Biomechanical Analysis for Effects of Neuromusculoskeletal Training for Older Adults on the Likelihood of Slip-induced Falls

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Abstract

The objective of this study was to evaluate if neuromusculoskeletal training (i.e., weight and balance training) for older adults could reduce the likelihood of slip-induced fall accidents. The study focused on evaluating biomechanics among the elderly at pre- and post-training stages during processes associated with slip-induced fall accidents.

18 older adults participated in the study for 8 weeks: 6 individuals in balance group, 6 individuals in weight group, and 6 individuals in control group (social group). Each group met three times a week and each session lasted for 1 hour. Biomechanical dependent measures and psychosocial dependent measures were evaluated to the effects of training. Balance training contributed to an improvement in ankle flexibility, whereas, weight training did not contribute to an improvement in ankle flexibility although either weight or balance training played a role in decreasing slip-propensity and the likelihood of slip-induced falls among older adults. An ability to integrate neuro-musculo-skeletal systems was improved by training and was a main contributor in reducing the likelihood of slip-induced falls. Proprioception sensitivity by itself did not play a role in decreasing the likelihood of slip-induced falls. In addition, the exercise training as well as social activities played a role in altering psychosocial behavior (i.e. fear of falling and independency) of older adults.

The author concluded that an ability to integrate neuro-musculo-skeletal systems could be improved by either balance or weight training and could be a primary factor contributing to a reduction in the likelihood of slip-induced falls among older adults. In addition, the author concluded that the regular social activities also could contribute to an enhancement in the psychosocial characteristics of older adults.

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Overview of the Study

Title

Biomechanical Analysis for Effects of Neuromusculoskeletal Training for Older Adults on Outcomes of Slip-induced Falls.

Research Objectives

The objective of this study was to evaluate if neuromusculoskeletal training (i.e., weight and balance training) for older adults could reduce the likelihood of slip-induced fall accidents. The study focused on evaluating biomechanics among the elderly at pre- and post-training stages during processes associated with slip-induced fall accidents.

Motivations

Older adults are at a higher risk of falls due to deficient gait characteristics and postural control, especially when facing unexpected external perturbations such as slippery surfaces. The literature (Alexander et al., 1992; Englander 1996; Hausdorff, 2001; Rizzo 1998) indicates that falls among the elderly over 65 result in enormous economic and personal losses, therefore, the losses must be diminished. The results from this study can provide intervention strategies for researchers, health care individuals, and the elderly and their families in reducing the likelihood of slip-induced falls.

Background

More than 25% of older adults fall every year (Sattin, 1992), and older adults and their family members fear their falls and fall-related injuries due to the associated high mortality rate (Jensen, 2003). The Center for Disease Control (CDC) reported in 2003 that emergency departments treated more than 1.6 million seniors due to fall-related injuries and, among them, 373,000 were admitted to the hospital. In 2002, The National Safety Council reported that 14,500 people died due to fall-related accidents, and 60 percent of them were 65 years of age and older. To minimize economic and personal losses, tribometric techniques for assessing shoe/floor interactions, the biomechanical responses in walking on slippery floor surfaces, and postural control were studied. Still, the elderly population is at a high risk of falling, severe enough that it is a major cause of hospitalization (CDC, 2003). Yet reasons for slip-induced fall accidents are not clear. Therefore, mechanisms involving fall accidents must be explored and, further, interventions to minimize fall accidents must be discovered and implemented.

The occurrence of falls among the elderly are postulated to result from neuromusculoskeletal aging. The changes in neuromusculoskeletal components with advancing age are commonly accompanied with mobility problems and poor health status contributing to a decreased physical capability such as a reduction in lower extremity strength (Larsson et al., 1979; Lord et al., 1991 and 1994; Murray et al. 1985; Stalberg et al., 1989; Whipple et al. 1987) and insecure and unconfident balance (Manchester et al. 1989; Stelmach and Sirica, 1987; Teasdale et al. 1991; Thelen et al., 1998; Woolacott, 1986) leading to unstable dynamic postural control and poor gait dynamics (Alexander, 1994; Judge, 2003; Lockhart et al., 2003; Wolfson, 2001). Unstable dynamic postural control and poor gait dynamics influence the likelihood of falls among older adults (Guralnik et al.1994; Judge et al.1996; Lockhart et al., 2003; Tinetti et al. 1988). Therefore, in an effort to improve unstable dynamic postural control and poor gait dynamics, strength and balance training have been proposed and implemented. (Campbell et al., 1999; Day et al., 2002; Fiatarone et al., 1994; Neil, 1994; Shepard et al., 1993; Tinetti et al, 1994; Wolfson et al, 1993).

Problem Statement

Although the significance of muscle strengthening and balance training in reducing falls for older adults has been addressed previously, most studies (Berg et al., 1992; Duncan et al., 1990; Guralnik et al.,1994; Hageman et al., 1995; Nashner, 1993; Nashner and McCollum, 1985; Nevitt et al., 1989; Overstall et al., 1977; Rikli and Jones, 1999; Tinetti, 1986) have focused on the effect of muscle strengthening and balance training on the static and dynamic postural control such as quite standing, one-leg stand, the sit-to-stand test, the test of precise movement, functional reaching, or the mobility test. Yet, research to evaluate the effectiveness of muscle strengthening and balance training on actual slip-induced fall events was lacking. This study were carried out to evaluate the likelihood of falls at pre- and post stages of training by incorporating and validating the effectiveness of training utilizing actual perturbations commonly associated with slips and falls.

Method

18 older adults participated in the study for 8 weeks: 6 individuals in balance group, 6 individuals in weight group, and 6 individuals in control group (social group). Each group met three times a week and each session lasted for 1 hour. Biomechanical dependent measures and psychosocial dependent measures were evaluated to the effects of training.

Results

The results indicated that, overall, training resulted in improvements in biomechanical dependent measures. Further, regular social activities resulted in improvements in proprioception sensory sensitivity and in ankle dorsiflexion muscular strength.

Conclusion

Balance training contributed to an improvement in ankle flexibility, whereas, weight training did not contribute to an improvement in ankle flexibility although either weight or balance training played a role in decreasing slip-propensity and the likelihood of slip-induced falls among older adults. An ability to integrate neuro-musculo-skeletal systems was improved by training and was a main contributor in reducing the likelihood of slip-induced falls. Proprioception sensitivity by itself did not play a role in decreasing the likelihood of slip-induced falls. In addition, the exercise training as well as social activities played a role in altering psychosocial behavior (i.e. fear of falling and independency) of older adults.

The author concluded that an ability to integrate neuro-musculo-skeletal systems could be improved by either balance or weight training and could be a primary factor contributing to a reduction in the likelihood of slip-induced falls among older adults. In addition, the author concluded that the regular social activities also could contribute to an enhancement in the psychosocial characteristics of older adults.

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1. INTRODUCTION

It has been suggested that falls are a major health hazard for older adults over 65 years of age because of the effects on the well-being and quality of life of those older adults and their family (Huang et al., 2003). Falls have been suggested to be a result of complex integration of physical, psychological and social factors among older adults (Figure 1).

It is believed that as the human body ages, the neuromusculoskeletal component continues to deteriorate (Alexander, 1994). These changes in the neuromuscular system contribute to limb immobilization and poor health status (Lipsitz et al., 1991; Lord et al., 1991). More interestingly, studies (Guralnik et al.1994; Judge et al.1996; Tinetti et al. 1988) suggest that problems with mobility and poor health status are closely related to the frequency of falls. Many older adults who experience falls become bed-bound and subsequently reduce daily activities such as gardening, going up and down stairs, driving, shopping, and walking (Huang H. et al.,2003; Judge et al., 1996). These phenomena, such as limiting daily activities and bounding to bed, occur due to the fear of falling that older adults face after they experience falls (Downton J., 1996); older adults fear falls more than younger adults (Brown et. al, 2002; Lachman et. al., 1998). Li et al. (2003) identified fear of falling as a key public health concern and stated, "fear of falling can result in self-induced restrictions in activity that could lead to muscle and lower-extremity strength depletion, thus restricting mobility and consequently reducing physical functioning." In addition to psychological issue such as the fear of falling, a decrease in involvement in social activities among the elderly such as visiting friends or relatives, going to the store, walk outside, and going to a place with crowds, has been another key concern for elderly population and their families. Older adults with functional and physical declines and the fear of falling are less likely to become involved in social activities such as visiting friends or relatives and going to the store (Li et al., and Lachman et al., 1998). Also, the physical activity level of older adults is also a reflection of their attitudes, self-efficacy, and support from family members and friends (Booth et al., 2000; Cumming et al., 2000; Li et al., 2002).

Therefore, it can be concluded that falls among the elderly are a result of a tightly knit amalgamation of physiological, psychological, and social factors.

1.1 Self-induced restrictions in activity due to fear of falling

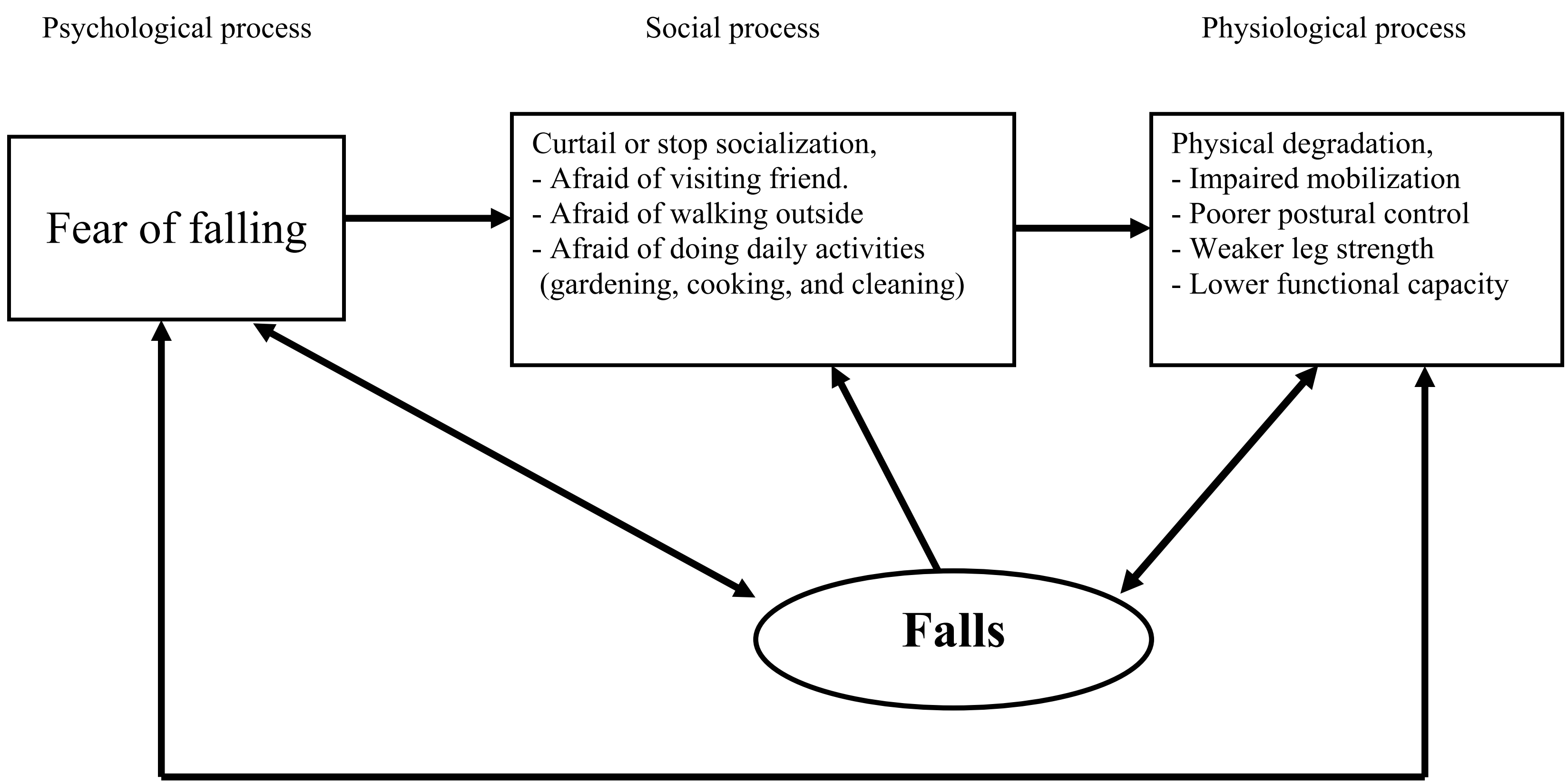
With advancing age, a psychological symptom called the fear of falling commonly develops in the elderly, whether or not they have experienced a fall (Chandler et al., 1996; Lawrence et al., 1998; Myers et al., 1996; Tinetti et al., 1988). Older adults fear falls because it is believed and said that falls are one of major leading cause of injury-related deaths for elderly over 65 (The National Safety Council, 2001) and a major reason for hospital admission; in 2003, emergency departments treated more than 1.6 million seniors due to fall-related injuries and 373,000 were admitted to the hospital (Center for Disease Control and Prevention, 2003).

