Effects of Age on Gait Parameters and Muscle Activity During Adjustment, and the Relationship of Fear of Falling

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ABSTRACT

Previous research has shown that with advancing age, there are increasing incidences of slip and fall injuries. Understanding mechanisms associated with gait adjustments across a known slippery surface may help in proactively avoiding slips and falls. The primary goal of this study involved examination of gait parameters and muscle activity characteristics of the lower extremities during two different walking conditions.

Research has shown that both physical and mental changes accompany the aging process in humans. Moreover, research has shown that emotions and physiological responses are related. A secondary goal of this study was to examine the relationships of fear of falling with gait parameters and muscle activity.

This study consisted of exposing 14 younger and 14 older participants to controlled slippery conditions safely, while studying normal and adjusted gait characteristics (friction requirement, heel contact velocity, and step length) and muscle activity characteristics (Integrated EMG). First, a baseline measure was done to study normal gait prior to any exposure to slipping. A second measure was done following a slip from a contaminated floor surface, but before the initiation of a second slip. The results indicate that there were significant gait parameter differences between younger and older participants for both walking conditions. Results also indicate that there were differences in muscle activity between to the two age groups for the adjusted condition. Findings suggest that older individuals require an additional step to properly adjust gait for a contaminated walking surface.

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INTRODUCTION

1.1 Justification for the study

There exists a great deal of research on understanding and reducing slip and fall accidents utilizing primarily tribometric and biomechanic techniques that address mechanical body parameters and shoe to floor interaction. Additionally, there is significant research involving postural control, behavior, psychophysics, and psychological conditioning to further understand the relationship of cognition to biomechanical, tribological, and physical measurements. Understanding causes and characteristics of slip and fall accidents could help prevent severe injuries and fatalities that result from these accidents. Deaths from unintentional accidents for older adults (over age 65) were ranked as the seventh leading cause of fatalities in 1996; the greatest number of these fatalities was attributed to deaths from falling (Stevens, Hasbrouck et al; 1999). As people age, the rate of fall related deaths increase dramatically (Campbell et al, 1981). Slips and trips often lead to, or are the cause of, fall related accidents (Cohen and Compton 1982; Manning et al. 1988). One study found that in one half of reported falls are a resultant of slips occurring most frequently on floor surfaces (Cohen and Compton, 1982). These studies support slip and falls being a severe problem for older adults. Injuries from falls result in a significant monetary impact. In 1994 this accounted for an estimated 20.2 billion dollars (CDC Fact Book, 2000). Moreover, the elderly population is increasing. Currently, there are approximately 35 million elderly individuals in the United States; this number is projected to double to more than 70 million by the year 2030 (Administration on Aging, 2000). One could infer that the problem with slips and falls for older adults will become more severe since the population of people over 65 years of age is increasing.

As people age, physical ability decreases. This may be due to the decrease of muscle strength, loss of motor neurons, loss of muscle fibers, and decline of aerobic capacity (Prince, Corriveau et al., 1997; Winter, 1991). There exists an adaptation of gait (decreased stride length and a decrease in toe clearance) and a decrease in walking velocity in senior individuals (aged 65 and older). This gait adaptation may be due to physical ability degradation.

Perception of slippery surfaces could be a very important factor for determining a gait alteration strategy so that the person may avoid slipping and possibly falling. Sensory input devices (vision, vestibular apparatus, and proprioceptive system) dictate the information the person receives regarding perception. Vision is the primary sensory input mechanism and may have priority over the other senses (Lishman and Lee, 1973). A person's judgment of the surface slipperiness may often be the determining factor of whether or not a fall occurs (Cohen and Cohen, 1994b; Lockhart 2001). As people age, these sensory inputs tend to become less effective and perception is not as acute (Lockhart, 2001).

In addition to perception, emotions such as fear or anxiety may have an effect on the processing stages of slips and falls. Although fear is often associated with anxiety, fear is a cognitive response to a situation, while anxiety is an emotional response (Beck et al., 1985). A fear of falling is defined as a low self-efficacy to avoid falls during normal activity. This could have an effect in the processing stage of slips and falls. As people age, there is an increase in self reported fear-of-falling which results in decreased physical activity due to the fear (Howland et al., 1993; Tinnetti et al, 1994; Tennstedt et al., 1998; Velozo and Peterson, 2001). Numerous studies show that there is a significant correlation between emotion and physical activity by relating emotional responses with physiological measurements and reactions (Adkin, Frank et al., 2000; Balaban and Thayer, 2001;Carpenter, Frank et al., 2001; Lang, Davis, and Ohman, 2000). Some studies demonstrate a relationship between fear, or fear related anxiety, and falling. For example, a study by Adkin and Frank et al. (2000) resulted in observable effects to balance being related to fear of falling by studying how people exert postural control reactions different conditions (Adkin, Frank et al., 2000).

Many factors are present in the stages of a slip and possible fall, even before it occurs. A further examination of literature, in the following section, shows many commonalities among biomechanics, musculature control, tribology (friction and contaminants between the shoe and floor), aging and sensory input; as well as, a significant link between fear and physiological response.

1.2 Research Objectives

The purpose of this study was to provide information about the muscle activity characteristics of the lower extremities during the walking cycle. Because increasing age and possibly a fear of falling may interfere or impact the gait process, this study compares force measurements, EMG measurements, and self reported fear information for two age groups for different walking conditions. Additionally, alteration of the muscle activity characteristics of the lower extremities, due to the impacting variables, may be related to gait adjustment mechanisms that aid in fall prevention.

The primary goal of this study was to measure the muscle activity characteristics (using EMG, measured in micro volts) of the lower extremities (hamstrings, calves, and quadriceps) of both young and older participants during a normal step cycle (heel contact to heel contact of opposing feet). During the step cycle the calf muscle extensor group is mainly active during the toe off phase and the quadriceps muscle extensor group is active following the toe off phase to lift the leg, giving the foot sufficient ground clearance; following this, the extensor muscle group in the hamstring is active during heel contact (Orlovsky et al., 1999). Changes to this muscle activity pattern of the calf and quadriceps during the normal walking cycle, due to age, may affect the hamstring usage and thus, may result in a larger friction utilization during the heel contact phase of the gait cycle due the changes in the vertical and horizontal force exerted by the individual. Simply put, muscle activity patterns of both legs may be different for young adults than for older adults. This difference may lead to a greater susceptibility to slip induced falls for the older adults.

Two measurement conditions were studied. First, a baseline measure was done to study normal gait prior to any exposure to slipping. This normal gait condition is referred to as condition 1. Second, a measure was done following a slip from a contaminated floor surface, but before the initiation of a second slip. Here participants were allowed to view the slippery floor surface before walking over it again trying not to slip. This second measure was used to study participants' adjustment in lower extremity muscle activity to avoid slipping. This is adjusted gait condition is referred to as condition 2.

Muscle activity in the lower extremities, during the walking cycle, was measured using electromyography (EMG). Using this EMG data, a baseline level for the data could be established (Hodges and Bui, 1996). From the baseline level, muscle activation, peak amplitude, mean amplitude, and activity duration can be calculated to represent muscle activity characteristics (Marras et al., 1987). These data could then be used to compare the same muscle groups across different testing conditions involving the same subject (for example, comparing the quadriceps muscle group mean activity during normal gait for a subject to the quadriceps muscle group mean activity during adjusted gait for the same subject due to a known slippery surface). Furthermore, muscle activation data (measured by EMG) could be represented graphically to show the muscle activity pattern of the muscle groups of interest in the lower extremities (Nashner, 1980; Orlovsky et al, 1999).

A secondary goal of this study was to determine whether or not a fear of falling may be related to muscle activity by alteration of the muscle activity pattern of an individual following exposure to a slippery surface, but before the initiation of a slip due to contamination, as noted previously. This situation may affect all participants, however, the individuals that report a fear of falling may have a greater gait adjustment, thus, a greater muscle activity pattern diversion from normal gait (as measured by EMG). Studies show that there is a correlation between emotion and physical activity by relating emotional responses with physiological measurements (Adkin, Frank et al., 2000; Balaban and Thayer, 2001;Carpenter, Frank et al., 2001; Lang, Davis, and Ohman, 2000). The study by Balaban and Thayer (2001) examines the neurological links of fear and anxiety to balance. The University of Illinois at Chicago Fear of Falling Measure (UICFFM) was designed to measure self-reported fear of falling for community-dwelling older adults individuals (Velozo and Peterson, 2001). This measure involves the use of sixteen questions related to different walking situations and a four-point rating scale for each question. The study provided a measure for assessing self-reported fear of falling for the older adults living in assisted communities (Velozo and Peterson, 2001).

The EMG measurement of lower extremity muscle activity pattern an individual exhibits may have an effect on the friction utilization by the individual. Lockhart (2000 and 2001) states that the adjusted friction utilization is a dynamic relationship of horizontal and vertical forces exerted during the slip process of the individual. This is further determined by heel contact velocity, stride length, and cadence. The hamstring (semitendinosis) muscle group may have an effect on the heel contact velocity, and the calf (gastrocnemius) and quadriceps (rectus femoris) muscle group may have an effect on the stride length and cadence of an individual. Thus, the muscle activity pattern of the lower extremities may have an effect on the vertical and horizontal forces exerted by the individual, as well as an effect on the friction utilization exerted by that individual. Additionally, there is a relationship between the friction utilization exhibited by an individual and the distance the individual slips. The higher the adjusted friction utilization (AFU) exerted by the individual during a slip due to contamination, the greater the distance the participant slips (Lockhart, 2000 and 2001). Thus, if the muscle activity pattern of the lower extremity extensor muscle groups (as measured by EMG) has an effect on friction utilization, the distance the individual slips should also be affected. As previously stated, this experiment involves two experimental conditions. Normal gait is condition one; condition two involves a measure following a slip from a contaminated floor surface, but before the initiation of a second slip, where the subject is allowed to view the slippery floor surface and try to cross it without slipping. Every individual adjusts his or her gait parameters (step length, heel contact velocity, slip distance, and friction utilization) to compensate for a slippery surface in order to avoid slipping. This study examined these gait adjustments and similarities across participants. Furthermore, it is possible that elderly individuals or individuals reporting a fear of falling may adjust their gait for situation 2 even greater than normal resulting in even shorter stride length, greatly reduced cadence, and lower horizontal force production, possibly leading to decreased stability and less coordinated muscle usage between lower extremity muscle groups.

The hypotheses of this research are as follows:

Hypothesis 1: Muscle activity pattern of the lower extremities will be adjusted (greater activation duration with lower peak amplitude and lower mean amplitude) from the normal to slippery condition resulting in a shorter step length, reduced heel contact velocity and lower friction demand for all participants

Hypothesis 2: Muscle activity pattern of the lower extremities during the normal condition, for the older subject population will be lower (lower peak amplitude, mean amplitude and longer activation duration) than the younger subject population, resulting in decreased step length, higher friction demand, and higher heel contact velocity

Hypothesis 3: Muscle activity pattern of the lower extremities during the slippery condition, for the older subject population, will result in a lower adjustment (less activation duration and lower mean amplitude and peak amplitude) versus the younger subject population, resulting in decreased step length, higher friction demand and higher heel contact velocity.

Hypothesis 4: Fear of falling, as measured by the University of Illinois at Chicago Fear of Falling Measure (UIC FFM), will be higher in older participants versus younger participants

Hypothesis 5: Fear of Falling will be related to adjustment in muscle activity pattern of the lower extremities.

Hypothesis 6: Among all participants, regardless of age, there will be a relationship between fear of falling and slip distance.

Hypothesis 7: Older participants will have higher friction utilization and thus, a longer slip distance and higher frequency of falls than the younger participants

1.3 Need for the Study

Research is needed to advance scholars and practitioners understanding of the process and implications of slips and falls. Strength may not be solely responsible for balance or recovery from a slip. Moreover, strength may not be completely responsible for balance and muscle usage during the walking process. The efficiency with which the muscle activity pattern is executed could decline with age as well. Furthermore, emotion such as fear could affect an individual's perception of a slippery floor surface resulting in a more exaggerated difference in muscle activity pattern. This research may show a need for muscle coordination improvement during the walking process in addition to strength rehabilitation for the elderly population.

This research may aid in design considerations regarding age and safety related design issues. As the older adult population increases, advancement in information regarding the mechanisms associated with proactively avoiding slips and falls by adjusting gait characteristics, and how these characteristics differ for young and older individuals, is necessary. This type of age related adjustment information could be incorporated into designs possibly increasing the overall safety of older adults.

LITERATURE REVIEW

The following sections contain information about the biomechanics, tribology, physiology, and epidemiology of human gait and slips and falls. In addition, a review of psychophysics and the perception and information processing stages for normal and perturbed gait is included.

2.1 Gait Biomechanics

2.1.1 Function of Gait

Gait is the style or characteristic of the walking pattern of an individual. Transporting the body safely and effectively across a surface is the sole purpose of walking. Human locomotion falls into the category of bipedal locomotion (walking on two legs) and involves carrying the body over alternating left and right feet. Throughout the course of the stride, five functions must occur within the biomechanical limits for the body and within the physical limits of the environment, according to numerous citations (Winter 1992, 1991, 1987, 1984, 1983a & b, 1980):

- Maintaining the support of the upper body (i.e. preventing collapse) during the stance phase.
- Maintaining balance and upright posture.
- Foot trajectory control; resulting in safe ground clearance and gentle heel placement.
- Utilizing mechanical energy to maintain velocity or to accelerate the body.
- Utilizing energy absorption to decelerate the body

Because gait is unique to each individual, each individual exhibits these five functions with varied characteristics. This leads to a further examination of the walking process.

2.1.2 Walking Process

Gait can be represented as a percentage of time between floor contacts of each foot successively. The gait cycle can be stated as the percentage of time from heel contact to heel contact successively from the same foot.

The walking cycle can be broken down into two phases: the swing phase and the stance phase. The swing phase occurs when the foot is elevated and the leg swings to change position between the toe-off and heel strike phases. The stance phase occurs when the foot is on the floor and the leg is used to propel the body forward between the heel strike and toe-off phases. During each walking cycle are two periods at which the body is being supported by two legs at the same time, and two periods where the body is supported by only one leg (Inman et al, 1981; Winter, 1992).

The pushing off of one leg and the swing phase of the other leg creates forward locomotion. At the point of heel contact the heel hits the ground and rapidly decelerates, causing an increase in the acceleration of the knee and hip (since the leg is relatively straight). As the body moves forward, the rest of the foot hits the ground and the push-off phase begins. During the push-off phase, the heel rises and pushes the rest of the foot backwards (plantar flexing of the foot by the muscles in the leg). This results in the beginning of the swing phase. The beginning of the swing phase occurs when the leg is flexed such that the knee is slightly flexed, the foot is dorsally flexed, and the hip is rotating, bringing the leg off the ground to a point. The rest of the swing phase is accomplished by gravity which brings the leg back down to the straightened position ready for heel strike (Inman et al, 1981; Winter, 1992).

The walking cycle can be represented in seconds or as percentages of the different stride phases (Grieve and Gear, 1966; Murray et al., 1966). In terms of percentages, stance time occupies 58% to 61% of the stride phase, and swing time occupies 39% to 42% of the stride phase. Certain parameters can be measured within the walking cycle to ascertain gait characteristics.

2.1.3 Parameters of Gait

Gait parameters are represented by objective measures such as stride length, walking velocity, required coefficient of friction (RCOF), as well as parameters dealing with perturbation such as slip distance (distance slipped or displacement of the foot, following a point at which the RCOF exceeds the available COF upon heel contact).

2.1.3.1 Cadence, Stride Length and Walking Velocity

Cadence is defined as the steps per minute an individual walks. Natural cadence is the frequency of steps as an individual walks as naturally as possible (Winter, 1991). Stride length is the distance of the stride of walking cycle traversed from heel strike to heel strike of the same foot (Murray et al., 1966). Walking velocity is the product of stride length and cadence. Furthermore, as walking velocity increases, stride length and cadence increase (Murray et al., 1966). As people age, there is a decrease in cadence and stride length (Murray et al., 1969). Moreover, male cadence is lower on average than female cadence resulting in a longer average stride length (Molen and boon, 1972)

2.1.3.2 Ground Reaction Force and Required Coefficient of Friction

Ground reaction forces are the vertical and horizontal forces that are measured by a force plate. These forces consist of a total representation of all body forces acting as the foot comes into contact with the force plate. These forces occur in three directions. The vertical component of the force is acceleration due to gravity combined with vertical forces (F_v) applied by the body (body weight and downward momentum of the leg). Additionally, there are horizontal forces (F_H) (in the direction of body motion) and transverse forces (F_T) (perpendicular to the direction of body motion) (Perkins, 1978).

Walking speed affects the magnitude of the horizontal forces as well as vertical forces. Horizontal and vertical forces increase with increasing stride length and increased cadence (Soames and Richardson, 1985). The required coefficient of friction (RCOF) is the lowest coefficient of friction required to keep the foot from sliding at the time of heel contact. Perkins (1978) measured the vertical and horizontal forces exerted by the foot during the stance phase of the gait cycle. The horizontal force divided by the vertical force (F_H/F_v) can be used to represent the RCOF. The study showed the RCOF as a continuous measure and resulted in six peaks. Peaks one and two represent the initial striking of the heel to the floor surface and the slight backwards force exerted on the heel. These forces are insignificant when studying the process of slipping. Peaks 3 and 4 represent the main downward force of the body and the least amount of horizontal or forward force of the body just following heel contact. This results in the lowest ratio of horizontal to vertical force (F_H/F_v) and the RCOF to keep the foot from slipping. If the ROCF exceeds the available COF at any point, a slip will result. Therefore, peaks 3 and 4 represent the part of the heel strike phase which is, most likely to result in a slip

(Perkins 1978; Perkins and Wilson, 1983). Floor surface and cadence, along with age (older individuals versus younger individuals), have a significant effect on adjusted friction utilization (AFU) (Lockhart, 1997, 2000). Elderly people could not effectively adjust friction utilization on very slippery surfaces or during periods of moderately fast to very fast walking velocities (Lockhart, 1997, 2000). This resulted in an increase of falls. This leads to tribology, which further helps describe frictional coefficients and required friction.

2.2 Tribology

Tribology is a study involving friction and lubricants or lubrication. The tribological approach involves the dissipation of the hydrodynamic properties of contaminants between the floor and the shoe, along with the characteristics of the material composition of the shoe sole and the floor surface (Andres and O'Conner, 1992).

The slip resistance of shoe soles to floor surfaces is very important to the safety of human locomotion since people need adequate friction between the shoe and floor in order to avoid slipping and effectively walk across the surface. This leads to the coefficient of friction.

2.2.1 Coefficient of Friction

The frictional force is the force created from two surfaces coming into contact and resistant to sliding across one another. The frictional force acts parallel to the two surfaces. Independent of both the area of contact and the sliding velocity, the frictional force is proportional to the normal force, or load applied. The constant of this is termed the coefficient of friction (COF). Rabinowicz (1956) stated that the frictional force was not due to load alone, but rather velocity as well since frictional force is not constant under every circumstance. Furthermore, investigators noted a difference in static versus dynamic coefficients of friction and the transition from static to dynamic (Sampson et al., 1943). Static COF is greater then dynamic COF for a given object; furthermore, as the velocity of the object increases, the dynamic COF decreases (James, 1983).

The coefficient of friction is the horizontal force created by the body divided by the vertical force created by the body (Chaffin, Woldstad, and Trujillo, 1992). This measure, performed on the forces of the foot, can be used to assess traction of the shoe or floor surface and will differ for various materials (steel, rubber, wood, etc.). The COF is the tangent of the angle of the applied force, or the ratio of horizontal force over vertical force. Researchers (James, 1983; Perkins 1978) have stated that although the foot is, for the most part, stationary during the step, the slip usually occurs while the foot is still slightly moving. Thus, the static COF of the surface and the dynamic COF exerted by the individual play a significant role in determination of required COF, adjusted friction utilization (AFU) and how this can affect a slip. The RCOF (required coefficient of friction) is the minimum coefficient of friction required to keep the body from slipping (as discussed previously). Friction utilization methods could be related to physiological measures.

2.3 Physiological Measures

2.3.1 Muscle Activation during the Walking Cycle

According to Orlovsky, Deliagina, and Grillner (1999), during the process of walking, two legs come into contact with the terrain, and the left leg, the right leg, or both support the body continuously. In the walking process, the hip and knee extensor muscles (antigravitational muscles) are activated slightly before and during the stance phase. During this phase, the ankle extensors are somewhat delayed in relation to the other extensors due to the weight of the body being transferred to this foot. At the final part of the stance phase, the body moves forward due to force produced by the extensor muscles. An important part of the end of the support phase is a significant force production from the contraction of the ankle extensors (including the gastrocnemius lateralis) which results in ankle extension, and propels the body forward (Orlovsky, Deliagina, and Grillner, 1999).

During the swing phase of the walking cycle, the leg is moved forward in relation to the rest of the body by a group of hip flexor muscles (including the rectus femoris). The lower part of the leg is only slightly elevated above the walking surface due to the flexion of the knee. At the end of the swing phase, the foot hits the ground gently with the heel striking first followed by the rest of the foot due to the extension of the ankle. This then initiates the stance and support phase of the walking cycle again.

During normal gait, there is pattern of activity, which may be measured by surface integrated EMG (electromyography), of the gluteus maximus (GIM), the rectus femoris (RF), the vastus lateralis (VL), the semitendinosus and semimembranosis (Stn-Sm), the gastrocnemius lateralis (GL), and the tibialis anterior (TA) (Orlovsky, Deliagina, and

Grillner, 1999). This muscle activity pattern corresponds with angular changes to the hip, knee, and ankle. For location representation, the GL is in the muscle region commonly known as the calf. The RF is located in the quadriceps group; the Stn-Sm is located in the hamstring group and the TA is in front of the shin. Electromyography can be used to characterize muscle activity.

