importance of these muscles for frontal plane balance (MacKinnon & Winter, 1993) in relationship to fall prevention during walking (Sato et al., 2002) there is a scarcity of research related to them in both middle-age and older adults. The most important factor affecting frontal plane whole body balance is the mediolateral foot position in relationship to COM, which is determined by hip abductors/adductors during swing (MacKinnon & Winter, 1993). In a study looking at the abductors/adductors, the middle-age adults (20 males, 20 females, age range: 40-55 years) were found to have significantly decreased abduction/adduction isometric torque compared to the younger adults (20 males, 20 females, age range: 18-33 years, $p < .01$) (Murray & Sepic, 1968). In a more recent study, hip abductor isometric torque was significantly lower in the middle-age and older adults ($p < .001$) than in the younger adults (Trudelle-Jackson et al., 2011). Similarly, Cahalan et al. (1989) found similar differences in abduction/adduction isometric and isokinetic strength at 30, 90, 150 and 210 deg/s between younger adults ($n = 18$, males $M_{age} = 28$ years, age range: 20-39, $n = 21$, females $M_{age} = 27$ years, age range: 20-39 years) and middle-age adults ($n = 17$, males $M_{age} = 54$ years, age range: 40-81 years, $n = 16$, females $M_{age} = 53$ years, age range: 40-64 years). The reductions in isometric and isokinetic torques in the hip abductors/adductors in the middle-age adults are potential factors in lateral instability in terms of their role in controlling foot position, as well as, altering head, arm and trunk position (MacKinnon & Winter, 1993) to control the COM within the BOS while taking a step forward.

During the transition from a double leg support (DLS) to a single leg support (SLS) the head, arm and trunk (HAT) in the frontal plane need to be controlled since the COM rapidly falls towards the unsupported swing side. If frontal plane muscular control is compromised then increased postural sway may occur. The postural system depends on the integrity of the visual, vestibular, somatosensory and musculoskeletal system to work together. Sensory organization tests (SOT) of computerized dynamic posturography (CDP) can be used to quantify an individual's change in body position and movement control altering visual, vestibular and somatosensory input. During static balance testing using the SOT, the middle-age adults ($n = 27$, $M_{age} = 50.9$ (*SD*) 5.7 years, age range: 40-59 years) were found to have significantly lower scores (somatosensory input middle age adults 81.7 %(*SD*) 6.9, vs. younger adults 87.6 % (*SD*) 6.9, $p < .01$; visual middle-age adults 65.0 % (*SD*) 10.4 vs. younger adults 74.9

% (*SD*) 8.0, $p < .01$; visual + somatosensory middle-age adults 65.1 % (*SD*) 11.0 vs. younger adults 72.0 % (*SD*) 11.6, $p < .01$) for maximal stability (score ranged from 100 % being the best to 0 % lowest) compared to the younger adults ($n = 45$, $M_{age} =$ 25.2 (*SD*) 5.6 years, age range 16-39 years) (Liaw et al., 2009). Previous studies in older adults (fallers and non-fallers) found that there was a strong link between balance and increased medial-lateral stability and increased risk of falling (Maki, Holliday, & Topper, 1994). The reductions in hip abductor/adductor strength and the effect on medial-lateral stability in the middle age adults may play a pivotal role in future falls.

The ability to maintain medial-lateral stability involves not just controlling displacement in a certain direction but also the speed in which one moves in that direction. Liaw et al. (2009) used a test called rhythmic weight shift (RWS) test, in addition to conducting the SOT with the middle-age adults, to measure the on-axis velocity (deg/s) to see how well middle-age adults could lean or shift weight over a stable surface compared to younger adults. The on-axis velocity was significantly reduced in the middle-age adults ($n = 27$, $M_{age} = 50.9$ (*SD*) 5.7 years, age range: 40-59 years; on-axis velocity 2.7 (*SD*) 0.9 deg/s) compared to the younger adults ($n = 45$, $M_{age} = 25.2$ (*SD*) 5.6 years, age range: 16-39 years; on-axis velocity 3.4 deg/s (*SD*) 0.7 deg/s). Other studies in older adults ($n = 38$, $M_{age} = 74$ (*SD*) 6.8 years) found that the rate of hip abduction/adduction torque development was declined compared to younger adults ($n = 38$, $M_{age} = 23$ (*SD*) 1.3 years) in a range of 40 % in both muscles comparatively (Johnson, Mille, Martinez, Crombie, & Rogers, 2004). This impairment in the time to reach maximal muscle force would have an influence on balance recovery when faster limb movements were required for recovery of balance. On-axis velocity showed the speed of the movement in the intended direction to be reduced in the middle-age adults. This suggests that at faster speeds the middle-aged adults may be further impaired in shifting in a certain direction. The effect on medial-lateral displacement in combination with speed in the middle-age adults during a functional activity, such as stepping, is still unknown.

Gait Initiation

Gait initiation, a time period during walking, is a period when the body moves from a static state standing to a dynamic state of walking (Mickelborough et al., 2004). It involves a combination of biomechanical requirement as well as a predictable pattern of muscle activations. Previously, gait initiation has been used to identify both neuromuscular and biomechanical deficits (Polycn et al., 1998) as well as to discriminate between nondisabled and disabled older adults (Chang & Krebs, 1999). The goal of gait initiation is to generate momentum, through muscle activation at the ankle and displacement of ground reaction forces, while minimizing disturbance to balance. The correlation between muscle activation and biomechanical displacement becomes stronger as speed increases. In light of this relationship, gait initiation may serve to provide insight into the effects of speed on biomechanical displacement and neuromuscular timing in the lower extremities in the middle-age adults.

The main biomechanical requirements are to shift the net Center of Pressure (COP) in both a lateral direction and a posterior direction toward the swing leg (Crenna & Frigo, 1991, Elble et al., 1994). This shift in COP posteriorly and laterally increases the ground reaction forces toward the stance leg causing the COM to move toward the stance leg and anteriorly, therefore, gradually increasing the momentum in that direction (Polycn et al., 1998). This approach to generating momentum minimizing the disturbance to the Center of Mass (COM) by keeping it within the base of support (BOS), in turn, maximizing the ability to maintain balance.

Momentum is driven by the displacement of the COP in the posterior/lateral direction, which creates a distance between the COP and COM, creating what is known as the COM-COP distance. The increase COM-COP distance results in a greater momentum forward (Honeine et al., 2014). The posterior displacement of the COP is driven by the contraction bilaterally of the TA muscles, in conjunction, with the inhibition of the gastrocnemius (GA)/soleus muscles (SOL) (Polycn et al., 1998). The peak TA amplitude has been correlated in younger adults (n = 6, M_{age} = 22.5 (*SD*) 1.5 years) with the amount of posterior displacement (R = .82 swing leg, R = .71 for stance leg); this relationship is stronger with increasing stepping speed (Crenna & Frigo, 1991). Understanding how amplitudes and speed effect posterior displacement of the COP may give us information on the effects of aging on generating momentum forward.

Unlike the posterior displacement, the muscles responsible for the lateral displacement of the COP continue to be debated. The displacement laterally of the COP toward the swing leg causes the COM to move towards the stance leg and forward in preparation for lifting the swing leg up (Elble et al., 1994). In a study using quiet standing (Winter, Patla, Ishac, & Gage, 2003) and gait initiation (Kirker et al., 2000), both studies found the abductor/adductor to be responsible for lateral displacement of COP. In the gait initiation study, the control subjects (*n* = 16, M_{age} = 46 years) initiated lateral displacement of the COP at a normal self-selected toward the swing leg by using the gluteus medius (GM) of the swing leg and the adductors (ADD) of the stance leg.

Contrary to the middle-age adults control subjects in Kirker et al. (2000), other researchers found the middle-age adults (*n* = 9, M_{age} = 52.3 (*SD*) 8.3 years) displayed significantly decrease occurrences of GM of the swing leg compared to younger adults (*n* = 9, M_{age} = 22.1 (*SD*) 2.6 years) at a fast step (Chu et al., 2009). Similarly, a study with only older adults found that only three-quarters of the subjects displayed GM activity on the swing leg. (Mickelborough et al., 2004). Other researchers suggest that swing leg MG along with flexion of the stance hip and knee contribute to the early lateral movement of the COP toward the swing leg (Elble et al., 1994). To date specific contributions of the lower extremity musculature involved in the salient lateral movement of the COP is still unknown in the middle-age adults.

Age-related Declines in Gait Initiation

The change from a static standing position to a stepping movement offers a unique opportunity to assess balance. Researchers can measure physiological strength and torque and sensory-motor systems separately yet it doesn’t give the same insight as measuring a functional activity, such as stepping, and how those systems react synchronously. A volitional step can be both task driven such as to initiate walking as well as protective to step out of someone’s way. The age-related changes that are measured in the following studies during this time period may reflect the physiological changes in the older adults and an opportunity to identify early signs of decline in the middle-age adults.

In Crenna and Frigo (1991), six healthy younger adults (*n* = 6, M_{age} = 22.5 (*SD*) 1.5 years) showed that gait initiation began with the COP shifting backward in response to the SOL muscle inhibition and TA activation bilaterally. The researchers found a good correlation between amplitude of the TA burst and the amount of posterior displacement of COP during gait initiation (*R* = .82 for swing leg, *R* = .71 for stance leg) and velocity of movement (*R* = .73); the expression of this relationship increased with speed. In agreement, Polycn et al. (1998) found the time integral of the posterior shift generated by the TA was highly correlated with the amount of momentum (younger adults *r* = .96 (*SD*) .01, older adults *r* = .94 (*SD*) .05) and walking speed (YA *r* = .88 (*SD*) .07, OA *r* = .78 (*SD*) .12) generated forward in both the younger and older adults.

In a study with older adults (*n* = 10, M_{age} = 60.9 years, age range: 56-65 years) compared to younger adults (*n* = 10, M_{age} = 27.1 years, age range: 22-37 years), the older adults showed a significantly less posterior displacement of COP (COPx) while initiating a step at a normal self-selected gait speed (Halliday et al., 1998). As a result, the older adults COM velocity was slower at the toe off of the swing leg and later during the end of the second step. Unlike the older adults, Chu et al. (2009) found the COPx in the middle-age adults (*n* = 9, M_{age} = 52.3 (*SD*) 8.3 years) was not significantly different yet tended to be smaller (effect size = 0.7; *p* = 0.15) and the step velocity (younger adults step velocity = 135.7 (*SD*) 30.8 cm/s, middle-age adults step velocity = 119.9 (*SD*) 23 cm/s) showed a trend in being slower than the younger adults (n = 9, M_{age} = 22.1 (SD) 2.6 years). The middle-age adults also displayed co-contraction of the biceps femoris (BF) and rectus femoris (RF) at the knee that the researchers felt may explain the decreases in COP posteriorly. Similar co-contraction as seen in the older adults with reduction in SOL inhibition would impede the TA activity to displace the COP posteriorly (Polycn et al., 1998).

The frequency of this relationship between the SOL inhibition and TA activation was significantly reduced in older adults (Polycn et al., 1998). The older adults' (9 males, 11 females, M_{age} = 72 years, age range: 64-80 years) compared to younger adults' (10 males, 10 females, M_{age} = 25 years, age range: 18-29 years), during slow, normal and fast gait speeds, did not inhibit the SOL/GA before activation of TA. Similarly, two other studies (Elble et al., 1994; Mickelborough et al., 2004) found the older adults continue to frequently fire the GA/SOL of the swing leg earlier during a normal self-selected (Mickelborough et al., 1994; older adults only n = 21, M_{age} = 70.77 years) and a fast step (Elble et al. older adults, n = 6, M_{age} = 74 years, age range: 64 to 82, younger adults n = 5, M_{age} = 29 years, age range: 22-47 years) forward. In contrast, the one study with middle-age adults (6 males, 3 females, M_{age} = 52.3 (SD) 8.3 years) compared to younger adults (6 males, 3 females, M_{age} = 22.1 (SD) 2.6 years) did not find early activation of the MG during a fast step forward (Chu et al., 2009). The variation in GA early activation may be a result of the influence of the motor demands during the stepping procedure in controlling the COM velocity vertically during gait initiation (Honeine et al., 2014).