Whether they have fallen or not, older people who fear falls restrict activities of their daily living (ADL), and other physical and social activities. Consequently, this life style ends up facilitating functional decline; everyone who has fear of falling tends to exhibit impaired physical performance, restricted ADL, and depressions (Chandler et al., 1996; Arfken et al., 1994; Howland et al., 1998; Silverton and Tideiksaar, 1989). Chandler et al. (1996) studied fear of fall syndrome in 306 community dwelling male veterans aged 70 to 104 years; 38% of those with no fall history and 49% of those with a history of falls were found to be very afraid of falling. Chandler et al. (1998) suggested that depression due to fear of falling contributed to these subjects to restrict daily activities such as physical and social activities. Furthermore, those who were very afraid of falling exhibited greater impairment in walk time, mobility skills, functional reach, and ADL than those who were not (Chandler et al., 1996). In this study (Chandler et al., 1996), those who restricted their physical activities due to fear of falling experienced greater physical impairments. Another study (Howland et al., 1998) with a sample survey (n=266) of elderly adults reported that 43% of respondents curtailed activities, or stopped doing activities due to fear of falling.

1.2 Effects of muscle and lower-extremity strength depletion due to fear of falling on falls.

In order to remain healthy and active individuals, older adults need to carry out independently daily activities such as cooking, showering, gardening, going up and down stairs, driving, and shopping (Judge et al., 1996). However, older adults with the fear of

Figure 1. A Proposed Fall Model



falling tend to restrict their daily activities (Chandler et al., 1996; Arfken et al., 1994; Howland et al., 1998; Silverton and Tideiksaar, 1989) because most falls among older adults stem from the daily activities; doing such activities requires precise coordination and integration of movements such as walking, standing, reaching, turning, bending, picking, and sitting (Nevitt et al. 1991; Vellas et al. 1993).

Intact coordination between sensory input (proprioception, somatosensory, and vestibular systems) and central processing (motor control), and proper development in muscle force are required in order for older adults to perform the activities correctly to avoid falls. However, restricting daily activities due to fear of falling facilitates age-related physiological declines (Chandler et al., 1996; Arfken et al., 1994; Howland et al., 1998; Silverton and Tideiksaar, 1989). The facilitated age-related physiological changes may contribute to impaired postural control (Alexander, 1994; Judge, 2003) or deterioration in motor control (Wolfson, 1995) contributing to the increased incidence of falls in older adults.

1.3 Social and environmental factors, self-efficacy, and physical capability

The fear of falling among the elderly can compromise socialization (Howland et al., 1998) thereby increasing isolation, depression, and anxiety (Arfken et al., 1994) and contributing to risks of falling. People with the fear of falling tend to curtail or stop socialization because of being afraid of falls (Arfken et al., 1994; Chandler et al., 1996; Howland et al., 1998; Li et al., 2002). Curtailment often leads to a decrease in physical capability and depression due to lack of socialization, in turn facilitating physiological aging more rapidly in comparison to active older adults (Chandler et al., 1996). However, those with the support of family or friends continue to do daily activities (Howland et al., 1998). This may indicate that encouragement from family members or friends is important for the elderly to continue to remain active (Howland et al., 1998). Older adults who participate in regular activities have better physical and psychological health (McAuley and Rudolph, 1995; Spirduso, 1995; ACSM, 1998). Motivational orientations such as family support and self-efficacy to exercise among elderly have been suggested to be an important factor that assists and facilitates elderly to remain active (Duda and Tappe, 1989; Dzewaltowski, 1989; Howland et al., 1998). Exercise behaviors and habits among elderly can be determined mainly by self-motivational constructs, self-efficacy, expectations of health benefits, spouse support, family and peer influences, and accessibility to facilities (Booth et al., 2000; Duda and Tappe, 1989; Dzewaltowski, 1989; Howland et al., 1998; Sallis and Owen, 1999). The older adults who believe more strongly that physical activity improves health, who have foot paths in their residential area that present fewer obstacles to safe and comfortable walking, and who live closer to facilities are more active than the older adults without those circumstances (Ajzen, 1991; Bandura, 1969; Booth et al., 2000; Duda and Tappe, 1989). Additionally, older adults who receive support to be active from family and friends and have high self-efficacy for physical activity are more likely to be involved in exercise programs and social meetings, consequently succeeding to improve the quality of life (Booth et al., 2000; Li et al., 2002).

1.4 Effect of strength and balance training for older adults on the quality of life in context of falls; directions for the proposed study and future studies and practice implications

Mortality and morbidity among older adults decrease as fitness level increases (Paffenbarger et al., 1993; Sandvik et al., 1998). Further, it is said that people with better health habits live longer and experience a better quality of life in the latter years of life (Vita et al., 1998). Moreove, it is said that falls are a major cause of death and disability among older adults (Braun, 1998). To improve quality of life among older adults, simply their falls rate needs to be decreased. As discussed above, a fall is an outcome of an amalgamation of physiological, psychological, and social factors (See figure 1). However, one common factor that may be used to decrease the falls rate is to improve the physical and functional capability of older adults (See Figure 1). The improvements of physical and functional capabilities of older adults should eventually decrease negative psychological and social factors such as fear of falling and curtailment of daily and social activities that influence the occurrence of falls. However, a question arises regarding how to improve the physical and functional capabilities of older adults. Currently, most interventions to minimize fall accidents among older adults have been focused on the improvement of lower extremity strength (Neil, 1994) and balance (Judge J., 2003). An exercise training program is found to be effective on lessening the degeneration of physical capability contributing to a reduction in fall rates (Campbell et al., 1999; Gardner et al., 2002). Advantages of strength and balance training among older adults are that it plays a significant role in improving neural recruitment patterns resulting in strength gain (Fiatarone et al, 1990). Moreover, strength gain by exercise training plays a role in the improved coordination of other fixator muscles necessary for body support while performing daily tasks such as cooking, gardening, reaching for an object, and walking, and in gaining more coordinated contractions between agonist and antagonist muscle groups leading to greater net force in the imposing movements (Jones et al., 1989; Rutherford and Jones, 1986; Sale 1988). Simply, the above studies (Fiatarone et al, 1990; Jones et al., 1989; Rutherford and Jones, 1986; Sale 1988) suggest that strength gains due to exercise training result in improving postural control while performing daily tasks. The improvement in postural stability while performing daily tasks will eventually lead to a reduction in fear of falling and an improvement in social interactions among older adults (Arfken et al., 1994; Chandler et al., 1996; Howland et al., 1998; Li et al., 2002).

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2. Study Objective

Our **long-term** goal of the study would to discover what causes older adults to fall, ultimately, providing a doable solution to decrease fall accidents for the elderly population. Specifically, the **objective** of this study was to evaluate if weight or balance trainings (neuromusculoskeletal trainings) improved older adults' gait biomechanics while walking over the slippery surface. The basic **hypothesis** to be tested was that age-related fall propensity was decreased by neuromusculoskeletal trainings for the elderly population. The **rationale** underlying the proposed study was that verification of intervention strategies (i.e. balance or weight training) to improve older adults' gait biomechanics was an important and critical step towards reducing slip-induced fall accidents.

The present study quantified gait biomechanics, and static and dynamic postural stability of the elderly while walking over a dry and slippery surface before and after balance and strength trainings. The following aims were evaluated after the proprioceptive trainings were completed 1) the trainings decreased the likelihood of slip-initiation, 2) the trainings improved the likelihood of slip-detection , 3) the training improved the likelihood of slip-recovery, 4) balance and weight trainings played a role in decreasing the likelihood of slip-induced falls. 5) balance or weight training played a role in improving the psychosocial characteristics of older adults. In order to answer for the aims, specific hypotheses were asked within each aim.

Aim 1: balance or weight training decreased the likelihood of slip-initiation.

After training;
1-1. Heel contact velocity would be slower.
1-2. Transitional acceleration of COM (center of mass) would be faster.
1-3. Required coefficient of friction would decrease.

Aim 2: balance or weight training improved the likelihood of slip-detection and recovery.

After training;
2-1. Leg strength would improve.
2-2. Slip distance II would be smaller.
2-3. Postural stability would improve.

2-4. Proprioceptive sensibility would improve.

2-5. Dynamic ankle joint stiffness would improve.

2-6. Limb stability would improve.

2-7. The number of falls would decrease.

Aim 3: training would decrease the likelihood of slip-induced falls.

3-1. Strength, RCOF, proprioception sensitivity, postural stability, limb stability, dynamic ankle joint stiffness and reaction time were related to the likelihood of slip-induced falls among older adults.

Aim 4: balance or weight training improved the psychosocial characteristics.

4-1. Participants would become more active.

4-2. Fear of falling would decrease.

4-3. Social activity level would increase.

3. Literature Review

3.1 Biomechanics of Gait and Slip-induced Falls

3.1.1 Human Gait

Locomotion, a characteristic of animals, is the process by which animals move themselves from one geographic position to another (Lockhart et al., 2000a; 2000b). Inman, Ralston, and Todd (1981) defines walking as "a method of locomotion involving the use of two legs, alternatively, to provide both support and propulsion." Lockhart et al. (2000a; 2000b) described gait as the manner or style of an individual's walking pattern. A major function of walking is to transport the body safely and efficiently across terrain (Lockhart et al., 2000). Winter (1991) listed five major functions that must be performed during each stride period to transport the body safely and efficiently across the terrain;

1. Maintenance of upper body support during the stance phase of gait (Winter, 1980; 1984).
2. Maintenance of upright posture and balance of the total body (Nashner, 1980, 1982; Cappozzo, 1981; Thorstensson, 1984).
3. Acquisition of safe ground clearance and smooth heel contact by foot trajectory control (Winter, 1992).
4. Generation of Mechanical energy to maintain or increase forward velocity (Winter, 1983a; 1983b).
5. Absorption of mechanical energy to decrease forward velocity (Winter, 1983a; 1983b).

3.1.2 Gait Cycle and Pattern

Walking involves two basic requisites (Inman et al., 1981). One is the periodic movement of each foot from one position of support to the next, and the other is sufficient ground reaction force (applied through the feet) to support the body. Inman et al. (1981) suggested that this periodic leg movement was the essence of the cyclic nature of human

Figure 2. The time of dimension of walking cycle (from Inman et al., 1981)

gait (i.e. the gait cycle). The activity of one leg can be divided into two phases: One is the swing phase and the other is the stance phase (See Figure 1). The stance phase starts when a foot contacts the ground and ends when the foot leaves the ground. The swing phase starts from the end of the stance phase and ends when the foot comes into contact with the ground (Inman et al., 1981).

Every gait cycle involves two periods of single support and two periods of double support (See Figure 2-1). Furthermore, two phases in the gait cycle are divided into eight sub-periods (Vaughan et al. 1987). The stance phase events are as follows:

1. *Heel contact* initiates the gait cycle and presents the point at which the body's center of gravity is at its lowest position.
2. *Foot-flat* occurs when the plantar surface of the foot touches the ground.
3. *Midstance* occurs when the swing foot passes the stance foot and the body's center of gravity is at its highest position.
4. *Heel-off* occurs as the heel loses contact with the ground, and push-off is initiated via triceps surae muscles, which plantar-flexes the ankle.
5. *Toe-off* terminates the stance phase as the foot leaves the ground.

The swing phase events are as follows:

6. *Acceleration* begins as soon as the foot leaves the ground and the hip flexor muscles are activated to accelerate the leg forward.
7. *Midswing* occurs when the foot passes directly beneath the body, coincidental with the midstance of the other foot.
8. *Deceleration* describes an action of the muscles as they slow the leg and stabilize the foot in preparation for the next heel contact.

Generally, seven major lower extremity muscles (gluteus maximus, gluteus medius, adductor magnus, quadriceps, tibialis anterior, and hamstring) are activated alternately or simultaneously during normal walking (Inman et al., 1981). Typically, a slip occurs during the heel contact phase of the gait cycle (Perkins 1978; Grönqvist et al., 1989). A critical factor for slip-induced falls (higher horizontal heel contact velocity) can be initiated in; 1) the heel contact period when most major muscles of the leg such as tibialis anterior, gluteus muscle group, gastrocnemius, quadraceps femoris muscle group, and hamstring muscle group are activated (Hashomoto et al., 2000; Lockhart et al., 2002); 2) the foot-flat period when push-off force by gastrocnemius muscle group plays a significant role in transferring COM in the forward direction (Lockhart et al., 2003); and 3) the deceleration periods when hamstring muscles are activated to decelerate forward leg momentum (Kim and Lockhart et al., 2004). Failure to produce and coordinate muscle forces adequately during these periods can result in slip-induced fall accidents.