2.3.2 Electromyography

Electromyography (EMG) is a signal that represents the muscle's electrical activity. This signal provides an insight into the muscle coordination and movement, and the muscles role in a particular task (Kleissen, Litgens et al., 1997). A measure of EMG provides the experimenter with an activation signal (a measurement that records the motor action potential of a particular muscle or a group of muscles in terms of electrical potential: Sutherland, 2001). The two types of EMG are fine wire and surface, which can be used to measure the action potential of certain muscles. A fine wire EMG is a measurement tool in which a "fine wire" or electrode is actually inserted into a particular muscle. Surface EMG is a larger electrode attached to the body's skin to measure the action potential of a particular muscle. Muscles that may be very small, deep inside, or particular parts of larger muscle groups, require measurement through application of fine wire EMG (Sutherland, 2001). In contrast, surface EMG can be used to measure a group of small muscles or larger muscles close to the surface, such as the gluteus maximus or larger extensor muscle groups (Sutherland, 2001).

2.3.3 Motor Control Issues

Several studies have been done to determine whether or not EMG measures during clinical gait analysis are consistent and repeatable (Kadaba, Ramakrishnan et al., 1989; Kleissen, Litjens et al., 1997; Wooten, Kadaba, and Cochran, 1990). These studies have shown that EMG measures are repeatable, relatively consistent, and standardized across studies involving surface EMG measures of muscle groups. Kleissen, Litjens, Baten, Harlaar, Hof, and Zilvold (1997) studied the EMG measurements of four muscles in the lower extremities (rectus femoris, semitendinosus, gastrocnemius medialis, and tibialis anterior) across various participants and laboratories. The study resulted in the EMG muscle profiles being independent of the laboratory in which it was measured, and that the measurement technique was standardized (Kliessen, Litjens et al., 1997).

Wootten, Kadaba, and Cochran (1990) examined the use of clustering algorithms to examine EMG measures of phasic muscle activity between different groups of people in order to determine if EMG measures of patterns vary from group to group. The results showed only one major variation. A factor that may affect phasic muscle activity may be walking velocity. Participants were instructed to walk using a natural cadence, however, there were differences in walking velocity across participants since no control measures were used to reduce or eliminate this. Nonetheless, this study resulted in significant similarities in the patterns of phasic muscle activity during locomotion in individuals with no physical or mental disabilities. Each different group of people was a subgroup. The only differences noted between subgroups were slight and insignificant (Wooten, Kadaba, and Cochran, 1990).

These studies show that surface EMG measurements of muscle pattern analysis are standardized and repeatable. Additionally, there exists a commonality among individuals in phasic muscle activity of lower extremity muscles during the gait process.

Hodges and Bui (1996) examined the period of muscle activation using electromyography (EMG). This study involved the computer-based determination of muscle contraction versus that of visual detection. This computer-based determination involved setting a baseline measure as a threshold level of detection (within 1, 2 or 3 standard deviations) and setting an algorithm that measured the activation point just above the threshold level. The research revealed very precise use of the computer-based protocols for measuring muscle activation thresholds (Hodges and Bui, 1996).

Electromyography data can be analyzed by examination of the visual representation of the data. Marras, Rangarajulu, and Lavender (1987) conducted a study of trunk muscle activity. To examine the activity of the trunk muscles, EMG integrated (RMS) data was represented graphically. Activation of the muscle, slope, activation peak, mean amplitude, and activation duration were measured. This calculated data was then used to measure expected and unexpected muscle activity for comparison (Marras et al., 1987). One can infer from the previous two studies that one can effectively set a baseline level from integrated EMG (RMS) data measured during the walking cycle and represent it graphically. It can be inferred further from Hodges and Bui (1996) and Marras et al. (1987) that activation onset, peak amplitude, mean amplitude, and activation duration can be used to analyze muscle usage in the muscles of the lower extremities during this walking process. Physiological and cognitive changes accompany aging and may affect motor control.

2.3.4 Aging

Throughout the course of aging, there are significant effects to the physical state of the body. The adaptation of gait in elderly people may be due to the decrease of muscle strength, loss of motor neurons, loss of muscle fibers, and decline of aerobic capacity (Prince, Corriveau et al., 1997; Winter, 1991). During normal walking, elderly individuals, despite walking much slower, consume significantly more oxygen than younger people (Prince, Corriveau et al., 1997). Additionally, there exists a loss of passive range of motion among older individuals specifically in the knees. It is possible that as a result of these physiological changes, the heel contact velocity of older individuals at the start of the stance phase is significantly higher for the older individuals than for younger individuals (Lockhart, 2000; Prince, Corriveau et al., 1997; Winter, 1991). There may be a greater possibility of slip induced falls due to the increased heel velocity. Furthermore, older individuals exhibit a higher absorption of energy by the knee during the transition from the stance phase to the swing phase during the walking cycle. This translates to lower push off from the ankle muscles and less demand on the leg muscles to lower angular velocity (Prince, Corriveau et al., 1997). There exist significant changes to the body during aging and these changes could possibly have an effect on the muscle patterns of the lower extremities during the walking cycle.

Accompanying motor control and age related changes to the body are cognitive changes. Psychophysics employs techniques to measure information input and response output and how this may be related to cognition.

2.4 Psychophysics

2.4.1 Function of Psychophysics

According to G.A. Gescheider (1997), psychophysics is a part of modern psychology that focuses on the relationships between sensations related to the intensity of the stimulation to mental processes. Psychophysical laws are used to describe these sensation-stimulus relationships and are often referred to as “stimulus transformation” (Gescheider, 1997). The underlying goal of the study of psychophysics is to provide information about how the sensory input and response functions of the brain relate to physiological responses and actions of the body. The study of psychophysics provides information in two basic areas: descriptive psychophysics and analytical psychophysics.

Descriptive psychophysics involves the study of thresholds and the sensitivity of the sensory system in a quantitative manner (Gescheider, 1985). The study of thresholds is important to determine the levels of stimulus required to produce a response or interfere with a response using the visual, auditory, or proprioceptive systems.

The study of analytical psychophysics involves the comparison of different stimuli and various responses. Analytical psychophysics is a type of psychophysics concerned with the nature of sensory information used to carry out a physiological or biomechanical response.

Studies involving analytical psychophysical parameters have shown that there is a mental component directly involved in the gait cycle (Adkin, Frank et al. 2000; Carpenter, Frank et al., 2001; Cohen and Cohen 1994a&b; and Zohar, 1978). These studies examined the perception of slipperiness and how vision is involved to detect hazards that may lead to a fall. It is also stated that the input of such visual information into the brain can alter the subject's gait.

In the following subsections, the relationship of psychophysics to physiology is further explained. Moreover, relationships of psychophysical parameters to cognitive processes are examined.

2.4.2 Sensory Perception

Sensory perception (information input and recognition) is imperative for recognition of risk factors during the normal gait process. Sensory input involves information gathering about the body's surrounding and internal environments, and inputting that information into the brain. Sensory perception involves recognition of a stimulus. Cognitive processes are used to interpret and execute necessary responses from this information. Risk perception is a cognitive process involving interpretation of a potentially hazardous situation that could consequentially lead to physical harm. There is a very close link between information stimulus recognition and interpretation. Studies have shown that people perceive the surrounding area in different ways. For example, a person could be sitting in a car atop a hill at a red light waiting for the signal change, and then another vehicle rolls slowly up next to the person. Interpreting this slow forward motion of the neighboring car as backward motion of the person's own car, the person presses firmly on the brake pedal to stop the car. This perceived motion caused the person to exert a biomechanical response even though the car was not really moving (Balaban and Thayer, 2001). This situation has been used to help describe and relate a momentary departure from a spatially stable, non-moving frame of mind with anxiety and fear. Sensory perception and interpretation is critical for deciphering the external environment and inputting information for the body to act upon.

2.4.2.1 Perception of Slipperiness

Sensory perception of slippery surfaces can be a very important determining factor for gait alteration in that the person may avoid slipping and possibly falling. Furthermore, a person's judgment of the surface slipperiness can often be the determining factor of whether or not a fall occurs (Cohen and Cohen, 1994b). Cohen and Cohen (1994a) studied the perception of slipperiness on a series of tiles in relation to the coefficient of friction of those tiles. They addressed the perception of slipperiness using a "slipperiness rating scale" in a realistic office setting. Conclusions from these two tests showed that the participants rated perception of slippery surfaces differently (compared with the actual coefficient of friction) under both wet and dry circumstances. Additionally, the participants rated wet surfaces as being more slippery than dry surfaces for almost all of the floor types, even if the actual COF was the same or lower (more slippery) for the dry surfaces than for the wet surfaces (Cohen and Cohen, 1994b). This sensory perception of slipperiness seems to follow a distinct mental model for participants even if that model is not actually correct in assumption.

2.4.2.2 Visual and Tactile Sensation:

In addition to being a major psychophysical parameter, the visual system is very important for sensory perception. A person walking has a constantly changing effective visual area. This visual area contains all visual information and details involving the

surrounding environment, yet the person selectively interprets only a small part of this information. Priority of visual information processing involves falling objects and objects moving within the person's field of view. Therefore, the person often fails to detect a slippery surface, which could eventually lead to a slip (Zohar, 1978).
Studies of visual rating of slippery surfaces (Cohen and Cohen 1994a and b) suggest that tactile information input was far superior to visual information input for rating slippery surfaces. Study participants often incorrectly rated non-slippery surfaces as slippery. Furthermore, persons who had experienced previous tactile information rated surface slipperiness more accurately. The findings suggested that people make predictions about the surface visually and verify these predictions after crossing the surface using tactile measurements. Thus, people use the verified tactile information to predict future walking surfaces (Cohen and Cohen, 1994a and b).

2.4.3 Psychological Emotions and Physiology

The numerous feelings that people tend to experience, such as joy, love, grief, anger, and fear are commonly referred to as emotions. These internal sensations, which we call emotions, are separate and distinguishable from one another. Therefore, it follows that there are certain neural events that are specific to each response (Schneider and Tarshis, 1995). The findings from numerous studies document the relationship between emotions and physiological activity by relating emotional responses to physiological measurements (Adkin, Frank et al., 2000; Balaban and Thayer, 2001; Carpenter, Frank et al., 2001; Lang, Davis, and Ohman, 2000). Adkin, Frank et al. (2000) reported that as the level of postural threat increased, participants' center of pressure showed a significant change. As the posture threat for the subject increased, the displacement of the center of pressure decreased (Adkin, Frank et al., 2000). Therefore, the study resulted in observable effects to postural control as a consequence of perceived fear of falling.

2.4.3.1 Anxiety and Fear

Anxiety is generally defined as a feeling of apprehension and fear that may be correlated with a specific object or event. This feeling, or emotion, is often accompanied by an increase in physiological arousal such as increased heart rate, elevated blood pressure, sweating, and changes in the autonomic nervous system (Lefton, 1994). Anxiety is an emotional response. Conversely, fear is a cognitive response to a situation and is often associated with anxiety (Beck et al., 1985). A fear of falling is a special circumstance of cognitive appraisal in which the fear is focused on circumstances related to falling. A fear of falling is defined as a low self-efficacy (one's own perception of capabilities within a particular range of activities) to avoid falling during day-to-day activities (Howland et al., 1993; Tinnetti et al, 1994; Tennstedt et al., 1998; Velozo and Peterson, 2001). Apprehension and fear, along with changes in the autonomic nervous system, are the result of cognitive processes and environmental stimuli (Lefton, 1994). A physiological result of fear is an increase in hand temperature (Schneider and Tarshis, 1995).

Studies have also shown a link between anxiety and balance control (Adkin, Frank et al., 2000; Balaban and Thayer, 2001; Carpenter, Frank et al., 2001). The studies by Carpenter, Frank et al. (2001), and Adkin, Frank et al. (2000) involved measurements of the center of pressure of an individual standing on a platform. The higher the platform was and the closer the person was positioned to the edge, the more concentrated the center of pressure exerted by the individual. Thus, as the threat level or height and orientation of the platform increased, the fear level of the individual, as measured through the concentration of the center of pressure, increased. As stated previously, fear of falling is defined as perceived low self-efficacy to avoid falls during normal activities (Carpenter, Frank et al. 2001). The study by Balaban and Thayer (2001) examined the neurological links for fear or anxiety in relation to balance. Anxiety is an emotion stemming from a part of the brain and is linked through a series of physical pathways to the part of the brain that controls balance. Thus, the anatomy of fear and anxiety could be related to fear of falling.

2.4.3.2 Anatomy of Fear and Anxiety

Fear and anxiety start with a stimulus entering the brain. The amygdala, which is a small, almond shaped region in the brain, is at the center of fear acquisition and response (Balaban and Thayer, 2001; Lang, Davis, and Ohman, 2000; Schneider and Tarshis, 1995). Fear can be learned or unlearned. The amygdala is centrally involved with both types of fear. Sensory information about the surrounding environment enters through sensory receptors and is directed to the amygdala through a region known as the thalamus. The thalamus is an area of the brain involved with sensory information reception and relay. Memory or conditioned information enters the amygdala through the hippocampus, which is an area of the brain involved with spatial information and long term memory processing (Schneider and Tarshis, 1995). The amygdala is also involved directly with the expression of fear. The amydala receives the processed fear information and projects this information to various regions of the brain involved with direct mediation of specific fear and anxiety responses and expressions (Lang, Davis, and Ohman, 2000). Balaban and Thayer (2001) deeply examined fear and anxiety further by linking anxiety with balance. The amygdala is indirectly linked to the vestibular cortex (the region of brain directly related to the vestibular apparatus and balance). Sensory inputs necessary to maintain balance are from vision, the proprioceptive system, and the vestibular apparatus. The vestibular apparatus is a region in the inner ear that provides the body with X, Y, and Z directional position coordinates. The link from the amygdala to the vestibular apparatus suggests that conditioned fear or anxiety could have a significant impact on balance. A threatening situation involving postural control can be introduced and immediately following, a fear or panic response can be triggered and the balance of the individual can be affected (Balaban and Thayer, 2001).

2.4.4 Measuring Anxiety and Fear

Measuring levels of anxiety and fear objectively is difficult to accomplish. With biomechanical parameters or EMG, a physical measure can be obtained using machines or calculations of physical parameters. To physically measure a level of fear or anxiety directly is nearly impossible. Thus, researchers have to rely on measurement tools such as rating scales, questionnaires, or structured interviews used in conjunction with a physical measurement.

One measurement tool commonly used to measure anxiety is the Hamilton Anxiety Rating Scale (HARS). This measurement technique is used to measure psychic and somatic anxiety symptoms, and is commonly used to assess the severity of generalized anxiety disorder (Shear, Vander Bilt et al., 2001). A study by Shear, Vander Bilt et al (2001) involved creation of a structured interview technique and rating scale to be used with the Hamilton anxiety test. The HAR scale is a four-point scale used by the interviewer to assess severity, ("none to mild, mild to moderate, moderate to severe, and severe to very severe" Shear, Vander Bilt et al., 2001). This scale is used primarily to assess general symptoms of anxiety or anxiety disorder, and is not used in depth to measure fearful or phobic situations.

Velozo and Peterson (2001) researched assessing a fear of falling measure for elderly individuals living in assisted communities. According to the study, one third to one half of community dwelling elders acknowledge a fear of falling and because of this, one third of these individuals limit physical activities as a result of this fear. The study notes that a fear of falling may make an independent contribution to declining psychosocial and physical parameters. A fear of falling measure developed at the University of Illinois at Chicago (UIC FFM) was used to create measures that can be linked to descriptions of fear of falling. This measurement tool consisted of 19 activities that may cause concerns or elicit fears about falling (APPENDIX C: UICFFM Questionnaire) and a four point rating scale was developed for these activities ("not at all worried, a little worried, moderately worried, and very worried" Velozo and Peterson, 2001). This study also used Rasch analysis to analyze the probability of each rating based on the individual's reported level of fear. Rasch analysis involves using goodness-of-fit statistics (mean square standardized results) to determine the extent to which an item fits the scale of measurement designed for it. Velozo and Perterson (2001) demonstrated the successful use of Rasch analysis to refine the UICFFM and improve its usefulness.

2.4.5 Sensory perception and Aging

Many changes take place as people age; as a result of this, the aging population is more predisposed to injuries caused by falling. Sensory inputs from vision, the proprioceptive system, and the vestibular apparatus are necessary to maintain balance. Any age related changes to these mechanisms could significantly impact the effectiveness of balance.

Lishman and Lee (1973) showed that vision is the primary sensory input over proprioceptive and vestibular functions. This study demonstrated postural sway being in synchronous rhythm with a visual queue on a wall as a subject observed the queue. This sway was prominent even though most of the participants were not aware of this motion. Fozard, Wolf, and Bell (1977) showed that a decrease in visual acuity, an increase in glare, and increased postural sway occur with advancing age. Since people experience degradation to the visual system with advancing age, this may increase the response time of the body and decrease the effectiveness of the response due to a slip.

Rabbit and Rogers (1965) concluded that there are significant proprioceptive deficits due to aging. In addition, older individuals tend to use afferent feedback systems more than younger individuals. Passive movement thresholds for the lower extremities (hips, knees, and ankles) were significantly reduced with advancing age (Barrack and Cook, 1984; Woollacott et al., 1982). These studies used the passive movement threshold as an indication of proprioceptive function. This resulted in the acuity of the proprioceptive system to decrease with advancing age. Visual system degradation, along with proprioceptive system degradation could lead to a significant decline in sensory perception and an increase in the likelihood of falling.

Older individuals, on average, have much higher self-reports of fear-of-falling than younger individuals do (Howland et al., 1993; Tinnetti et al, 1994; Tennstedt et al., 1998; Velozo and Peterson, 2001). Studies by Howland et al. (1993) and Tinnetti et al. (1994) show that fear-of-falling reports increase as age increases. Furthermore, elderly individuals often limit physical activity because of a fear of falling. Tennstedt et al., (1998) used group intervention to combat and reduce fears of falling in elderly individuals. As a result, individuals in the intervention group showed increased levels of physical activity and "less health related dysfunction with mobility control" immediately following the intervention (Tennstedt et al., 1998). Perception may be affected and anxiety increased due to age. Additionally, physical activity can be significantly reduced because of fear and may ultimately lead to further degeneration of muscle control from inactivity.

2.5 Epidemiology

2.5.1 Slip and Fall Accidents

Slips and trips often lead to or are the cause of fall related accidents (Cohen and Compton 1982; Manning et al. 1988). Cohen and Compton (1982) conducted a study on fall related accidents resulting in injuries from various companies and typical work surfaces associated with a variety of jobs. The authors concluded that workers in construction trades had the highest incidence of falling on different levels of surfaces. Office, restaurant, service, hospital, retail, and textile workers tended to fall on the same surfaces on which the perturbation occurred. Slips, most frequently on floor surfaces, caused one half of the reported falls (Cohen and Compton, 1982). Unskilled workers experienced 26 % of the fall related injuries. However, skilled workers, office workers and managerial workers, etc., experienced a significant amount of injuries as well.

Manning et al. (1988) conducted a study of accidents caused by underfoot perturbations in a population of 10,000 workers. The results showed that 62% of these underfoot accidents were the result of slipping. Furthermore, 28% of these slipping accidents were reportedly caused by floor surface contamination by various liquids.

2.5.2 Slips and Falls in the Elderly Population

The population of older adults is increasing in size. In 1999, the older adult population (65 and older) represented 12.7% of the total United States population of 34.5 million individuals. One out of every eight Americans is 65 years of age or older (Administration on Aging, 2000). A child born in the US in 1998 is expected to live approximately 29 years longer than a child born in the US in 1900 (Administration on Aging, 2000). In 1999, approximately 2 million people celebrated a 65th birthday and only 1.8 million died (Administration on Aging). Indeed, the elderly population is not only expected to live longer, but this population is increasing in size every day.

The incidence of falls increases with age. Approximately 33% of the senior population living at home will fall each year (Campbell et al., 1981). Campbell et al (1981) reported that the incidence of falls in the elderly increased from 25% at 70 years old to 35% at 75 years old. Additionally, prior to the age of 75 years, women tend to fall more frequently than men (Campbel et al 1981).

According to a study by the Center for Disease Control (Stevens, Hasbrouck et al., 1999) deaths from unintentional injuries rank seventh in the United States for adults aged 65 and older. Falls account for the highest numbers of deaths from unintentional injuries, which is approximately 10 percent. Nearly 8500 adults in this category died as a result of unintentional falls in 1996 (Stevens, Hasbrouck et al., 1999).

Falls are a significant cause of injury and in 1994 accounted for an estimated 20.2 billion dollars (CDC Fact Book year 2000). Fractures are a very serious injury for older individuals with hip fractures being the greatest in number. This results in the most hospitalizations over any other injury. Furthermore, 87% of all fractures are caused by falls (CDC Fact Book year 2000). Finally, the leading cause of death from injuries for people 65 years and older is from falls; nearly 9000 older individuals died from falls in 1997 (CDC Fact Book year 2000).

METHOD

3.1 Participants

Fourteen older (65 and older) persons and fourteen younger (18 – 35 years of age) persons participated in the experiment. Both groups consisted of seven females and seven males. The participants from the younger age group were recruited from the Virginia Tech Campus and the older individuals were recruited from the local community in Blacksburg, Virginia via word-of-mouth and through the use of newspaper advertisements. The older participants were required to have successfully completed a medical examination within the past 6 months, be in good physical and mental heath, and have no restrictions to physical activity. The younger individuals had completed a medical examination within the past year, were in good physical and mental heath, and had no physical restriction to activity as well. Participants were required to sign a release form for this experiment, which had been approved by Virginia Polytechnic Institute and State University IRB. No other participant criteria were applied. Refer to Table 1 for participant characteristics.

3.1.1 Sample Size Estimation

The required sample size estimation for this experiment was obtained through estimation of variation of heel velocity across participants obtained from previous studies by Lockhart (2000a and b). To determine older and younger subject populations large enough to differentiate, power calculations were performed. The standard two-tailed t-test was used as the general test for the two subject populations. The power of the test (Neter et al., 1996) is given by:

$$\text{Power} = P\{|t^*| > t(1-\alpha/2; n-2) | \delta\}$$

The distance between the means (elderly and young age groups' heel velocity) is represented by δ (the non-centrality parameter). This is represented by the following equation:

$$\delta = |A-B| / \sigma \sqrt{(2/n)}$$

The standard deviation of heel velocity distribution is represented by σ, and n represents the number of participants for a group.