The GA modulates the position of the COM relative to COP, referred to as the COM-COP distance. This distance is the determinant for the propulsive force to move forward and for walking velocity (Honeine et al., 2014). The older adults compared to the younger adults show a trend of reduction in the COM-COP distances during normal self-selected gait speed (Martin et al., 2002). The earlier activation of GA would explain the reduction in the COM-COP in the older adults due to its influence on the COM displacement. The relationship between the GA activity, COM and COM-COP distances has not been investigated in terms of the middle-age adults.

A study was done looking at the influence of visual, somatosensory inputs and motor demands on braking of the COM fall during initiation of gait using younger adults (9 males, 13 females, M_{age} = 37.9 (*SD*) 12.2 years) (Chastan et al., 2010). The subjects were asked to initiate gait at a normal self-selected speed on a force plate and with an interposed foam-rubber mat with eyes both open and closed. In the altered somatosensory trial, the younger adults' stance leg muscle activity was modified with an increase in both the TA and the SOL activity before foot-off of the swing leg. Another study shows older adults to have decreased static postural stability due to altered visual, vestibular and somatosensory inputs that may explain the earlier activation of the SOL/GA as seen in previous gait initiation studies in older adults; similar decreases in static postural stability were also found in the middle-age adults (Liaw et al., 2009).

In Chastan et al. (2010), six healthy subjects were used to look at motor demands of the SOL during gait initiation using normal gait (NG, five steps), late gait interrupted (LGI, two steps) and early-gait interrupt (EGI, one step) conditions as measured by the brake index, a measure of COM control by the SOL. The brake index was defined as the absolute ([maximum value COM velocity (V1) - foot contact velocity (V2)] /V1. The EGI condition, where the subjects were asked not to raise the trailing leg, was found to have a significantly decreased braking index compared to the other two conditions where the trailing foot left the ground. In the study, the stance leg SOL was correlated with braking and related to postural control. The researchers hypothesis for the decrease braking index in the EGI condition was that by not needing to lift the trailing leg, as seen in the middle age adults' study by Chu et al. (2000), the stance leg SOL didn't need to raise the COM to prepare for the next step. This change in the level of demand placed on the SOL in controlling the COM in the sagittal plane as the trailing leg was lifted in the older adults may explain the early activation in the SOL/GA in the older adults as oppose to in the middle-age adults.

Not only does the COM shift forward in the sagittal plane but it also moves laterally in the frontal plane (Elble et al., 1994). The shift of the COP towards the swing leg (COPy) displaces the COM in the frontal plane toward the stance leg. The displacement of COPy (younger adults COPy = 3.63 (*SD*) 0.9 cm, older adults COPy = 2.91(*SD*) 1.1 cm) in the frontal plane was not found to be significantly different in OA (n = 10, $M_{age =}$ 60.9 years) compared to younger adults (n = 10, M_{age} = 27.1 years) during gait initiation at normal self-selected speed (Halliday et al., 1998). At a fast step, the middle age adults were found to have similar COPy displacements (younger adults COPy = 7.4 cm, middle-age adults COPy = 7.6 cm) in the frontal plane compared to younger adults (Chu et al., 2009). Stepping at a slow, normal and fast speed, the time integral of the lateral COPy shift and the amount of momentum generated in the direction of the stance limb was highly correlated in a study with older adults (9 males, 11 females, M_{age} = 72 years, age range: 64-80 years) and younger adults (10 males, 10 females, M_{age} = 25 years, age range: 18-29 years) (Polycn et al., 1998). There is still controversy over the frontal plane musculature active during displacement of the COPy. Mickelborough et al. (2004) measured surface EMG in older adults (10 males, 11 females, M_{age} = 70.77 (*SD*) 3.48 years) without a control group during gait initiation at a normal self-selected speed. A quarter of all the subjects did not appear to use swing leg GM at the start of gait initiation. Similarly in Chu et al. (2009), the middle-age adults had a significantly lower rate of occurrence in the GM of the swing leg ($p < .05$, effect size = 1.2) and a higher occurrence of erector spinae ($p < .01$, effect size = 1.8) compared to younger adults. Previous studies have suggested other muscle(s) might be involved with lateral displacement of the COP. Therefore more research is needed to investigate this issue.

Chapter III

METHODS

Subjects

The Seton Hall University Institutional Review Board (SHU-IRB) reviewed and approved the study. Potential subjects responded to flyers posted throughout the Seton Hall University community. The volunteers contacted the primary investigator (PI) via phone to explain procedures and describe criteria for inclusion in the study. If the subject met the inclusion criteria, a date, time and location for the study were given. Data collection was performed in one session for about 1½ hrs for each subject from January 2014 to June of 2014 at Seton Hall Human Functional Performance Laboratory. Once the subjects arrive at the Seton Hall Functional Performance Laboratory, each subject read and signed the informed consent form after all potential questions were answered.

Younger adults (YA) (4 males, 11 females, M_{age} = 25.0 years, age range: 18-35 years) and middle-aged adults (MA) (5 males 10 females, M_{age} = 57.5 years, age range: 50-67 years) without disabilities or musculoskeletal impairments were recruited for this study. In the data analysis six MA and two YA were excluded due to data acquisition issues. This sample of convenience from the Seton Hall University received screening for inclusion and exclusion criteria.

For normal walking, textbooks report 60° of knee flexion (Levangie & Norkin, 2005) and 10° of dorsiflexion is required for normal walking (O'Sullivan, Schmitz, and Fulk, 2014). In this study, ankle dorsiflexion with knee bent with a minimum of 5° at the ankle and knee flexion at 60° and less than or equal to 10° of knee straightening was necessary for inclusion in the study.

Inclusion Criteria. Subjects were included in the study if they: (a) were between the two age groups 18-35 and 50-70 years old; (b) an independent community ambulator, as determined by screening questions; (c) have active knee range of motion of 60° or greater for knee bending and less than or equal to 10° of knee straightening; (d) active ankle flexibility of 5° or greater for dorsiflexion and 20° of plantarflexion; (e) leg length discrepancy no greater than 1.9 cm; and (f) be free of pain in the lower extremities on day of testing.

Exclusion Criteria. Subjects were excluded if they: (a) had any recent history for the past six months of trauma to the lower back or extremities including fractures, severe sprains, or surgeries including joint fusions or history of lower extremity joint replacement; (b) use an orthoses/splints, assistive device or aide from another; (c) visual or vestibular dysfunction resulting in decreased balance or walking; (d) limiting cardiovascular, neurological or respiratory problems; (e) blood pressure greater than 160/100 or less than 90/50; (f) individuals with a history of two or more falls in the last six months; and (g) individuals who are defined at legally blind or who are visually limited such that they cannot see clearly enough to ambulate independently, walk without assistance or perceive the change of a light turning on 5 feet away from them.

Following the interview, subjects had blood pressure, leg length and active range of motion of the knee and ankle to verify cardiac and musculoskeletal inclusion/exclusion criteria. Lastly, height and weight measurements were captured for all participants. All subjects who qualified for the study were assigned a number code before beginning data collection to maintain anonymity.

Procedures

The subject had his or her blood pressure measured using a standard blood pressure cuff. The subject had blood pressure taken on his or her right arm, unless a medical reason called for the other arm, in a seated position with the arm at 90° of flexion with the elbow straight. If systolic blood pressure was above 160 or below 90, the subject was excused. If diastolic blood pressure was above 100 or below 50, the subject was excused. Subjects were advised to follow up with his/her physician if blood pressure was too high or low. No subjects presented with the need to follow up with his or her doctor.

Next, each subject, with footwear donned (sneakers or laced shoes), had his or her leg length measured in standing. The investigator obtained bilateral measures of leg lengths, in centimeters, using a steel tape measure placed against the subject's greater trochanter and then measuring the vertical distance from this body landmark to the floor, bisecting the lateral malleolus (Cutlip, Mancinelli, Huber, & DiPasquale, 2000).

Furthermore, the subject had his or her active knee and ankle range of motion measured bilaterally in degrees, using a plastic goniometer placed against the subject's skin or clothing. The PI demonstrated knee flexion and extension for the subjects. Subjects were supine on padded table positioned with the knee to be measured maximally bent and the foot flat on the table to measure knee flexion. This protocol is standard physical therapy measurement as described by Norkin and White (2009). The anatomical landmarks were the greater trochanter for the stationary arm, the knee joint for the fulcrum and the lateral malleolus for the movement arm of the goniometer. The subject was asked to bend the knee back as far as possible. While in the same position the subject was asked to straighten the knee fully to measure knee extension.

The subject then sat on the table with the knee bent at least 90° and foot in a neutral position to measure ankle dorsiflexion and plantarflexion. The anatomical landmarks were the head of the fibula for the stationary arm of the goniometer, the lateral malleolus for the fulcrum while the movement arm of the goniometer was aligned parallel to the fifth metatarsal shaft of the foot. The PI demonstrated actively ankle motions for the subjects. The subjects then actively pointed the foot upward to measure dorsiflexion and downward to measure plantarflexion (Norkin & White, 2009). A 3-min rest period followed range of motion measurements. If all the measurements were consistent with the criteria, the subjects were included in the study.

Subjects had his or her body weight measured twice using a scale and height measured in standing using a wall-mounted tape measure. Body weight was recorded using a standard bathroom scale measured in pounds and converted into kilograms. Each subject stepped onto a scale two times; the average then calculated. Each subject stood with his or her back to the wall where a tape measure had been secured to the wall to measure height in centimeters. Height was determined by placing a piece of cardboard atop the person's head at a right angle to the tape measure. A 3-min rest period was given following all these measurements.

Design, Independent and Dependent Variables. The study used a mixed quasi-experimental design with two factors: between (age) and within (speed) subjects repeated measures. The dependent variables included the distances of the COPx in the sagital plane and COPy in the frontal plane, the COM-COP distances, and the surface EMG activity of four lower extremity muscles identifying onset/offset times and average amplitude.

Measurements. The researcher cleaned the skin on shins, calves, and thighs and on each side of the outer trunk just below the waistline with soap and water using a paper towel. The skin was dried thoroughly with a paper towel. When necessary, excessive hair was cut with a blunt tipped scissor in the same areas that were cleaned prior to the placement of the surface EMG electrodes. Four electrodes to record the electrical activity were attached to motor points on each leg and the lateral hip region. Double-sided tape was used to attach the surface EMG electrodes to four large muscle groups bilaterally including gluteus medius (GM), hip adductor group (inner thigh muscle) (ADD) as well as the tibialis anterior (TA) and medial gastrocnemius (MG) (Cram, Kasman, & Holtz, 2011). The ground electrode was placed over the outside of the right or left elbow.

To compare the data from the electrodes between subjects, the Maximum Voluntary Contractions (MVCs) were determined using standard measures of strength in each of the four muscles on both legs (Hislop & Montgomery, 2002). For the GM muscle, subjects were positioned side-lying on a table and were asked to raise the leg in the air and hold for 5 s while the researcher pushed the leg down toward the table. For the ADD muscle the subject was in the same side-lying position on a table with the researcher supporting the upper leg up toward ceiling at approximately 25° while the subject lifted the bottom leg up in the direction of the upper leg. The researcher then resisted the movement on the medial aspect of the thigh of the bottom leg (Reese, 2005). For the TA muscle, subjects sat up on the table with the heel resting on the researcher's leg with the knee slightly bent. Subjects were asked to bring the foot up and in and then hold this position for 5 s as the researcher pressed the foot down and out. For the MG muscle, subjects stood on one foot with two fingers on a table for support and were asked to raise the heal from floor and hold for 5 s. There was a 3-min rest period following manual muscle testing of MVCs.

Next, the researcher demonstrated normal self-selected stepping for the subject while standing on the GAITRite® mat. The subject was then asked to stand on the GAITRite® mat with the electrodes in place and perform three practice trials of taking three steps at normal self-selected speed. In an effort to enhance between trial consistencies, the subject's feet were outlined on the GAITRite® mat and the outline was used prior to the start of each new trial for foot placement. The leading foot found during two of the three practice trials was determined, and this foot, right or left, was then used as the leading foot for all other trials. The subject initiated forward walking at a normal self-selected speed once a 2 x 3 inch light trigger, located 5 feet in front of the subject at table height, was activated. The light triggered an electronic event marker for both collecting information from the GAITRite® mat and surface EMG and was activated by the PI. For each subject, three practice trials were followed immediately by 10 data collection trials for normal self-selected stepping. A research assistant walked along with the subject parallel to the carpet during the trials in case the subject needed assistance. Subjects had a 45 s rest between each trial, with a 1-min rest after the practice trials, and also a 3-min rest period between the two different walking speed trials.