3.1.3 Fall Process

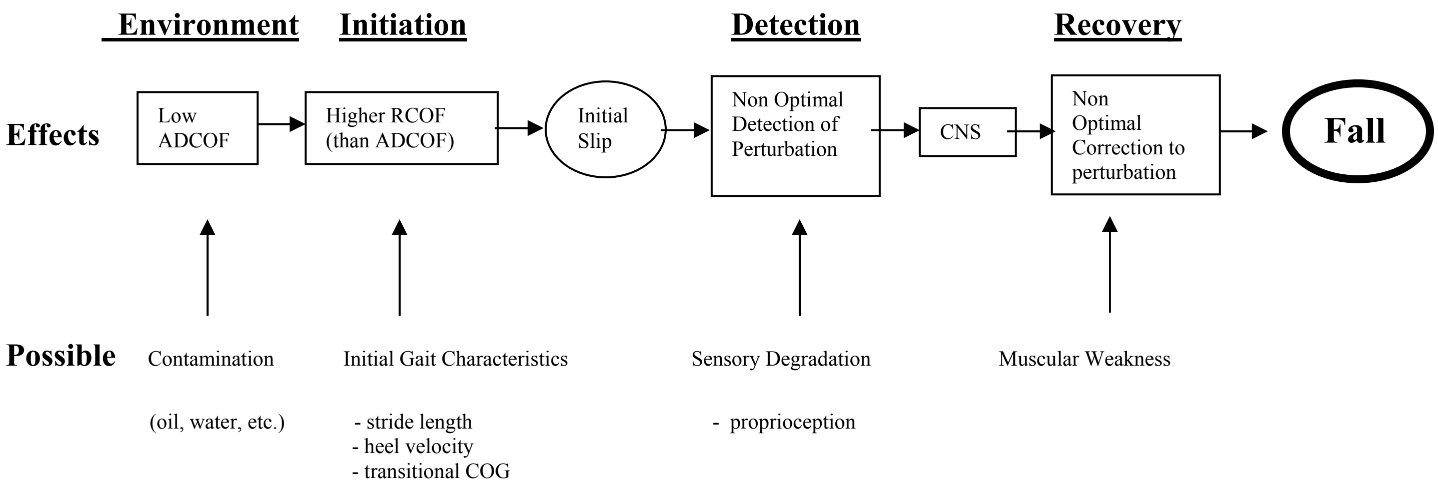
Processes that involve a slip-induced fall event can be divided into three phases: slip initiation, detection, and recovery (figure 2). Dangerous slips are most likely to occur when the required coefficient of friction (RCOF) at the shoe-floor interface exceeds the available coefficient of friction (ACOF) of the floor. RCOF represents the minimum coefficient of friction that must be available at the shoe-floor interface to prevent slip initiation. RCOF is determined by a ratio of F_h (vertical force) over F_v (horizontal force) (Redfern, 1984). Changes in either F_h or F_v may alter RCOF. Faster heel contact velocity, slower transitional walking velocity, and longer step length have been thought to increase the RCOF contributing to an increased risk of slip-induced falls (James, 1983; Myung et al., 1992; Lockhart et al., 2003; Soames and Richardson, 1985).

In order to perform daily activities such as walking and reaching, intact coordination between sensory input (proprioception, somatosensory, and vestibular system) and central processing (motor control), and proper development in muscle force are required. Body posture cannot be maintained properly during these daily activities without accurate processes and integrations among sensory input, central processing, and proper muscle force development. Consequently, failure of detecting improper body posture as well as of regaining loss of balance increase the likelihood of falls (Alexander, 1994; Judge, 2003; Lockhart et al., 2002 and 2003; Lord et al. 1991 and 1994; Robbins et al., 1989; Stelmach and Worringham, 1985; Wolfson, 2001).

3.1.3.1 Initiation

3.1.3.1.1 Heel contact velocity

Figure 3. The process of initiation, detection, and recovery of inadvertent slips and falls with possible causes and effects.



Most slips resulting in falls occur when the frictional force ($F\mu$) opposing the movement of the foot is less than the shear force (Fh) of the foot immediately after the heel contacts the floor (Perkins and Wilson, 1983). During normal walking, the vertical foot force at heel contact is fairly constant (Irwine, 1986). Therefore, the horizontal foot force at heel contact primarily determines RCOF (Irvine, 1986). Horizontal foot force at heel contact is a product of foot mass and foot horizontal acceleration of the contacting foot. Given the constant contact time (t) and mass (m) associated with the heel contact phase of the gait cycle, the impulse-momentum relationship indicates that horizontal shear force (F_h) increases proportionally with horizontal heel contact velocity (V_h) :

$$F_h = ma = m\, V_h / t;$$

$$\therefore\ F_h \propto V_h \text{ (where mass (m) and time (t) are constant)}$$

Therefore, inability to reduce heel contact velocity during the heel contact phase of the gait cycle can result in higher horizontal foot force leading to higher RCOF and contributing to the risk of slip-induced falls. Activation of hamstring muscles, tibialis anterior muscles and gluteus maximas and minimus muscles are functionally important indicators for horizontal heel contact velocity since one role of these muscles is to decelerate the forward leg momentum during the heel contact phase of the gait cycle. In the present study, it was assumed that strengthening these muscles and improving neuromuscular coordination utilizing balance training or weight training for older adults had an influence on a decrease in heel contact velocity contributing to lowering RCOF.

3.1.3.1.2 Transitional walking velocity, Step length and Muscle strength.

Two other main factors that can play a role in altering RCOF are step length and walking velocity. RCOF (F_h / F_v) increases if resistance (horizontal) force (F_h) increases or normal (vertical) force decreases. In large part, the former is the case in normal walking since vertical foot force at heel contact is fairly constant (Irvine, 1986). Horizontal foot force can be increased if tan θ increases due to an increased distance (L) between the center of mass (COM) and heel contact position as illustrated in figure 3. Therefore, a longer step length can lead to an increased likelihood of dangerous slips. However, it is suggested that faster transition of COM leads to lowering RCOF (Kim and Lockhart, 2004) since tan θ decreases at peak 3 where a dangerous slip is most likely to occur (See Figure 3).

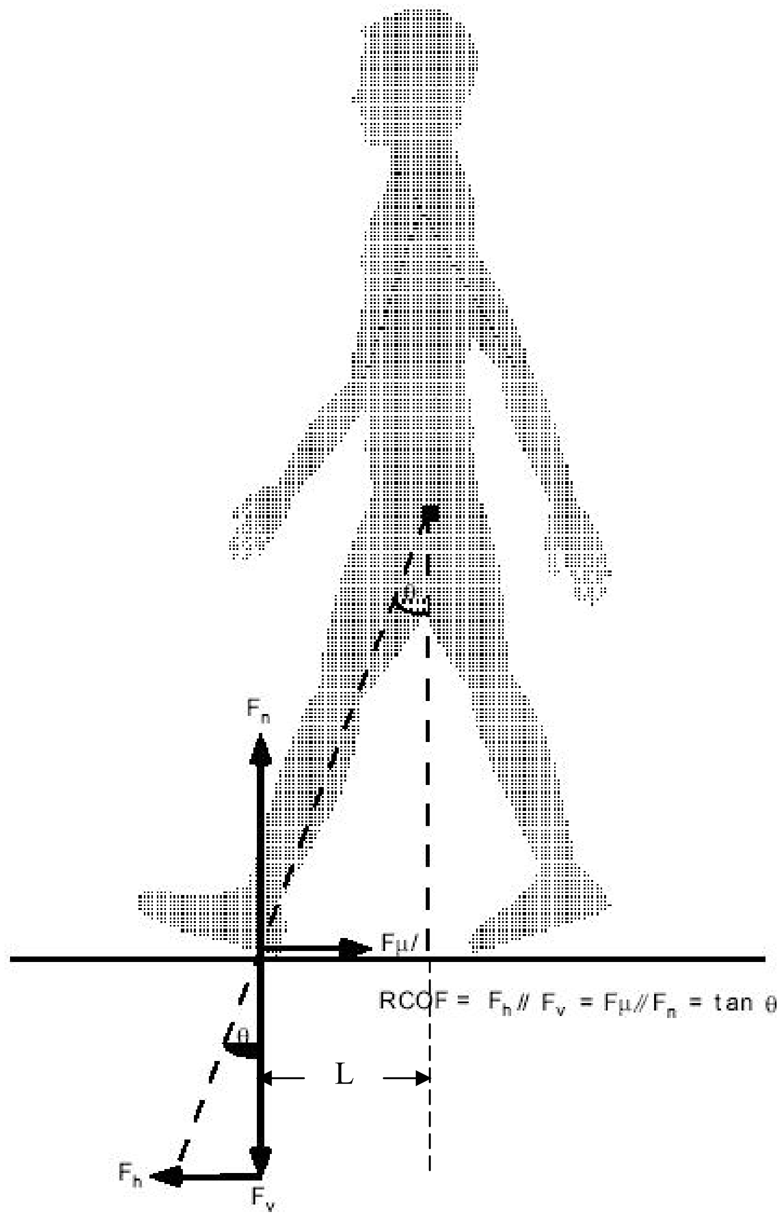


Figure 4. Frictional (F_u) and normal force (F_n) force vectors vs. horizontal (F_h) and vertical (F_v) force vectors applied by the foot during the heel contact phase in normal level walking (adapted from Lockhart, 2000).

Effects of the characteristics associated with transition of the whole body COM on RCOF are further illustrated in figure 4. As the transfer of the whole body COM progresses forward, tan θ decreases from θ_1 to θ_2 leading to smaller RCOF.

The push-off strength of gastrocnemius muscles while walking is an important indicator for transitional COM velocity since one role of the muscles is to accelerate forward body momentum after the heel contact. In the present study, it was assumed that strengthening gastrocnemius muscles for older adults had an influence on improving the forward progression of COM contributing to lowering RCOF. In other word, strength training would improve gait characteristics among older adults and would reduce the likelihood of slip initiation and falls among older adults.

3.1.3.2 Detection and Recovery

The integration of information from three sensory systems (visual, somatory sensory (proprioception), and vestibular systems) is necessary in order to illustrate a controlled balance profile. However, deteriorations in these systems such as, increased threshold in cutaneous sense, loss of spatial sensitivity, reduction in the number of axons in the optic nerve, reduced visual contrast sensitivity, reduction of hair cells in the semicircular canals, and decreased macula of the utriculus and sacculus have been reported with advancing age (Johnsson and Hawkins, 1972; Johnson et al. 1987; Lord et al. 1991 and 1994; Rosenhall 1973; Sekuler et al., 1980). Visual and vestibular systems are no concern in the proposed study since it is not certain whether they can be improved by neuromusculoskeletal (proprioceptive) training. Therefore, discussion involving these two systems is excluded in this section.

Joint proprioception plays an important role in maintaining the functional stability of the joint. Information from proprioceptive receptors is integrated for the motor programming required for precision movements and contributes to reflex muscle contraction, providing dynamic joint stability (Johansson et al., 1987). Proprioceptive thresholds are dulled with aging (Skinner et al.,1984; Stelmach and Sirica, 1987). Dulled proprioceptive thresholds are directly related to impaired postural stability (Thelen et al., 1998) and delayed responses to the perturbations (Horak et al., 1989; Isaacs, 1978;

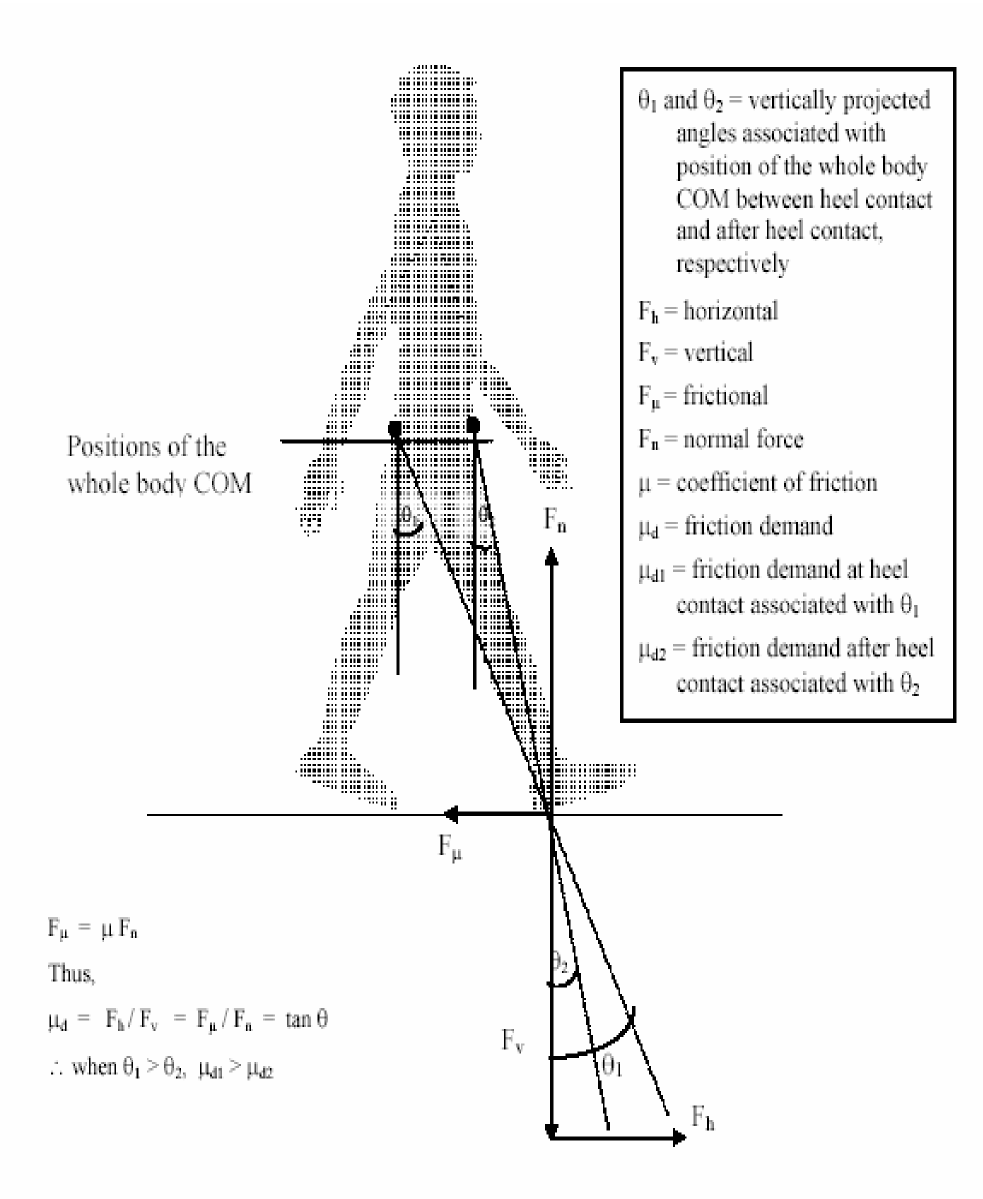


Figure 5. Positions of the whole body COM and force vectors applied by the left foot during heel contact phase in normal level walking (adapted from Lockhart, 2000)

Sheldon, 1963; Stelmach et al. 1989; Teasdale et al. 1991). Diminished proprioception with aging may result in failure to sensing changes in the displacement of the center-of-mass (Woolacott M. 1986, Manchester et al. 1989). These results suggest that older adults may not be able to detect and correct postural disturbances in as timely manner as younger adults (Sheldon, 1963; Isaacs, 1978; Stelmach and Worringham, 1985). Particularly, these results from the studies above suggested that, due to the deteriorations in proprioception, the effectiveness of somatosensory information on postural control decreased with advancing age.