The minimum high probability detection difference between A and B is assumed to be 15 cm/sec (Lockhart 2000a, 2000b) for this study. Previous studies by Lockhart (2000 a and b) indicate that heel velocity standard deviation was 15 cm/sec. In order to determine the specified differences in heel velocity (α = 0.05), 14 participants in each age group (younger and older) will be needed in order to have type II error probability of < 0.3 and a power > 0.7.

Table 1: Participant characteristics (Age, Weight, & Height)

	Young (19-35 years old) Mean (S.D.)	Old (67-79 years old) Mean (S.D.)
Age (yr)	23.21 (4.41)	72.64 (4.36)
Weight (kg)	71.74 (11.97)	72.59 (16.31)
Height (cm)	172.41 (10.94)	168.49 (9.1)

3.2 Apparatus

A linear walking track, illustrated by Figure , was used to conduct the walking trials. An overhead track supporting a fall-arresting support system was utilized to protect individuals from fall related injury. Vinyl flooring materials (Armstrong) were used in this experiment to simulate a realistic environment. An area of the flooring surface was covered with a mixture of dish soap (Ivory) and water (2 parts soap to 3 parts water) to lower the available coefficient of friction (COF). A horizontal-pull slip meter with a shoe-simulating rubber material was used to measure the available dynamic coefficient of friction (ADCOF).

The area of contaminated flooring was located on a sliding track and operated by the experimenter to alternate contaminated and non-contaminated surfaces without the subject's knowledge. Two workstations were placed at each end of the track to direct the attention of the subject away from the floor surface. The function of this system was to control the experiment such that the floor surface could be changed from not slippery to slippery without the participants' awareness. The fall-arresting rig, being used to protect the participants from fall related injuries, was designed to allow the subject to slip and catch the falling participant immediately. This prevented any further contact with the surface and any injury to falling.

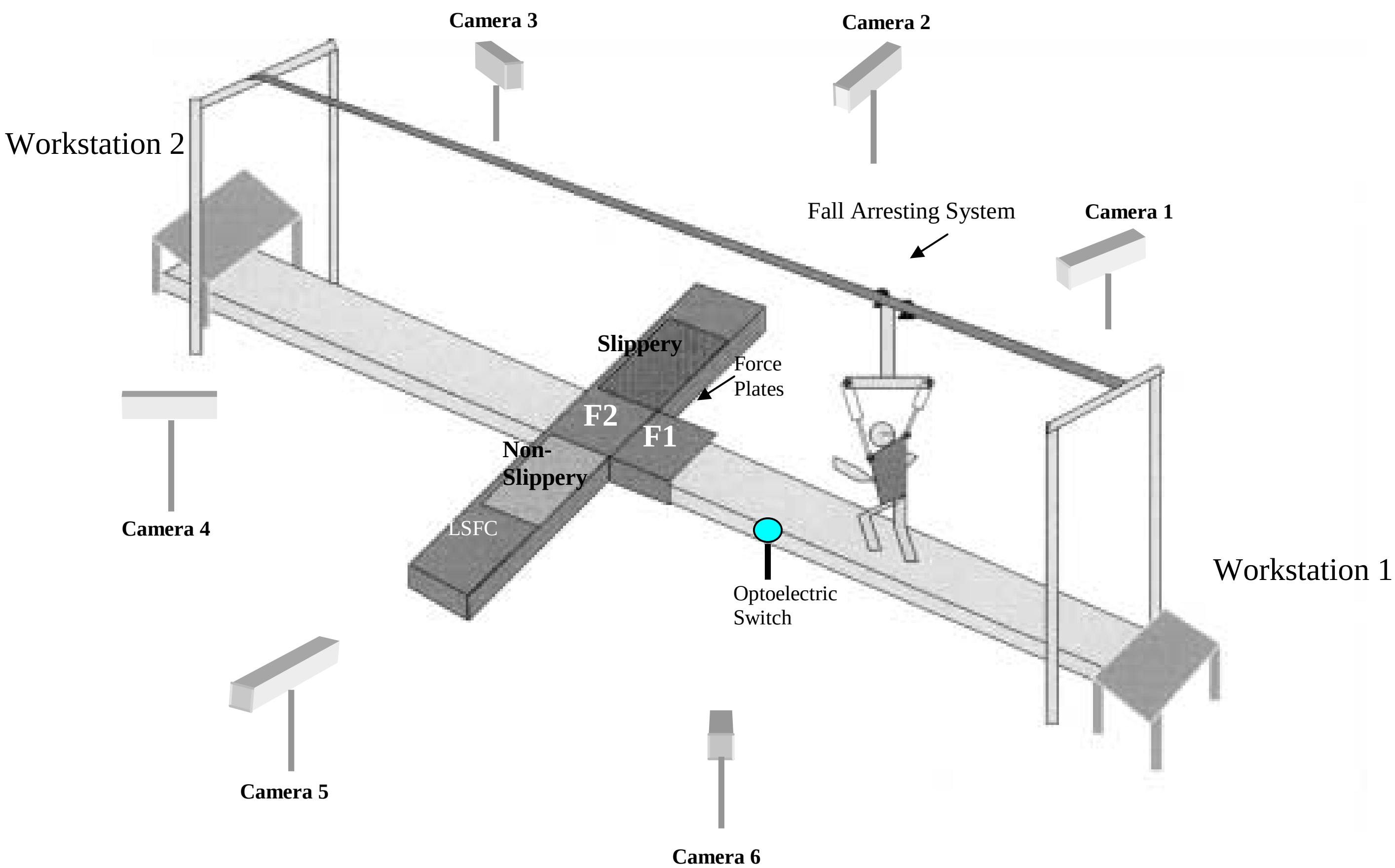


Figure 1: Walking track with fall arresting harness. The flooring in the middle is interchangeable from slippery to non-slippery at the will of the experimenter. F1 and F2 represent the force plates and the 6 cameras are for use with the Qtrac motion capture

An infrared passive marker system (ProReflex Qualysis) utilizing six cameras was used to collect three dimensional posture data (sampled and recorded at a rate of 120 Hz) of the participants walking through the test area. Two Bertec force plates at a sampling rate of 1200 Hz measured ground reaction forces exerted by the participants as they walked over the test surface.

Lower extremity muscle activity (as measured through the gastocnemius lateralis, semitedinosis, and rectus femoris) was measured using surface electromyography (EMG). EMG signals were sampled and measured by a wireless, eight-channel EMG system (Noraxon), and displayed and stored on a PC with LabView software and National Instrument hardware at a sampling rate of 1200 Hz. The Bertec force plates were used to collect force profiles through an analogue-to-digital convertion capture card and computer workstation (Windows PC). This information was displayed and stored via LabView software.

3.3 Questionnaire

The questionnaire used to measure fear of falling was obtained from the Journal of Physical Medicine and Rehabilitation. The University of Illinios at Chicago Fear of Falling Measure contains 16 questions each having a 4-point rating scale (See **Error! Reference source not found.** on page **Error! Bookmark not defined.**). The instrument is designed to measure fear of falling in community dwelling older persons via self-report. The measure was created, refined, and deemed valid by Velozo and Peterson (2001). No other references were available to further validate the fear of falling measure.

3.4 Procedures

3.4.1 Familiarization Session

Prior to any scheduling of experiments involving data collection, the participants took part in a familiarization session. This familiarization session was used as an introduction to the experiment for the individual being tested. During this session, each participant was given literature regarding the experiment, signed a release form, and was administered the UICFFM questionnaire to assess fear of falling. During this time, they also became familiar with the equipment, the fall-arresting harness and the experimental protocol. The individual being tested was asked to test the fall-arresting harness in order to gain confidence in the rig and the self-assurance that it worked as intended. This familiarization session was finalized by preparing the individual for the walking protocol. In preparation for the walking protocol, EMG sensors were placed on the calf, hamstring, and quadriceps muscle groups on both lower extremities. Additionally, markers were placed on twenty-eight anthropometrical landmarks for 3D dynamic motion capture using the six-camera Q-Trac System (Figure 1). Finally, the person was placed in the arresting harness and positioned on the walking track.

3.4.2 Walking Protocol

The walking protocol, which was the second part of the experiment, was used to gather biomechanical data from the participant. This was done utilizing the walking track, fall-arresting harness, force plates, EMG, and the Qualysis motion-capture system. Prior to this, the participant was given standard tennis style walking shoes in order to reduce variation caused by shoe type or shoe surface. Skin was prepared and surface EMG sensors were attached to the lower extremity muscle groups (quadriceps, hamstring, and calf) on both legs of the subject.   Furthermore, the participant had reflective markers attached to anthropometrical landmarks (ankle, knee, hip shoulder, elbow, wrist, etc…) to be used for motion capture. Every participant wore a fall arresting harness that supported the full body and did not allow the participant to have hand contact with the floor even in the event of a fall. This was done to eliminate any possibility of injury. Additionally, this harness did not affect the participant's field of view or motion of the lower and upper extremities since the harness was attached to the overhead structure at the participant's shoulder position.

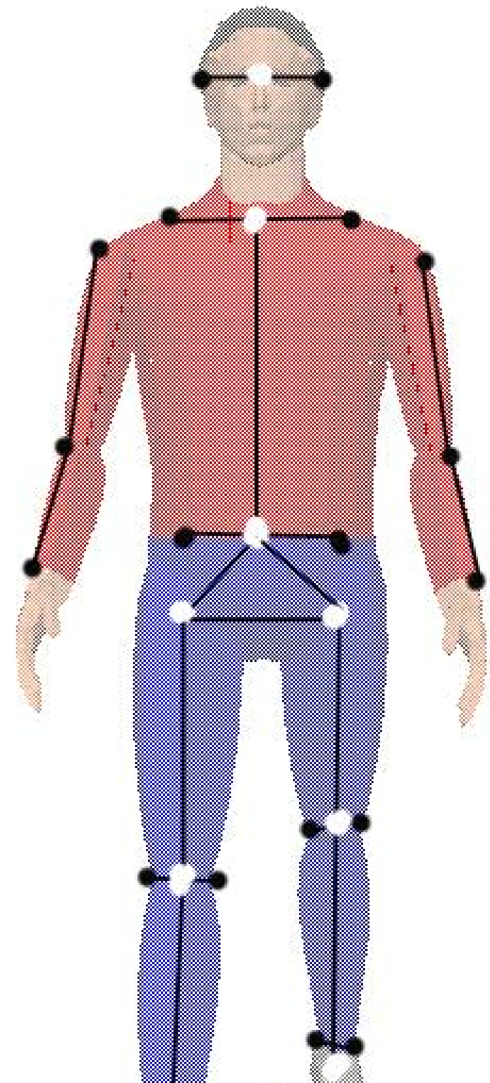


Figure 1: This figure illustrates the placement of the makers for the motion capture system. The marker placements are represented by the black dots. Additionally, markers will be places on the knuckles and the heels

The walking protocol was done after the participant was prepared and safely in the fall arresting harness. At this point, the participant was asked to walk back and forth along the track in order to establish natural cadence and relatively constant walking velocity. Once this had been established, normal gait (condition 1) was measured. The participant was not told to stop, since after this, at a random interval, the floor surface was changed from non-slippery to slippery without the knowledge of the participant. In order to draw attention away from the participant, either end of the walking track contained a workstation with a simple task and video monitor. The video monitor showed alternating color information that the participant was asked to view while traversing the floor surface. Additionally, the participant used a personal radio with headphones for listening to comedy routines. The center of the walking track housed two floor surfaces that were changed at the will of the experimenter (See Figure on page 38) and these distractions concealed any sounds of the floor surface changing. At a random point, the floor surface was changed to the slippery surface and force, motion and EMG data were collected. After the participant slipped, his or her shoes and floor surface outside the slippery area was cleaned, to prevent any unwanted slips. For a final measure, the participant was positioned back at the beginning of the track and asked to look at the slippery floor surface and walk across it while trying not to slip. Adjusted gait data was collected as the subject traversed the slippery surface (condition 2).

3.5 Experimental variables

3.5.1 Independent Variables

The independent variables for the experimental study are listed as follows:

- Age – Participants were classified into two groups - young (18-35) and elderly (65 +).
- Floor surface slipperiness - the experimenter had full control of the non-slippery and slippery floor conditions

3.5.2 Dependent variables

The dependent variables for the experimental study are listed as follows:

- Friction utilization (This is the ratio of horizontal to vertical force (F_H/F_v) at peak 3). This was measured for each subject through information gained by the force platforms for walking conditions 1 and 2.
- Heel contact velocity – HCV = $|(X_{i+1} - X_{i-1}) / 2\Delta t|$ cm/sec (where t = time, and X = horizontal displacement component). This was calculated for 10 frames proceeding and one frame following heel contact. The heel velocity results for the 11 frames were averaged to obtain an average heel contact velocity. Heel contact velocity was measured for each force plate for both walking conditions.
- Step length – length (in centimeters) from heel contact to heel contact of one foot to the other. This was measured for each subject through the motion capture system utilizing the distance formula ($\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$) where (X1,

Y1) represents the position of the first foot and (X2, Y2) is the position of the alternating foot. This was done by measuring the heel position during the final heel contact on the first force plate to the initial heel contact on the second force plate.

- Slip distance – the slip distance each subject slips was determined using the force platform and displacement data. The total slip distance is a combination of slip distance 1 and slip distance 2. Slip distance 1 is the distance from slip start to peak heel velocity, and slip distance 2 is the distance from peek heel acceleration to peak sliding heel velocity (PSHV) (Figure 2). SD1 and SD2 are calculated with the distance formula ($\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$).
- Muscle activity pattern – Figure 3. After the bounded are was established, muscle activity within this region was measured via, peak amplitude, mean amplitude and activity duration of the signal (Marras et al., 1987) after a baseline level (+ 2 standard deviations) was established (Hodges and Bui, 1996) from EMG data integrated (RMS) for the quadriceps, hamstring and calf muscle groups in both legs.
- Fear of falling (UICFFM) – This was measured using University of Chicago at Illinios Fear of Falling Measure (Velozo and Peterson, 2001) (a 16 item questionnaire with a four point rating scale) for every subject for determination of fear of falling level.

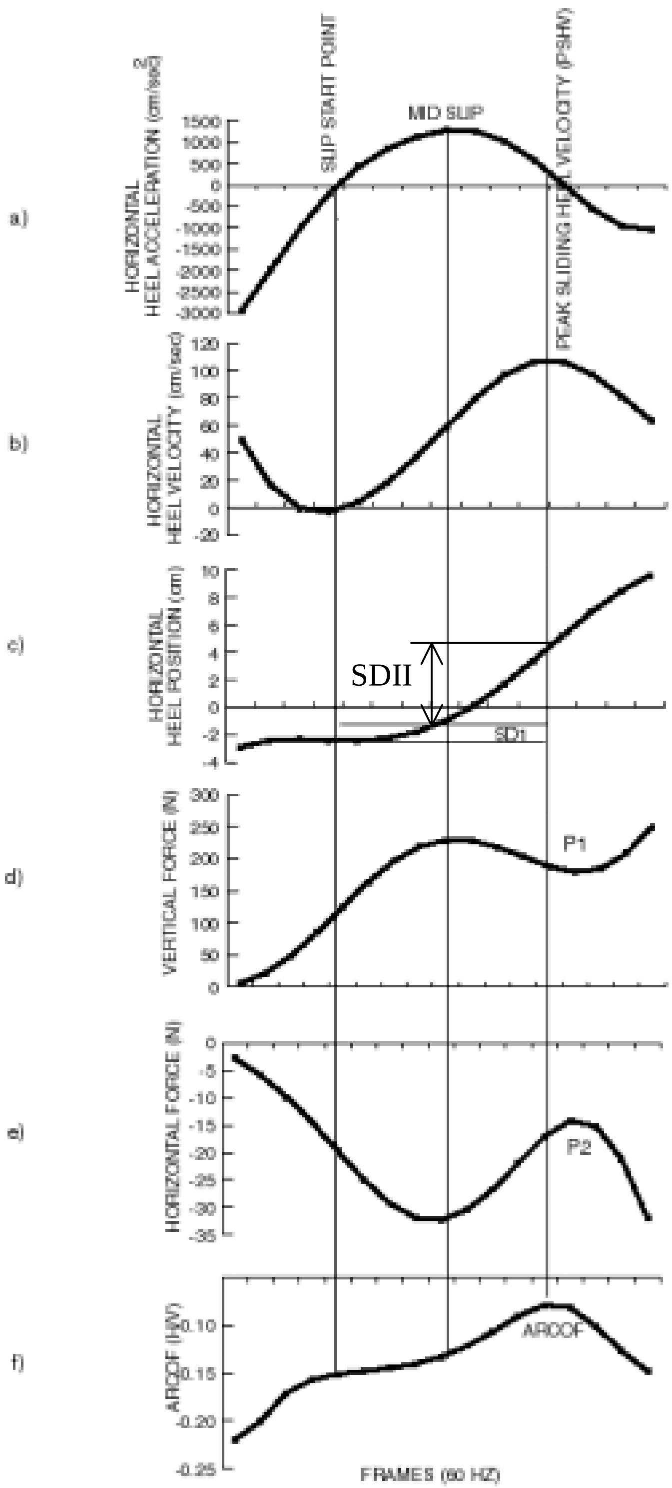


Figure 2: Gait parameters during the slip process

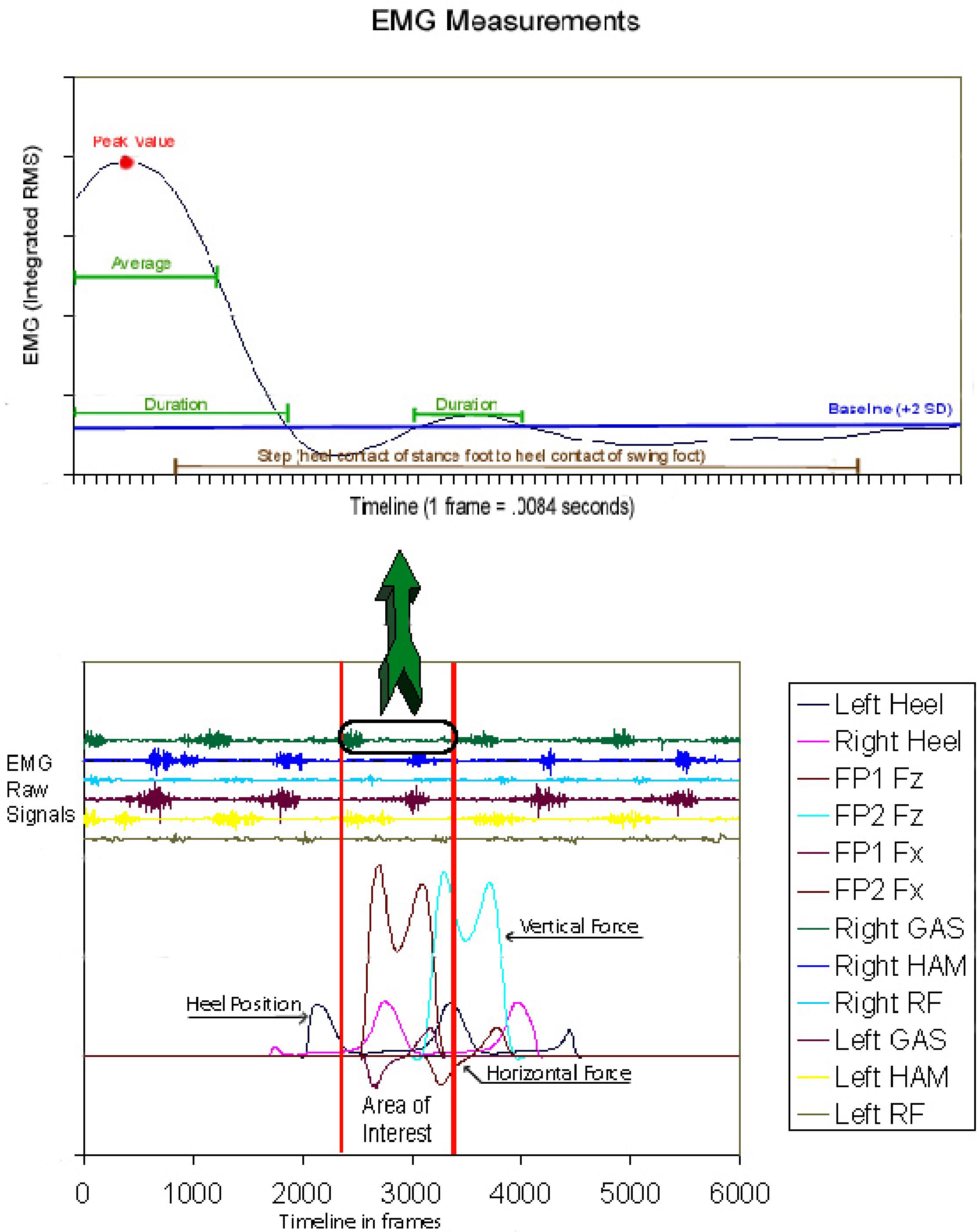


Figure 3: Example of bounded area including gait parameters. Raw EMG signal converted to integrated RMS. Muscle activity (duration, peak, & mean) measured for all six muscles

3.6 Data Analysis

As previously stated, the study addressed seven research hypotheses. Analysis consisted of repeated measures analysis of variance (ANOVA), bivariate correlation analyses, and F-test. Converted body marker coordinate data, ground reaction forces, and EMG data was smoothed utilizing a digital fourth-order, low-pass Butterworth filter (Winter, 1990). Additionally, cutoff frequency for the EMG data was set at 12 Hz. The data analysis methods for each hypothesis are shown below.

Hypothesis 1: Muscle activity pattern of the lower extremities will be adjusted (greater activation duration with lower peak amplitude and lower mean amplitude) from situation 1 to situation 2 resulting in a shorter step length, reduced heel contact velocity and lower friction demand for all participants

Hypothesis 2: Muscle activity pattern of the lower extremities during the normal condition, for the old subject population will be lower (lower peak amplitude, mean amplitude and longer activation duration) than the young subject population, resulting in decreased step length, higher friction demand, and higher heel contact velocity

Hypothesis 3: Muscle activity pattern of the lower extremities during the slippery condition, for the old subject population, will result in a lower adjustment (less activation duration and lower mean amplitude and peak amplitude) versus the young subject population, resulting in decreased step length, higher friction demand and higher heel contact velocity.