During the 3-min rest after normal self-selected gait trials, the PI demonstrated fast stepping for the subject while standing on the GAITRite® mat. The subject was then asked to stand on the GAITRite® mat with the electrodes in place and perform three practice trials of taking three steps at a fast walking speed. The leading foot, left or right, was determined from the previous normal self-selected gait trials. Identical to the normal self-selected speed, subjects had three practice trials, followed by 10 data collection trials for the fast walking speed. The research assistant again walked along with the subject parallel to the carpet and subjects had the same rest sequences.

Instrumentation

GAITRite® computerized system. Center of Pressure in both sagittal COPx and frontal COPy planes as well as the COM-COP distances were recorded using the GAITRite® Platinum computerized walkway (CIR Systems Inc.; Sparta NJ) and ProtoKinectics Movement Analysis Software-PKMAS (ProtoKinetics; Havertown PA, 2012). The mat was connected to a serial port to an IBM computer running the PKMAS software on a Windows 7 operating system. The stepping data was captured at a sampling frequency of 200 Hz.

Electromyography. Biometrics DataLINK900 (Biometrics Ltd; Newport, UK) is a Data Acquisition System that allows collection both analog and digital data from active surface EMG sensors. Eight channels were used to collect data from four muscles of the lower extremities: GM, ADD, TA and MG. Sampling frequency was at 1,000 samples/channel/s. All data was filtered with root mean square (RMS) using 100 ms. The high/low pass filter range was 15 Hz to 450 Hz. A sliding window of 100 ms was used to calculate maximum voluntary contraction. The base unit connects to the PC using a USB port where the data was exported to Microsoft Excel.

Data Analysis. G*power software (Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G., 2009; Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A., 2007) provided the software to calculate sample size from the pilot study and afterwards the power analysis. It was determined in a pilot study that a minimum of 30 subjects was more than necessary to demonstrate significance with an α of 0.5.

Descriptive statistics (primarily mean, standard deviation, range) was used to describe demographic variables such as age, leg length, height, and weight. Descriptive Statistics was also determined on the major dependent variables to describe normality of data.

To determine COP & COM-COP distances, the PKMAS software captured the data that was then exported to Microsoft Excel (Microsoft, 2011). The onset and offset of the EMG activity of each of the muscles was recorded and to determine average amplitude of the surface EMG data it was normalized first using the Maximal Voluntary Contraction (MVC). Excel was used to perform calculations for normalizing data. Means of at least three to maximum of five trials of the 10 trials performed for each condition was determined and then exported for further analyses into The Statistical Package for the Social Sciences (SPSS) software, version 22 for Mackintosh (IBM Corp., 2013).

Intraclass Correlation Coefficients (ICCs) and Cronbach's Alpha were to measure intra trial reliability of all variables. Portney and Watkins' (2009) guidelines are ICCs that are .75 and above show good reliability and those below .75 are moderate to poor. Cronbach's Alpha scale for strong reliability is .70 to .90.

For all hypotheses, a mixed design was the most appropriate design to determine difference in COP, COM-COP and surface EMG dependent variables since the study incorporates two independent variables, one repeated across all subjects (within) and the other randomized to independent groups (between) (Portney & Watkins, 2009).

Chapter IV

RESULTS

Subjects and Demographics

Nine middle-aged adults (MA) and thirteen younger adults (YA) participated in this study. Participant demographics, range of motion and leg lengths, which were related to the inclusion and exclusion criteria, are presented in Tables 1, 2 and 3. Considering the groups, the MA were significantly overweight (p =. 017) with a slightly significantly higher BMI (p = .045) and lower bilateral ankle dorsiflexion (DF) range of motion (ROM) compared to the YA (R ankle p = .006, L ankle p = .004). MA showed a trend of being taller compared to YA but not significantly different (p = .095). Ankle PF and knee range of motion were not significantly different between the YA and the MA.

Table 1

Descriptive Statistics

Demographic	Younger adults			Middle-age adults		
	Total n = 13	Female n = 9	Male n = 4	Total n =9	Female n = 4	Male n = 5
Mean age (SD)	25.5(4.4)	25.3(4.6)	25.8(4.9)	54(3.0)	53.0(2.0)	54.8(3.6)
Range	19-35	19-35	21-32	52-61	52-56	52-61
Height (cm) (SD)	169(7.4)	167(6.8)	175(4.2)	176(11.0)	168(9.4)	182(8.1)
Weight (kg) (SD)	67.3(12.9)	62(5.3)	84.3(14.0)	83.2(15.1)	72(15.8)	92(6.8)
BMI (kg/cm) (SD)	23.5(3.8)	22.4(2.0)	27.5(4.5)	26.7(3.3)	25.4(4.2)	27.7(2.2)

Table 2

Range of Motion for the Knee and Ankle Joints

	Younger adults M (SD)			Middle-age adults M (SD)		
Joint (deg)	Total n = 13	Female n = 9	Male n = 4	Total n = 9	Female n = 4	Male n = 5
Knee flex R	141(4.9)	142(4.6)	134(6.6)	140(4.4)	142(5.0)	139(4.1)
Knee flex L	142(6.1)	144(5.5)	133(6.2)	140(5.4)	143(5.7)	138(5.0)
Knee ext R	1(2.1)	2(1.2)	- 0.25(2.0)	2(2.0)	2.5(1.3)	- 0.2(1.8)
Knee ext L	2(2.0)	3(1.3)	- 0.25(2.1)	1(2.8)	3(2.2)	- 0.2(2.5)
Ankle DF R	22(2.6)	22(2.6)	17(3.5)	15(4.8)	15(3.8)	16(5.8)
Ankle DF L	21(3.6)	22(3.1)	17(3.0)	15(3.9)	15(3.6)	16(4.6)
Ankle PF R	52(6.5)	54(5.2)	46(4.3)	48(6.9)	52(7.5)	44(4.2)
Ankle PF L	49(5.0)	50(3.5)	45(5.8)	48(4.7)	50(5.3)	46(4.3)

Note. flex = flexion; ext = extension; DF = dorsiflexion; PF = plantarflexion.

Table 3

Leg Length for the Right and Left Leg

	Younger adults M (SD)			Middle-age adults M (SD)		
Leg length	Total n = 13	Female n = 9	Male n = 4	Total n = 9	Female n = 4	Male n = 5
Leg length (R) cm	86.3(3.8)	86(4.2)	87.0(2.2)	91.2(6.1)	86.8(5.0)	95(4.9)
Leg length (L) cm	85.4(3.8)	85(4.3)	85.7(2.2)	90.8(3.8)	86.6(4.2)	94(4.5)

Reliability

Balance Variables. Intraclass Correlation Coefficients (ICCs) and Cronbach's Alpha for the MA and YA at a normal self-selected and fast speed ranged from moderate to excellent for COPx, COPy and COM-COP as seen in Table 4.

Table 4
Reliability for Balance Variables at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Balance Variables	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
COPx				
Normal	0.99	0.99	0.68	0.68
Fast	0.95	0.95	0.89	0.89
COPy				
Normal	0.97	0.97	0.99	0.99
Fast	0.99	0.99	0.99	0.99
COM-COP				
Normal	0.92	0.92	0.95	0.95
Fast	0.95	0.95	0.86	0.86

EMG Variables. For the majority of EMG variables, the ICCs and Cronbach's Alpha for the MA and YA at a normal self-selected and fast speed ranged from moderate to excellent as shown in Tables 5 to Tables 12. However, some of the variables were found to have poor reliability as shown in Table 7 and Table 8.

Table 5
Reliability for Onset times for the Stance Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.86	0.86	0.88	0.88
Fast	0.82	0.82	0.82	0.82
MG				
Normal	0.66	0.66	0.63	0.63
Fast	0.84	0.84	0.58	0.58
ADD				
Normal	0.90	0.90	0.98	0.98
Fast	0.94	0.94	0.98	0.98
GM				
Normal	0.84	0.84	0.90	0.90
Fast	0.86	0.86	0.85	0.85

Table 6
Reliability for Onset times for the Swing Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.89	0.89	0.86	0.86
Fast	0.83	0.83	0.90	0.90
MG				
Normal	0.87	0.87	0.93	0.93
Fast	0.91	0.91	0.82	0.82
ADD				
Normal	0.91	0.91	0.91	0.91
Fast	0.97	0.97	0.94	0.94
GM				
Normal	0.84	0.84	0.80	0.80
Fast	0.87	0.87	0.99	0.99

Table 7

Reliability for Offset times for the Stance Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.70	0.70	0.08	0.02
Fast	0.67	0.67	-0.01	-0.01
MG				
Normal	0.85	0.85	0.52	0.52
Fast	0.64	0.64	0.31	0.31
ADD				
Normal	0.77	0.77	0.76	0.76
Fast	0.81	0.81	0.91	0.91
GM				
Normal	0.53	0.53	0.87	0.87
Fast	0.68	0.68	0.56	0.56

Table 8

Reliability for Offset Times for the Swing Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.67	0.67	0.71	0.71
Fast	0.51	0.51	0.55	0.55
MG				
Normal	0.82	0.82	0.80	0.80
Fast	0.78	0.78	0.71	0.71
ADD				
Normal	0.74	0.74	0.76	0.76
Fast	0.87	0.87	0.95	0.95
GM				
Normal	0.82	0.82	0.91	0.91
Fast	0.89	0.89	-0.21	-0.21

Table 9
Reliability for Average Amplitude (COPx) for the Stance Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.91	0.91	0.45	0.45
Fast	0.90	0.90	0.85	0.85
MG				
Normal	0.71	0.71	0.48	0.48
Fast	0.96	0.96	0.76	0.76
ADD				
Normal	0.97	0.97	0.87	0.87
Fast	0.81	0.81	0.95	0.95
GM				
Normal	1.00	1.00	0.93	0.93
Fast	1.00	1.00	0.97	0.97

Table 10
Reliability for Average Amplitude (COPx) for the Swing Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.94	0.94	0.86	0.86
Fast	0.92	0.92	0.92	0.92
MG				
Normal	0.89	0.89	0.81	0.81
Fast	0.94	0.94	0.90	0.90
ADD				
Normal	0.98	0.98	0.92	0.92
Fast	0.85	0.85	0.95	0.95
GM				
Normal	0.95	0.95	0.66	0.66
Fast	0.94	0.94	0.95	0.95

Table 11
Reliability for Average Amplitude (COPy) for the Stance Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.90	0.90	0.96	0.96
Fast	0.96	0.96	0.98	0.98
MG				
Normal	0.93	0.93	0.92	0.92
Fast	0.96	0.96	0.89	0.89
ADD				
Normal	0.97	0.97	0.96	0.96
Fast	0.95	0.95	0.93	0.93
GM				
Normal	1.00	1.00	0.96	0.96
Fast	1.00	1.00	0.96	0.96

Table 12
Reliability for Average Amplitude (COPy) for the Swing Leg Muscles at a Normal Self-Selected and Fast Gait Speed

	Younger adults		Middle-age adults	
Muscle	Cronbach's Alpha	ICC	Cronbach's Alpha	ICC
TA				
Normal	0.94	0.94	0.98	0.98
Fast	0.98	0.98	0.98	0.98
MG				
Normal	0.92	0.92	0.88	0.88
Fast	0.94	0.94	0.94	0.94
ADD				
Normal	0.98	0.98	1.00	1.00
Fast	0.95	0.95	0.98	0.98
GM				
Normal	0.99	0.99	0.71	0.71
Fast	1.00	1.00	0.83	0.83

Balance Variables and Gait Initiation Duration

Mean values for GI duration, COPx, COPy and COM-COP distances at a normal self-selected and fast speed are found in Table 13 and 14. The YA and MA were not significantly different in gait initiation (GI) duration or COPx distances as shown in Table 15. As the YA and MA went faster both groups significantly decreased their COPy distances and significantly increased their COM-COP as shown in Table 15.