Wolfson et al. (1995) stated that lower extremity strength was a fundamental component of the sensorimotor function which supported mobility. Continuous decline in lower extremity strength with advancing age is a well known (Larsson et al., 1979; Lord et al., 1991 and 1994; Murray et al., 1985; Stalberg et al., 1989; Whipple et al. 1987). Fallers demonstrated decreased lower extremity strength in comparison to non-fallers and lower extremity muscle weakness among fallers was suggested as a prominent risk factor for falls (Lipsitz et al., 1991; Lord et al., 1991; Lord et al., 1994; Robbins et al., 1989; Wolfson et al., 1995). In addition to lower extremities, the upper body (trunk and arms) has been suggested to play a role in proactive balance control during normal gait as well as reactive recovery during perturbed gait (Allum et al., 1988; Keshner et al., 1988; Tang et al., 1998). While slipping, as a reactive recovery strategy, arms are elevated rapidly, are indicated as a reactive recovery since there is no passive loading at arm muscles (Mcllroy, W., and Maki B., 1995). Further, the arm movement is suggested as a strategy to keep upright position (McIlroy and Maki, 1995; Marigold and Patla, 2002). Decline in upper and lower body muscle strength among older adults may contribute to the inability to produce timely, adequate force in order to recover from postural disturbance such as slips (Neil, 1994).

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3.2 Age-related Risk Factors for Slip-induced Falls

The continuous regulation of upright posture grows difficult with advancing age (Stelmach et al., 1989). Further, postural recovery after introduction of an external perturbation (i.e. a slippery surface) becomes much more difficult for older adults (Fernie et al., 1982; Kim and Lockhart, 2004; Lipsitz et al., 1991; Lockhart et al., 2002 and 2003; Lord et al., 1991; Robbins et al., 1989; Tinetti et al., 1988). Older individuals are found to detect and correct postural disturbances slower and more erroneously than younger adults (Isaacs, 1978; Lockhart et al., 2002; Sheldon, 1963; Stelmach and Worringham, 1985; Stelmach et al., 1989). Impaired integration of somatosensory (a major factor) feedback, and visual and vestibular feedback (supporting factors) (Diener et al., 1986 and 1984; Lockhart et al. 2002, Woolacott et al., 1982, Stelamch et al., 1989) with advancing age is suggested to be major causes for inadequate detections and corrections of postural disturbance.

The decline in the physiology of systems is a major cause for the postural instability seen among older adults. Impaired visual (i.e. loss of visual acuity, depth perception, peripheral vision and contrast sensitivity), vestibular (i.e. delayed vestibular response), and somatosensory (i.e. loss of proprioceptive sensitivity) functions are representative examples for age-related degradations of the human physiology (Tinetti et al., 1988; Lipsitz et al., 1991; Robbins et al., 1989; Alexander et al., 1992; Lord et al., 1991; Nevitt et al., 1989; Tobis et al., 1985; Felson et al., 1989; Wyke, 1979). These dysfunctions in these sensory modalities increase with advancing age and are suggested to be a major factor for increased falls among older adults. Degradations in somatosensory (i.e. proprioception) and visual systems are suggested to be major causes for age-related balance characteristics, whereas the contribution of age-related degradations in vestibular systems to balance is found to be less influential than proprioceptive and visual systems to age-related balance characteristics. In addition, visual acuity, depth perception, peripheral vision, and contrast sensitivity could not be improved by existing training regimens, however, proprioceptive sensitivity is found to improve with balance training (Borsa et al., 1994; Kathleen et al., 2002; Toshio 1993).

In addition to sensory degradation, decreases in physical abilities, such as strength attenuation, were put forth as the leading cause for the poor mobility and health status among older adults (Wolfson et al. 1995) and for contributing to impaired postural control (Alexander, 1994; Judge, 2003) or deterioration in motor performance (Wolfson, 2001). As age-related decreases in leg muscle strength (i.e. isometric and isokinetic strengths) continue to occur with advancing age, these changes have been noted as contributing to falls among older adults (Guralnik et al.1994; Judge et al.1996; Tinetti et al. 1988).

These decreases in the lower extremity strength with advancing age may influence postural responses after slip initiation. Particularly, since slip-induced fall events include explosive, sudden, and severe movements, individuals are required to produce a matching force in their lower extremities in order to recover from slipping.

Wolfson et al. (1995) stated that lower extremity strength was a fundamental component of the sensorimotor function which supports mobility. Decreases in physical abilities were suggested as the leading cause for the poor mobility and health status among older adults (Wolfson 1995) contributing to falls among older adults (Lipsitz et al., 1991; Lord et al., 1991; Lord et al., 1994; Robbins et al., 1989; Wolfson et al. 1995).

3.2.1 Significances of balance capability on slip-induced falls

Maintaining balance is required everyday for humans to carry out daily activities or tasks without falling. Postural control can be defined as "the maintenance of the body center of mass over its base of support or, more generally, within the limits of stability" (Alexander, 1992). Stability can be influenced by intrinsic and extrinsic factors. The intrinsic factors vary within a person's biomechanics such as body configuration, age, strength, and physical capability. The extrinsic factors are the tasks, any support for the body, and the support surface conditions (angle, compliance, and friction) (Alexander, 1998). However, for cases where the extrinsic factors are constant, differences in the intrinsic factors contribute most to an inappropriate postural response leading to falls. Inability to detect postural disturbances while walking (i.e. slipping) represents or reflects the likelihood of falls among older adults. Erroneous detections of postural disturbances would lead to falls if inadequate integrative outcomes from somatosensory (a major factor), visual and vestibular (supporting factors) systems are used to correct balance. Studies indicate that older adults exhibit impaired balance including larger sway during quiet and perturbed stances (Fernie et al., 1982) and show greater difficulties carrying out daily activities when compared to younger adults. Sensory degradations typical in the proprioceptive system are suggested to be a major factor for these abnormal postural controls and gait (Tinetti et al., 1988; Lipsitz et al., 1991; Lord et al., 1991; Robbins et al., 1989).

When compared to younger adults, older adults over 65 years who have no neurological and pathological impairments show little or no difference in sways during quiet standing (Alexander et al., 1992; Bohannon et al., 1984; Chandler et al. 1990; Murray et al., 1975; Teasdale et al., 1991). However, the differences become noticeable as the severity of perturbation (i.e. more compliant surfaces and less contact area at foot, one-leg standing, reduced visual feedback, and translational and rotational perturbations) during quiet standing increases (Bohannon et al., 1984; Ekdahl et al., 1989; Ring et al., 1989; Teasdale et al., 1991). Older adults are observed to respond more slowly than younger adults to the external perturbations, as measured by COP excursion speed which measures the frequency of postural correction made (Maki et al., 1990; Ring et al., 1988). Furthermore, sway among older adults grows larger as the speed and amplitude of perturbations such as rotation and translation decreases when compared to younger adults (Stelmach et al., 1989). These results suggest that older adults are able to react to fast perturbations where fast responses (stretch reflex) are needed, yet they are unable to react properly to relatively slow perturbations where slower responding central integrative processes (coordination of the neuromusculoskeletal system) are required (Alexander, 1998). To ensure adequate motor output such as walking, first of all, the correct sensory information from proprioceptive, visual, and vestibular systems must enter the CNS. Second, the CNS must send out adequate information to muscle. Finally, muscle has to generate adequate force. Failure to do so would result in failure to maintain balance while walking. Proprioceptors reside in muscles, tendons, and joints (Ennbom 1990) and include muscle spindle, Golgi tendon organ, and joint receptors. They are functionally important in terms of postural control since their information is used to find the orientation and position of limbs and body as well as the forces acting on the body (limbs and joints).

Age-related degradations in muscle not only cause muscle weakness, but also, influence sensitivity of proprioceptors (Diener et al., 1984; Skinner et al., 1984; Stelmach et al., 1989). The impaired postural stability among older adults is associated with a decline in the sensitivity of the proprioceptors (Kokmen et al., 1978; Skinner et al., 1984; Diener et al., 1984; Stelmach et al., 1989). Older adults exhibit higher proprioceptive thresholds as well as higher errors in reproducing joint angles (Skinner et al., 1984; Stelmach and Sirica, 1987) in comparison to their younger counterparts. While slipping, the ankle, knee, and hip joints rotate differently from normal walking. Therefore, detecting changes in joint angles and limb orientations while slipping is a critical component for successful recovery.

3.2.2. Significances of muscle strength on slip-induced falls

Mainly, slip-induced fall accidents are initiated while walking. Inman, Ralston, and Todd (1981) defined walking as "a method of locomotion involving the use of two legs, alternatively, to provide both support and propulsion." Walking involves two basic requisites (Inman et al., 1981). One is periodic movement of each foot from one position of support to the next, and the other is sufficient ground reaction force (applied through the feet) to support the body. This periodic leg movement is the essence of the cyclic nature of human gait (i.e. the gait cycle) (Inman et al., 1981). Generally, seven lower extremity muscles (gluteus maximus, gluteus medius, adductor magnus, quadriceps, tibialis anterior, and hamstring) are activated alternately or simultaneously during normal walking. One of principal actions of these muscles is to accelerate and to decelerate angular motions of the legs (Inman et al., 1981) while walking. Therefore, the likelihood of slip-induced fall accidents while walking increases if the periodic leg movement, which is governed by seven major muscle groups, is troubled by alterations in aging musculoskeletal properties. Slower gait velocity, reduced step length, loss of dynamic stability, greater trunk sway, lower foot clearance, and shuffling gait are suggested to predict decreased functional capability and high risks of falls among older adults (Campbell et al., 1989; Tinetti et al., 1988; Wolfson et al., 1996). Also, age-related changes in leg muscle weakness are indicated as a major reason for these gait instabilities seen in older adults (Buchner et al., 1997; Buchner et al., 1996; Hausdorff et al., 1997; Lord et al., 1995; Skelton et al., 1994 and 1995; Rantanen and Avela, 1997; Whipple et al., 1987). Central integrative processes (coordination of the neuromusculoskeletal system) are required (Alexander, 1998) to maintain balance or gait stability while walking or to regain balance while slipping. To ensure adequate motor output to regain balance from slipping, adequate muscle forces must be generated. Inability to produce an adequate force level following postural disturbance would lead to failure in regaining balance while slipping.

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4. Methodology and Statistical Analysis

4.1 Participants

Six individuals for each group totaling 18 individuals were examined: weight, balance, and control groups. Prior to recruiting participants for the study, a power analysis was perform to determine the number of participants necessary to satisfy Type I error of 0.05 and Type II error of <0.35 (Power>0.65) using JMP statistical packages (SAS Institute Inc. Cary, NC, USA).

Twenty-four healthy, community-dwelling older individuals (2 males and 22 females) agreed to participate. Older adults were excluded from the sample if they indicated any physical problems (i.e. hip, knee, ankle problems). Individuals who had no history of the formal weight and balance exercises in the past 6 months were identified as eligible participants for this study. It was acceptable for persons to be involved in other types of physical exercise (e.g., walking, golf, tennis, swimming) or if exercises to improve muscle strength as well as balance did not exceed more than total 30 minutes a week (i.e. for example, weight or balance exercise for 2 time a week for 10 minutes for a session (total 20 minutes) will not be considered as the formal weight and balance training). The investigator interviewed the elderly for screening for the study before evaluating their gait characteristics and other parameters.

Twenty four individuals were randomly assigned to the groups. After 4 weeks, 5 individuals dropped out of the program leaving 7 people in balance, 6 people in weight, and 6 people in control groups. All 19 people completed for 8 week training period. However, in order to balance out the number of participants for each group, only 18 individuals' data were evaluated (one male participant was eliminated).

To ensure that the weight and balance training group did not engage to any other exercises or physical activities during 8 weeks, the investigator monitored their daily activities for 8 weeks. Also, individuals in the control group were not permitted to engage in any form of exercise or physical activity; again, the investigator interviewed the control group party during the social meetings. In order to isolate effects of group training among training groups, the control group also met regularly, and performed social activities (i.e. picnic, bingo and etc.). Any activity that required physical performance was not included for control group except walking. Each group met 3 times a week for 8 weeks for 50-60 minutes.