These first three hypotheses were analyzed using a 2 factor repeated measures mixed factors ANOVA. Age was a between subjects factor, and Condition (1 and

2) was a within subjects factor; each factor will had two levels. This experimental design was as follows:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_{k(i)} + \alpha\beta_{ij} + \beta\gamma_{jk(i)} + \varepsilon_{l(ijk)}$$

Where μ is the population mean, α (age group) and β (Condition) are fixed effects factors, and γ (subjects) was random (i = 2, j = 2, and k = 14).

ANOVA Table:

Source of Variaiton	df	SS	E(MS)
Between			
Factor A: Age group	(a-1)	SS_A	$bn\sigma_\alpha^2+b\sigma_\gamma^2+\sigma_\varepsilon^2$
S/A	a(n-1)	$SS_{S/A}$	$b\sigma_\gamma^2+\sigma_\varepsilon^2$
Within			
Factor B: Condition	(b-1)	SS_B	$an\sigma_\beta^2+ \sigma_{\beta\gamma}^2+\sigma_\varepsilon^2$
A X B	(a-1)(b-1)	SS_{AXB}	$n\sigma_{\alpha\beta}^2+\sigma_{\beta\gamma}^2+\sigma_\varepsilon^2$
B X S/A	a(b-1)(n-1)	$SS_{BXS/A}$	$\sigma_{\beta\gamma}^2+\sigma_\varepsilon^2$
Total	abn-1	SS_{TOTAL}	

For this experiment there are two levels of each factor (a=2 and b=2) and n=14.

Additionally, bivariate correlation analysis was used to describe relationships among step length, friction utilization, heel contact velocity, and muscle activation in each of the three hypotheses.

Hypothesis 4: Fear of falling, as measured by the University of Illinois at Chicago Fear of Falling Measure (UICFFM), will be higher in older participants versus younger participants

The UICFFM measures were analyzed utilizing an F-test for significance between younger and older age groups.

Hypothesis 5: Fear of Falling will be related to adjustment in muscle activity pattern of the lower extremities.

Bivariate correlation analysis was utilized to describe relationships muscle activity with UICFFM scores.

Hypothesis 6: Among all participants, regardless of age, there will be a relationship between fear of falling and slip distance.

Bivariate correlation analysis was utilized to describe relationships of slip distance with UICFFM values.

Hypothesis 7: Older participants will have higher friction utilization and thus, a longer slip distance and higher frequency of falls than the younger participants

Slip distance was analyzed utilizing an F-test for significance between younger and older age groups. Bivariate correlation analysis was utilized to describe relationships of friction utilization at peak 3 (RCOF), and slip distance.

RESULTS

Treatment of Data

Dependent measures of gait parameters (friction demand, heel contact velocity, and step length) and muscle activity (duration, peak and mean values) were analyzed using repeated measures (age x condition) analysis of variance (ANOVA) design. Tukey-Kramer post hoc analysis was performed on measures with more than 2 repetitions for significance. Slip distance was analyzed with a one-way (by age) analysis of variance (ANOVA) design. UICFFM total scores were analyzed using a 2 x 2 (age x gender) repeated measures analysis of variance (ANOVA). UICFFM individual questions were analyzed with one-way (by age) analysis of variance (ANOVA) designs. Bivariate correlation analysis was performed to describe possible relationships among dependant variables. The JMP statistical package was used for all data analysis and results were considered significant at $\alpha = 0.05$.

Summary Tables

Overall group effects for gait parameters:

Table 2: Age group summary table

Gait Parameter	Younger Mean (SD)	Older Mean (SD)
*RCOF	0.145548 (0.067248)	0.114595 (0.056287)*
*HCV (cm/sec)	219.993 (92.493)	150.904 (108.394)*
*Step Length (cm)	61.5201 (9.6773)	54.7598 (14.3943)*
Total Slip distance (cm)	10.3190 (7.88019)	5.3474 (5.41652)

** Significant at $\alpha = 0.05$*

Overall condition effects for gait parameters and muscle activity

Table 3: Condition summary table

Gait Parameter	Normal Condition Mean (SD)	Adjusted Condition Mean (SD)
RCOF	0.189786 (0.029485)	0.064464 (0.028875)
HCV (cm/sec)	200.274 (59.903)	122.829 (102.299)
Step Length (cm)	65.0430 (7.0180)	51.2369 (13.2837)

Muscle activity	Normal Condition Mean (SD)	Adjusted Condition Mean (SD)
Stance HAM overall activity duration (sec)	0.480300 (0.117401)	0.592200 (0.181655)
Stance RF mean activity (mV)	0.113663 (0.122982)	0.085037 (0.072483)
Swing GAS peak activity (mV)	0.337393 (0.272243)	0.227214 (0.373822)
Swing GAS mean activity (mV)	0.127977 (0.083185)	0.094928 (0.082633)
Swing HAM overall activity duration (sec)	0.512100 (0.087070)	0.598500 (0.147182)
Swing RF mean activity	0.106224 (0.093127)	0.064331 (0.068304)

All significant ($\alpha = 0.05$)

4.1 Friction demand

4.1.1 Age:

There was a statistically significant difference found for the age main effect for overall friction utilization ($F_{1,26}$ = 12.3356, P = 0.0016). Overall, older participants required a lower coefficient of friction than younger participants (Table 4 and Figure 4).

Table 4: Friction Demand Age main effect

Age Group	RCOF - Overall
Young	0.145548 (0.067248)
Old	0.114595 (0.056287)

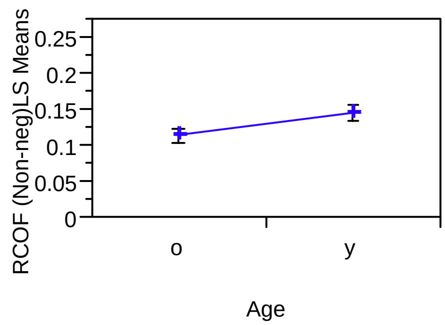


Figure 4: Friction Demand Age main effect

4.1.1.1. Age for Normal Condition:

Younger participants RCOF was statistically significantly higher than older participants for a normal gait condition ($F_{1,26}$ = 11.2843, P = 0.0024). Refer to Table 6 and Figure 6.

4.1.1.2. Age for Adjustment Condition:

Younger participants RCOF was statistically significantly higher than older participants for the adjusted gait condition (1) proceeding the slippery surface ($F_{1,26}$ =

9.2350, $P = 0.0054$).   No statistically significant difference was reported for the age effect of RCOF on the adjustment (2) condition on the slippery surface ($F_{1,26} = 0.9230$, $P = 0.3455$). Refer to Table 6 and Figure 6.

4.1.2 Condition Main Effect:

There was a statistically significant difference found for the condition (normal to adjusted) main effect for overall friction utilization ($F_{2,25} = 125.2063$, $P < 0.0001$). Overall, a higher required coefficient of friction was found for a normal walking condition versus both adjustment 1, prior to stepping upon a slippery surface, and adjustment 2, stepping upon a slippery surface (Table 5 and Figure 5). Additionally, a higher RCOF value was found for adjustment 1 than for adjustment 2 overall. A Tukey-Kramer post hoc analysis resulted in a significant difference between all three measurements for all three conditions at $\alpha = 0.05$.

Table 5: Friction Demand Condition main effect

Condition	RCOF - Overall
Normal	0.189786 (0.029485)
Adjustment 1	0.135964 (0.050226)
Adjustment 2	0.064464 (0.028875)

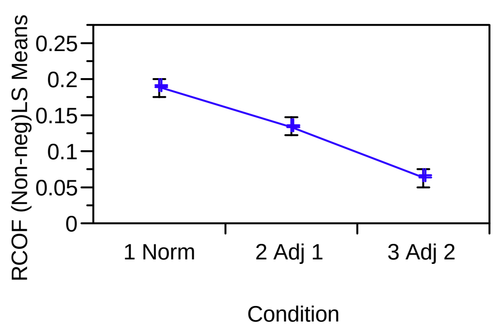


Figure 5: Friction Demand Condition main effect

4.1.3. Age by condition:

A statistically significant difference was found for the age by condition effect overall ($F_{2,25}$ = 3.1727, P = 0.0501). However, A Tukey-Kramer post hoc analysis resulted in no significant difference for younger and older participants for the adjustment 2 condition at α = 0.05. For this study, older participants required a lower coefficient of friction for adjustment 1 than younger participants, whereas both age groups required a similar coefficient of friction for adjustment 2 (Table 6 and Figure 6).

Table 6: Friction Demand age by condition

Condition	Young RCOF	Old RCOF
Normal	0.205714 (0.026788)	0.173857 (0.023271)
Adjustment 1	0.161214 (0.051087)	0.110714 (0.035443)
Adjustment 2	0.069714 (0.024065)	0.059214 (0.033062)

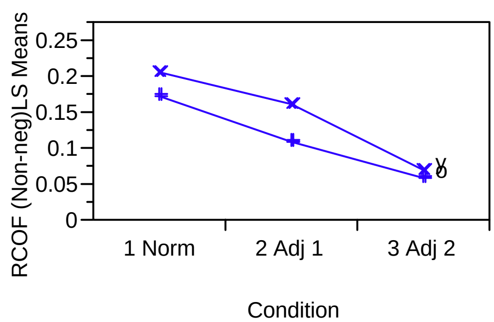


Figure 6: Friction Demand age by condition

4.2 Heel Contact Velocity

4.2.1 Age main effect:

There was a statistically significant difference found for the age main effect for overall heel contact velocity ($F_{1,26}$ =10.6733, P = 0.0030). Overall, older participants exerted a lower heel contact velocity than younger participants (Table 7 and Figure 7).

Table 7: Heel contact velocity age main effect

Age Group	HCV - Overall
Young	219.993 (92.493)
Old	150.904 (108.394)

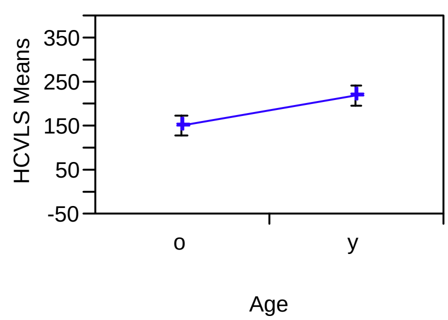


Figure 7: Heel contact velocity age main effect

4.2.1.1. Age effect for normal condition

Younger participants HCV was statistically significantly higher than older participants for the normal gait condition for the heel contact upon the first force plate ($F_{1,26}$ = 7.6377, P = 0.0104). However, there was no statistically significant difference for the normal condition upon the second force plate ($F_{1,26}$ = 2.4725, P = 0.1279). Refer to Table 9 and Figure 9.

4.2.1.2. Age effect for Adjusted condition

Younger participants HCV was statistically significantly higher than older participants for the adjusted gait condition for the heel contact upon the dry force plate

($F_{1,26}$ = 12.7816, P = 0.0014). However, there was no statistically significant difference for age for the adjusted 2 condition upon the contaminated force plate ($F_{1,26}$ = 1.7738, P = 0.1945). Refer to Table 9 and Figure 9.

4.2.2 Condition main effect:

There was a statistically significant difference found for the condition main effect for overall heel contact velocity ($F_{3,24}$ =25.0980, P < 0.0001). Overall, HCV was lower for adjustments one and two than for both normal conditions for all participants (Table 8 and Figure 8).

Table 8: Heel contact velocity condition main effect

Condition	HCV - Overall
Normal 1	200.274 (59.903)
Normal 2	273.040 (80.407)
Adjusted 1	145.651 (109.080)
Adjusted 2	122.829 (102.299)

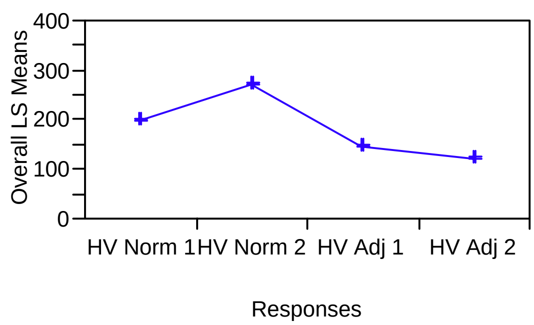


Figure 8: Heel contact velocity condition main effect

4.2.3 Age By Condition

No statistically significant difference was found for the age by condition effect for heel contact velocity ($F_{3,24}$ =1.8353, P = 0.1476) Additionally, a Tukey-Kramer post hoc analysis resulted in a significant difference for young and elderly individuals for the adjustment 1 condition at α = 0.05. For this condition, older participants exerted a lower HCV than younger individuals (Table 9 and Figure 9).

Table 9: Heel contact velocity age by condition

Condition	Young HCV	Old HCV
Normal 1	228.304 (41.274)	172.244 (63.6957)
Normal 2	296.308 (57.725)	249.773 (94.4965)
Adjustment 1	207.144 (91.448)	84.158 (90.5795)
Adjustment 2	148.216 (103.554)	97.441 (98.1007)

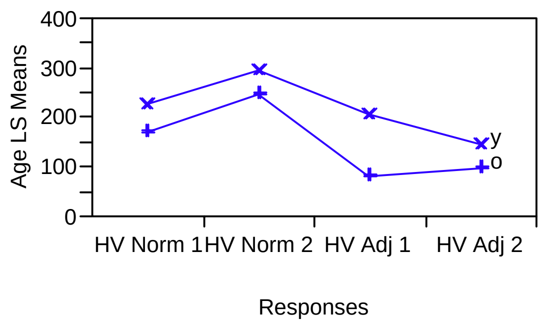


Figure 9: Heel contact velocity age by condition

4.3 Step Length

4.3.1 Age Main Effect:

A statistically significant difference was found for the age main effect ($F_{1,26}$ = 4.7245, P = 0.0390). Overall, older participants had a shorter step length (in centimeters) than younger participants (Table 10 and Figure 10).

Table 10: Step length age main effect

Age Group	Step Length (cm) - Overall
Young	61.5201 (9.6773)
Old	54.7598 (14.3943)

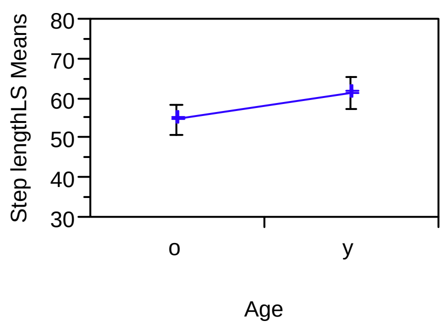


Figure 10: Step length age main effect

4.3.2 Condition main effect

A statistically significant difference was found for the condition main effect ($F_{1,26} = 36.7522$, $P < 0.0001$). For all participants, step length (cm) was reduced for the adjustment condition (Table 11 and Figure 11).

Table 11: Step length condition main effect

Condition	**Step Length (cm) - Overall**
Normal	65.0430 (7.0180)
Adjusted	51.2369 (13.2837)

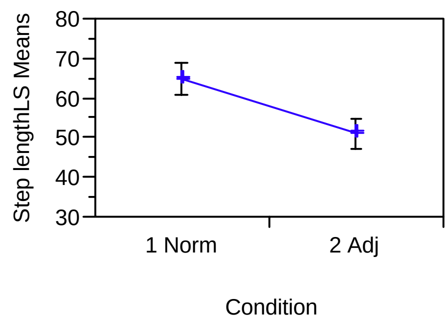


Figure 11: Step length condition main effect

4.3.3 Age by condition

No statistically significant difference was found for the age by condition effect ($F_{1,26}$ = 0.6242, P = 0.4367). Although young participants had a longer step length than older participants for both conditions, and both age groups had a shorter step length for the adjusted condition, there was not a significant age by condition effect (Table 12 and Figure 12).

Table 12: Step length age by condition

Condition	Young Step Length (cm)	Old Step Length (cm)
Normal	67.5236 (6.30641)	62.5624 (7.0192)
Adjusted	55.5167 (8.78097)	46.9571 (15.8092)

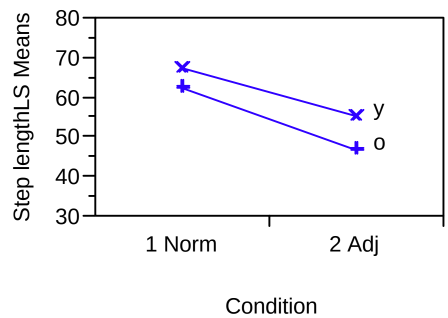


Figure 12: Step length age by condition

4.4 Muscle Activity

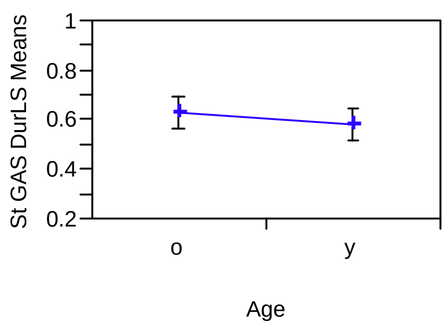
4.4.1 Stance GAS

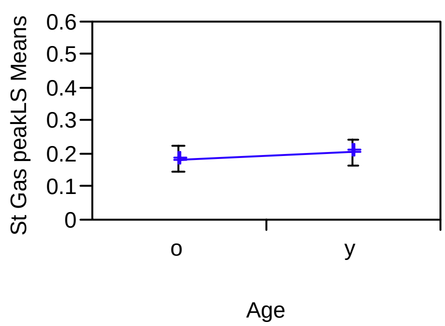
4.4.1.1. Age main effect

Overall, there was no statistically significant difference found for the age main effect on the stance GAS duration in seconds ($F_{1,26} = 0.9371$, $P = 0.3420$). Overall, there was no statistically significant difference found for the age main effect on the stance GAS peak value in mV ($F_{1,26} = 0.3310$, $P = 0.5700$). Overall, there was no statistically significant difference found for the age main effect on the stance GAS mean value in mV ($F_{1,26} = 0.2971$, $P = 0.5903$). For each measurement, refer to Table 13 and Figure 13.

Table 13: Stance GAS age main effect

Measurement Condition	Young	Old
Duration (seconds)	0.582600 (0.161046)	0.634500 (0.168396)
Peak (mV)	0.206536 (0.100888)	0.186893 (0.111818)
Mean (mV)	0.098806 (0.047008)	0.090458 (0.044844)





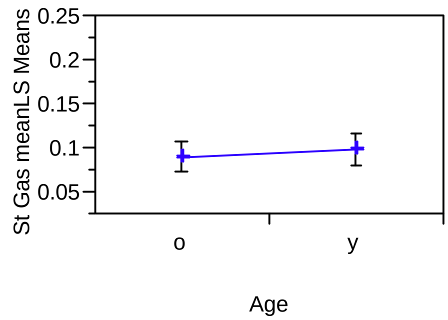


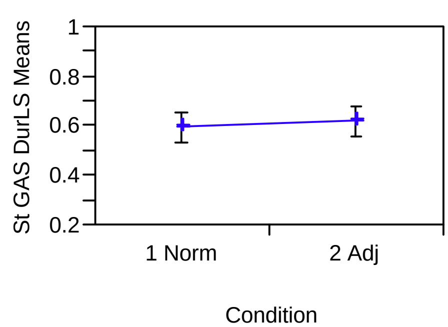
Figure 13: Stance GAS age main effect

4.4.1.2. Condition main effect

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) main effect on the stance GAS duration in seconds ($F_{1,26}$ = 0.5594, P = 0.4612). Overall, there was no statistically significant difference found for the condition main effect on the stance GAS peak value in mV ($F_{1,26}$ = 0.3595, P = 0.5540). Overall, there was no statistically significant difference found for the condition main effect on the stance GAS mean value in mV ($F_{1,26}$ = 0.6633, P = 0.4228). For each measurement, refer to Table 14 and Figure 14.

Table 14: Stance GAS condition main effect

Measurement Condition	**Normal**	**Adjusted**
Duration (seconds)	0.596100 (0.109725)	0.621000 (0.208155)
Peak (mV)	0.203429 (0.088058)	0.190000 (0.122613)
Mean (mV)	0.098146 (0.042989)	0.091118 (0.048818)



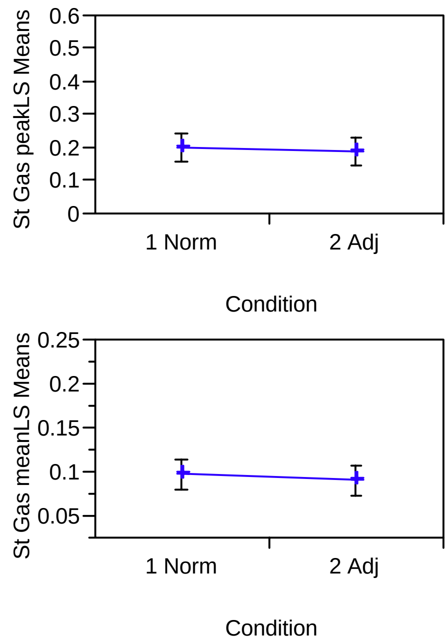


Figure 14: Stance GAS condition main effect

4.4.1.3. Age by condition

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) by age effect on the stance GAS duration in seconds ($F_{1,26}$ = 0.4815, P = 0.4939). Overall, there was no statistically significant difference found for the condition by age effect on the stance GAS peak value in mV ($F_{1,26}$ = 0.4274, P = 0.5190). Overall, there was no statistically significant difference found for the condition by age effect on the stance GAS mean value in mV ($F_{1,26}$ = 0.7572, P = 0.3922). For each measurement, refer to Table 15 and Figure 15.