Table 13
Gait Initiation Mean Duration and Balance Variables Mean Distances at Normal Self-Selected Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
GI duration (s)	0.89(.17)	0.94(.18)
Distances		
COPx (cm)	7.52(1.41)	6.81(1.46)
COPy (cm)	2.70(3.60)	0.98(4.73)
COM-COP (cm)	6.38(1.38)	6.38(2.09)

Table 14
Gait Initiation Mean Duration and Balance Variables Mean Distances at a Fast Speed

Variables	Younger adults *M* (*SD*)	Middle age adults *M* (*SD*)
GI duration (s)	0.83(.14)	0.93(.23)
Distances		
COPx (cm)	7.35(2.13)	7.65(2.31)
COPy (cm)	2.04(4.04)	0.74(4.42)
COM-COP (cm)	7.52(1.41)	6.81(1.46)

Table 15
Within, Between and Interaction Effects for Balance Variables and Gait Initiation Duration

Variable	*df*	*F* value	*p* value	Effect size
GI duration				
Speed	(1,20)	1.87	.19	0.30
Age	(1,20)	1.18	.29	0.24
Speed*Age	(1,20)	1.43	.25	0.27
COPx				
Speed	(1,20)	0.31	.58	0.12
Age	(1,20)	0.14	.71	0.08
Speed*Age	(1,20)	0.71	.41	0.19
COPy				
Speed	(1,20)	4.73	.04*	0.49
Age	(1,20)	0.72	.41	0.19
Speed*Age	(1,20)	1.01	.33	0.22
COM-COP				
Speed	(1,20)	14.33	.001*	0.85
Age	(1,20)	0.29	.59	0.12
Speed*Age	(1,20)	2.96	.10	0.38

* $p < .05$

Electromyography

Onset and Offset Times. In general, at the start of gait initiation bilateral MG were inhibited and bilateral TA were activated at both a normal self-selected and fast gait speed as shown in Figure 1 and Table 16 to Table 19. However, the TA on the swing leg shuts off significantly later as the MA stepped faster compared to the YA as seen in Figure 1 and Table 20 (Mean TA offset times swing leg at normal and fast speed as shown in Table 17 & Table 19). In addition, the MG on the stance leg activated significantly earlier as the MA stepped at a faster speed compared to the YA as seen in Figure 2 and Table 21 (Mean MG onset times stance leg at normal and fast speed are shown in Table 16 & Table 18). Both groups turned on the TA on the stance leg significantly earlier and shut off the MG on the stance leg earlier as they went faster as seen in Table 21 (Mean TA onset times and MG offset times for the stance leg at a normal and fast speed are shown in Table 16 and Table 18).

In the hip region during gait initiation, both groups significantly turned on and shut off earlier the ADD of the swing leg as they stepped faster as shown in Table 20 (Mean onset times and offset times for ADD of the swing leg at a normal and fast speed are shown in Table 17 and Table 19). There were no significant differences between MA and YA for onset and offset times for the GM for both the stance and swing leg as seen in Table 20 and Table 21 (Mean values for GM for stance and swing leg at a normal and fast speed refer to Table 16 to Table 19).

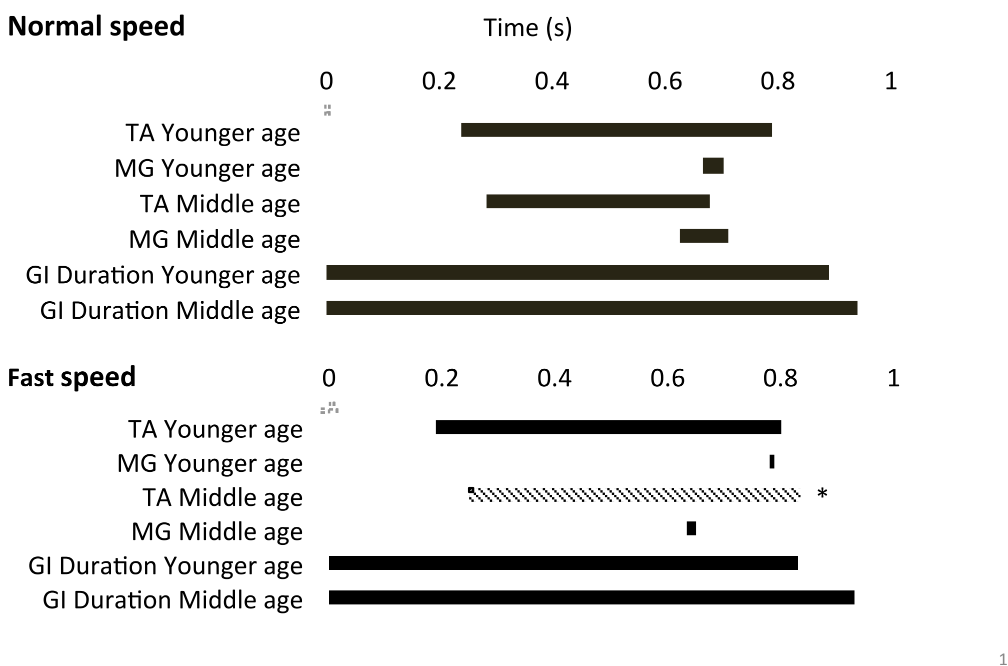

Figure 1. Timing TA, MG & GI Duration in the MA and YA. The figure shows the mean onset and offset times of the TA and MG and the GI duration at both a normal self-selected and fast gait speed for the MA and YA. The significantly later offset time of the TA of the swing leg of the MA at a fast speed is represented in cross hatch. All other variables are in black. TA = Tibialis Anterior; MG = Medial Gastrocnemius; GI = Gait Initiation; MA = middle-age adults; YA = younger adults; s = seconds.
* Interaction for TA swing leg fast speed $p < .05$.

Table 16

The Mean Onset and Offset Times of Muscles on the Stance leg in the Younger and Middle-Age Adults at a Normal Self-Selected Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Onset (s)	0.25(.14)	0.31(.21)
Offset (s)	0.80(.14)	0.75(.15)
Medial Gastrocnemius		
Onset (s)	0.72(.16)	0.83(.21)
Offset (s)	0.82(.17)	0.85(.18)
Hip		
Adductor		
Onset (s)	0.37(.17)	0.42(.31)
Offset (s)	0.70(.18)	0.77(.24)
Gluteus Medius		
Onset (s)	0.65(.14)	0.60(.16)
Offset (s)	0.83(.12)	0.93(.16)

Table 17

The Mean Onset and Offset times of Muscles on the Swing Leg in the Younger and Middle-Age Adults at a Normal Self-Selected Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Onset (s)	0.24(.11)	0.28(.18)
Offset (s)	0.79(.14)	0.68(.19)
Medial Gastrocnemius		
Onset (s)	0.67(.27)	0.63(.36)
Offset (s)	0.70(.15)	0.71(.18)
Hip		
Adductor		
Onset (s)	0.54(.23)	0.63(.23)
Offset (s)	0.74(.19)	0.85(.19)
Gluteus Medius		
Onset (s)	0.44(.23)	0.30(.11)
Offset (s)	0.57(.23)	0.48(.16)

Table 18

The Mean Onset and Offset Times of Muscles on the Stance Leg in the Younger and Middle-Age Adults at a Fast Speed

Variable	Younger adults *M* (*SD*)	Middle age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Onset (s)	0.20(.08)	0.27(.18)
Offset (s)	0.79(.11)	0.83(.13)
Medial Gastrocnemius		
Onset (s)	0.71(.21)	0.68(.22)
Offset (s)	0.79(.12)	0.79(.10)
Hip		
Adductor		
Onset (s)	0.31(.14)	0.43(.34)
Offset (s)	0.75(.15)	0.86(.24)
Gluteus Medius		
Onset (s)	0.60(.14)	0.59(.21)
Offset (s)	0.78(.13)	0.89(.16)

Table 19

The Mean Onset and Offset Times of Muscles on the Swing leg in the Younger and Middle-Age Adults at a Fast Self-Selected Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Onset (s)	0.19(.67)	0.25(.19)
Offset (s)	0.80(.11)	0.83(.14)
Medial Gastrocnemius		
Onset (s)	0.78(.36)	0.63(.25)
Offset (s)	0.71(.15)	0.71(.21)
Hip		
Adductor		
Onset (s)	0.37(.22)	0.46(.26)
Offset (s)	0.69(.19)	0.72(.30)
Gluteus Medius		
Onset (s)	0.42(.20)	0.30(.10)
Offset (s)	0.55(.23)	0.47(.13)

Table 20
Within, Between and Interaction Effects for Onset and Offset Times of the Muscles on Swing Leg

Variable	*df*	*F* value	*p* value	Effect size
Ankle				
Tibialis Anterior				
Onset				
Speed	(1,20)	3.34	.08	0.41
Age	(1,20)	0.03	.35	0.21
Speed*Age	(1,20)	0.10	.76	0.07
Offset				
Speed	(1,20)	6.66	.02*	0.58
Age	(1,20)	0.60	.45	0.17
Speed*Age	(1,20)	4.92	.04*	0.50
Medial Gastrocnemius				
Onset				
Speed	(1,20)	1.15	.30	0.06
Age	(1,20)	0.55	.47	0.17
Speed*Age	(1,20)	0.93	.35	0.21
Offset				
Speed	(1,20)	0.002	.97	0.00
Age	(1,20)	0.03	.86	0.002
Speed*Age	(1,20)	0.004	.95	0.00
Hip				
Adductors				
Onset				
Speed	(1,20)	54.48	.00*	1.65
Age	(1,20)	0.82	.38	0.20
Speed*Age	(1,20)	0.04	.85	0.05
Offset				
Speed	(1,20)	4.72	.04*	0.49
Age	(1,20)	0.66	.43	0.18
Speed*Age	(1,20)	0.75	.40	0.19
Gluteus Medius				
Onset				
Speed	(1,17)	0.04	.85	0.04
Age	(1,17)	2.98	.10	0.42
Speed*Age	(1,17)	0.12	.74	0.08
Offset				
Speed	(1,17)	0.18	.68	0.10
Age	(1,17)	0.99	.33	0.24
Speed*Age	(1,17)	0.002	.97	0.00

*$p < .05$

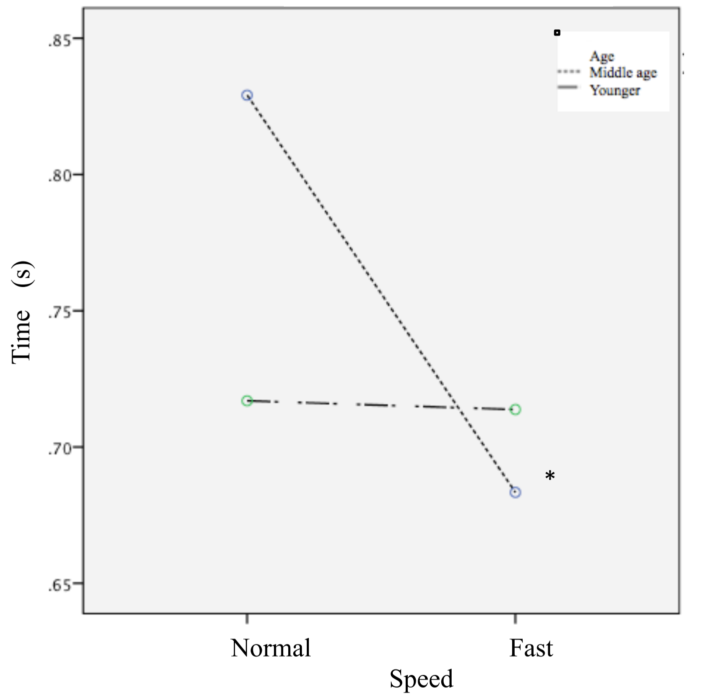

Figure 2. MG Stance Leg Onset Time at Two Different Speeds in the MA and YA. The figure shows the significantly earlier onset time of the MG of the stance leg in the MA during a fast step compared to the YA. MG = medial gastrocnemius; MA = middle-age adults; YA = younger adults; s = seconds.
* Interaction $p < .05$.