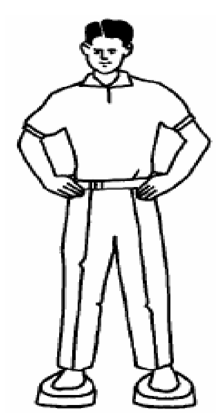
4.2 Training (treatment group) and Social Activity (control group)

4.2.1 Balance training

Balance training was performed in a multipurpose room in the Montgomery County Government Center, Christiansburg, VA as well as in the Locomotion research lab, Virginia Tech, Blacksburg, VA. During the first week of training, to familiarize the older adults with the exercise routines, they were instructed to perform the exercises provided in the instructional manual of Stability Trainer (Thera-Band®, 1245 Home Avenue, Akron, OH 44310) on firm surfaces such as floors. At week two, all participants were evaluated to determine if they were able to perform the exercises on green stability trainer which was more compliance, therefore, designed to use for intermediate challenge level. Individuals not able to perform the exercises safely on green stability trainer were allowed to perform the exercise on firm surface until they was able to perform the exercises safely on the green stability trainer. In addition, blue stability trainers (advanced challenge level) were introduced if an individual performed exercises perfectly and confidently on the green stability trainer. Among 6 volunteers, only 2 progressed to perform the exercises on blue stability trainer.

All volunteers performed the 16 lower body exercise routines described by the Thera-Band Stability Trainer manual everyday.

<u>BILATERAL (2-LEG) BALANCE WITH SQUAT</u>

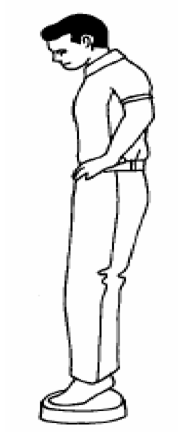


There are two exercises for bilateral balance.

1. Standing shoulder apart on the foams with hands on waist, participants bring hip down as low as possible like sitting on a chair while pausing the position for 3 second and bring hip up while resting for 3 second. Participants repeat the exercise for 10 times.

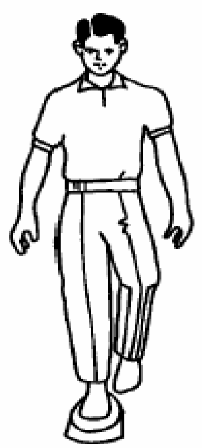
2. Standing with two knees and ankles as close as possible, do exactly same exercise like first exercise. Participants repeat it for 10 times.

BILATERAL CALF RAISES



Standing on the foams with hands on waist, participants raise ankles as high as possible while holding the position for 2 seconds and bring ankle down while resting for 3 second. Participants repeat the exercise for 10 times.

UNILATERAL (1-LEG) BALANCE

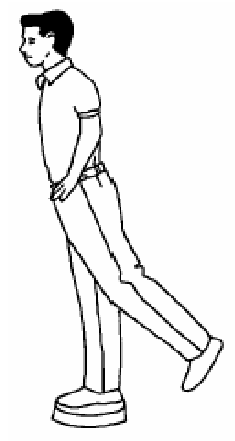


Participants stand on one leg on the foam. Standing on the foams with hands on waist, participants keep balance as long as possible. Participants repeat the exercise for 3 times for each leg.

UNILATERAL CALF RAISES

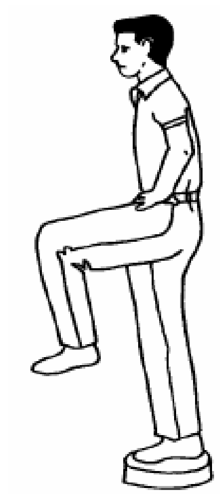
Participants stand on one leg on the foam. Standing on the foams with hands on waist, participants raise ankle as high as possible. Participants repeat the exercise for 10 times for each leg.

UNILATERAL BALANCE WITH LEG BACKWARD KICK



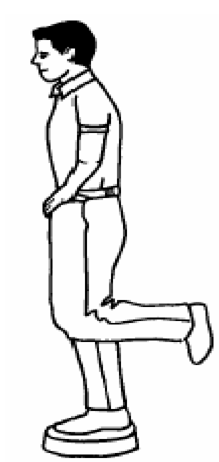
Participants stand on one leg on the foam. Standing on the foam with hands on waist, participants bring back non-supported leg as much as possible without loosing balance and hold the position for 3 seconds. Participants repeat for 10 times for each leg.

UNILATERAL BALANCE WITH HIP FLEXION



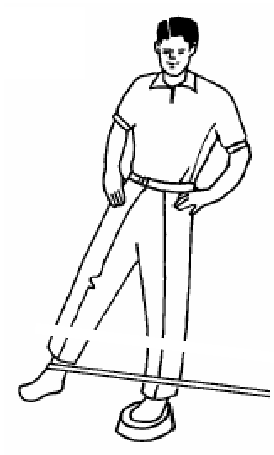
Participants stand on one leg on the foam. Standing on the foam with hands on waist, participants bring forward non-supported leg as much as possible without loosing balance and hold the position for 3 seconds. Participants repeat for 10 times for each leg.

UNILATERAL BALANCE WITH KNEE FLEXION



Participants stand on one leg on the foam. Standing on the foam with hands on waist, participants flex their non-supported knee about 90° without loosing balance and hold the position for 3 seconds. Participants repeat for 10 times for each leg.

KICKS (ABDUCTION)

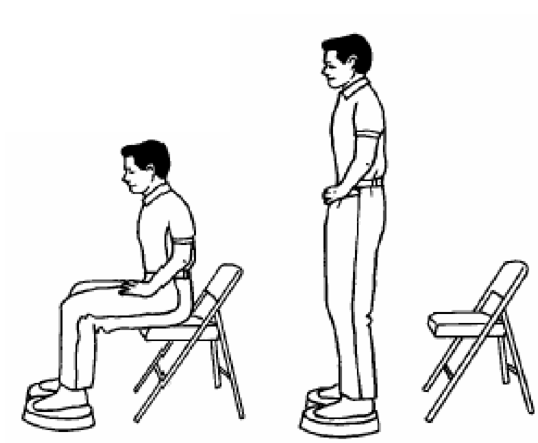


Participants stand on one leg on the foam. Standing on the foam with hands on waist, participants abduct their non-supported leg as much as possible without loosing balance and hold the position for 3 seconds. Participants repeat for 10 times for each leg.

KICKS (ADDUCTION)

Participants stand on one leg on the foam. Standing on the foam with hands on waist, participants adduct their non-supported leg as much as possible without loosing balance and hold the position for 3 seconds. Participants repeat for 10 times for each leg.

SIT-TO-STAND

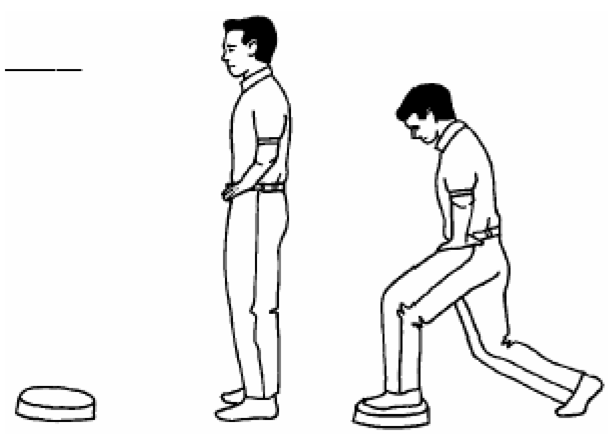


stand up without loosing balance and repeat for

<u>FORWARD REACH</u>

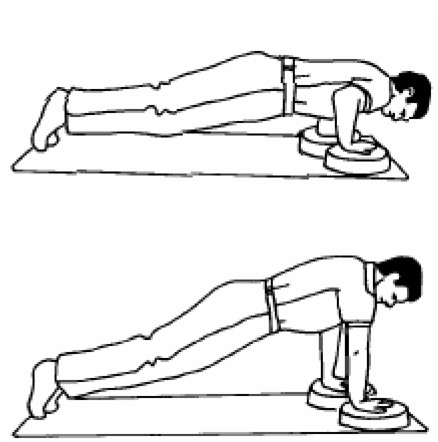
While standing on the foam, participants reach an object at their waist height and hold the position for 3 seconds. It is repeated for 10 times.

<u>LUNGE</u>



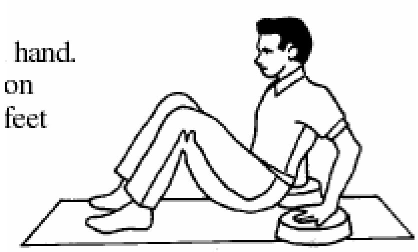
While standing on the floor, step on the foam and lower the body as much as possible. Participants hold the position for 3 seconds and repeat the exercise for 10 times.

<u>PUSH-UPS</u>

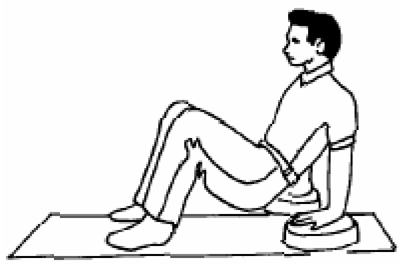


Participants do push-up exercise on the foam and repeat for 10 times.

PRESS-UPS



Participants do press-up exercise on the foam and repeat for 10 times.



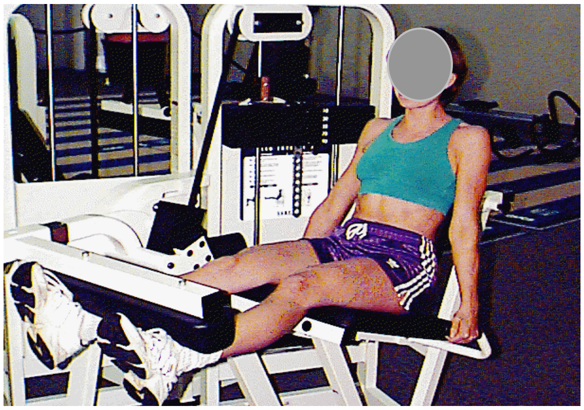
4.2.2 Weight training

Weight training was performed in a weight training room in the Montgomery County Government Center, Christiansburg, VA. NS-4000 home gym model (Nautilus®, Vancouver, Washington 98684) was used.

For weight training, periodized strength training was implemented as it was proven to be more effective in gaining strength than non-periodized strength training (Baker et al., 1994; Fleck, 1999; O'Bryant et al., 1988, Willoughby, 1993). Two different hypertrophy phases was introduced for 5 weeks; 3 sets of 10 repetitions with 50% of maximum exertion for 2 weeks and 3 sets of 10 repetitions for 70% of maximum exertion for 3 week. Strength phase lasted for the last 3 weeks; 3 sets of 7 repetitions with 85% of maximum exertion.

All volunteers performed 9 weight lifting exercises.

Leg Extension



Target muscles: Quadriceps

Synergists: None

Seated Leg Press

Target muscles: Quadriceps

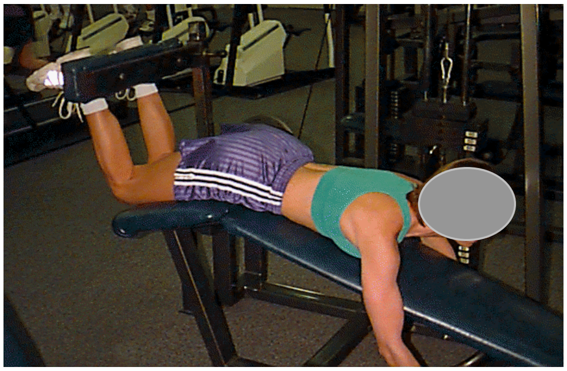
Synergists: Gluteus Maximux, Adductor Magnus, Soleus

Calf Press

Target muscles: Gastrocnemius

Synergists: Soleus

Leg Curl



Target muscles: Hamstrings

Synergists: Gastrocnemius, Sartorius

Leg Extension

Target muscles: Quadraceps Femoris

Synergists: Gleuteus Maximus, Adductor Magnus, Soleus

Hip Abduction

Target muscles: Gluteus Medius, Gluteus Minimus, Gluteus Maximus

Synergists: Gluteus Medius, Gluteus Minimus, Gluteus Maximus

Hip adduction

Target muscles: Hip Adductors

Synergists: Pectineus, Gracilis

Lat Pull Down

Target muscles: Latissimus Dorsi

Synergists: Brachialis, Brachioradialis, Biceps Brachii, Teres Major, Posterior Deltoid, Infraspinatus, Teres Minor, Rhomboids, Levator Scapulae, Lower Trapezius, Middle Trapezius, Pectoralis Minor

Tricep Pushdown (Machine)

Target muscles: Triceps Brachii

Stabilizers: Latissimus Dorsi, Teres Major, Posterior Deltoid, Sternal Pectoralis Major, Pectoralis Minor, Lower Trapezius, Rectus Abdominis, Obliques, Wrist Flexors

4.2.3 Control group (Social activity group)

Control group members also met three times a week for 8 weeks in accordance to balance and weight training groups. During the 60 minute sessions, they participated in planned social activities (such as picnics, bingo, shopping, and park visits) provided by the Department of Parks and Recreation (Montgomery County, Virginia). The purpose of introducing social activities for the control group was to isolate and signify the effects of physical treatments on psychosocial characteristics. It was hypothesized that the individuals in the training group would experience social effects inherent to the treatment such as motivation, competition, and cooperation that would confound the effects of physical training on psychosocial outcomes. To isolate these confounding variables, the control group also was to meet regularly as the training groups, but did not participate in any activity that required physical performance.