Table 15: Stance GAS age by condition

Measurement Condition	Normal Young	Normal Old	Adjusted Young	Adjusted Old
Duration (seconds)	0.558600 (0.104903)	0.633600 (0.104746)	0.427800 (0.149120)	0.487800 (0.218710)
Peak (mV)	0.205929 (0.098562)	0.200929 (0.079857)	0.207143 (0.106886)	0.172857 (0.138445)
Mean (mV)	0.098565 (0.045213)	0.097727 (0.042351)	0.099046 (0.050449)	0.083189 (0.047636)

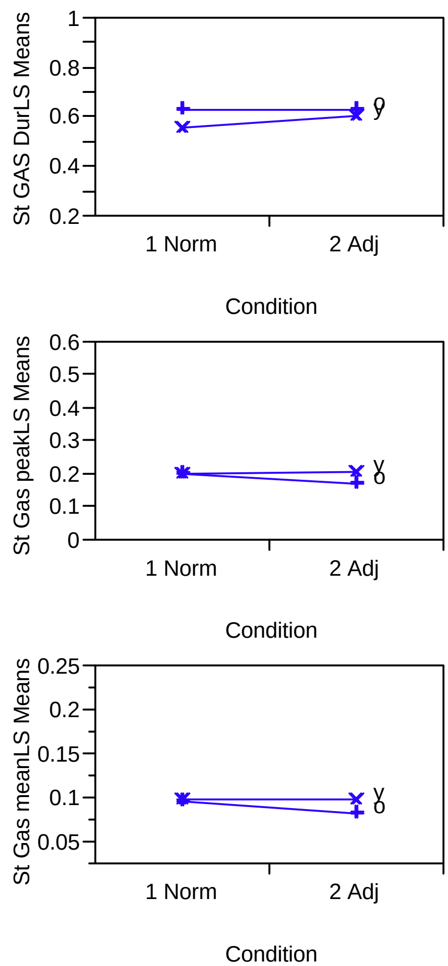


Figure 15: Stance GAS age by condition

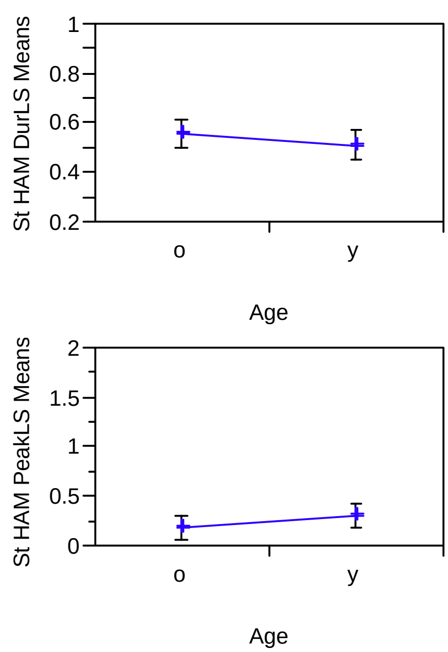
4.4.2 Stance HAM

4.4.2.1. Age main effect

Overall, there was no statistically significant difference found for the age main effect on the stance HAM duration in seconds ($F_{1,26}$ = 1.1922, P = 0.2849). Overall, there was no statistically significant difference found for the age main effect on the stance HAM peak value in mV ($F_{1,26}$ = 2.2019, P = 0.1499). Overall, there was no statistically significant difference found for the age main effect on the stance HAM mean value in mV ($F_{1,26}$ = 2.1539, P = 0.1542). For each measurement, refer to Table 16 and Figure 16.

Table 16: Stance HAM age main effect

Measurement Condition	**Young**	**Old**
Duration (seconds)	0.513600 (0.176433)	0.558900 (0.145195)
Peak (mV)	0.318714 (0.416719)	0.186321 (0.148920)
Mean (mV)	0.130295 (0.148867)	0.074970 (0.045873)



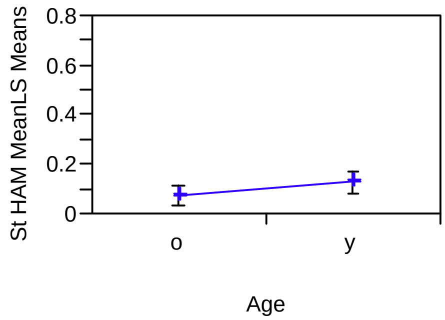


Figure 16: Stance HAM age main effect

4.4.2.2. Condition main effect

Overall, there was a statistically significant difference found for the condition (From normal gait to adjusted gait) main effect on the stance HAM duration in seconds ($F_{1,26}$ = 7.6075, P = 0.0105). In general all participants had a longer HAM activity duration in seconds for an adjusted gait condition than for a normal gait condition. Overall, there was no statistically significant difference found for the condition main effect on the stance HAM peak value in mV ($F_{1,26}$ = 1.4133, P = 0.2452). Overall, there was no statistically significant difference found for the condition main effect on the stance HAM mean value in mV ($F_{1,26}$ = 2.9281, P = 0.0990). For each measurement, refer to Table 17 and Figure 17.

Table 17: Stance HAM condition main effect

Measurement Condition	**Normal**	**Adjusted**
Duration (seconds)	0.480300 (0.117401)	0.592200 (0.181655)
Peak (mV)	0.297679 (0.414319)	0.207357 (0.170382)
Mean (mV)	0.118150 (0.146642)	0.087115 (0.062043)

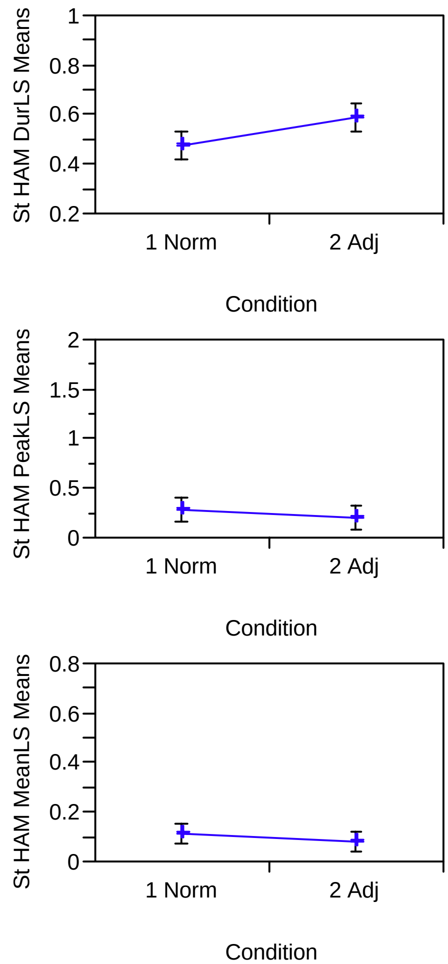


Figure 17: Stance HAM condition main effect

4.4.2.3. Age by condition

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) by age effect on the stance HAM duration in seconds ($F_{1,26}$ = 0.3767, P = 0.5447). Overall, there was no statistically significant difference found for the condition by age effect on the stance HAM peak value in mV ($F_{1,26}$ = 0.0336, P = 0.8559). Overall, there was no statistically significant difference found for the condition by age effect on the stance HAM mean value in mV ($F_{1,26}$ = 1.0166, P = 0.3226). For each measurement, refer to Table 18 and Figure 18.

Table 18: Stance HAM age by condition

Measurement Condition	Normal Young	Normal Old	Adjusted Young	Adjusted Old
Duration (seconds)	0.445200 (0.143047)	0.515400 (0.074231)	0.582000 (0.184695)	0.602400 (0.184930)
Peak (mV)	0.370214 (0.554471)	0.225143 (0.194309)	0.267214 (0.217985)	0.147500 (0.071124)
Mean (mV)	0.154956 (0.196658)	0.081345 (0.055405)	0.105633 (0.077735)	0.068596 (0.034833)

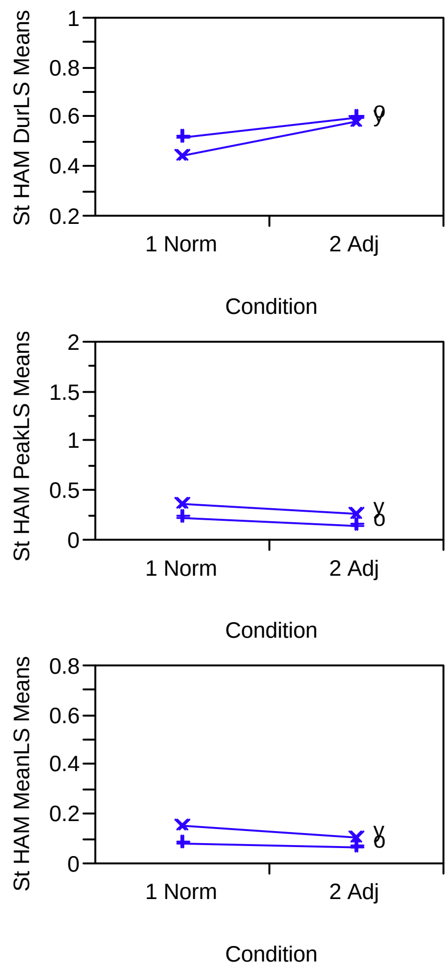


Figure 18: Stance HAM age by condition

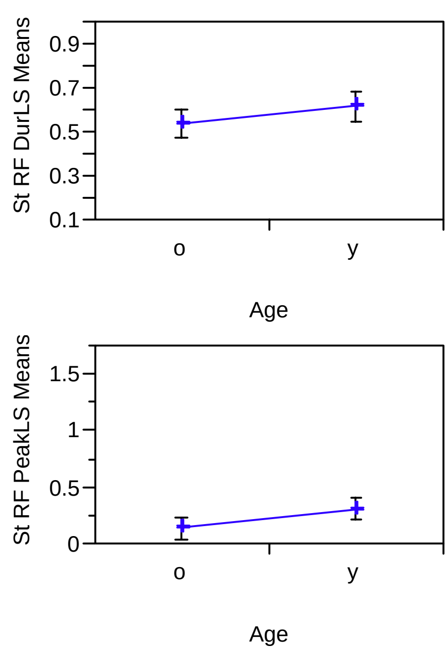
4.4.3 Stance RF

4.4.3.1. Age main effect

Overall, there was no statistically significant difference found for the age main effect on the stance RF duration in seconds ($F_{1,26}$ = 2.1673, P = 0.1530). Overall, there was no statistically significant difference found for the age main effect on the stance RF peak value in mV ($F_{1,26}$ = 3.7283, P = 0.0645). Overall, there was no statistically significant difference found for the age main effect on the stance RF mean value in mV ($F_{1,26}$ = 3.3193, P = 0.0800). For each measurement, refer to Table 19 and Figure 19.

Table 19: Stance RF age main effect

Measurement Condition	**Young**	**Old**
Duration (seconds)	0.619200 (0.106838)	0.539400 (0.227213)
Peak (mV)	0.317964 (0.357798)	0.141500 (0.129905)
Mean (mV)	0.130478 (0.127347)	0.068223 (0.050759)



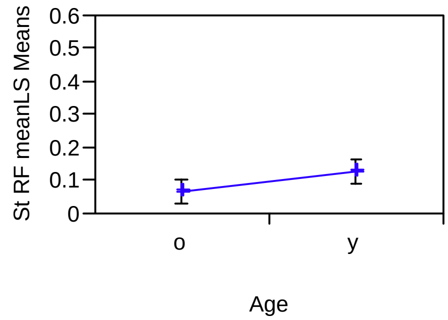


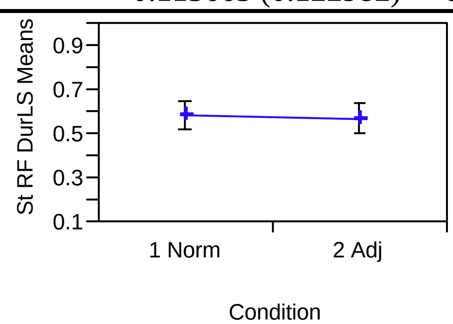
Figure 19: Stance RF age main effect

4.4.3.2. Condition main effect

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) main effect on the stance RF duration in seconds ($F_{1,26}$ = 0.1822, P = 0.6730). Overall, there was no statistically significant difference found for the condition main effect on the stance RF peak value in mV ($F_{1,26}$ = 2.2984, P = 0.1416). Overall, there was a statistically significant difference found for the condition main effect on the stance RF mean value in mV ($F_{1,26}$ = 5.0324, P = 0.0336). In general, all participants had a lower RF mean activity for an adjusted gait condition than for a normal gait condition. For each measurement, refer to Table 20 and Figure 20.

Table 20: Stance RF condition main effect

Measurement Condition	**Normal**	**Adjusted**
Duration (seconds)	0.586800 (0.107784)	0.571800 (0.233683)
Peak (mV)	0.264143 (0.345216)	0.195321 (0.198523)
Mean (mV)	0.113663 (0.122982)	0.085037 (0.072483)



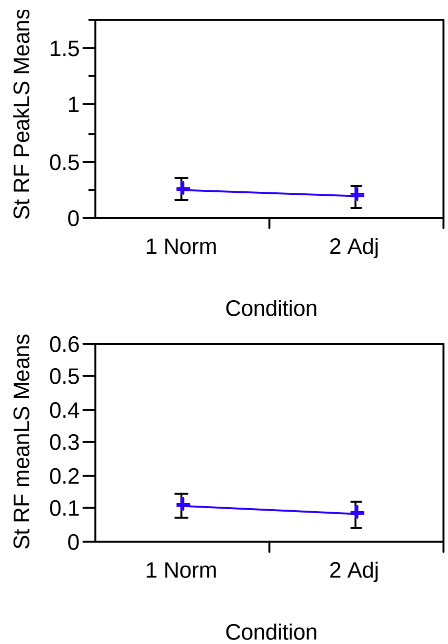


Figure 20: Stance RF condition main effect

4.4.3.3. Age by condition

Overall, there was a statistically significant difference found for the condition (From normal gait to adjusted gait) by age effect on the stance RF duration in seconds ($F_{1,26}$ = 10.4162, P = 0.0034). Younger participants' RF activity duration increased from a normal gait condition to an adjusted gait condition. Conversely, older participants' RF activity duration decreased from a normal gait condition to an adjusted gait condition. Overall, there was no statistically significant difference found for the condition by age effect on the stance RF peak value in mV ($F_{1,26}$ = 1.9239, P = 0.1772). Overall, there was a statistically significant difference found for the condition by age effect on the stance RF mean value in mV ($F_{1,26}$ = 5.1165, P = 0.0323). Young participants' RF mean activity decreased from a normal gait condition to an adjusted gait condition, whereas older participants' RF mean activity remained approximately the same for both conditions. For each measurement, refer to Table 21 and Figure 21.

Table 21: Stance RF age by condition

Measurement Condition	Normal Young	Normal Old	Adjusted Young	Adjusted Old
Duration (seconds)	0.570000 (0.093240)	0.603600 (0.121766)	0.668400 (0.098991)	0.475200 (0.288995)
Peak (mV)	0.383857 (0.448687)	0.144429 (0.123802)	0.252071 (0.234978)	0.138571 (0.140369)
Mean (mV)	0.159223 (0.155020)	0.068103 (0.053953)	0.101733 (0.088720)	0.068342 (0.049398)

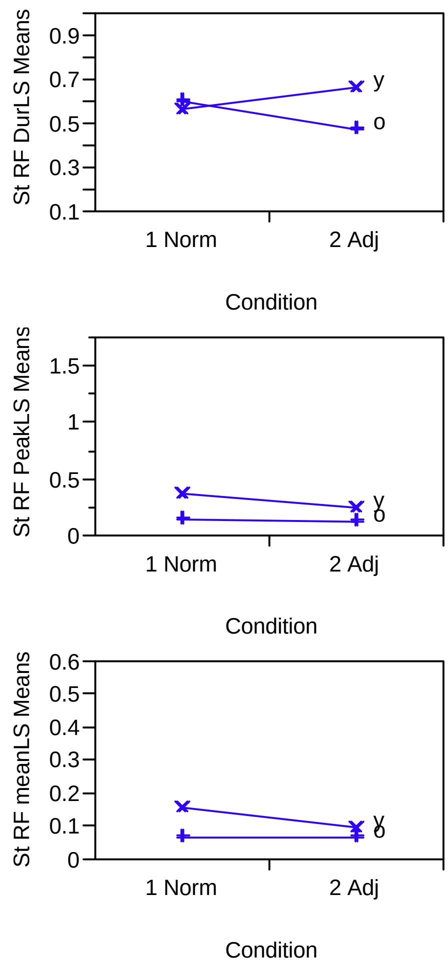


Figure 21: Stance RF age by condition

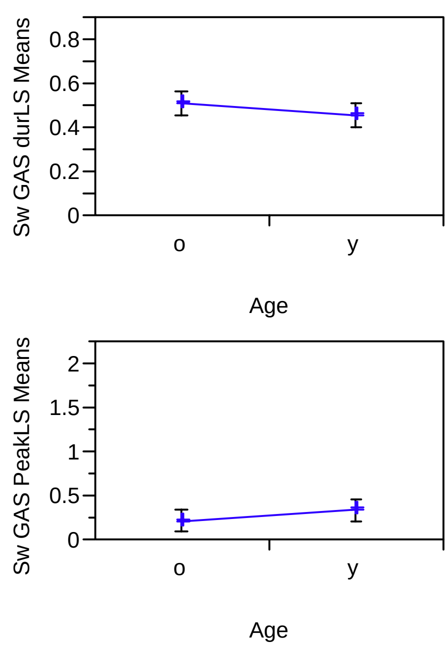
4.4.4 Swing GAS

4.4.4.1. Age main effect

Overall, there was no statistically significant difference found for the age main effect on the swing GAS duration in seconds ($F_{1,26}$ = 2.2553, P = 0.1452). Overall, there was no statistically significant difference found for the age main effect on the swing GAS peak value in mV ($F_{1,26}$ = 1.0955, P = 0.3049). Overall, there was no statistically significant difference found for the age main effect on the swing GAS mean value in mV ($F_{1,26}$ = 0.9407, P = 0.3410). For each measurement, refer to Table 22 and Figure 22.

Table 22: Swing GAS age main effect

Measurement Condition	**Young**	**Old**
Duration (seconds)	0.456300 (0.124089)	0.515700 (0.165356)
Peak (mV)	0.341679 (0.426918)	0.222929 (0.174879)
Mean (mV)	0.125791 (0.097763)	0.097114 (0.065805)



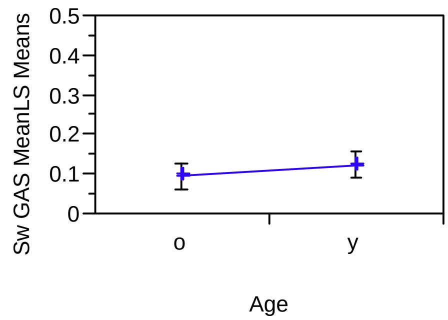


Figure 22: Swing GAS age main effect

4.4.4.2. Condition main effect

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) main effect on the swing GAS duration in seconds ($F_{1,26}$ = 2.1443, P = 0.1551). Overall, there was a statistically significant difference found for the condition main effect on the swing GAS peak value in mV ($F_{1,26}$ = 4.9986, P = 0.0342). Overall, participants had a lower GAS activity peak for an adjusted gait condition than for a normal gait condition. Overall, there was a statistically significant difference found for the condition main effect on the swing GAS mean value in mV ($F_{1,26}$ = 9.6012, P = 0.0046). In general, all participants had a lower GAS mean activity for an adjusted gait condition than for a normal gait condition. For each measurement, refer to Table 23 and Figure 23.

Table 23: Swing GAS condition main effect

Measurement Condition	**Normal**	**Adjusted**
Duration (seconds)	0.514200 (0.090827)	0.457800 (0.186202)
Peak (mV)	0.337393 (0.272243)	0.227214 (0.373822)
Mean (mV)	0.127977 (0.083185)	0.094928 (0.082633)

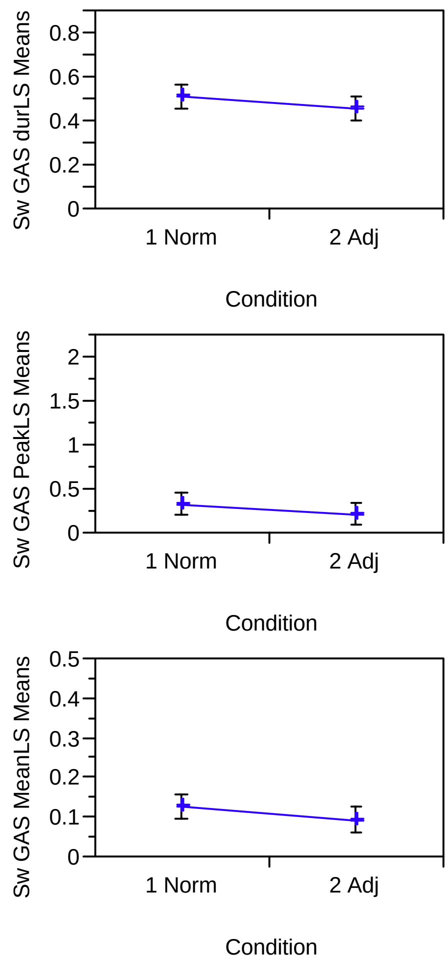


Figure 23: Swing GAS condition main effect

4.4.4.3. Age by condition:

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) by age effect on the swing GAS duration in seconds ($F_{1,26}$ = 0.0002, P = 0.9877). Overall, there was no statistically significant difference found for the condition by age effect on the swing GAS peak value in mV ($F_{1,26}$ = 0.2118, P = 0.6492). Overall, there was no statistically significant difference found for the condition by age effect on the swing GAS mean value in mV ($F_{1,26}$ = 0.0340, P = 0.8551). For each measurement, refer to Table 24 and Figure 24.