Table 21
Within, Between and Interaction Effects for Onset and Offset Times of the Muscles on Stance Leg

Variable size	*df*	*F* value	*p* value	Effect
Ankle				
Tibialis Anterior				
Onset				
Speed	(1,20)	6.26	.02*	0.56
Age	(1,20)	0.96	.34	0.23
Speed*Age	(1,20)	0.06	.81	0.05
Offset				
Speed	(1,20)	1.28	.27	0.25
Age	(1,20)	0.01	.93	0.00
Speed*Age	(1,20)	2.51	.13	0.36
Medial Gastrocnemius				
Onset				
Speed	(1,20)	5.12	.04*	0.51
Age	(1,20)	0.26	.62	0.11
Speed*Age	(1,20)	4.69	.04*	0.48
Offset				
Speed	(1,20)	5.22	.03*	0.51
Age	(1,20)	0.07	.80	0.01
Speed*Age	(1,20)	0.57	.46	0.17
Hip				
Adductors				
Onset				
Speed	(1,20)	0.67	.42	0.18
Age	(1,20)	0.69	.42	0.18
Speed*Age	(1,20)	1.10	.31	0.23
Offset				
Speed	(1,20)	3.83	.06	0.44
Age	(1,20)	1.24	.28	0.25
Speed*Age	(1,20)	0.33	.57	0.13
Gluteus Medius				
Onset				
Speed	(1,20)	1.20	.29	0.24
Age	(1,20)	0.25	.63	0.11
Speed*Age	(1,20)	0.35	.56	0.13
Offset				
Speed	(1,20)	3.22	.09	0.40
Age	(1,20)	3.28	.09	0.41
Speed*Age	(1,20)	0.04	.85	0.04

* $p < .05$.

Amplitudes COPx and COPy. As both groups stepped faster, the average amplitude (COPy) of the TA significantly increased in the stance and swing as seen in Table 22 and Table 23 (Mean values for TA for the stance and the swing leg (COPy) at a normal and fast speed refer to Table 24 to Table 27). The MA increased the TA average amplitude during fast stepping by 104 % on the stance leg and 128 % on the swing versus the YA that increased by 64 % on the stance leg and 76 % on the swing leg while approaching an interaction for age and speed on the stance leg (p = .07); this percentage of increase was based on the average amplitude generated during normal walking.

Similarly, both groups significantly increased the average amplitude (COPx & COPy) of the MG of the stance leg as they stepped faster as seen in Table 22 and Table 28 (Mean values for MG (COPx & COPy) stance leg for both groups refer to Table 24 & Table 26). The MA increased the MG average amplitude (COPy) by 49 % compared to the YA by 25 % while approaching significance for a main effect for age (p = .07); this percentage of increase was based on the average amplitude generated during normal walking.

In the hip region, both groups significantly increased the average amplitude (COPy) in the hip ADD on both the stance and swing leg as they stepped faster as seen in Table 22 and Table 23 (Mean values for ADD (COPy) for stance and swing leg at a normal and fast speed refer to Table 24 to Table 27). The MA increased the average amplitude by 56 % on the stance leg compared to the YA that increased by 33 % as they stepped faster; this percentage of increase was based on the average amplitude generated during normal walking. No significant differences were found for the muscles of the swing leg (COPx) as seen in Table 29.

Table 22
Within, Between and Interaction Effects for Amplitudes of the Muscles on the Stance Leg (COPy)

Variable	*df*	*F* value	*p* value	Effect size
Ankle				
Tibialis Anterior Amplitude				
Speed	(1,20)	32.54	.00*	1.27
Age	(1,20)	3.20	.09	0.40
Speed*Age	(1,20)	3.65	.07	0.43
Medial Gastrocnemius Amplitude				
Speed	(1,20)	8.25	.01*	0.64
Age	(1,20)	3.66	.07	0.43
Speed*Age	(1,20)	1.58	.22	0.28
Hip				
Adductors Amplitude				
Speed	(1,20)	6.08	.02*	0.23
Age	(1,20)	1.02	.33	0.22
Speed*Age	(1,20)	0.72	.41	0.19
Gluteus Medius Amplitude				
Speed	(1,20)	0.54	.47	0.18
Age	(1,20)	1.77	.20	0.69
Speed*Age	(1,20)	2.11	.16	0.35

* $p < .05$

Table 23
Within, Between and Interaction Effects for Amplitudes of the Muscles on the Swing Leg (COPy)

Variable	*df*	*F* value	*p* value	Effect size
Ankle				
Tibialis Anterior Amplitude				
Speed	(1,20)	23.47	.00*	1.08
Age	(1,20)	0.46	.51	0.15
Speed*Age	(1,20)	1.61	.22	0.28
Medial Gastrocnemius Amplitude				
Speed	(1,20)	1.68	.21	0.29
Age	(1,20)	1.66	.21	0.29
Speed*Age	(1,20)	0.78	.39	0.20
Hip				
Adductors Amplitude				
Speed	(1,20)	10.04	.01*	0.71
Age	(1,20)	0.49	.49	0.16
Speed*Age	(1,20)	0.18	.68	0.10
Gluteus Medius Amplitude				
Speed	(1,17)	0.08	.78	0.06
Age	(1,17)	2.71	.12	0.37
Speed*Age	(1,17)	0.23	.64	0.11

* $p < .05$.

Table 24

The Mean Amplitudes of the Muscles at COPx max and COPy max on the Stance Leg at a Normal Self-Selected Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Amplitude (mV) (COPx)	0.12(.11)	0.16(.14)
Amplitude (mV) (COPy)	0.21(.09)	0.26(.17)
Medial Gastrocnemius		
Amplitude (mV) (COPx)	0.06(.04)	0.09(.04)
Amplitude (mV) (COPy)	0.05(.03)	0.08(.04)
Hip		
Adductor		
Amplitude (mV) (COPx)	0.13(.22)	0.12(.09)
Amplitude (mV) (COPy)	0.08(.06)	0.10(.04)
Gluteus Medius		
Amplitude (mV) (COPx)	0.08(.09)	0.10(.06)
Amplitude (mV) (COPy)	0.07(.09)	0.09(.07)

Note. mV = millivolt.

Table 25

The Mean Amplitudes of the Muscles at COPx max and COPy max on the Swing Leg at a Normal Self-Selected Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Amplitude (mV) (COPx)	0.14(.17)	0.19(.26)
Amplitude (mV) (COPy)	0.29(.17)	0.29(.29)
Medial Gastrocnemius		
Amplitude (mV) (COPx)	0.09(.05)	0.10(.06)
Amplitude (mV) (COPy)	0.06(.03)	0.08(.05)
Hip		
Adductor		
Amplitude (mV) (COPx)	0.18(.23)	0.18(.18)
Amplitude (mV) (COPy)	0.10(.09)	0.13(.07)
Gluteus Medius		
Amplitude (mV) (COPx)	0.12(.15)	0.16(.13)
Amplitude (mV) (COPy)	0.15(.16)	0.17(.08)

Note. mV = millivolt.

Table 26
The Mean Amplitudes of the Muscles at COPx max and COPy max on the Stance Leg at a Fast Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Amplitude (mV) (COPx)	0.08(.10)	0.19(.24)
Amplitude (mV) (COPy)	0.35(.15)	0.53(.26)
Medial Gastrocnemius		
Amplitude (mV) (COPx)	0.09(.06)	0.15(.13)
Amplitude (mV) (COPy)	0.06(.03)	0.10(.05)
Hip		
Adductor		
Amplitude (mV) (COPx)	0.08(.10)	0.24(.44)
Amplitude (mV) (COPy)	0.11(.06)	0.15(.15)
Gluteus Medius		
Amplitude (mV) (COPx)	0.08(.09)	0.14(.17)
Amplitude (mV) (COPy)	0.06(.06)	0.12(.11)

Note. mV = millivolt.

Table 27
The Mean Amplitudes of the Muscles at COPx max and COPy max of the Swing Leg at a Fast Speed

Variable	Younger adults *M* (*SD*)	Middle-age adults *M* (*SD*)
Ankle		
Tibialis Anterior		
Amplitude (mV) (COPx)	0.06(.12)	0.20(.34)
Amplitude (mV) (COPy)	0.51(.34)	0.67(.44)
Medial Gastrocnemius		
Amplitude (mV) (COPx)	0.10(.06)	0.11(.07)
Amplitude (mV) (COPy)	0.07(.03)	0.08(.05)
Hip		
Adductor		
Amplitude (mV) (COPx)	0.10(.10)	0.13(.09)
Amplitude (mV) (COPy)	0.13(.10)	0.16(.07)
Gluteus Medius		
Amplitude (mV) (COPx)	0.11(.15)	0.14(.08)
Amplitude (mV) (COPy)	0.16(.17)	0.15(.09)

Note. mV = millivolt.

Table 28
Within, Between and Interaction Effects for Amplitudes of the Muscles on the Stance Leg (COPx)

Variable	*df*	*F* value	*p* value	Effect size
Ankle				
Tibialis Anterior Amplitude				
Speed	(1,20)	0.01	.95	0.00
Age	(1,20)	2.27	.15	0.33
Speed*Age	(1,20)	0.96	.34	0.22
Medial Gastrocnemius Amplitude				
Speed	(1,20)	5.67	.03*	0.53
Age	(1,20)	2.33	.14	0.34
Speed*Age	(1,20)	0.75	.40	0.19
Hip				
Adductors Amplitude				
Speed	(1,20)	0.29	.60	0.12
Age	(1,20)	0.83	.37	0.20
Speed*Age	(1,20)	1.66	.21	0.29
Gluteus Medius Amplitude				
Speed	(1,20)	1.22	.28	0.25
Age	(1,20)	1.05	.32	0.23
Speed*Age	(1,20)	1.35	.26	0.26

*$p < .05$

Table 29
Within, Between and Interaction Effects for Amplitudes of the Muscles on the Swing Leg (COPx)

Variable	*df*	*F* value	*p* value	Effect size
Ankle				
Tibialis Anterior Amplitude				
Speed	(1,20)	0.23	.64	0.11
Age	(1,20)	1.68	.21	0.29
Speed*Age	(1,20)	0.48	.50	0.16
Medial Gastrocnemius Amplitude				
Speed	(1,20)	0.25	.63	0.11
Age	(1,20)	0.35	.56	0.13
Speed*Age	(1,20)	0.00	.99	0.00
Hip				
Adductors Amplitude				
Speed	(1,20)	2.92	.10	0.38
Age	(1,20)	0.09	.76	0.07
Speed*Age	(1,20)	0.12	.74	0.03
Gluteus Medius Amplitude				
Speed	(1,17)	2.30	.15	0.37
Age	(1,17)	0.25	.62	0.12
Speed*Age	(1,17)	0.54	.47	0.18

Chapter V

DISCUSSION

The purpose of this study was to investigate the effects of both age and speed on balance and muscle activation patterns of the lower extremities between middle-aged adults and younger adults. When asked to walk at a faster than normal speed middle-age adults showed age-related differences that were not evident at their normal self-selected speed, nor seen at all in the younger adults. Regardless of speed, both groups had similar patterns of inhibiting bilateral MG and activating bilateral TA. However the middle-age adults, when compared to the younger adults, shut off the TA of the swing leg significantly later and turn on the MG of the stance leg significantly earlier when asked to take a faster step. The impetus of these changes in neuromuscular timing in the middle-age adults lies in the competing goals of the TAs for increasing velocity and MGs for maintaining balance.

In order to go faster, the TAs needs to generate a greater amount of amplitude in order to displace the COPx further (Crenna & Frigo, 1991). Both groups in this study generated significantly more amplitude bilaterally in the TAs as they stepped faster; finding similar to other studies (Crenna & Frigo, 1991; Honeine et al., 2014). In addition, Honeine et al. (2014) also reported that the younger adults produced the highest TA amplitudes just prior to foot off during gait initiation at a fast walking speed, when compared to slow or normal walking speed, in order to assist in generating velocity forward. Interestingly, the middle-age subjects in this study activated their TA significantly longer on the swing leg just prior to foot off compared to the younger adults. The greater amplitude in the TAs and the longer duration in the TA on the swing leg during fast stepping created greater displacement of the COPx posteriorly in the middle-age adults. This is different from the patterns of the younger adults, who showed slight decreases in COPx displacement. Surprisingly, the younger adults had a large percentage of increase from a normal to fast speed in COM-COP distances. This corresponded to a decrease in gait initiation duration at a faster stepping speed in the younger adults. Whereas, the middle-age adults show a negligible change in gait initiation duration at a faster speed compared to normal walking speed. Thus, the prolonged activation of the TA on the swing leg does not appear to accomplish the ultimate goal of generating a greater velocity forward.