4.3 Apparatus

One commonly used floor material (vinyl tile, Armstrong) will be used in this experiment to represent a realistic environmental setting. The entire walking track will be covered with vinyl tile, and the dynamic coefficient of friction (DCOF) of the dry vinyl floor surface will be set at more than 1.80. For slippery conditions, the vinyl tile surface will be covered with a lubricant to reduce COF of the floor surface. DCOF of the soapy vinyl floor surface will be set between 0.07-0.08. The DCOF for each surface will be measured using a standard 4.54 kg (10 lb.) horizontal pull slip-meter with a rubber sole material on the force plates. Walking trials will be conducted on a linear walking track ($1.5m \times 15.5m$) embedded with two force plates (BERTEC # K80102, Type 45550-08, Bertec Corporation, OH 43212, USA). The test surface will be mounted on a moveable platform and connected to force plates. The overall function of the system will be to control the experimental conditions without participants being aware of any floor surface change. All the participants will be provided with the exact same running shoes in black (Athletic Works). A fall-arresting rig will be used to protect participants from falling during the experiment and will be designed to permit participants to fall approximately 30 cm before arresting the falls and stopping any forward motion. A six-camera ProReflex system (Qualysis) will be used to collect three-dimensional posture data of participants as they will walk over the test floor surface. Kinematic data will be sampled and recorded at 120 Hz. Ground reaction forces of participants walking over the test surfaces will be measured using two force plates and sampled at a rate of 1200 Hz. Leg muscle activities (hamstring, gastrocnemius, and rectus femoris) will be measured using electromyography (EMG). The EMG system (Noraxon Telemyo System, Noraxon USA, INC Scottsdale, AZ) will be composed of one transmitter, one receiver, and surface electrodes. The transmitter will be portable and powered by a battery (9Volts), and the receiver tele-communicated to the transmitter. A built-in amplifier will bandpass-filter the signal (10-500 Hz) and will be performed an RMS conversion (50ms-time constant). Raw EMG signals will be monitored, sampled, and stored by the National Instrument hardware and the LabView system with sampling rate of 1200 Hz.

4.4 Procedure

Psycho-social aspects for all groups (weight, balance, and control groups) were assessed. A fear of falling (psycho) (Appendix 1) and modified CHAMPS (social) questionnaires (Appendix 2) were used to evaluate psycho-social aspects, respectively. Psycho-social questionnaires were introduced prior to the slip-induced fall experiments.

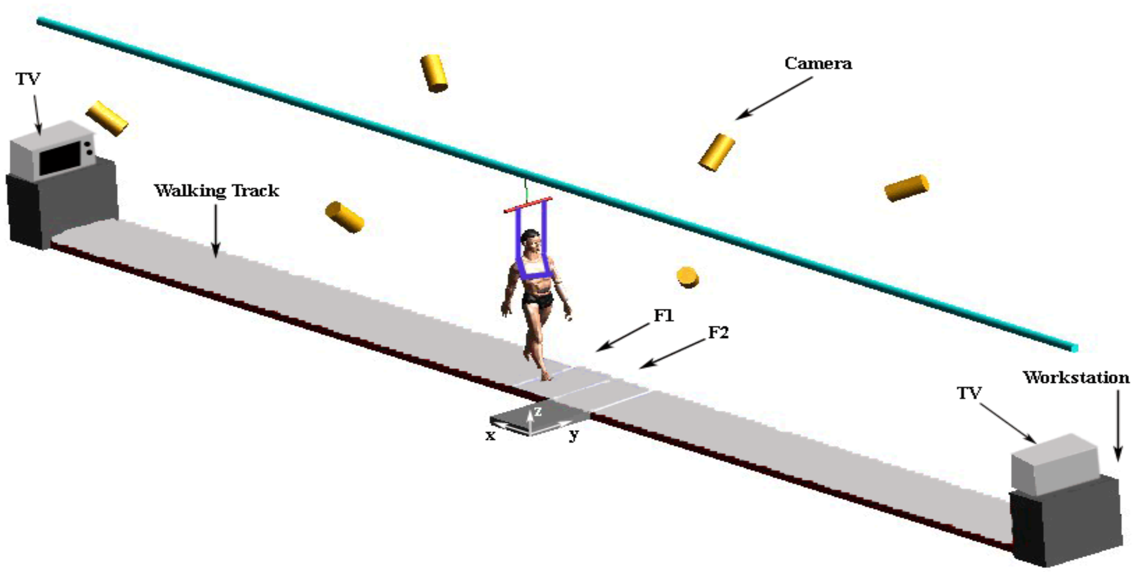
Gait parameters, slip parameters, dynamic and static stability, proprioceptive sensibility, reaction time, dynamic ankle stiffness while walking over a dry surface as well as a slippery surface were collected among all the 18 participants before the trainings start. All the results found before the trainings will be used to compare to data that will be collected after the trainings are completed.

Twenty-six reflective-markers will be attached to anatomically significant landmarks to represent the whole body, and 2 markers were attached to the heel to measure heel velocity. Two EMG electrodes will be placed over the belly of semitendinosus, quadriceps femoris, and later head of gastrocnemius in each leg. The electrodes will be placed at 50% on the line from the ischial tuberosity to the medial condyle of the tibia, at 50% on the line from the anterior spina iliaca superior to the superior part of the patella, and 1/3 of the line between the head of the fibula and the heel. Inter-electrode distance will be 20mm. Thereafter, participants will be equipped with the fall arresting rig. All the instructions will be presented in written and oral forms. Participants will be asked to keep walking back and forth from one work station to the other work station. They will be instructed to always initiate walking by standing behind a line with feet together. In order for experimenters to access adequate ground reaction forces for each foot (left and right), experimenters adjusted the start line near by the workstations all the time so that their left and right heels struck on the first force plate and on the following force plate respectively. When their feet consistently will strike on the force plates, it will be considered that participants will be walking with their natural gait characteristics. While walking, they will be instructed to count a colored circle and to listen to comedy routine via Walkman. The colored circle will be in three different colors. They will flash one at a time randomly on TV screen located on each work station. These secondary tasks will be provided to get participants' attention away from floor surface. The main purpose of walkway (25m long) with two force plate embedded in the center will be to simulate a real slip-induced fall events. Some studies simulated slip-induced fall events utilizing only 2-3 steps. In the future study, it will be thought that 2-3 steps will not be able to account for participants' natural gait characteristics; the future study will attempt to evaluate biomechanical response and characteristics while all the participants will be walking naturally in a laboratory setting. All walking trials will last in range between 15 to 25 minutes and they will be told to stop once a slippery surface will be introduced. Within each session, two base-line data for normal gait parameters [i.e., posture, GRF, and EMG] will be collected and, then, a slippery condition will be introduced.

4.4.1 Slip-induced falls

Walking trials including the slipping and falling trials were conducted on a walking track (20m), which was elevated 15cm above the floor surface (Figure 6). The entire deck was covered with vinyl tile. Participants were instructed to walk straight and to look forward while walking at their preferred walking speed. Participants' cadence was measured within a subsequent 20 minute session to ensure that their preferred walking speeds were consistent throughout the experiment. After ensuring that the preferred walking speeds were consistent, participants' natural posture and ground reaction forces were collected.

Figure 6. Field layout of the experimental set-up including; Fall Arresting System, Infra-red cameras (6), Two force plate (F1 and F2), and workstations. X,Y, and Z = global references for force and position.



While walking, they were instructed to count a colored circle. The colored circle was in three different colors. They flashed one at a time randomly on a TV screen located on each work station. These secondary tasks were provided to take away participants' attention from the floor surfaces. One of the main purposes of a walkway (during the slippery conditions) with two force plates embedded in the center (with sliding floor to switch from normal-dry floor surface to slippery floor surface) was to simulate real slip-induced fall events. Some studies simulated slip-induced fall events utilizing only 2-3 steps. In the present study, it was thought that 2-3 steps could not account for participants' natural gait characteristics. All walking trials lasted in range between 15 to 20 minutes and participants stopped once a slippery surface was introduced. Exact same procedure was performed during experiment before and after training.

4.4.2 Passive-to-passive reproduction of joint position (ankle and knee)

For ankle proprioception test, participants were seated with their right foot on a footplate attached to Biodex System 3 (Biodex Medical Systems, Inc., Shirley, New York 11967). For knee proprioception test, participants were seated with their right ankle strapped to a knee attachment fixed to Biodex System 3. The subjects' ability to reproduce ankle and knee joint position was tested once in each of 2 positions (10° plantarflexoin and 5° of dorsiflexion). These positions were identified to be least influenced by cutaneous sensory input in association with the extremes of the ROM (Deshpande et al., 2003).

For ankle proprioception test, from a neutral start position, participants' right foot rotated passively at ankle joint in a direction of either plantarflexion or dorsiflexion while right foot was placed on the footplate of ankle attachment. The ankle attachment was rotated at the speed of 1° / second and stopped at either 10° plantarflexion or 5° dorsiflexion from the neutral start position. 10 seconds were given for participants to concentrate on these positions and then the ankle attachment was rotated back to the neutral position. Participants were asked to press the switch when they perceived the original position (10° plantarflexion or 5° dorsiflexion) while ankle attachment was rotating at the speed of 1° /second.

For knee proprioception test, from a neutral start position (90 degree knee flexion), knee attachment was rotated allowing extension at the knee joint. The knee attachment was rotated at the speed of 1° / second and stopped at 15° extension from the neutral start position. 10 seconds were given for participants to concentrate on the position and then the knee attachment was rotated back to the neutral position. Participants were asked to press the switch when they perceived the original position (15° extension) while knee attachment was rotating at the speed of 1° / second.

4.4.3 Isokinetic and isometric strength

Peak isokinetic ankle and knee strengths at 30°, 90°, 120° / second, and isometric ankle strengths at 15° plantarflexion, and isometric knee strengths at 15° extension were evaluated using Biodex System 3. Starting positions were as same as explained in 4.4.2.

4.4.4 COP (Postural stability)

Center of Pressure (COP) was evaluated using a force platform (BERTEC # K80102, TYPE 45550-08, Bertec Corporation, OH 43212, USA). In this study, multivariate analysis (factor analysis) was used to evaluate balance stability while standing quietly. Specifically, the eigenvalue-based descriptors in multivariate analysis were used to describe the variance on each factor (x or y of COP); furthermore, ellipse areas were calculated using one eigenvalue as a long axis and the other eigenvalue as a short axis (Nussbaum, 2003). Better stability was considered if the ellipse area calculated was smaller; smaller ellipse area indicated smaller variance. In addition, COP*distance* were calculated to evaluate the reaction mechanisms by the following formula;

COPdistance = X (i+1) – X (i), where X = position of COP

Average of the COP distance during 30 second standing was parameterized.

4.4.5 Questionnaires (Psychosocial factors)

Psycho-social aspects for all groups (weight, balance, and control groups) were evaluated at pre- and post-training. Fear of falling (psychological) (Friedman et al., 2002; Howland, 1998) (see Appendix 1) and a portion (social) of CHAMP questionnaires (Harada et al., 2001) (see Appendix 2) were used to evaluate psycho-social aspects, respectively. Both questionnaires were introduced in prior to the laboratory study such as slip-induced fall experiment in order to evaluate adequate responses: their psychosocial answers could alter if they answered the questions after they fell.

Social activity questions were adopted from CHAMPS questionnaires (Harada et al., 2001). Questions 1-6 were to evaluate psycho-social interactions, and questions 7 and 8 were to evaluate independencies. These measures were compared to see if training has an effect on their aspects on falls and their social interactions. To synchronize anchors in the rating scale with anchors in the fear of falling scales, 1 indicated less interaction and activity, and 6 indicated more interaction and activity (if a participant answer "no" in any question, this automatically is rated as 0 which indicates the least interaction).

4.5 Dependent Variables

Heel contact velocity (HCV)

The instantaneous horizontal heel contact velocity (HCV) was calculated utilizing the heel position in horizontal direction at the foot displacement of 1/120 second before and after the heel contact phase of the gait cycle using the instantaneous heel velocity formula. Heel contact was defined when the vertical force exceeded more than 7 N after the heel contacted the ground.

The whole body Center-of-Mass (COM) velocity (i.e., walking velocity)

The Center of Mass was calculated by averaging all the centers of mass from the 14 segments (left and right feet, left and right shanks, left and right thighs, trunk, left and right hands, left and right lower arms, left and right upper arms, head). The COM velocity of all the participants was calculated using the formula:

COM velocity = $[X(i+1) - X(i-1)]/ 2\Delta t$, where X = COM,

Then, all COG velocities from heel contact to heel contact were averaged.

PFx, PFz, and Required Coefficient of Friction (RCOF)

Peak of horizontal and vertical ground reaction force (PFx and PFz) during heel contact phase was used to identify if non-dominant leg exhibited different horizontal or vertical force components from dominant leg. The required coefficient of friction was obtained by dividing the horizontal ground reaction force by the vertical ground reaction force (Fx/Fz) shortly after the heel contacted the dry vinyl floor surface (peak 3 as defined by Perkins, See Figure 1-5).

Initial Slip Distance (SDI)

Slip distance was divided into slip distance I (SDI) and slip distance II (SDII). SDI was measured to provide information concerning the severity of slip initiation. Slip-start point was defined as the point where non-rearward positive acceleration of the heel after heel contact, equivalently where the first minimum of the horizontal heel velocity after the heel contact (Figure 7). The slip-stop point for SDI was defined as the point where peak horizontal heel acceleration occurred after the slip-start point (mid slip on Figure 7). SDI was obtained using the heel coordinates between slip-start and slip-end point on the vinyl floor surface (Figure 7).