Table 24: Swing GAS age by condition

Measurement Condition	**Normal**		**Adjusted**	
	Young	**Old**	**Young**	**Old**
Duration (seconds)	0.484800 (0.089410)	0.543600 (0.085310)	0.427800 (0.149120)	0.487800 (0.218710)
Peak (mV)	0.385429 (0.324585)	0.289357 (0.208826)	0.297929 (0.518710)	0.156500 (0.102007)
Mean (mV)	0.141332 (0.087146)	0.114622 (0.079958)	0.110251 (0.108333)	0.079606 (0.044047)

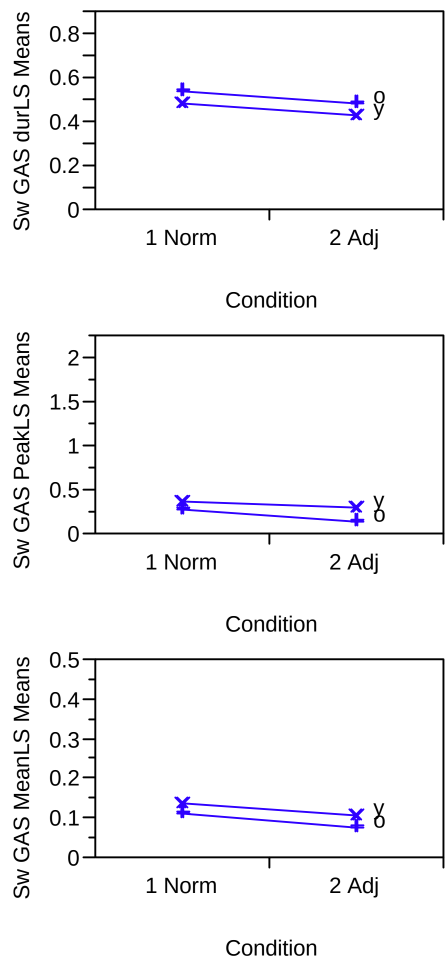


Figure 24: Swing GAS age by condition

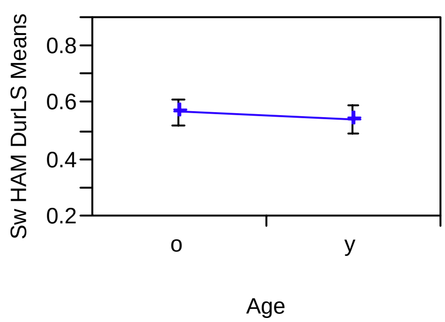
4.4.5. Swing HAM

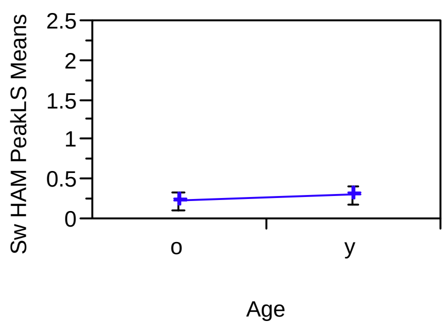
4.4.5.1. Age main effect

Overall, there was no statistically significant difference found for the age main effect on the swing HAM duration in seconds ($F_{1,26}$ = 0.4802, P = 0.4945). Overall, there was no statistically significant difference found for the age main effect on the swing HAM peak value in mV ($F_{1,26}$ = 0.9162, P = 0.3473). Overall, there was no statistically significant difference found for the age main effect on the swing HAM mean value in mV ($F_{1,26}$ = 2.2309, P = 0.1473). For each measurement, refer to Table 25 and Figure 25.

Table 25: Swing HAM age main effect

Measurement Condition	Young	Old
Duration (seconds)	0.542700 (0.116109)	0.567900 (0.138938)
Peak (mV)	0.304321 (0.393194)	0.227893 (0.107347)
Mean (mV)	0.108392 (0.060272)	0.085010 (0.045861)





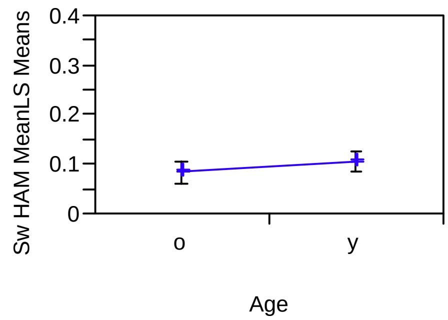


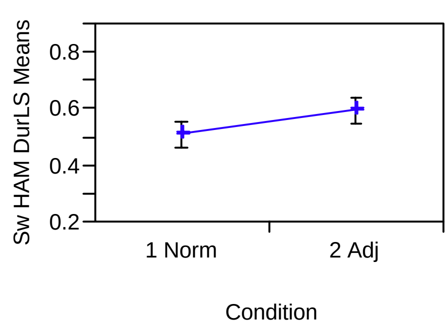
Figure 25: Swing HAM age main effect

4.4.5.2. Condition main effect

Overall, there was a statistically significant difference found for the condition (From normal gait to adjusted gait) main effect on the swing HAM duration in seconds ($F_{1,26}$ = 9.0823, P = 0.0057). All Participants' HAM activity duration increased from a normal gait condition to an adjusted gait condition. Overall, there was no statistically significant difference found for the condition main effect on the swing HAM peak value in mV ($F_{1,26}$ = 0.4682, P = 0.4999). Overall, there was no statistically significant difference found for the condition main effect on the swing HAM mean value in mV ($F_{1,26}$ = 0.0007, P = 0.9786). For each measurement, refer to Table 26 and Figure 26.

Table 26: Swing HAM condition main effect

Measurement Condition	Normal	Adjusted
Duration (seconds)	0.512100 (0.087070)	0.598500 (0.147182)
Peak (mV)	0.240500 (0.105313)	0.291714 (0.395857)
Mean (mV)	0.096521 (0.049424)	0.096881 (0.059804)



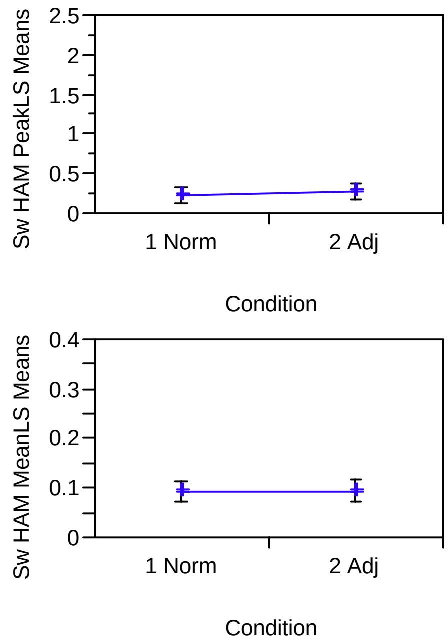


Figure 26: Swing HAM condition main effect

4.4.5.3. Age by condition

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) by age effect on the swing HAM duration in seconds ($F_{1,26}$ = 0.0109, P = 0.9175). Overall, there was no statistically significant difference found for the condition by age effect on the swing HAM peak value in mV ($F_{1,26}$ = 1.1302, P = 0.2975). Overall, there was no statistically significant difference found for the condition by age effect on the swing HAM mean value in mV ($F_{1,26}$ = 0.5740, P = 0.4555). For each measurement, refer to Table 27 and Figure 27.

Table 27: Swing HAM age by condition

Measurement Condition	Normal Young	Normal Old	Adjusted Young	Adjusted Old
Duration (seconds)	0.501000 (0.070326)	0.523200 (0.102637)	0.584400 (0.138955)	0.612600 (0.158917)
Peak (mV)	0.238929 (0.110273)	0.242071 (0.104257)	0.369714 (0.547471)	0.213714 (0.112386)
Mean (mV)	0.103179 (0.040524)	0.089863 (0.057756)	0.113605 (0.076447)	0.080158 (0.031333)

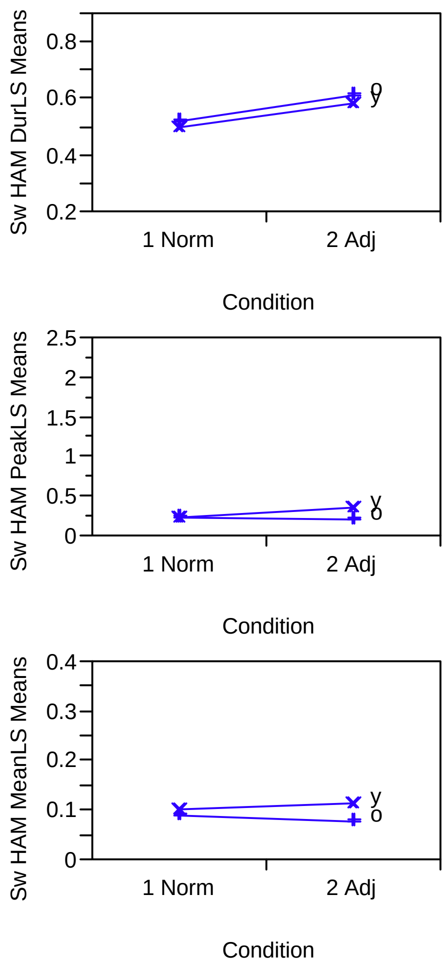


Figure 27: Swing HAM age by condition

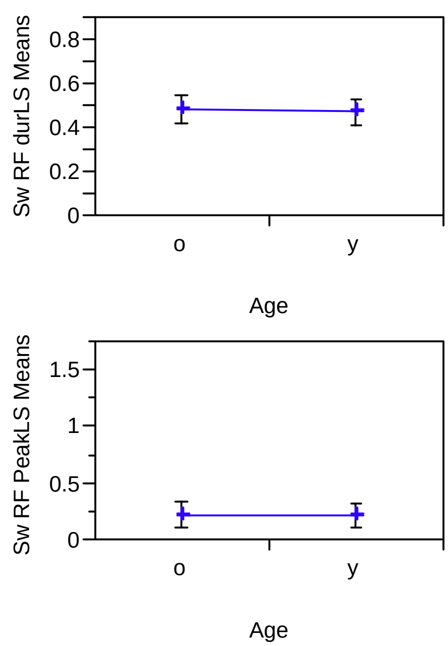
4.4.6. Swing RF

4.4.6.1. Age main effect

Overall, there was no statistically significant difference found for the age main effect on the swing RF duration in seconds ($F_{1,26} = 0.1091$, $P = 0.7438$). Overall, there was no statistically significant difference found for the age main effect on the swing RF peak value in mV ($F_{1,26} = 0.0037$, $P = 0.9518$). Overall, there was no statistically significant difference found for the age main effect on the swing RF mean value in mV ($F_{1,26} = 0.1688$, $P = 0.6846$). For each measurement, refer to Table 28 and Figure 28.

Table 28: Swing RF age main effect

Measurement Condition	Young	Old
Duration (seconds)	0.473400 (0.148236)	0.489000 (0.173198)
Peak (mV)	0.220429 (0.205731)	0.225714 (0.363032)
Mean (mV)	0.090803 (0.077646)	0.079752 (0.090311)



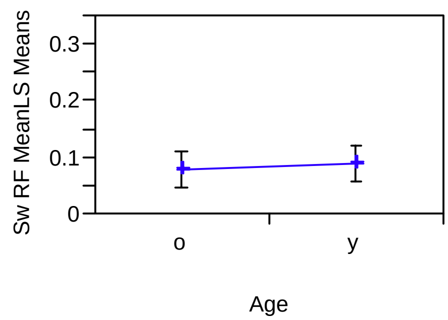


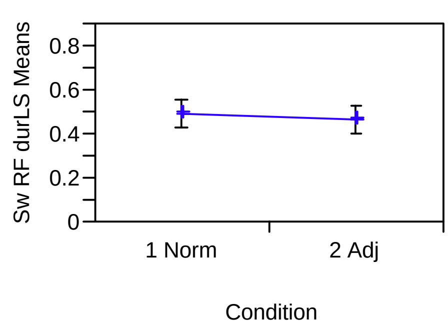
Figure 28: Swing RF age main effect

4.4.6.2. Condition main effect

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) main effect on the swing RF duration in seconds ($F_{1,26}$ = 0.5003, P = 0.4857). Overall, there was no statistically significant difference found for the condition main effect on the swing RF peak value in mV ($F_{1,26}$ = 2.6548, P = 0.1153). Overall, there was a statistically significant difference found for the condition main effect on the swing RF mean value in mV ($F_{1,26}$ = 7.6516, P = 0.0103). All participants' RF mean activity decreased from a normal gait condition to an adjusted gait condition. For each measurement, refer to Table 29 and Figure 29.

Table 29: Swing RF condition main effect

Measurement Condition	Normal	Adjusted
Duration (seconds)	0.495300 (0.076425)	0.467100 (0.214114)
Peak (mV)	0.278214 (0.343244)	0.167929 (0.223626)
Mean (mV)	0.106224 (0.093127)	0.064331 (0.068304)



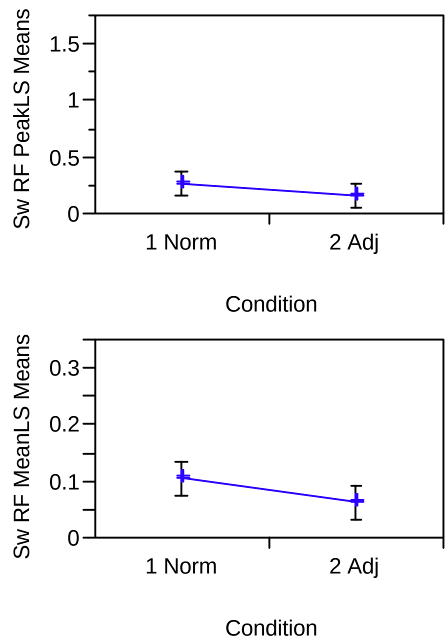


Figure 29: Swing RF condition main effect

4.4.6.3. Age by condition

Overall, there was no statistically significant difference found for the condition (From normal gait to adjusted gait) by age effect on the swing RF duration in seconds ($F_{1,26}$ = 0.0654, P = 0.8001). Overall, there was no statistically significant difference found for the condition by age effect on the swing RF peak value in mV ($F_{1,26}$ = 2.1208, P = 0.1573). Overall, there was no statistically significant difference found for the condition by age effect on the swing RF mean value in mV ($F_{1,26}$ = 3.6155, P = 0.0684). For each measurement, refer to Table 30 and Figure 30.

Table 30: Swing RF age by condition

Measurement Condition	Normal Young	Normal Old	Adjusted Young	Adjusted Old
Duration (seconds)	0.482400 (0.099647)	0.508200 (0.042927)	0.464400 (0.188506)	0.469800 (0.244267)
Peak (mV)	0.226286 (0.200772)	0.330143 (0.445622)	0.214571 (0.217998)	0.121286 (0.227277)
Mean (mV)	0.097351 (0.071638)	0.115097 (0.112742)	0.084255 (0.085422)	0.044408 (0.039216)

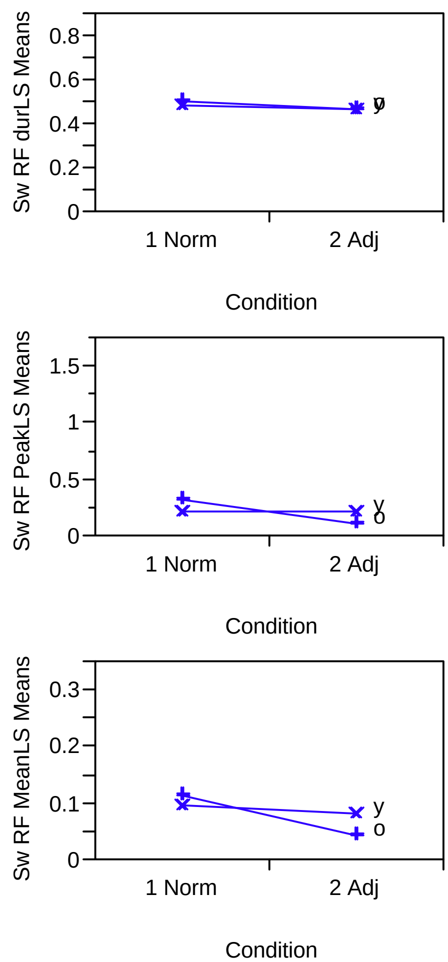


Figure 30: Swing RF age by condition

4.5. Slip Distance

4.5.1. Slip distance I:

No statistically significant difference was found for slip distance I ($F_{1,26}$ = 1.2935, P = 0.2658). Although slip distance I was slightly shorter for older participants than for younger participants, the difference was not significant (Table 31 and Figure 31).

Table 31: Slip Distance I age group difference

Age Group	Slip Distance I
Young	2.03974 (1.36709)
Old	1.38200 (1.67733)

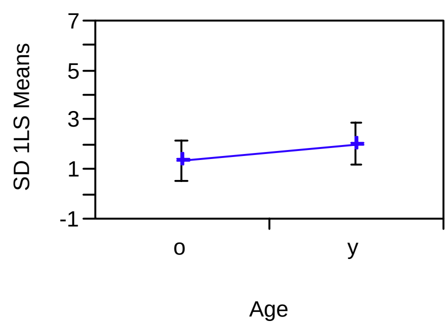


Figure 31: Slip Distance I age group difference

4.5.2. Slip distance II

A statistically significant difference was found for slip distance II ($F_{1,26}$ = 4.0002, P = 0.0560). Slip distance II was shorter for older participants than for younger participants (Table 32 and Figure 32).

Table 32: Slip Distance II age group difference

Age Group	**Slip Distance II**
Young	8.27931 (6.91051)
Old	3.96538 (4.16861)

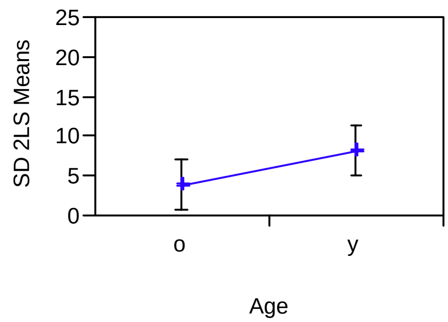


Figure 32: Slip Distance II age group difference

4.5.3. Total Slip distance

No statistically significant difference was found for total slip distance ($F_{1,26}$ = 3.7846, P = 0.0626). Although slip distance I was slightly shorter for older participants than for younger participants, the difference was not significant (Table 33 and Figure 33).

Table 33: Total Slip Distance age group difference

Age Group	**Total Slip Distance**
Young	10.3190 (7.88019)
Old	5.3474 (5.41652)

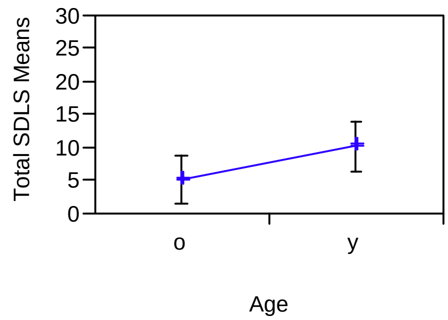


Figure 33: Total Slip Distance age group difference

4.6 Fear of falling

4.6.1. Age Main Effect

4.6.1.1. Total questionnaire

No statistically significant difference was found for the age effect of the UICFFM self report measure ($F_{1,26}$ = 3.0409, P = 0.0930). Refer to Table 34 and Figure 34 for age group differences in UICFFM scores

Table 34: Fear of falling age group differences

Question	Ratings (Standard Deviation) Young	Old
Take walk	4.00000 (0.05051)	3.92857 (0.05051)
Pick up something	4.00000 (0.000000)	3.92857 (0.267261)
Carry plate	3.50000 (0.650444)	3.85714 (0.363137)
In/out car	3.92857 (0.267261)	4.00000 (0.000000)
Crowded sidewalk	3.57143 (0.513553)	3.85714 (0.363137)
Well lit stairs	3.78571 (0.425815)	3.78571 (0.578934)
Poorly lit stairs	3.28571 (0.825420)	3.28571 (0.611250)
Bundles up well lit	3.14286 (0.662994)	3.50000 (0.518875)
Bundles up poorly lit	2.50000 (0.940540)	2.92857 (0.828742)
Bus stairs	3.71429 (0.468807)	3.85714 (0.363137)
Step stool	3.35714 (0.841897)	3.50000 (0.650444)
Step off curb	3.64286 (0.633324)	3.85714 (0.363137)
In/out bathtub	3.64286 (0.497245)	3.64286 (0.497245)
Stand on bus	3.21429 (0.699293)	3.64286 (0.497245)
Escalator	3.57143 (0.513553)	3.92857 (0.267261)
Alone when icy	2.14286 (0.864438)	2.71429 (0.611250)
Total Questions	**55.0000 (5.60220)**	**58.2143 (4.02260)**

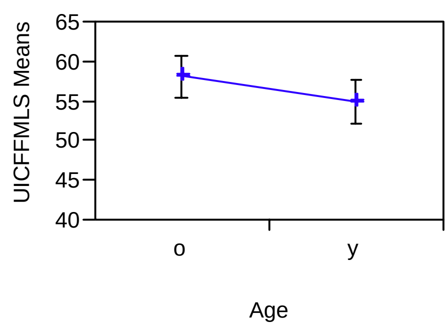


Figure 34: Fear of falling age group differences

4.6.1.2. Question 1 (Take walk)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 1 ($F_{1,26}$ = 1.0000, P = 0.3265). Refer to Table 34.

4.6.1.3. Question 2 (Pick up something)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 2 ($F_{1,26}$ = 1.0000, P = 0.3265). Refer to Table 34.

4.6.1.4. Question 3 (Carry plate)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 3 ($F_{1,26}$ = 3.2178, P = 0.0845). Refer to Table 34.

4.6.1.5. Question 4 (In/out car)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 4 ($F_{1,26}$ = 1.0000, P = 0.3265). Refer to Table 34.

4.6.1.6. Question 5 (Crowded sidewalk)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 5 ($F_{1,26}$ = 2.8889, P = 0.1011). Refer to Table 34.

4.6.1.7. Question 6 (Well lit stairs)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 6 ($F_{1,26}$ = 0.0000, P = 1.0000). Refer to Table 34.

4.6.1.8. Question 7 (Poorly lit stairs)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 7 ($F_{1,26}$ = 0.0000, P = 1.0000). Refer to Table 34.

4.6.1.9. Question 8 (Bundles up well lit)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 8 ($F_{1,26}$ = 2.5194, P = 0.1245). Refer to Table 34.

4.6.1.10. Question 9 (Bundles up poorly lit)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 9 ($F_{1,26}$ = 1.6364, P = 0.2121). Refer to Table 34.