One possible explanation for the prolonged TA activity may be related to previous studies that found a decline in TA isometric and isokinetic strength in the middle-aged adults compared to younger adults (Kim et al., 2010). However, if the prolonged activity of the TA is a result of compensation for weakness in the TA then the increased activity should be reflected in greater COM-COP distances and shorter gait initiation duration. However, those findings were not present in the middle-age adults as expected compared to the younger adults.

Another possible explanation involves the COM displacement that was not measured. The COM displacement forward appears to be hindered as reflected in the COM-COP distances and as a result the gait initiation duration in the middle-age adults remains unchanged. Other studies measured the COM AP and vertical momentum during slow, normal and fast speeds during gait initiation in younger adults (Honeine et al., 2014). Honeine et al. (2014) found COM AP momentum at its greatest at foot off during fast speeds compared to normal and slow speeds; no difference between normal and slow speeds. Furthermore in the same study, the COM vertical momentum was lowest for slow walking and highest for fast walking. The prolonged TA activity in the swing leg appears to be a response by the middle-age adults to a competing muscle force controlling the COM vertical momentum as they go faster.

The major muscle involved with controlling the COM vertical momentum would be the gastrocnemius. The gastrocnemius (medial (MG) and lateral head (LG)) and the soleus (SOL) were previously researched and found to play a major role in controlling the vertical momentum of the COM during gait initiation at a normal and a fast speed (Honeine et al, 2013, 2014). Our results show that the MG of the stance leg activates significantly earlier in the middle-age adults compared to the younger adults when stepping faster. In addition, the middle-age adults show a trend in increasing the average amplitude in MG on the stance leg as they step faster. A significantly earlier activation with increasing speed may be related to the physiological declines in generating torques at higher speeds in the gastrocnemius in the middle-age adults that has been previously documented (Gajdosik et al., 1999; Kim et al., 2010). In contrast, the only other study found in the literature with middle-age adults performing gait initiation at a fast speed did not show earlier activations in the gastrocnemius (Chu et al., 2009). This difference may be explained by the trailing leg remaining behind in Chu et al. (2009) study which has been shown to change the muscle activity of plantarflexor (soleus) during gait initiation (Chastan et al., 2010). Similar to our study, older adults have shown earlier activation of the gastrocnemius of the swing leg during gait initiation (Elble et al., 1994, Mickelborough et al., 2004). This earlier activation of the MG used to modulate the COM vertical momentum competes with the TA efficiency in generating velocity forward and appears to explain the longer activation of the TA by the middle-age adults in an attempt to take a faster step.

Although not significantly different in this study, the middle-age adults' MG on the swing leg showed a less efficient braking during the time period of foot off during a fast step. The presence of earlier activation of the stance leg and the absence of control at the end of gait initiation by the swing leg MG when transitioning from a double leg stance to single leg stance may challenge the balance system, especially at a faster speed, as it relates to regulating the vertical momentum of the COM as the COM moves forward from its base of support.

The impact of earlier activation of the MG in the stance and inefficient braking of the MG on the swing leg at a faster speed is reflected in the compromise COM-COP distances and negligible change in gait initiation duration in the middle-age adults. The faster speed causes a greater challenge to balance in the middle-age adults compared to normal walking speed due to the greater momentum at foot off of the COM going forward and the greater vertical momentum of the COM downward (Honeine et al., 2014). The middle-age adults may need to activate the MG earlier due to the challenge to their balance and could be related to another study reporting increased balance and gait impairment related to falls in middle-age adults (Talbot et al., 2005). Furthermore, previous studies have shown the MG to regulate step length and velocity indirectly through duration of single leg stance time and in modulation of the COM vertical momentum, which suggests involvement of the medial gastrocnemius in influencing gait and balance (Honeine et al., 2014).

In addition to MG influencing the COM displacement, the hip adductors and abductors can also influence the displacement of COM in the frontal plane. The displacement of COPy toward the swing leg, generated by the stance leg hip adductors and swing leg abductors (Kirker et al., 2000), causes the COM to move toward the stance leg during preparation for single leg stance to begin (Elble et al., 1994). In the present study, the COPy distances are not significantly different yet are small enough in value in the middle-age adults that further investigation seemed warranted. Upon comparison between normal self-selected and fast gait speed it appears that the simultaneously activation of both the adductors of the stance leg and abductors of the swing leg reveals a timing differences, although not significantly different, that becomes more pronounced as the speed increased. The lack of over lap in activation times of both those muscles may explain the smaller values in COPy in the middle-age adults and could be related to physiological declines in the hip adductor and abductor isometric and isokinetic strength (Cahalan et al., 1989; Murray & Sepic, 1968; Trudelle-Jackson et al., 2011) that have been previously documented; these smaller COPy distances in the middle-age adults may also contribute to the decrease in the COM-COP distance that could indirectly influences velocity forward.

Chapter VI

CONCLUSION

In this study, gait initiation provided insight into the timing and amplitude patterns used by the middle-age adults during a normal self-selected and fast speed. Prior to this study, only one study was found in the literature that looked at gait initiation at a fast stepping speed in the middle-age adults compared to younger adults. The findings from this current study add to the previous work with middle-age adults and further helps to demonstrate that middle-age adults do use different motor strategies at a faster speed compared to the younger adults. Interestingly, these neuromuscular timing differences were apparent as early as age 50.

The middle-age adults and younger adults use similar muscles to generate velocity forward during a normal self-selected and fast speed. Yet the middle-age adults showed more significant differences in timing at the ankle compared to the hip region during gait initiation. This may suggest that changes in hip strategies occur later in the life span than in middle age or possibly the incomplete data collection in a few of the middle-aged subjects may have underpowered the findings at the hip in this study.

The middle-age adults were found to activate the MG earlier in response to the greater amount of COM displacement at a faster speed. The demand of speed was harder to manage for the middle-age adults compared to the younger adults.

As a result the efficiency of the tibialis anterior activation, which is used to generate velocity, is compromised in order to maintain balance. The changes in timing in the middle-age adults may be precursors to age-related spatial and temporal changes. These findings suggest further investigation into the role of the MG and its effect on functional activities.

Limitations

The inclusion criteria age group range was from 50 to 70 years old yet the sample from this study was clustered between 50 to 60 years old. This clustering may have resulted in non-significant findings for some of the variables. In addition, the procedures required the subjects to use his/her dominant leg to initiate gait. However, this resulted in weight shifting to subjects' stance leg that reduced forces in the swing leg prior to lift off of the swing leg. This reduction in force created an inability of the sensors to detect displacement of the variables in the study. Therefore, data was lost and subjects had to be excluded. Other aspects of the procedures such as setting the onset and amplitude detection based on a three standard deviation might have caused a Type II error. If a two standard deviation was set it may have resulted in more significant findings in the study.

Widening the scope of areas examined to include the trunk may have lead to more significant findings. A previous study had found significant differences in the middle-age adults' activation of trunk musculature compared to younger adults (Chu et al., 2009). However, the Biomechanics 9000 Electromyography (EMG) had only 8 leads and limited collection of EMG data to four lower extremity muscles on each leg.

Clinical Implications

This study highlights the impact of speed on initiating gait and the importance of incorporating it into the evaluation of middle-age adults. This may help in determining if speed is a factor contributing to falls in the middle-age adults.

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APPENDIX A

Pilot Study Abstract

The following abstract was accepted for poster presentation at the Combined Sections Meeting of the American Physical Therapy Association, Indianapolis, Indiana. 2015

Title: DIFFERENCES IN COM-COP DISTANCES & MUSCLE ACTIVITY DURING GAIT INITIATION IN HEALTHY OLDER ADULTS AND YOUNGER ADULTS: A PILOT STUDY. Lynn Curtis-Vinegra, Doreen Stiskal, Lee Cabell, & Genevieve Pinto-Zipp, *Seton Hall University*, *GMHE*

Purpose/Hypotheis: Older adults begin walking using motor patterns, which are different from younger adults. Research suggests that earlier activation and increased amplitudes of key lower extremity muscles contribute to maintaining balance at normal self-selected walking speed during dynamic gait. It is unknown if older adults use similar gait initiation strategies at normal self-selected and faster gait speeds. The objectives of this study were to assess the effects of age and speed (normal self-selected and fast gait) on balance by measuring 1) the Center of Pressure (COP) in two planes: COPx (sagittal) and COPy (frontal) and the Center of Mass-Center of Pressure (COM-COP) distances and 2) activation of lower-extremity muscles (onset/offset, peak and average amplitudes) during gait initiation.

Number of subjects: 10

Materials/Methods: Electromyography (EMG) signals of the gluteus medius (GM), tibialis anterior (TA) and medial gastrocnemius (MG) were recorded as healthy young and older adults initiated gait by taking 3 steps forward while walking on a GAITRite platinum mat at a normal self-selected and fast walking speed for 5 trials each. Four healthy older adults (mean age 53.5 range 50-57) and 6 healthy younger adults (mean age 22.2 range 20-24) participated. Rectified EMG signals were normalized using Maximum Voluntary Contractions (MVCs). COP and COM-COP distances were measured using M2 software.

Results: Shapiro-Wilk testing showed some cases of violation of normality. ICCs varied from high to poor for within subject correlation for COP and COM-COP distances, average/peak amplitudes and onset/offset times. COPx distances significantly increased as the speed increased in both younger and older subjects. TA average and peak amplitude of the stance leg in the COPx direction was significantly greater in the older subjects compared to the younger subjects. The age differences also occurred with an earlier MG onset time of the stance leg and a greater MG average and peak amplitude of the stance leg in the COPx direction.

Conclusions: In this small pilot study, older subjects generate more TA muscle activity to accomplish the same COPx and COM-COP distances as younger adults. Earlier onset and increased amplitudes of the MG increases the amount of co-contraction during gait initiation in the older adults. Therefore, older adults are then required to generate greater amplitude of the TA to displace the COP posteriorly to minimize disturbing balance.

Clinical Relevance: Age-related changes affect the neuromuscular control of initiating a step forward. Insight into how older adults recruit leg muscles during gait initiation relative to the prevalence of co-contractions during gait initiation can provide information about improving neuromuscular control. These data may assist in reducing energy expenditure needed to generate excess amplitude to displace the COP.

APPENDIX B

Letter of Approval

SETON HALL UNIVERSITY

1856

October 30, 2013

Lynn Curtis-Vinegra
67 Amber Place,
Bernardsville, NJ 07924

Dear Ms. Curtis-Vinegra,

The Seton Hall University Institutional Review Board has reviewed and approved as submitted under expedited review your research proposal entitled "Differences in COM-COP Distances and Lower Extremity Musclar Activity During Gait Initiation in Healthy Older and Young Adults". The IRB reserves the right to recall the proposal at any time for full review.

Enclosed for your records are the signed Request for Approval form, the stamped original Consent Form and Recruitment flyer. Make copies only of these stamped documents.

The Institutional Review Board approval of your research is valid for a one-year period from the date of this letter. During this time, any changes to the research protocol must be reviewed and approved by the IRB prior to their implementation.

According to federal regulations, continuing review of already approved research is mandated to take place at least 12 months after this initial approval. You will receive communication from the IRB Office for this several months before the anniversary date of your initial approval.

Thank you for you cooperation.

In harmony with federal regulations, none of the investigators or research staff involved in the study took part in the final decision.

Sincerely,

Mary F. Ruzicka, PhD

Mary F. Ruzicka, Ph.D.
Professor
Director, Institutional Review Board

cc: Dr. Doreen Stiskal

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APPENDIX C

Flyer

Volunteers Needed

For the study:

"Differences in COM-COP distances and lower extremity muscle activity during gait initiation in healthy older and healthy younger adults"

This study will evaluate how healthy younger and older adults start to walk. This study is being conducted by Lynn Curtis-Vinegra, PT MS, who is a student enrolled in the PhD Program in Health Sciences at the School of Health and Medical Sciences, Seton Hall University.