Slip Distance II (SDII)

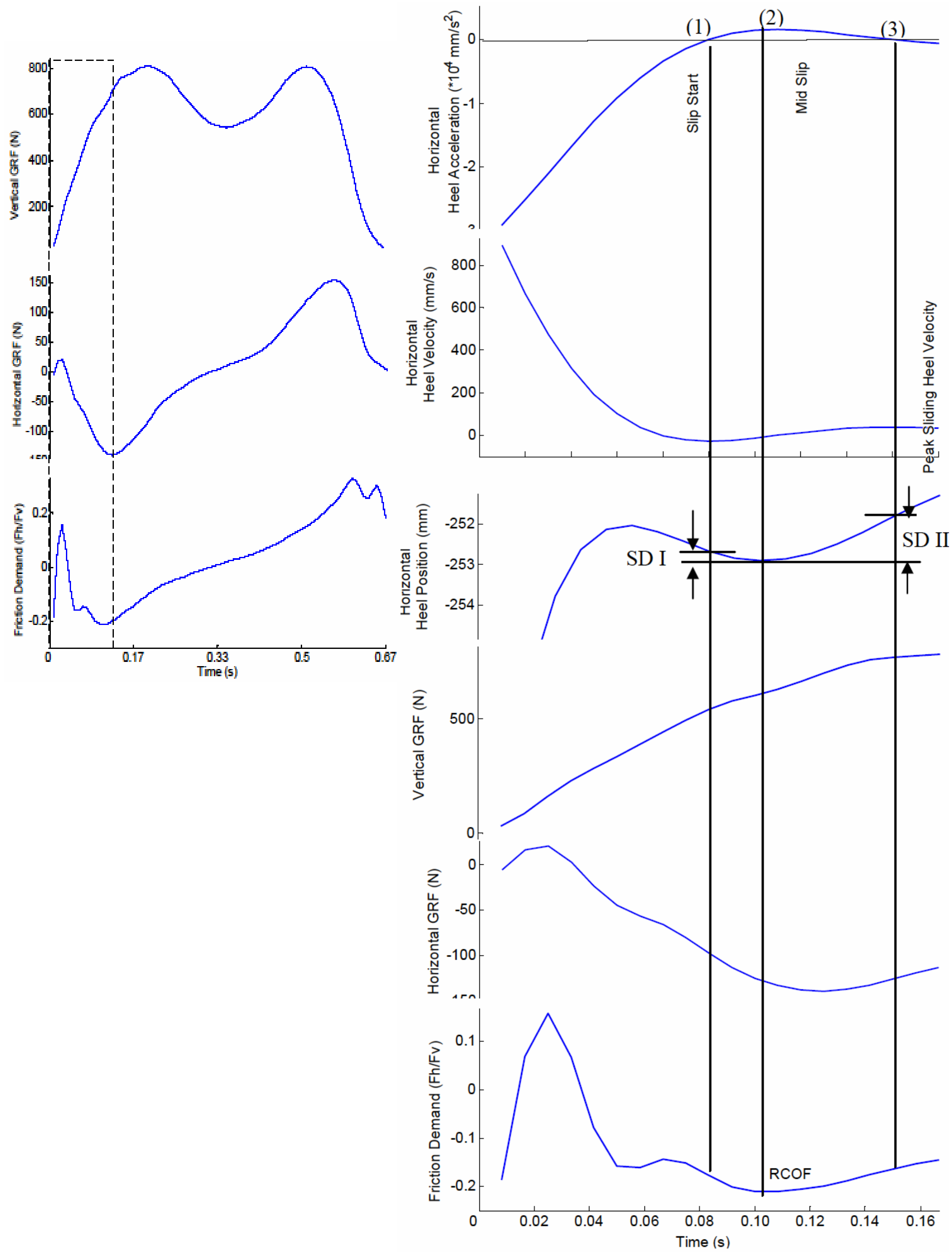
Slip distance II provided information concerning the slip behavior after the initiation of slips. The start point for the slip distance II was defined from SDI slip-stop point (peak heel acceleration "mid slip" in Figure 7) to the end of slip (Lockhart et al., 2002 and 2003). The end of the slip was estimated as the time where the first maximum of the horizontal heel velocity after slip start point occurred (Figure 7). SDII was calculated from the heel coordinates using the distance between the two points as with SDI (Figure 7b).

Peak Sliding Heel Velocity

The peak sliding heel velocity after slip-start point was measured while slipping. This measure was used to predict slip severity in addition to slip distances.

Step Length (SL)

The linear distance was measured in the direction of progression between successive points of foot-to-floor contact of the first foot (X_1, Y_1) and other foot (X_2, Y_2). Step length was calculated from the distance between consecutive positions of the heel contacting the floor. This measure was used only for test of "inadvertency" to see if participants walked at the same speed all the time during different trials.



(A) (B)

Figure 7. Composite view of the heel dynamics (kinetics and kinematics) during a typical normal walking on dry surface. (A): Vertical and horizontal GRFs and friction demand during stance phase. (B): Heel dynamics during the first 0.16 s of stance phase.

Dynamic Limb stability

Dynamic gait stability measures the ability to maintain balance while in motion (Woollacott and Tang 1997). Measuring dynamic gait stability may be a better way to evaluate likelihood of falls since 30-70% of all falls in the elderly occurs while they are in motion such as walking (Topper et al., 1993). In the proposed study, covariance analysis were used to evaluate dynamic gait stability while walking. Specifically, the eigenvalue-based descriptors were used (Kuo et al., 1998, See Figure 8). For the dynamic stability, covariance would be forward direction (X) and vertical direction (Z).

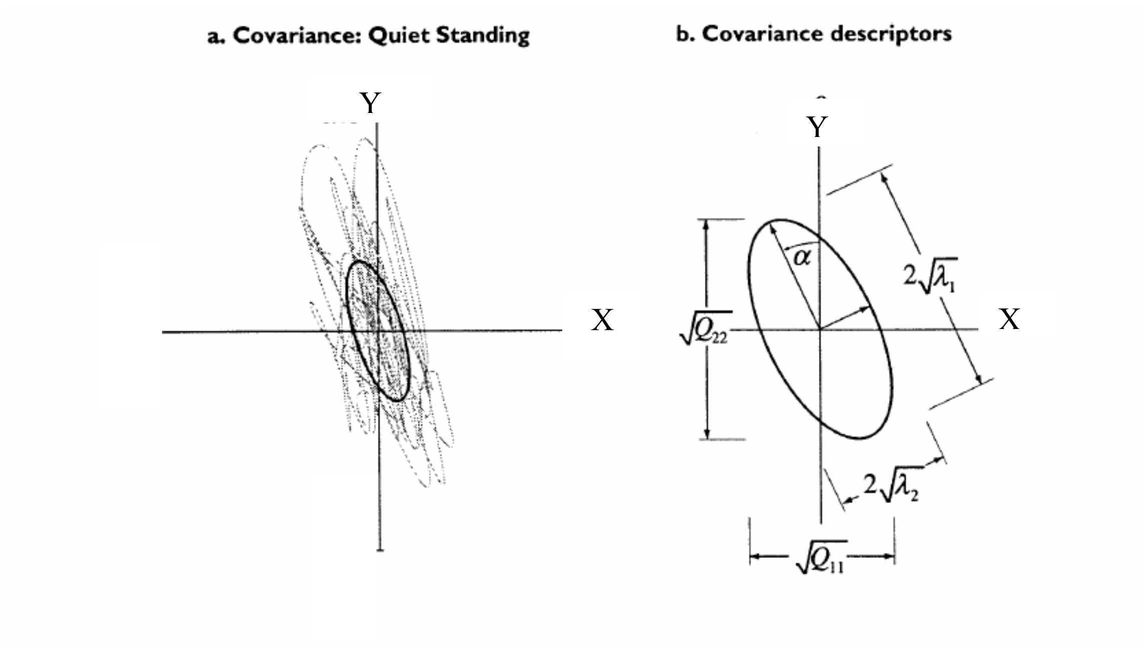


Figure 8. Covariance measures to describe sway, (a: Covariance of center of pressure (COP) X and COP Y. A bigger ellipse indicates instability. b: Illustration of definitions of covariance descriptors, using matrix entries (rms of hip and shank angles) and eigenvector parameters (λ_1, λ_2, α).) (adapted from Kuo et al., 1998)

Static balance stability

Static balance stability measures the ability to maintain posture when stationary (Woollacott and Tang 1997). It has been used to predict risks of falling among the elderly (Peterka and Black, 1990; Wolfson et al., 1992; Maki et al., 1990) although relationships between a risk of falling and static balance stability has been controversial (Winstein, 1989). In this study, multivariate analysis was used to evaluate balance stability while standing quietly. Specifically, the eigenvalue-based descriptors in multivariate analysis were used as described in Kuo et al. (1998) (figure 8).

Reaction time

In order to detect and recover from dangerous slips, appropriate central information processing to respond quickly enough to the disturbances is required. Older adults takes longer time to respond to stimuli in comparison to younger adults (Birren & Fisher, 1995; Cerella & Hale, 1994) due to a decline in the rate of central information processing (Marketta and Hirschfeld, 2004; Mayo et al., 1990). In this study, interval time between two continuous COPs was evaluated while standing quite. Mean interval time while quite standing were evaluated.

Isokinetic and isometric muscle strength

An age-related decrease in muscle strength can contribute to inability to produce adequate force to counteract loss of balance (Neil, 1994; Thelen et al., 1996). Isokinetic and isometric muscle strengths at ankles, knees, and hips were measured at pre- and post-training.

Proprioceptive Sensitivity (Joint position sensibility)

Proprioception has been suggested to be important for postural stability. Joint position sensibility can be evaluated by measuring the components of proprioceptive sensibility which can be assessed by active-to-active reproduction of joint position (Borsa et al., 1994; Nandini et al., 2003). This measures the ability to actively reproduce ankle and knee joint position (Borsa et al., 1994; Nandini et al., 2003; Kazutomo et al., 2004). From a seated-back resting position, 10° of plantarflexion and 10° of dorsiflexion for ankle and 30° and 45° extensions for knee were measured.

Dynamic Ankle Joint Stiffness

Reduced muscle strength and flexibility at the ankle joint among older adults are indicatives for the risk of falling (Whipple et al., 1987; Gehlesen amd Whaley, 1990; Lark et al., 2003; Thelen et al., 1996). Gretchen and Mueller (2000) indicated that “measuring ankle joint stiffness provide insight into limb control and muscle performance during walking.” As suggested by Gretchen and Mueller (2000), dynamic ankle joint stiffness during walking were measured as the change in ankle moment through a particular ankle range of motion (See Figure 9). Gait stiffness as indicated in figure 4-4 were measured.

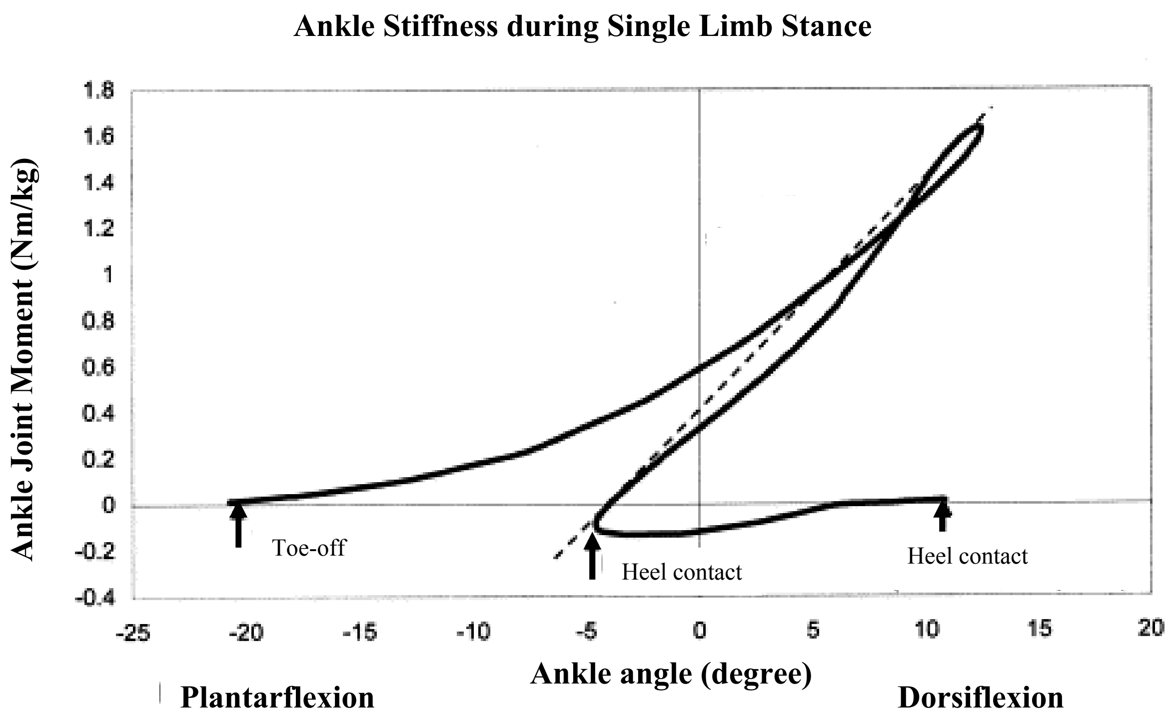


Figure 9. Representative Plantar flexor peak moment (PFPM) versus ankle angle curve (stance phase). Ankle joint stiffness is slope (a dotted line).