4.6.1.11. Question 10 (Bus stairs)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 10 ($F_{1,26}$ = 0.8125, P = 0.3757). Refer to Table 34.

4.6.1.12. Question 11 (Step stool)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 11 ($F_{1,26}$ = 0.2524, P = 0.6196). Refer to Table 34.

4.6.1.13. Question 12 (Step off curb)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 12 ($F_{1,26}$ = 1.2062, P = 0.2822). Refer to Table 34.

4.6.1.14. Question 13 (In/out bathtub)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 13 ($F_{1,26}$ = 0.0000, P = 1.0000). Refer to Table 34.

4.6.1.15. Question 14 (Stand on bus)

No statistically significant difference was found for the age effect of the UICFFM self report measure question 14 ($F_{1,26}$ = 3.4925, P = 0.0730). Refer to Table 34.

4.6.1.16. Question 15 (Escalator)

A statistically significant difference was found for the age effect of the UICFFM self report measure question 15 ($F_{1,26}$ = 5.3279, P = 0.0292). Both age groups reported being “a little worried” to “not at all worried” about riding on an escalator. However, the older age group reported less fear than the younger age group. Refer to Table 34.

4.6.1.17. Question 16 (Alone when icy)

A statistically significant difference was found for the age effect of the UICFFM self report measure question 16 ($F_{1,26}$ = 4.0784, P = 0.0539). Both age groups reported between being “moderately worried” to “a little worried” about walking alone when it is icy. However, the older age group reported less fear than the younger age group. Refer to Table 34.

4.6.2. Gender Main Effect

A statistically significant difference was found for the gender effect of the UICFFM self report measure ($F_{1,26} = 9.8897$, $P = 0.0041$). Overall, male participants reported having less fear than female participants (Table 35 and Figure 35).

Table 35: Fear of falling gender differences

Question	**Ratings (Standard Deviation)**	
	Male	**Female**
Total Questions	59.2143 (2.99175)	54.0000 (5.43493)

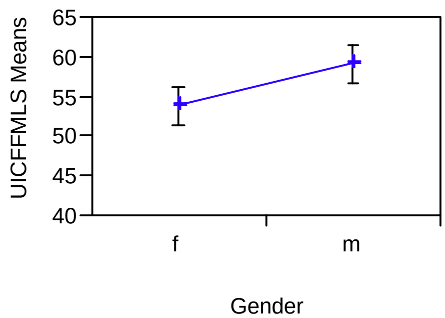


Figure 35: Fear of falling gender differences

4.6.3. Age by Gender

A statistically significant difference was found for the age by gender effect of the UICFFM self report measure ($F_{1,26} = 1.1082$, $P = 0.3029$). Overall, male participants reported having less fear than female participants (Table 36 and Figure 36).

Table 36: Fear of falling age by gender

Age Group	Ratings (Standard Deviation) Male	Female
Young	58.4286 (3.10146)	51.5714 (5.56349)
Elderly	60.0000 (2.88675)	56.4286 (4.39155)

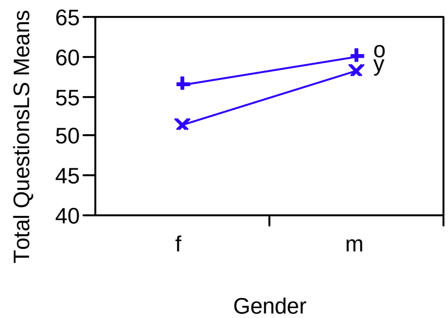


Figure 36: Fear of falling age by gender

4.7. Bivariate correlation analysis

4.7.1 Bivariate correlation analysis for a normal gait condition

Table 37: Significant ($\alpha = 0.05$) bivariate correlation results for the normal condition

Bivariate Correlation Analysis of normal condition	
Relationship	**r**
RCOF and HCV2	0.150
Stance GAS Duration and RCOF	-0.390
Swing GAS Mean and RCOF	0.197
Swing GAS Duration and HCV 2	-0.159
Stance RF Mean and Step Length	0.162
Stance RF Peak and UICFFM	-0.194
Swing GAS Mean and UICFFM	-0.212
Swing RF Duration and UICFFM	0.154
UICFFM and slip distance II	-0.212
UICFFM and total slip distance	-0.169
RCOF and slip distance I	0.196
RCOF and slip distance II	0.264
RCOF and total slip distance	0.282

4.7.1.1 Description of significant relationships

RCOF and HCV2

There was statistically significant relationship between normal RCOF and normal HCV 2 ($F_{1,26}$ = 4.5937, P = 0.0416) where r = 0.150. This positive relationship indicated that as RCOF for the normal gait condition increased, HCV on the second force plate increased.

Stance GAS Duration and RCOF

There was statistically significant relationship between normal GAS activity duration for the stance leg and RCOF for a normal condition ($F_{1,26}$ = 16.6404, P =

0.0004) where r = 0.390. This negative relationship indicated that as GAS activity duration for the stance leg for a normal gait condition increased, RCOF for the normal gait condition decreased.

Swing GAS Mean and RCOF

There was statistically significant relationship between normal GAS mean activity for the swing leg and RCOF for a normal condition ($F_{1,26}$ = 6.3982, P = 0.0178) where r = 0.197. This positive relationship indicated that as GAS mean activity for the swing leg for a normal gait condition increased, RCOF for the normal gait condition increased.

Swing GAS Duration and HCV 2

There was statistically significant relationship between normal GAS activity duration for the swing leg and HCV 2 for a normal condition ($F_{1,26}$ = 4.9089, P = 0.0357) where r = 0.159. This negative relationship indicated that as GAS activity duration for the swing leg for a normal gait condition decreased, HCV on the second force plate for the normal gait condition increased.

Stance RF Mean and Step Length

There was statistically significant relationship between normal RF mean activity for the stance leg and step length for a normal condition ($F_{1,26}$ = 5.0104, P = 0.0340) where r = 0.162. This positive relationship indicated that as RF mean activity for the stance leg for a normal gait condition increased, step length for the normal gait condition increased.

Stance RF Peak and UICFFM

There was statistically significant relationship between normal RF peak activity for the stance leg and UICFFM total rating scores ($F_{1,26} = 6.2734$, $P = 0.0189$) where r = 0.194. This negative relationship indicated that as stance RF peak values for a normal gait condition increased, UICFFM total rating scores decreased.

Swing GAS Mean and UICFFM

There was statistically significant relationship between normal GAS mean activity for the swing leg and UICFFM total rating scores ($F_{1,26} = 6.9827$, $P = 0.0138$) where r = 0.212. This negative relationship indicated that as swing GAS mean values for a normal gait condition increased, UICFFM total rating scores decreased.

Swing RF Duration and UICFFM

There was statistically significant relationship between normal RF activity duration for the swing leg and UICFFM total rating scores ($F_{1,26} = 4.7338$, $P = 0.0389$) where r = 0.154. This positive relationship indicated that as swing RF activity duration for a normal gait condition increased, UICFFM total rating scores increased.

UICFFM and slip distance II

There was statistically significant relationship between slip distance II and UICFFM total rating scores ($F_{1,26}$ = 6.9927, P = 0.0137) where r = 0.212. This negative relationship indicated as slip distance II increased, UICFFM total rating scores decreased.

UICFFM and total slip distance

There was statistically significant relationship between total slip distance and UICFFM total rating scores ($F_{1,26}$ = 5.2960, P = 0.0296) where r = 0.169. This negative relationship indicated as total slip distance increased, UICFFM total rating scores decreased.

RCOF and slip distance I

There was statistically significant relationship between slip distance I and RCOF for a normal gait condition ($F_{1,26}$ = 6.3504, P = 0.0182) where r = 0.196. This positive relationship indicated as RCOF values for a normal gait condition increased, slip distance I increased.

RCOF and slip distance II

There was statistically significant relationship between slip distance II and RCOF for a normal gait condition ($F_{1,26}$ = 9.3045, P = 0.0052) where r = 0.264. This positive relationship indicated as RCOF values for a normal gait condition increased, slip distance II increased.

RCOF and total slip distance

There was statistically significant relationship between total slip distance and RCOF for a normal gait condition ($F_{1,26}$ = 10.2004, P = 0.0037) where r = 0.282. This positive relationship indicated as RCOF values for a normal gait condition increased, total slip distance increased.

4.7.2. Bivariate correlation analysis for an adjusted gait condition

Table 38: Significant (α = 0.05) bivariate correlation results for the slippery condition (adjusted)

Bivariate Correlation Analysis of adjusted condition	
Relationship	**r**
RCOF Adj. 1 and HCV 3	0.194
HCV 3 and Step Length	0.378
HCV 4 and Step Length	0.381
RCOF Adj. 1 and Step Length	0.189
Stance GAS Peak and RCOF Adj. 2	0.154
Stance HAM Duration and RCOF Adj. 2	-0.134
Stance RF Duration and Step Length	0.299
Swing RF Peak and Step Length	0.167
Swing RF Mean and Step Length	0.151
Swing GAS Peak and UICFFM	-0.176
Swing GAS Mean and UICFFM	-0.289
Swing RF Duration and UICFFM	0.134

4.7.2.1 Description of significant relationships

RCOF Adj. 1 and HCV 3

There was statistically significant relationship between adjusted 1 RCOF and adjusted HCV 3 ($F_{1,26}$ = 6.2688, P = 0.0189) where r = 0.194. This positive relationship indicated that as RCOF on a dry surface for an adjustment condition increased, HCV on a dry surface for an adjusted gait condition increased.

HCV 3 and Step Length

There was statistically significant relationship between step length and adjusted HCV 3 ($F_{1,26}$ = 15.7873, P = 0.0005) where r = 0.378. This positive relationship indicated that as step length for an adjusted gait condition increased, HCV on a dry surface for an adjusted condition (preceding the step) increased.

HCV 4 and Step Length

There was statistically significant relationship between step length and adjusted HCV 4 ($F_{1,26}$ = 16.0191, P = 0.0005) where r = 0.381. This positive relationship indicated that as step length for an adjusted gait condition increased, HCV on a contaminated surface for an adjusted condition increased.

RCOF Adj. 1 and Step Length

There was statistically significant relationship between step length and adjusted 1 RCOF ($F_{1,26}$ = 6.0396, P = 0.0210) where r = 0.189. This positive relationship indicated that as step length for an adjusted gait condition increased, RCOF on a dry surface for an adjusted condition (preceding the step) increased.

Stance GAS Peak and RCOF Adj. 2

There was statistically significant relationship between adjusted GAS peak activity for the stance leg and RCOF 2 for an adjusted condition ($F_{1,26}$ = 4.7497, P = 0.0386) where r = 0.390. This positive relationship indicated that as GAS peak activity for the stance leg for an adjusted gait condition increased, RCOF on a contaminated surface for the adjusted gait condition increased.

Stance HAM Duration and RCOF Adj. 2

There was statistically significant relationship between adjusted HAM activity duration for the stance leg and RCOF 2 for an adjusted condition ($F_{1,26}$ = 4.0335, P = 0.0551) where r = 0.134. This negative relationship indicated that as HAM activity duration for the stance leg for an adjusted gait condition increased, RCOF on a contaminated surface for the adjusted gait condition decreased.

Stance RF Duration and Step Length

There was statistically significant relationship between adjusted RF activity duration for the stance leg and step length for an adjusted condition ($F_{1,26}$ = 11.0778, P = 0.0026) where r = 0.299. This positive relationship indicated that as step length for an adjusted gait condition increased, stance RF activity duration for an adjusted condition increased.

Swing RF Peak and Step Length

There was statistically significant relationship between adjusted RF peak activity for the swing leg and step length for an adjusted condition ($F_{1,26}$ = 5.2151, P = 0.0308) where r = 0.167. This positive relationship indicated that as step length for an adjusted gait condition increased, swing RF peak activity for an adjusted condition increased.

Swing RF Mean and Step Length

There was statistically significant relationship between adjusted RF mean activity for the swing leg and step length for an adjusted condition ($F_{1,26}$ = 4.6114, P = 0.0413) where r = 0.151. This positive relationship indicated that as step length for an adjusted gait condition increased, swing RF mean activity for an adjusted condition increased.

Swing GAS Peak and UICFFM

There was statistically significant relationship between adjusted GAS peak activity for the swing leg and UICFFM total rating scores ($F_{1,26}$ = 5.5587, P = 0.0262) where r = 0.176. This negative relationship indicated that as swing GAS peak activity for an adjusted gait condition increased, UICFFM total rating scores decreased.

Swing GAS Mean and UICFFM

There was statistically significant relationship between adjusted GAS mean activity for the swing leg and UICFFM total rating scores ($F_{1,26}$ = 10.5739, P = 0.0032) where r = 0.289. This negative relationship indicated that as swing GAS mean activity for an adjusted gait condition increased, UICFFM total rating scores decreased.

Swing RF Duration and UICFFM

There was statistically significant relationship between adjusted RF activity duration for the swing leg and UICFFM total rating scores ($F_{1,26}$ = 4.0339, P = 0.0551) where r = 0.134. This positive relationship indicated that as swing RF activity duration for an adjusted gait condition increased, UICFFM total rating scores increased.

4.8 Summary of Results

Results of the present study are summarized in the following section. First, the findings regarding age related differences involving gait parameters and muscle activity for a normal gait condition (dry condition) to an adjusted gait condition (slippery condition) are addressed. Following this, relationships among gait parameters and muscle activity are examined for both conditions.

Gait parameters (such as step length, RCOF, heel velocity) could be very important for influencing the ultimate outcomes of slip induced falls. There may exist age related changes to gait parameters suggesting that older individuals may be more susceptible to slip induced falls. Results indicate several significant differences in gait parameters found between younger and older participants. Overall, older participants required a lower coefficient of friction (RCOF) than younger individuals ($F_{1,26}$ = 12.3356, P = 0.0016), exerted a lower heel contact velocity than younger individuals ($F_{1,26}$ =10.6733, P = 0.0030), and had a shorter step length (in centimeters) than younger participants ($F_{1,26}$ = 4.7245, P = 0.0390).

Bivariate correlation analysis indicated that as RCOF for the normal gait condition increased, HCV on the second force plate increased ($F_{1,26}$ = 4.5937, P = 0.0416) where r = 0.150. Additionally, as RCOF values for a normal gait condition increased, total slip distance increased ($F_{1,26}$ = 10.2004, P = 0.0037) where r = 0.282. No overall main effects due to age were found for muscle activity.

Fear of falling may be a factor influencing gait adjustment over a known slippery surface. However, no statistically significant difference between age groups for the UICFFM self report measure ($F_{1,26}$ = 3.0409, P = 0.0930).

Gait parameters may be adjusted as people traverse slippery surfaces to improve their likelihood of not slipping and falling. Furthermore, differences in muscle activity could reflect differences in gait parameters. Results indicate several significant differences for both gait parameters and muscle activity regarding the two different walking conditions. Overall, a higher required coefficient of friction (ROCF) was found for a normal walking condition versus both adjustment conditions ($F_{2,25}$ = 125.2063, P < 0.0001). Additionally, a higher RCOF value was found for adjustment 1 than for adjustment 2. Overall, HCV was lower for adjustments one and two than for both normal condition measurements for all participants ($F_{3,24}$ =25.0980, P < 0.0001). Step length was shorter for the adjustment condition than for the normal condition for all participants ($F_{1,26}$ = 36.7522, P < 0.0001).

Differences in muscle activity characteristics were also found for all participants between both the normal and adjusted gait conditions. In general all participants had a longer stance leg HAM activity duration in seconds for an adjusted gait condition than for a normal gait condition ($F_{1,26}$ = 7.6075, P = 0.0105). Overall, all participants had a lower stance leg RF mean activity for an adjusted gait condition than for a normal gait condition ($F_{1,26}$ = 5.0324, P = 0.0336). Participants also had a lower swing leg GAS peak activity ($F_{1,26}$ = 4.9986, P = 0.0342) and mean activity ($F_{1,26}$ = 9.6012, P = 0.0046) for an adjusted gait condition than for a normal gait condition. Additionally, all participants' swing leg HAM activity duration increased from a normal gait condition to an adjusted gait condition ($F_{1,26}$ = 9.0823, P = 0.0057). In general, all participants' swing leg RF mean activity decreased from a normal gait condition to an adjusted gait condition ($F_{1,26}$ = 7.6516, P = 0.0103).

Relationships between gait parameters indicate that as RCOF on a dry surface for an adjustment condition increased, HCV on a dry surface for an adjusted gait condition increased ($F_{1,26}$ = 6.2688, P = 0.0189) where r = 0.194. As step length for an adjusted gait condition increased, HCV on a dry surface for an adjusted condition (preceding the step) increased ($F_{1,26}$ = 15.7873, P = 0.0005) where r = 0.378. Additionally, as step length for an adjusted gait condition increased, HCV on a contaminated surface for an adjusted condition increased ($F_{1,26}$ = 16.0191, P = 0.0005) where r = 0.381. Furthermore, as step length for an adjusted gait condition increased, RCOF on a dry surface for an adjusted condition (preceding the step) increased ($F_{1,26}$ = 6.0396, P = 0.0210) where r = 0.189.

As stated previously, gait parameters may be important for influencing the outcomes of slip induced falls. Differences in muscle activity may be related to differences in gait parameters. Several relationships were found for muscle activity and gait parameters (RCOF, HCV, and step length) for both walking conditions for all participants. As the stance leg GAS activity duration for a normal gait condition increased, RCOF for the normal gait condition decreased ($F_{1,26}$ = 16.6404, P = 0.0004) where r = -0.390. Also, as swing leg GAS mean activity for a normal gait condition increased, RCOF for the normal gait condition increased ($F_{1,26}$ = 6.3982, P = 0.0178) where r = 0.197. Additionally as swing leg GAS activity duration for a normal gait condition decreased, HCV on the second force plate for the normal gait condition increased ($F_{1,26}$ = 4.9089, P = 0.0357) where r = -0.159. Furthermore, as RF mean activity for the stance leg for a normal gait condition increased, step length for the normal gait condition increased ($F_{1,26}$ = 5.0104, P = 0.0340) where r = 0.162.

Relationships between muscle activity and gait kinematics were also found during an adjusted gait condition for all participants. As stance leg GAS peak activity for an adjusted gait condition increased, RCOF on a contaminated surface for the adjusted gait condition increased ($F_{1,26}$ = 4.7497, P = 0.0386) where r = 0.390. As stance leg HAM activity duration for an adjusted gait condition increased, RCOF on a contaminated surface for the adjusted gait condition decreased ($F_{1,26}$ = 4.0335, P = 0.0551) where r = -0.134. As step length for an adjusted gait condition increased, stance RF activity duration [($F_{1,26}$ = 11.0778, P = 0.0026) where r = 0.299], swing RF peak activity [($F_{1,26}$ = 5.2151, P = 0.0308) where r = 0.167] and mean activity [($F_{1,26}$ = 4.6114, P = 0.0413) where r = 0.151] for an adjusted condition increased.

Ultimately, muscle activity and gait parameter characteristics may be different for older individuals and younger individuals. Additionally, muscle activity and gait parameters may be different for normal walking condition and adjusted walking conditions. Thus, for this study, adjusted gait over a contaminated surface may be different for younger participants than for older participants. Older participants required a lower coefficient of friction for adjustment 1 (the step prior to stepping upon the contaminated force plate) than younger individuals, whereas both age group required a similar coefficient of friction for adjustment 2 (the step upon the contaminated force plate $F_{2,25}$ = 3.1727, P = 0.0501). Younger individuals HCV was higher than older individuals for heel contact prior to stepping upon the contaminated force plate for an adjusted gait condition ($F_{1,26}$ = 12.7816, P = 0.0014). However, there was no statistically significant difference for age for the adjusted stepping condition on the contaminated force plate. ($F_{1,26}$ = 1.7738, P = 0.1945). There were also differences in muscle activity between the two age groups. Younger participants' stance leg RF activity duration increased from a normal gait condition to an adjusted gait condition, whereas, older participants' stance leg RF activity duration decreased from a normal gait condition to an adjusted gait condition ($F_{1,26}$ = 10.4162, P = 0.0034).

DISCUSSION

5.1 Hypotheses and experimental results

5.1.1. Hypothesis 1

Muscle activity pattern of the lower extremities will be adjusted (greater activation duration with lower peak amplitude and lower mean amplitude) from normal to slippery resulting in a shorter step length, reduced heel contact velocity and lower friction demand for all participants.

A primary objective of this study was to examine gait modifications over a contaminated floor surface. Results from the present study support this hypothesis by showing differences in gait parameters between a normal gait condition (condition 1) and an adjusted gait condition over a known slippery surface (condition 2).

As previously stated in the summary of results, gait parameters (such as step length, RCOF, and heel velocity) could be very important for influencing the outcomes of slip induced falls. Persons with higher heel contact velocity and higher RCOF are more susceptible to slip induced falls (Lockhart 2000; Lockhart and Woldsted et al., 2000). Additionally other factors, such as step length and walking velocity can be attributed to an increased likelihood of slips and falls (Cham and Redfern, 2001; Lockhart 2000; Lockhart and Woldsted et al., 2000; Winter, 1991).

To help avoid slip induced falls, gait parameters are adjusted to correct for contaminated or slippery conditions. Persons who have a prior knowledge of a contaminated walkway adjust gait parameters by reducing RCOF, heel velocity and step length (Cham and Redfern, 2002; and Cham, Moyer, and Redfern, 2002; Do, Schneider, and Chong, 1999). Cham and Redfern, 2002, stated that individuals reduce step length, RCOF and heel velocity to reduce likelihood of slipping. Resulting data from the present study support findings from previous studies by showing significant differences from a normal condition to an adjusted condition for step length, friction requirement (RCOF), and heel contact velocity for all participants.