If you are: 18-35 or 50-70 years old are invited to participate. Subjects should have no history of orthopedic conditions or surgeries, other health problems that interfere with walking, or use a cane or walker. Subjects will have height, weight, blood pressure, length of both legs, knee and ankle flexibility and strength of leg muscles measured by a researcher. Subjects will be asked to stand on a computerized walkway and take 3 steps forward 10 different times at normal speed and fast speed. Subject's movements will be recorded via sensors in the mat and via small electrodes placed by the female researcher over the skin of the bilateral leg muscles and lateral hip region that detect muscle activity. This study will take place at Seton Hall University in the Functional Human Performance Lab, Corrigan Hall, South Orange, N.J. and should take no more than 1 1/2 hours. Participants will need to wear laced shoes and shorts. All information will be kept strictly confidential. Participation is voluntary.

For more information or to answer any questions, please call or E-mail: Lynn Curtis-Vinegra, P. T.
(201) 320-4615 or LynnACurtis@verizon.net

APPENDIX D

Informed Consent

SETON HALL UNIVERSITY
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Informed Consent

Differences in COM-COP distances and lower extremity muscle activity during gait initiation in healthy older adults and healthy younger adults.

Investigator
This study is being conducted by Lynn Curtis -Vinegra, PT, MS, who is a PhD student in the School of Health and Medical Sciences at Seton Hall University.

Purpose
The purpose of the study is to examine potential differences between younger and older adults when they begin to walk (gait initiation) at two different speeds (normal self-paced and fast). Specifically this study will examine how the body weight under each foot moves by standing and walking 3 feet along a computerized walkway called a GAITRite™Mat. This study will also record how the lower leg muscles contract (as measured by Electromyography (EMG)) during the 3 foot walk. The study requires one visit to the Human Functional Performance Laboratory, Room 67 in Corrigan Hall at Seton Hall University lasting no more than one and a half hours.

Procedures
Subjects will be asked to wear sneakers or laced flat-heeled shoes and shorts on the day of the testing. The first things to be measured are leg length, blood pressure and range of motion (flexibility) of both knees and ankles in order to meet the inclusion criteria. In standing the investigator will obtain measurements of both leg lengths, in centimeters, using a steel tape measure placed against the subject 's lateral hip bone and then measuring the vertical distance from this body landmark to the floor. This is a standard procedure for measuring leg length. The subject will have his or her active knee range of motion measured bilaterally in degrees, using a plastic protractor placed against the subject's skin or clothing. This protocol is a standard physical therapy procedure to measure how much a joint bends and straightens. Subjects will lie on a firm padded table on his or her back positioned with the knee to be measured maximally bent and the foot flat on the surface. The protractor will be lined up to the knee joint and two bony prominences that are used for landmarks during movement. The subject will be asked to bend the knee back as far as possible. While in the same position the subject will be asked to straighten the knee fully. Both knees will be measured. The subject will then have his or her active ankle range of motion measured bilaterally in degrees, using a plastic protractor up against subject's skin or clothing. The subject will sit up on the table with the knee bent at least 30 degrees and foot in a neutral position (neither turned in or out). The goniometer will be lined up to the lateral side of the ankle bone and two boney prominences on the foot and the calf will be

School of Health and Medical Sciences
Department of Graduate Programs in Health Sciences
Tel 973 275 2076 Fax 973 275 2171
400 South Orange Avenue, South Orange, New Jersey 07079 shms.shu.edu

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used for landmarks during movement. The proximal arm lines up with the lateral boney prominence below knee joint and the distal arm is parallel to the lateral side of the foot. The subject will then point foot upward and then downward.

The subject will then have his or her blood pressure measured using a standard blood pressure cuff. The subject will have blood pressure taken on his or her right arm unless a medical reason calls for the other arm, in a seated position, with the arm at shoulder height with the elbow straight. Subject's blood pressure must be less than 160/100 or greater than 90/50. After all inclusion criteria have been met, the subject will have his or her body weight measured twice using a scale and his or her height measured using a tape measure.

The female researcher will clean small parts (no more than 2 inches round) of the skin on both legs (shins, calves, and thigh) and on each side of the outer trunk just below the waistline with soap and water using a paper towel and will then dry the skin thoroughly with a paper towel. If necessary, excessive hair will be cut with a blunt tipped scissor in the same areas that are cleaned prior to the placement of the sensors (EMG electrodes). These sensors are placed on the skin over 4 large muscle groups bilaterally. They are the gluteus medius (lateral hip muscle), adductors (medial thigh) and anterior tibialis and medial gastrocnemius (shin & calf) muscles. **Four pieces of double-sided tape with surface sensors attached to record the electrical activity will be placed on each leg and the lateral hip region below the waistline on the side of the trunk in a private room by the female researcher and female faculty advisor.** One side of the waistband on the subject's shorts will be lowered temporarily by 2 inches in order to place the electrode over the outer trunk muscle just below the waist line. The hem of the shorts will be lifted within 4 cm below the crease of the buttocks to place the electrodes on the inner thigh. The other leg muscles on the calf and shin are normally exposed when wearing shorts. A small dime-sized ground electrode will be placed over the outside of the right or left elbow.

To be able to compare the data from the electrodes between subjects, standard measures of strength in each of the 4 muscles on both legs will be obtained. For the muscle on the trunk that lifts the leg to the side, subjects will side lie on a table and be asked to raise the leg in the air and hold for 5 seconds while the female researcher pushes the leg down toward the table. For the thigh muscle that brings the leg inward towards the body, subjects will side lie with leg to be tested on bottom while the investigator supports the uppermost leg at approximately 25 degrees during which the subjects lifts the bottom leg upward in the direction of the ceiling. The female researcher will apply resistance to the distal aspect of
the inner thigh just above the knee for 5 seconds. For the shin muscle, subjects will remain sitting with the heel resting on the female researcher's leg. Subjects will be asked to bring the foot up and in and then hold this position for 5 seconds as the researcher presses the foot down and out. For the final muscle, subjects will stand on one foot with one-two fingers on a table for support and be asked to raise the heal from floor and hold for 5 seconds.

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Next, subjects will be shown the gait initiation procedures while on the GAITRite mat. Subjects will be allowed three practice trials by taking 3 steps at both normal self-selected and again at fast stepping speeds. To enhance consistency between trials, subjects' feet will be outlined on the GAITRite mat and this outline will be used as the starting position for each new trial. The leading foot found during 2 of the 3 practice trials will be determined, and this foot, right or left, will then be used as the leading foot for all other trials. Subjects will initiate forward walking at normal and fast speeds once they see a light trigger that is activated by the researcher. The light trigger is an electronic event marker for both collecting information from the GAITRite™ Mat and Electromyography (EMG). After the three practice trials at each speed, subjects will perform 10 trials at normal self-selected speed and 10 trials at a fast speed. A research assistant will walk along with the subject parallel to the carpet during all trials to ensure safety. Subjects will get 1 minute rest after the practice trials, 45 seconds between each trial and a 3 minute rest period between the two different gait speeds. Subjects will sit in a chair that is adjacent to the GAITRite Mat during the rest periods.

Voluntary Nature of Project
Participation in the study is completely voluntary. Subjects may stop participation at any time, even in the middle of testing, without any penalty or consequence.

Anonymity
All recorded information from this study will be kept in coded form so only the principal investigator and faculty supervisor are able to link the data to any individual.

Confidentiality
All identifying information is contained in a research folder with the subject's signed informed consent and data recording sheet. This along with all electronic information stored on a CD will be kept in a locked cabinet in the Dr. Doreen Stiskal's (faculty supervisor) office (973-275-2320). Only the principal investigator and the faculty supervisor will have access to subjects' data that will be stored electronically on a CD.

Risks
Subjects should not feel any pain or discomfort while taking the three steps forward 10 times as this is a very common everyday activity that healthy adults perform. Frequent seated rest periods are provided to avoid fatigue while standing. The skin preparation for the surface electrodes involves washing the skin with soap and water, cutting any excessive hair with a blunt ended scissors, if necessary, and should not cause any discomfort or redness. After these items are removed, the skin will be inspected for irritation. In the event skin looks reddened, subjects will be told to monitor color for 24 hours. If redness continues, subjects will be advised to seek medical attention from your healthcare provider.

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The Department of Health and Human Services requires that subjects be advised as to the availability of medical treatment if a physical injury should result from research procedures. No special medical arrangements have been made regarding participation in this project. If subjects are registered students at SHU, they are eligible to receive medical treatment at the University Health Service. If subjects are not registered students at SHU, immediate medical treatment is available at usual and customary fees at a local community hospital or care center.

Benefits
The subject understands that he or she will receive no direct benefit from participating in this study. The results of this study may help establish initiation of walking as a tool to measure deficits during that period.

Alternative Therapies
This experiment does not involve treatment of the subject's leg conditions.

Contact Information
If you have any pertinent questions about the research study please contact the principal investigator, Lynn Curtis-Vinegra, student in the Health Sciences Program in the School of Health and Medical Sciences at Seton Hall University at 201-320-4615, or at LynnACurtis@verizon.net. Her Faculty supervisor, Dr. Doreen Stiskal can be reached at 973-275-2320.

To ask any pertinent questions about the research subject's rights, please contact the Chairperson of the IRS, Mary F. Ruzicka, PhD, (973-313-6314), or at irb@shu.edu.

Video or Audio-tapes
There will be no video or audio-tapes used in the study.

A copy of the Informed Consent Form will be provided to all subjects.

____________________________________ ________

Subject Date

School of Health and Medical Sciences
Department of Graduate Programs in Health Sciences
Tel 973 275 2076 Fax 973 275 2171
400 South Orange Avenue, South Orange, New Jersey 07079 shms.shu.edu

APPENDIX E

Interview Sheet

Subject Initials: __ INTERVIEW SHEET

Part A: Investigator will complete this section. She will ask the subject the following and dismiss if subject meets exclusion criteria:

1. ·What is your Date of Birth" : _

   Is this age-appropriate (18·35 or 50-70)? Yes No

   If NO: THANK PARTICIPANT AN D EXCLUDE

2. "What is your Gender": Male Female

3. "Can you take 3 steps 10 times at two different speeds (normal walking speed and fast walking speed)?"

   Yes No

   If NO: THANK PARTICIPANT AND EXCLUDE

4. "Do you use an assistive device or aide from another person to walk? Do you use an orthoses/splints?"

   Yes No

   If YES: THANK PARTICIPANT AND EXCLUDE

5. "Do you have any cardiovascular, neurological or respiratory problem that might limit your participation in the study?"

   Yes No

   If YES : THANK PARTICIPANT AND EXCLUDE

6. "Have you had any recent history (past six months) of trauma to the lower back or extremities including fractures, severe sprains or surgeries including joint fusions or history of lower extremity joint replacement:

   a. Low Back" Yes No If yes, what?____________

   b. Hip" Yes No If yes, what?____________

   c. Knee" Yes No If yes, what?____________

   d. Ankle" Yes No If yes, what?____________

   e. Foot" Yes No If yes, what?____________

   If YES: THANK PARTICIPANT AND EXCLUDE

7. "Do you have any pain in your lower extremities today?"

   If YES: THANK PARTICIPANT AND EXCLUDE

APPENDIX E

Interview Sheet (con't)

8. "Have you been told that you are legally blind or do you have limited vision that interferes with your walking?"

    If YES: THANK PARTICIPANT AND EXCLUDE

9. "Can you see lights turn on at a distance of no more than 5 feet in front of you?"

    If NO: THANK PARTICIPANT AN D EXCLUDE

12. "Do you have a history of falling more than twice in the last six months?"

    If YES: THANK PARTICIPANT AND EXCLUDE

Thank you so much for your cooperation. I will now provide you with the Informed Consent and answer any questions that you or your family might have.

Confirm participant wishes to continue.

APPENDIX F

Oral Script

DIFFERENCES IN COM-COP DISTANCES AND LOWER EXTREMITY MUSCLE ACTIVITY DURING GAITINITIATION IN HEALTHY OLDER ADULTS AND HEALTHY YOUNG ADULTS

Oral script for initial phone contact with subject

Subject Name _____________ __ Date: _____ _

I. "Thank you for your interest in the research study. Let me tell you about the study.

• My name is Lynn Curtis-Vinegra and I am a physical therapist. This study is to fulfill my requirements for completion of a Ph D in Health Sciences with an emphasis in Movement Science at Seton Hall University's School of Health and Medical Sciences.

• The purpose of the study is to see how younger and older adults shift their weight as they take their first three steps and how the muscles coordinate themselves during these movements.

• Your participation is purely voluntary.

• All your information will be confidential and kept in a locked cabinet in the office of Dr. Doreen Stiskal in McQuaid Hall, and destroyed 3 years after publication. "

"Are you still interested?"

Yes: Proceed No: "Thank You" & I will excuse you from the study

2. "Let me inform you of what the study will consist of should you be included in the study:

• You will be asked your age
• You will be asked about your medical history, and especially if you have any limiting orthopaedic, cardiovascular, neurological or respiratory problems, and vision problems
• You will be asked if you have a history of falling more than 2 times in the last 6 months

APPENDIX F

Oral Script (con't)

• You will be asked to wear sneakers or laced flat-heeled shoes and shorts on the day of the testing.
• Your blood pressure as well as the length of each leg will be measured.
• In a reclining position your knee mobility and in sitting your ankle mobility will be measured.
• Body weight will be measured twice using a bathroom scale and your height will be measured using a tape measure.
• I will clean small areas of skin with soap and water on each side of your body, including along the sides of the trunk just under the waist (about 2 inches); the inner thigh area 4 cm below the area where the pelvis meets the thigh; the front of both shins; and the back of the calves, and one the side of one elbow. These areas are where I place small pieces of double sided tape with sensors that are attached to the skin to record how the muscles perform during the stepping activity. If necessary, the hair under an electrode will be trimmed using a blunt edged scissors to improve the recording quality of the sensor.
• I will then test the strength of the leg and calf muscles by asking you to hold different positions to challenge each individual muscle for 5 seconds. Rests periods will be given following the testing of the strength of the legs.
• Following I will demonstrate walking at a normal walking speed and then I will ask you to walk 3 steps forward 10 times each at your normal speed over a carpeted mat that has sensors built into the surface. You will then be asked to take 3 steps at your fastest speed as safely as possible and without running, for ten more trials. A chair will be positioned along the walkway to allow for scheduled rests throughout the walking trials. Three practice trials will be performed prior to both regular and fast walking trials with rests periods in between trials.
• This study is expected to last no longer than 1 1/2 hours."

"Do you understand how the study will be done?"

Yes: Proceed No: Answer any question and repeat if necessary

"This project has been reviewed and approved by the Seton Hall University Institutional Review Board for Human Subjects Research."

"Let me ask you some questions to see if you meet the study's conditions (inclusion criteria) or if any of the exclusion criteria are present. Please understand that in order to ensure the research study is performed in a standardized manner, there are certain medical conditions or physical features that might keep you from participating. This is purely because of the design of the study.

Appendix F

Oral Script (con't)

1. "Are you between 50-70 years? Are you between 18-35?"

_______ YES NO.

If No: THANK PARTICIPANT AND EXCLUDE

2. "Can you take 3 steps 10 times at two different speeds (normal walking speed and fast walking speed)?" YES NO

If No: THANK PARTICIPANT AND EXCLUDE

3. "Do you use an assistive device or aide from another person to walk? Do you use an orthoses/splints?"

If Yes: THANK PARTICIPANT AND EXCLUDE

4. "Do you have any cardiovascular, neurological or respiratory problems that might limit your participation in the study?" Yes No

If Yes: THANK PARTICIPANT AND EXCLUDE

5. "Do you have any visual or vestibular dysfunction resulting in decreased balance or walking?" YES NO

If Yes: THANK PARTICIPANT AND EXCLUDE

6. "Have you had any recent history (past six months) of trauma to the lower back or extremities including fractures, severe sprains or surgeries including joint fusions or history of lower extremity joint replacement?" Yes No

If Yes: THANK PARTICIPANT AND EXCLUDE

7. "Have you been told that you are legally blind or do you have limited vision that interferes with your walking?" Yes No

Appendix F

Oral Script (con't)

If YES: THANK PARTICIPANT AND EXCLUDE

8. "Can you see lights turn on at a distance of no more than 5 feet in front of you?"
Yes No

If NO: THANK PARTICIPANT AND EXCLUDE

9. "Do you have a history of falling more than twice in the last six months?" Yes No

If YES: THANK PARTICIPANT AND EXCLUDE

IF YOU HAVEN'T BEEN EXCLUDED FROM THE STUDY AT THIS POINT:

• Thank you so much for your cooperation. You can be included in the research study and we will now set up a time for the testing procedure. Please remember to wear a pair of laced shoes and shorts on the day of the study.
DATE/TIME OF APPOINTMENT: _______________

APPENDIX G

Data Collection Flow Sheet

1. Subject signs Informed Consent_____
   Interview Sheet______

   Ensure subject is wearing ties shoes and shorts_____

2. Instruct subject in the assessment of leg length, blood pressure and active range of motion at the knee and ankle joint

3. a)Begin by taking blood pressure_______________ s/d
   ***If systolic BP is above 160 or below 90, subject will be excused

   ***If diastolic BP is above 100 or below 50, subject will be excused

   Right Left

   b)Leg Length measurement ______________cm ____________cm

   ***If greater than 1.9 cm difference, subject will be excused

   Right Left

   c)Active range of motion knee: Extension_____ Flexion _____
   Extension_____ Flexion_____

   d)Active range of motion ankle
   dorsiflexion___plantarflexion____dorsiflexion___plantarflexion_

4. Provide 3 minute rest after range of motion assessment_________

   If inclusion criteria have been met at this point go on to the next phase of the study.

5. Subject will have body weight measured using a standard bathroom scale.
   The subject's weight will be measured two times and then the average will be calculated.

   a.________lb Mean=_______lb

   b.________lb

6. The subject's height will be measured using a tape measure.

APPENDIX G

Data Collection Flow Sheet (con't)

a.___________cm

7. Provide 3 minute rest after body weight/height measurements (sitting in chair). _________

8. Placement of EMG surface electrodes on subject.
   a) Subject will have skin cleaned with soap and water in the area of electrode placement and ground electrode. The subject will have the hair on the area where the electrode will be placed cut with blunt scissors if excessive hair is present in that area._____________

   b) Electrodes will be placed on bilateral Gluteus Medius, Adductors, Medial Gastrocnemius and the Anterior Tibialis. Ground placed on elbow. Verify all signals are recording.__________

   A) Manual muscle testing of MVC: 1 rep of a 5 second hold each

	Right	Left
a) Gluteus Medius (sidelying)	____________	_____________
b) Adductor (sidelying)	____________	____________
c) Medial Gastrocnemius (standing):	____________	_____________
d) Anterior Tibialis (long sitting):	____________	____________

9. Provide 3 minutes rest after Manual Muscle Testing.__________

10. Provide demonstration of normal walking speed for three steps while standing on the GAITRite mat while subject observes._________

11. a) The subject will stand on the GAITRite mat with electrodes in place and have his/her foot placement outlined using chalk.__________

    b) The subject will perform three practice trials with 45 second rest after each practice trial.___

APPENDIX G

Data Collection Flow Sheet (con't)

c) The leading foot will be found during 2 out of the 3 practice trials and this, right or left, will be used as the leading foot for all other trials.

a. R or L   Dominate foot= ____________
b. R or L
c. R or L

12. Provide 1 minute rest after practice trials (sitting in chair adjacent to walkway). ________

13. The subject will perform 3 steps at normal self-selected stepping using the previously determined leading leg from the practice trials. There will be 10 trials for normal walking speed.The subject will have a 45 second rest between each trial (sitting in chair adjacent to walkway)

a. ________________ 1 trial
b. ________________ 1 trial
c. ________________ 1 trial
d. ________________ 1 trial
e. ________________ 1 trial
f. ________________ 1 trial
g. ________________ 1 trial
h. ________________ 1 trial
i. ________________ 1 trial
j. ________________ 1 trial

14. Provide 3 minute rest after Normal Self-Selected Stepping Trials (sitting in chair adjacent to walkway).______________

15. Provide demonstration of fast stepping for three steps while standing on the GAITRite mat while subject observes._____________

16. The subject will stand on the GAITRite mat with electrodes in place and feet within chalk outlined area on the GAITRite mat. The subject will perform three practice trials with 45 second rest after each practice trial.____________

17. Provide 1 minute rest after practice trials (sitting in chair adjacent to walkway)._____________

18. The subject will perform fast stepping for 3 steps using the previously determined leading leg from the practice trials. There will be 10 trials for fast walking speed.

APPENDIX G

Data Collection Flow Sheet

The subject will have a 45 second rest between each trial (sitting in chair adjacent to walkway).

a. ________________ 1 trial
b. ________________ 1 trial
c. ________________ 1 trial
d. ________________ 1 trial
e. ________________ 1 trial
f. ________________ 1 trial
g. ________________ 1 trial
h. ________________ 1 trial
i. ________________ 1 trial
j. ________________ 1 trial

19. Provide 3 minute rest after Fast Stepping Trials (sitting in chair adjacent to walkway)._____

20. Remove electrodes and inspect skin._________

21. Thank Subject.__________

APPENDIX H

Definitions

Acceleration: the rate of change of velocity of a person.

Baby boomers: people born during the demographic Post World War II baby boom between the years 1946 and 1964.

Balance variables: the Center of Pressure distances in both frontal and sagittal plane (COPx and COPy) and the Center of Mass-Center of Pressure distances (COM-COP).

Base of Support (BOS): the perimeter of the contact area between the body and its support surface.

Center of Mass (COM) distance: the distance traveled by the COM from the time of the trigger to the point that the swing leg (SL) has no contact with the mat.

Center of Mass (COM): an estimated point that corresponds to the center of the total body mass.

Center of Pressure (COP) distance: the distance traveled by the net COP from the time of the trigger to the point that the swing leg (SL) has no contact with the mat.

Center of Pressure (COP): a point that represents the net sum of the vertical projections of the ground reaction forces.

COM AP momentum: the product of the total body mass and velocity of a person in the forward direction.

COM Momentum: the product of the total body mass and velocity of a person.

COM vertical momentum: the product of the total body mass and velocity of a person in the vertical direction.

COM-COP distance: the distance between the COP and the COM at the point where the COP is at its maximum posterior position.

Computerized dynamic posturography: technique to quantify an individual's change in body position and movement control when maintaining static and dynamic balance by eliminating or sway-referencing one's visual surround, or conflicting somatonsensory input by using a swaying support surface to evaluate the ability to maintain an upright posture.

COPx: the movement of the COP in the posterior direction toward the swing leg.

COPy: the movement of the COP in the lateral direction toward the swing leg.

Double Leg stance (DLS): the period of time when both feet are in contact with the ground.

Fast Speed: qualitative descriptor of a subject's fastest speed safely, without running, in a forward progression.

Frontal plane: any vertical plane that divides the body into belly and back (ventral and dorsal) sections.

Gait Initiation: a time period that moves the body from a static state of standing into a dynamic state of walking. It involves a stereotyped activity that includes the series or sequence of events that occur from the initiation of movement to the point at which the swing leg lifts of the ground.

Ground Reaction Force (GRF): the downward force (s) acting on the area in contact with the ground.

Normal self-selected speed: qualitative descriptor of a subject's self-selected rate of forward progression.

Rhythmic Weight Shift (RWS): one test of computerized dynamic posturography (CDP) that measures motor responses to see how well an individual can lean or shift weight over a stable support surface.

Sagittal plane: a vertical plane which passes from anterior to posterior, dividing the body into right and left halves.

Sensory Organization Test (SOT): one test of computerized dynamic posturography (CDP) that uses 6 different sensory conditions to quantify subjects' motor response under each condition.

Single Leg Stance (SLS): the period of time during walking when one foot leaves the ground and the other foot is still in contact with the ground.

Speed: qualitative descriptor of the rate of progression during walking.

Stance leg: the leg that remains in contact with the ground during gait initiation.

Step length: the horizontal distance covered along the plane of progression during one step; is the distance measured from a point on one foot to the same point on the other foot, expressed in centimeters.

Swing leg: the leg that is lifted of the ground during gait initiation.

Torque/Moment: the tendency of a force to rotate an object about an axis, fulcrum or pivot; measured in Newton meters (Nm).

Velocity: the average horizontal speed of the body along the plane of progression measured over one or more stride periods; is reported in cm/sec.