The present study extends beyond the scope of previous studies by finding significant differences in muscle activity between the two gait conditions. Wooten, Kadaba, and Martin (1990) found that although there is more than one pattern for muscle activity, patterns were found overall for muscle activity during a normal gait cycle. Their results show activity in both the swing phases and stance phases of the legs, which were believed to control hip abduction, weight shift, and foot placement. Nashner (1980) found that muscle activity patterns change when gait is perturbed. As people traversed a platform, involving a sudden shift of position, adjustments in EMG activity were found. In this case, the lowering platform resulted in an increase in amplitude leading to extension of the support leg. Another study by Brown, Gage, Polych, Sleik and Winder (2002) concluded that there were modifications in muscle activity from a period of normal gait to periods of constrained gait. The present study examined muscle activity differences from normal walking conditions to conditions involving a known contaminated surface. The results indicated differentiating characteristics for five of the six muscle groups between the two conditions. Participants were reducing the magnitude of activity in the calf muscles and quadriceps, and increasing overall activity time of the hamstrings for the adjusted condition versus the normal walking condition.

Results of the present study indicate that relationships existed among muscle activity and gait parameters. As hamstrings activity duration in the stance leg increased, friction requirements in the opposing leg decreased. This may suggest that muscles in the stance leg were acting as a possible control mechanism as the participants' stepped onto the slippery surface. Moreover, as the mean activity of the quadriceps in the swing leg decreased, step length decreased. This may suggest that, not only was the stance leg being used for control, but also the muscle activity in the swing leg was being controlled as the participants' stepped onto the slippery surface. Data from this study are consistent with previous results by showing that participants do modify gait parameters while traversing contaminated floor conditions (Cham and Redfern, 2002; Cham and Redfern, 2002; and Cham, Moyer, and Redfern, 2002; Do, Schneider, and Chong, 1999; Lockhart 2000; Lockhart and Woldsted et al., 2000; Nashner, 1980; Winter, 1991; Wooten, Kadaba, and Martin, 1990). The present study attempts to link previous studies by showing significant relationships between muscle activity and gait parameters as participants adjust gait characteristics to accommodate for slippery floor conditions.

5.1.2. Hypothesis 2

Muscle activity pattern of the lower extremities during the normal condition, for the older subject population will be lower (lower peak amplitude, mean amplitude and longer activation duration) than the younger subject population, resulting in decreased step length, higher friction demand, and higher heel contact velocity.

In addition to gait modifications, a primary goal of this study was to examine age related differences to gait modifications. The purpose of this hypothesis was to determine if there are differences in muscle activity and gait parameters during normal gait for younger and older participants.

Overall, age differences for normal gait parameters were found in friction utilization, heel contact velocity, and step length. As hypothesized, step length was shorter for older participants than for younger participants. Studies show that older individuals' step length is much less than that of younger individuals (Prince, Corriveau, Hebert, and Winter, 1997; Winter, 1991, Winter and Patia et al., 1990). Heel contact velocity and friction requirement (RCOF), opposite of what was hypothesized, were lower for older participants than for younger participants. Previous studies by Lockhart (1997 and 2000) resulted in no significant differences in RCOF between older and younger participants.

Older participants, as observed in the present study, were walking slower than the younger participants. Bivariate correlation, for the present study, indicated that as HCV for the normal gait condition increased, RCOF increased as well. It is documented in previous research that older individuals have a significantly reduced walking velocity than younger individuals and that heel velocity was related to walking velocity (Prince, Corriveau, Hebert, and Winter, 1997; Winter, 1991, Winter and Patia et al., 1990). Thus, slower walking velocity may be related to lower heel contact velocity and lower friction requirements. This supports results of the present study, which show differences in gait parameters (step length, RCOF, and HCV) for younger and older participants during a normal gait condition.

Overall, there were no age related differences in muscle activity. Although results may show very slight differences between younger and older individuals during a normal gait condition, most of these differences were insignificant. Prince et al. (1997) reports that older individuals may have delayed muscle activation. However, no significant data was found regarding overall differences in activity during a step or stride when comparing younger and older populations. This study finds that for a normal gait condition, the healthy older participants' overall muscle activity was very similar to the younger participants, whereas gait parameters were different for the two age groups. This may suggest that even though older participants had different gait parameter measures than the younger participants, both age groups were utilizing similar muscle activity characteristics during gait.

5.1.3. Hypothesis 3

Muscle activity pattern of the lower extremities during the slippery condition, for the older subject population, will result in a lower adjustment (less activation duration and lower mean amplitude and peak amplitude) versus the younger subject population, resulting in decreased step length, higher friction demand and higher heel contact velocity.

As stated previously, a primary goal of the present study was to examine age related differences to gait modifications. This study resulted in significant differences for younger and older participants for gait parameter measures and muscle activity for an adjusted condition versus a normal condition. As stated previously, factors including heel velocity, RCOF, and step length are more susceptible to slip induced falls (Cham and Redfern, 2001; Lockhart 2000; Lockhart and Woldsted et al., 2000; Winter, 1991).

Also previously stated, gait parameters are adjusted correct for contaminated or slippery conditions. Results from the present study support previous research by showing that gait parameters are adjusted for contaminated walking conditions for all participants.

Persons who have a prior knowledge of a contaminated walkway adjust gait parameters by reducing RCOF, heel velocity and step length (Cham and Redfern, 2002; and Cham, Moyer, and Redfern, 2002; Do, Schneider, and Chong, 1999). Cham and Redfern, 2002, stated that individuals reduce step length, RCOF and heel velocity to reduce likelihood of slipping. Additionally, Nashner (1980) found that muscle activity patterns change when gait is perturbed.

The present study attempts to add to previous research by showing that there are not only differences in muscle activity and gait parameters for normal to adjusted walking conditions, but that there are also differences between the two age groups (younger and older). There were significant age related differences in muscle activity between the two age groups from the normal condition to the adjusted condition (slippery condition). Age group differences in muscle activity were located in the quadriceps muscle on the stance leg. Younger individuals increased activity duration and decreased mean activity from normal gait to adjusted gait, whereas, older individuals decreased activity duration from normal gait to adjusted gait with mean activity remaining roughly the same. This may suggest that older and younger participants had different adjustment strategies. This supports the previous data by Brown et al. (2002), and Nashner (1980) suggesting that there are differences in muscle activity for adjusted gait. However, this study adds to previous findings by showing that older participants had a slightly different muscle activity than younger participants for the adjusted gait condition. The age group differences in muscle activity also support age group differences in gait parameters.

For both age groups, there were significant reductions in step length, friction utilization, and heel contact velocity for the gait condition (the transitional step from a normal surface to a contaminated surface). Another interesting finding for the adjustment condition lies not on the contaminated force plate as hypothesized, but on the dry force plate preceding it. For preliminary adjustment step, heel contact velocity and friction utilization were considerably lower for older participants than for younger participants. These findings add to previous research by showing both groups reduced friction utilization and heel contact velocity from normal gait to adjusted gait, but that older individuals reduced both of these parameters well before the younger individuals during this adjustment condition. An age group difference in adjustment strategy is evident in the preliminary adjustment prior to stepping on the contaminated floor surface for the older participant group. This preliminary adjustment may help support the age group difference in muscle activity for the gait adjustment on the contaminated surface.

5.1.4. Hypothesis 4

Fear of falling, as measured by the University of Illinois at Chicago Fear of Falling Measure (UIC FFM), will be higher in older participants versus younger participants.

A secondary goal of this study was to examine the relationships of fear of falling with gait parameters and muscle activity for younger and older participants.

Studies show that there is an increase in reported fear of falling in older adults (Howland et al., 1993; Tinnetti et al, 1994; Tennstedt et al., 1998; Velozo and Peterson, 2001). Velozo and Peterson (2001) state that a fear of falling is reported by one third to half of community dwelling older adults. The results from the UICFFM measure showed that an age related difference for the total questionnaire was insignificant. Although both age groups self-reported fear levels very close to "not at all worried", older individuals actually reported less fear than did younger individuals. Lower scores indicate greater self reported fear, even though both age groups reported very little to no fear. A further examination of this showed that both older and younger females reported a greater fear (although still insignificant between "not at all worried" and "a little worried") than both older and younger males. Additionally, older females reported less fear than younger females, older males reported less fear than younger males. A study done by Davis (2002), on the same subject population and during the same time as the present study, concluded that older participants had higher levels of stress than younger participants. The measurement of stress, for the Davis (2002) study, was obtained utilizing salivary amylase.

Although stress may be related to anxiety, and anxiety may be related to fear, it is possible that many other factors could contribute to fear of falling. The UICFFM is a self-reported measure and some participants may not have been forthright in their rating responses. Moreover, the older participants in the present study were very healthy and active. It may be possible that they simply did not have a fear of falling. Although older participants reported less fear than the younger participants (even though both age groups reported very little to no fear), it is unclear why and many factors may be contributing to this phenomenon.

5.1.5. Hypothesis 5

Fear of Falling will be related to adjustment in muscle activity pattern of the lower extremities.

As stated previously, a secondary goal of this study was to examine the relationships of fear of falling to muscle activity characteristics for younger and older participants. As indicated by the results, there are relationships between UICFFM and muscle activity in both the normal and adjusted conditions.

A study by Brown et al. (2002) concludes that a fear of falling could influence a motor response during a slip event. The study by brown et al also states that these motor responses were evident in EMG data for muscles in the lower extremities. The present study shows relationship during normal and slippery conditions. As UICFFM scores decreased (lower scores indicate greater self reported fear, even though both age groups reported very little to no fear), peak activity of the quadriceps in the stance leg increased, mean activity of the calf muscle in the swing leg increased, and the activity duration of quadriceps muscle in the swing leg decreased. During the slippery condition, as UICFFM scores decreased, peak and mean activity of the calf muscle in the swing leg increased, and the activity duration of quadriceps muscle in the swing leg decreased.

The present study support previous studies by showing that, although participants did not report a fear of falling overall, there was a relationship of fear of falling to muscle activity for both conditions. Many factors may be contributing to possible relationships and it may be possible that fear of falling is related to muscle activity.

5.1.6. Hypothesis 6

Among all participants, regardless of age, there will be a relationship between fear of falling and slip distance.

As stated previously, a secondary goal of this study was to examine the relationships of fear of falling to gait parameters for younger and older participants. As stated previously, a study by Brown et al. (2002) reports that a fear of falling could influence a motor response during a slip event. The study by Brown et al. (2002) also results that there were differences in motor control responses between younger and older participants. During a period of constrained gait, older individuals showed an activation increase in the lower extremity muscles via EMG. The present study results in relationships between UICFFM scores and slip distance. The results indicated that as total slip distance increased, fear of falling scores decreased (lower scores indicate greater self reported fear, even though both age groups reported very little to no fear). Younger individuals had lower UICFFM scores and longer slip distances than older individuals. Many factors may be contributing to possible relationships and it may be possible that fear of falling is related to slip distance.

5.1.7. Hypothesis 7

Older participants will have higher friction utilization and thus, a longer slip distance and higher frequency of falls than the younger participants.

Previous research by Lockhart (1997 and 2000) and Lockhart et al. (2000) reports that older individuals had a greater susceptibility to slip induced falls than younger individuals due to many contributing factors including RCOF. A study by Hanson, Redfern, and Mazumdar (1999) concludes that although falls are related to RCOF, they may be due to a variety of factors. Conversely to what was hypothesized, younger individuals had a longer slip distance. However, there was a positive relationship between friction utilization and slip distance. As RCOF values increased, slip distance also increased. Participants with a higher required coefficient of friction also had a longer slip distance. Younger participants had higher required coefficients of friction than older participants. The relationship of slip distance to RCOF does support findings from previous studies, even though younger participants had a longer slip distance than older participants.

5.2. Summary and Recommendations

Previous research has shown that gait parameters (e.g. step length, RCOF, heel velocity) could be very important for influencing the ultimate outcomes of slip induced falls. The primary objective of this study was to examine gait modifications over a contaminated floor surface. Furthermore, the present study goes beyond the scope of previous studies by finding significant differences in muscle activity and relating these differences to differences in gait parameters.

Significant differences were found for younger and older participants for gait parameter measures and muscle activity for a walking condition over a contaminated floor surface versus a normal surface. One could infer that it was necessary for all participants to adjustment gait characteristics in order to avoid slipping on the contaminated surface. This was shown by the results of the present study. Interestingly, differences in gait adjustment strategies were found between older participants versus younger participants. This information could be very important to take into consideration when designing environments specifically focused on an older adult population. Design consideration could be taken specifically in regards to risk communication and hazard recognition. Furthermore, conventional design considerations may be of importance as well (such as flooring materials, environment, and lighting). However, future research may be needed before specific design considerations could be made.

Previous research has shown that persons who have a prior knowledge of a contaminated walkway adjust gait parameters by reducing RCOF, heel velocity and step length (Cham and Redfern, 2002; and Cham, Moyer, and Redfern, 2002; Do, Schneider, and Chong, 1999). Previous research also shows that older gait characteristics are different than that of their younger counterparts (Prince, Corriveau, Hebert, and Winter, 1997; Winter, 1991, Winter and Patia et al., 1990). The present study attempts to link gait adjustment strategies to age group differences when traversing a contaminated surface. Not only did the present study show differences in gait parameters between the two age groups, but differences in muscle activity were also found. The present study shows that older participants adjusted their gait differently that younger participants. Data from the present study also indicate that, in general, older participants required an additional step to adjust their gait before stepping on the contaminated surface. These findings strongly suggest that the older participants required more time and walking space to effectively adjust their gait parameters for the contaminated floor surface. Ultimately, this type of information could be very useful for design and risk related issues.

A secondary goal of this study was to examine the relationships of fear of falling with gait parameters and muscle activity for younger and older participants. Although this measure showed no significant differences, previous research has shown that older adults report higher levels of fear in relation to falling.

In regards to underlying causes of the cause of gait parameter and muscle activity differences during adjusted gait, and a possible relationship of anxiety due to a fear of falling, further research is still needed. The present study shows that older participants adjusted their gait differently than the younger participants. However, future research is still needed to expand upon the present study and may attempt to explain why this occurs. This may ultimately be very important regarding risk assessment, warning information, and how older individuals perceive a potentially hazardous situation. From an engineering perspective, environment design issues, such as flooring or lighting, could be an important factor in the reduction of these potential hazards. Recommendations made are kept general due to possible limitations of the present study. Findings from the present experiment, suggesting that older persons have a different adjustment strategy than younger persons, are only true for the subject population studied. This participant population was very small and may not be representative of a more global population. Future research may expand upon findings from the present study and advance scholars and practitioners understanding of gait adjustment strategies. As the older adult population increases, advancement in information regarding the mechanisms associated with proactively avoiding slips and falls, by adjusting gait characteristics, may lead to a decrease in fall related accidents. Moreover, relationships were found between self-reported fear of falling and muscle activity, as well as slip distance. Future research is needed to expand upon this and attempt to find out why these relationships may be occurring.

5.3. Limitations and Assumptions

The situation of inadvertency is a main limitation of this study. Even though unexpected falls were induced, by methods earlier discussed, there was a tendency to anticipate these falls. Thus, "complete unexpectedness" was limited by the experiment and setting. To reduce the confounding effect of anticipation, the participants were required to walk at a natural cadence for a given period of time (10-15 minutes) without exposure to the slippery surface. They were also required to accomplish simple tasks at either end of the walking track, and be exposed to audio and visual distractions while traversing the track to the workstations. The experimenter monitored unexpectedness, while the participants were in natural cadence (monitoring stride length). During the familiarization session, the participants were made aware that he or she would be exposed to a slippery surface and that a slip-induced fall was possible during the experiment. This awareness may have lead to pretension of the muscles in the lower extremities and heighten attention, which could have resulted in a confounding effect on the reactions of the nervous system and muscle activation in event of a slip.

The safety harness, being used to protect the subject in the case of fall, presented another limitation to the proposed experiment. This harness could have possibly altered the biomechanic parameters of the body in the case of a fall, resulting the vertical and horizontal forces being exerted by the individual to be affected. In order to correct for such an alteration, the person was allowed to drop approximately 15 cm before the harness arrested the individual. Furthermore, data collection was limited to only time before the harness successfully arrested the falling individual. This was done to ensure that realistic slip and fall characteristics were portrayed.

A final limitation of this study is that all participants were recruited from the local community in Blacksburg, Virginia. Resulting data from this study may not be representative of the entire population of older or younger adults.

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APPENDIX A: Informed Consent

Informed Consent for Participants of Investigative Projects
Grado Department of Industrial and Systems Engineering
Virginia Polytechnic Institute and State University

TITLE: Effects of Aging on the Biomechanics of Slips and Falls

PRINCIPAL INVESTIGATOR: Thurmon E. Lockhart Ph.D.

PURPOSE

This is an experiment to investigate the changes in biomechanical parameters and ground reaction forces due to increase in age. The objective of this experiment is to measure the aging effect on different conditions with or without contaminant (oil).

PROCEDURE

This study will last three hours with the first part of the experiment consisting of a familiarization session and body composition measurements, and the second part consisting of a walking experiment. Prior to this experiment, you will be given an opportunity to walk around the laboratory wearing a harness to familiarize yourself with the equipment (fall arresting harness), and floor surfaces. During the second part of the experiment, you will be asked to walk across the oily or dry floor surface for 20 minutes. While you are walking along the path, please keep your eyes looking straight ahead and try to maintain the speed that you practiced.

After the familiarization session, you will be asked to walk on specially prepared floor surfaces. The floor surface that you will walk across may or may not be slippery. As you experienced in the familiarization session, the harness system will protect you if device and allow you to “fall or slip” only 3 or 4 inches.

RISKS OF PARTICIPATION

Minor muscle sprain, if you lose my balance while walking on the floors.

BENEFITS AND COMPENSATION

The benefits to you are a better understanding of floor surface slipperiness, which could lead to preventing slips and falls in the elderly. Additionally, monetary compensation will be provided ($10.00 per hour).

ANOYNMITY AND CONFIDENTIALITY

The data from this study will be kept strictly confidential. No data will be released to anyone but the principal investigator and graduate students involved in the project without written consent of the subject. The data collected will be identified by subject number.

FREEDOM TO WITHDRAW

You are free to withdraw at any time from the study for any reason. Circumstances may come up that the researcher will determine that you should not continue as a subject in the study. For example, an illness could be a reason to have the researchers stop your participation in the study.

APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech, and by the Grado Department of Industrial and Systems Engineering. You will receive a copy of this from to take with you.

SUBJECT PERMISSION

I have read the informed consent and fully understand the procedures and conditions of the project. I have had all my questions answered, and I hereby give my voluntary consent to be a participant in this research study. I agree to abide by the rules of the project. I understand that I may withdraw from the study at any time.

If I have questions, I will contact:

Pricipal Investigator: Thurmon E. Lockhart, Assistant Professor, Grado Department of Industrial and Systems Engineering, 231-9088.

Chairman, Institutional Review Board for Research Involving Human Subjects: David Moore, 231-4991.

Signature of Subject

____Date________________

Signature of Project Director or his Authorized Representative:

____Date________________

Signature of Witness to Oral Presentation:

____Date _______________

APPENDIX B: Personal Data & Medical History

Personal Data and Medical History
Grado Department of Industrial and Systems Engineering
Virginia Polytechnic Institute and State University

Effects of Aging on the Biomechanics of Slips and Falls
Date______________

Personal Data

Name____ Age _______________
Sex ___________ Height (cm) _______________ Weight (kg) ___________________
In case of emergency contact: Name _____________________ Phone_______________

Medical History

1. Please check if susceptible to
_____ Shortness of breath _____ Fatigue _____ Headaches
_____ Dizziness _____ Pain in arm, shoulder or chest
If you checked any of the items above, please explain:

____

2. Please answer these questions (Yes or No)

2.1 Have you ever had a heart attack? __________ If so, please explain

____

2.2 Are you currently taking any type of medication? _________ If so, please explain

____

2.3 Have you had or do you now have any problems with your blood pressure?
____
If so, please explain ____

____

2.4 In the last 6 months, have you had any back pain? __________ If so, please explain____

2.5 Have you had or do you now have a hernia? __________ If so, please explain

____

2.6 Have you had or do you now have any problems with ankle, knee, or hip (surgery, injuries, replacements)? ______ If so, please explain _________________________

____

2.7 Have you currently had osteoporosis or treated with osteoporosis? ____________
If so, please explain ____

____

2.8 Have you had or do you now have any inner ear or balance problems?
____
If so, please explain ____

____

2.9 Have you experienced slips and falls? _________ If so, how long ago? _________
Please explain ____

____

2.10 Have you had visual problems? _____________ If so, please explain

____

APPENDIX C: UICFFM Questionnaire

Please indicate how worried you are about falling while performing the following activities:

1) Take a walk.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

2) Pick up something lightweight off the floor.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

3) Carry a full plate.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

4) Get in/out of a car.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

5) Walk on a crowded sidewalk.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

6) Climb up well lit stairs.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

7) Climb up poorly lit stairs.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

8) Carry bundles up well-lit stairs.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

9) Carry bundles up poorly lit stairs.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

10) Climb up bus stairs.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

11) Use a step stool to reach in a cabinet.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

12) Step off a curb.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

13) Get in/out of bathtub.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

14) Stand on a moving bus.

|_______________|_______________|_______________|
1 Very Worried — 2 Moderately Worried — 3 A little Worried — 4 Not at all Worried

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

15) Use an escalator.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

16) Walk outside alone when it is icy.

1	2	3	4
Very Worried	Moderately Worried	A little Worried	Not at all Worried

VITA

Jeremy Spaulding

Upon graduation from High School in 1993, Mr. Spaulding enrolled at Virginia Polytechnic Institute and State University. He earned a Bachelor of Science degree In June 1998 from the department of Crop and Soil Environmental Science. From 1998 to 2001, Mr. Spaulding worked for Video Broadcast Services, at Virginia Tech, as a Television Production Technician and as a Television Systems Technician. While working for Video Broadcast Services, Mr. Spaulding worked closely with distance learning, videoconferencing and videoconferencing network operations, as well as traditional broadcast systems.

Mr. Spaulding has worked as a graduate research assistant on several projects since 2001. Sponsors of these research projects have included the National Institute of Occupational Safety and Health, the Center for Disease Control, the Jeffress Foundation, and the Toyota Motor Corporation. Mr. Spaulding was the recipient of the 2001/2002 NIOSH Safety Engineering Training Award, and the 2002/2003 NIOSH Safety Engineering Training Award. Mr. Spaulding is also a member of the American Society of Safety Engineers and the Human Factors and Ergonomics Society.