<u>Questionnaires (Psychosocial factors)</u>

Psycho-social aspects for all groups (weight, balance, and control groups) were evaluated at pre- and post-training. Fear of falling (psychological) (Friedman et al., 2002; Howland, 1998) (Appendix 1) and a portion (social) of CHAMP questionnaires (Harada et al., 2001) (Appendix 2) were used to evaluate psycho-social aspects, respectively. Both questionnaires were introduced in prior to the laboratory study such as slip-induced fall experiment in order to evaluate adequate responses: their psychosocial answers could alter if they answered the questions after they fell.

Social activity questions were adopted from CHAMPS questionnaires (Harada et al., 2001). Questions 1-6 were to evaluate psycho-social interactions, and questions 7 and 8 were to evaluate independencies. These measures were compared to see if training has an effect on their aspects on falls and their social interactions. To synchronize anchors in the rating scale with anchors in the fear of falling scales, 1 indicated less interaction and activity, and 6 indicated more interaction and activity (if a participant answer “no” in any question, this automatically is rated as 0 which indicates the least interaction).

4.6 Data Analysis

2 x 3 **(time** (pre and post training) x **training** (balance, weight, and control)**) mixed** factor repeated measure design were used to evaluate the study. Training was a between-subjects factor and time was a within-subjects factor. The dependant measures, Heel contact velocity (HCV), The whole body Center-of-Mass (COM) velocity, Required Coefficient of Friction (RCOF), Initial Slip Distance (SDI), Slip Distance II (SDII), Peak Sliding Heel Velocity, Step Length (SL), Dynamic gait stability, Static balance stability, Reaction time, Isokinetic and isometric muscle strength, Proprioceptive Sensitivity (Joint position sensibility), and Reproduction of torque (Proprioception evaluation) were analyzed. Descriptive and inferential statistical analyses were performed by utilizing the JMP statistical packages (SAS Institute Inc. Cary, NC, USA).

In addition, bivariate correlation analysis and logistic regression analysis were used. The results were considered as statistically significant when $p \leq 0.05$.

Each hypothesis under each specific aim was tested utilizing analyses below;

Aim 1: the training would decrease the likelihood of slip-initiation.

1-1. Heel contact velocity would be slower.
2-way repeated measure ANOVA were used to evaluate differences in heel contact velocity between pre- and post-training stages.

1-2. Transitional acceleration of COM (center of mass) would be faster.
2-way repeated measure ANOVA was used to evaluate differences in Transitional acceleration of COM between pre- and post-training stages.

1-3. Required coefficient of friction would decrease.

2-way repeated measure ANOVA was used to evaluate differences in heel contact velocity between pre- and post-training stages.

Aim 2: the training would improve the likelihood of slip-detection and recovery.

2-1. Leg strength would improve.

2-way repeated measure ANOVA was used to evaluate differences in leg strength between pre- and post-training stages.

2-2. Slip distance I would be smaller.

2-way repeated measure ANOVA was used to evaluate differences in slip distance I between pre- and post-training stages.

2-3. Slip distance II would be smaller.

2-way repeated measure ANOVA was used to evaluate differences in slip distance II between pre- and post-training stages.

2-4. Proprioception sensitivity would improve.

2-way repeated measure ANOVA was used to evaluate differences in proprioception sensitivity between pre- and post-training stages.

2-5. Postural stability would improve.

2-way repeated measure ANOVA was used to evaluate differences in postural stability between pre- and post-training stages.

2-6. Dynamic ankle joint stiffness would improve.

2-way repeated measure ANOVA was used to evaluate differences in dynamic joint stiffness between pre- and post-training stages.

2-7. Limb stability would improve.

2-way repeated measure ANOVA was used to evaluate differences in limb stability between pre- and post-training stages.

2-8. The number of falls would decrease.

Aim 3: the training would improve the likelihood of slip-induced falls.

3-1. Logistic regression analysis was used to test if strength, RCOF, dynamic and static stability, strength, proprioceptive sensibility, dynamic ankle joint stiffness, and reaction time were related to the likelihood of slip-induced falls.

Aim 4: balance training or weight training would improve the psychosocial characteristics.

4-1. Participants would become more active.

2-way repeated measure ANOVA was used to evaluate differences in activity levels between pre- and post-training stages.

4-2. Fear of falling would decrease.

2-way repeated measure ANOVA was used to evaluate differences in fear of falling between pre- and post-training stages.

4-3. Social activity level would increase.

2-way repeated measure ANOVA was used to evaluate differences in social activity level between pre- and post-training stages.

5. Results

5.1 Leg Strength

5.1.1 Ankle Strength

Right and left isokinetic ankle strengths as well as right isometric ankle strength were evaluated at pre-training stage and post-training stage to assess the effects of 8-week balance or weight training. 2 × 2 ANOVA analysis indicated that right and left isokinetic extensor strengths were improved after 8-week training in both balance training and weight training groups in comparison to control group (please refer to interactions (TM × Time) of all isokinetic extensor strengths in table 1), whereas, isokinetic flexor strengths as well as isometric strengths improved in all groups including the control group (please refer to interaction (TM × Time) in table 1 and 2).

Table 1. Isokinetic Ankle Strength.

		Weight (N = 6)	Balance (N = 6)	Control (N = 6)	P (Time)	P (TM × Time)
R 30 Ex	Pre	38.3 ± 17.5	34.5 ± 8.5	22.7 ± 7.6	0.003	0.003
	Post	48.0 ± 9.2	45.7 ± 12.1	23.7 ± 6.0		
R 30 Fx	Pre	8.2 ± 2.6	10.5 ± 4.2	7.2 ± 3.4	0.0003	0.15
	Post	11.2 ± 2.6	11.5 ± 5.1	8.2 ± 3.0		
R 90 Ex	Pre	27.3 ± 17.3	30 ± 9.2	17.5 ± 6.9	0.01	0.05
	Post	40.2 ± 8.1	35.5 ± 11.8	17.0 ± 4.3		
R 90 Fx	Pre	5.7 ± 1.9	6.3 ± 3.3	4.0 ± 3.2	0.01	0.94
	Post	7.0 ± 1.4	6.3 ± 2.9	5.0 ± 3.0		
R 120 Ex	Pre	25.7 ± 16.0	29.0 ± 10.0	16.7 ±6.6	0.001	0.02
	Post	35.0 ± 8.0	33.3 ± 9.8	16.7 ± 5.2		
R 120 Fx	Pre	5.2 ± 2.2	4.5 ± 3.4	2.4 ± 2.5	0.004	0.76
	Post	6.3 ± 1.0	5.0 ± 3.0	4.0 ± 2.8		
L 30 Ex	Pre	35.3 ± 9.6	37.2 ± 12.2	24.3 ± 6.9	0.0006	0.07
	Post	49.3 ± 9.0	45.0 ± 12.0	26. 7 ±10.0		
L 30 Fx	Pre	9.0 ± 4.0	11.0 ± 4.1	8.5 ± 7.3	0.03	0.55
	Post	11.0 ± 3.8	12.3 ± 4.3	9.0 ± 4.7		
L 90 Ex	Pre	29.2 ± 11.1	27.3 ± 12.1	17.3 ± 8.0	0.0006	0.02
	Post	38.5 ± 10.9	34.2 ± 10.9	17.3 ± 6.7		
L 90 Fx	Pre	5.8 ± 2.5	6.2 ± 3.1	4.7 ± 2.8	0.0001	0.1
	Post	7.7 ± 3.9	6.8 ± 2.0	5.3 ± 2.9		
L 120 Ex	Pre	27.0 ± 11.0	26.5 ± 12.3	17.7 **± 7.1**	0.002	0.008
	Post	34.7 ± 9.3	30.2 ± 9.3	18.5 ± 6.3		
L 120 Fx	Pre	5.0 ± 2.3	5.0 ± 3.4	3.9 ± 2.1	0.0007	0.41
	Post	7.0 ± 3.1	5.3 ± 2.1	5.0 ±2.9		

* TM = training method, R = right, L = left, Ex = extension, Fx = Flexion.

Table 2. Isometric Ankle Strength.

		Weight (N = 6)	Balance (N = 6)	Control (N = 6)	P (Time)	P (TM × Time)
R 15 Ex	Pre	52.2 ± 18.9	48.0 ± 13.7	31.8 ± 9.2	0.002	0.28
	Post	66.5 ± 22.3	59.8 ± 17.5	35.7 ± 7.2		
R 15 Fx	Pre	12.2 ± 4.5	14.8 ± 4.3	8.7 ± 5.5	0.02	0.08
	Post	13.5 ± 3.4	16.5 ± 6.9	8.2 ± 4.6		

* TM = training method, R = right, L = left, Ex = extension, Fx = Flexion.

5.1.2 Knee Strength

Right and left isokinetic knee strengths as well as right isometric knee strength were evaluated at pre-training stage and post-training stage to assess the effects of 8-week balance or weight training. 2 × 2 ANOVA analysis indicated that right and left isokinetic extensor and flexor strengths and isometric strengths were improved in both balance and weight training groups in comparison to control group (please refer to interactions (TM × Time) in table 3 and 4). Interestingly, the results in interactions (TM × Time in table 3) of left knee strength indicated that the control groups, also, exhibited some improvements.

Table 3. Isokinetic Knee Strength.

		Weight (N = 6)	Balance (N = 6)	Control (N = 6)	P (time)	P (TM ×Time)
R 30 Ex	Pre	68 ± 5.9	63.7 ± 12.7	53.5 ± 9.9		
	Post	79.3 ± 13.9	73.3 ± 18.8	52.5 ± 10.3	0.0001	0.001
R 30 Fx	Pre	41.7 ± 6.7	40.7 ±10.4	32.8 ± 6.8		
	Post	47.3 ± 11.8	45.3 ± 11.0	34.5 ± 8.1	0.0001	0.05
R 90 Ex	Pre	52.3 ± 7.0	48.3 ± 14.5	40.7 ± 8.7		
	Post	59.5 ± 7.6	56.0 ± 13.7	38.8 ± 10.8	0.001	0.006
R 90 Fx	Pre	36.7 ± 6.3	37 ± 12.4	28 ± 2.5		
	Post	43.0 ± 6.3	43.5 ± 11.0	27.8 ± 4.0	< 0.0001	0.001
R 120 Ex	Pre	47 ± 7.6	45.2 ± 16.2	36.2 ± 6.9		
	Post	53.5 ± 8.1	48.2 ± 12.2	34.3 ± 7.2	0.0001	0.0004
R 120 Fx	Pre	34.8 ± 7.6	36 ± 13.6	28.3 ± 2.2		
	Post	41.3 ± 7.7	42.2 ± 11.1	26.2 ± 6.1	0.0009	0.0013
L 30 Ex	Pre	57.8 ± 9.8	79.8 ± 32.6	40.8 ± 3.1		
	Post	75.5 ± 14.4	81.8 ± 29.9	44.2 ± 7.7	0.001	0.07
L 30 Fx	Pre	35.0 ± 7.3	46.7 ± 18.3	30.8 ± 11.2		
	Post	49.5 ± 8.9	53.2 ± 14.2	30.0 ± 8.9	< 0.0001	0.0009
L 90 Ex	Pre	46.5 ± 5.1	55.0 ± 27.5	28.2 ± 5.2		
	Post	55.7 ± 9.9	62.8 ± 22.1	31.3 ± 4.5	0.0007	0.24
L 90 Fx	Pre	31.3 ± 11.3	36.3 ± 16.0	25.5 ± 7.6		
	Post	43.0 ± 9.0	48.0 ± 12.5	25.5 ± 5.5	0.0004	0.01
L 120 Ex	Pre	41.5 ± 5.6	48.7 ± 22.6	28.7 ± 3.9		
	Post	49.3 ± 9.4	55.5 ± 19.5	28.5 ± 3.9	0.005	0.09
L120 Fx	Pre	32 ± 5.1	38.3 ± 15.1	25.7 ± 7.1		
	Post	42.3 ± 7.3	46.0 ±12.4	24.3 ± 4.8	< 0.0001	

* TM = training method, R = right, L = left, Ex = extension, Fx = Flexion

Table 4. Isometric Knee Strength.

		Weight (N = 6)	Balance (N = 6)	Control (N = 6)	P (time)	P (TM × Time)
R 15 Ex	Pre	75.5 ± 18.7	75.3 ± 21.2	65.0 ± 11.9	0.001	0.009
	Post	94.5 ± 15.7	98.7 ± 23.9	61.8 ± 11.2		
R 15 Fx	Pre	34.3 ± 12.4	40.7 ± 12.1	31.2 ± 7.5	0.03	0.02
	Post	40.3 ± 12.0	45.3 ± 12.6	28.8 ± 7.8		

5.2 Consistent gait characteristics (Floor x Time) throughout the different floor surfaces

Table 5 and 6 suggested that there was no difference in HCV and step length while walking on the difference floor surface. These results indicated that participants did not notice slippery surface while approaching to the slippery area.

Table 5. ANOVA summary of Right HCV (2 factors: Floor x Time).

Source	DF	Sum of Squares	F Ratio	Prob > F
Floor	1	452.8044	0.7613	0.3860
Time	1	1086.6190	1.8270	0.1810
Floor*Time	1	606.5528	1.0198	0.3161

Table 6. ANOVA summary of Step Length (2 factors: Floor x Time).

Source	DF	Sum of Squares	F Ratio	Prob > F
Floor	1	35.849278	0.2416	0.6246
Time	1	89.688457	0.6045	0.4395
Floor*Time	1	1.006071	0.0068	0.9346

5.3 The risk of slips (Time x Group)

5.3.1 HCV (cm/s)

Table 7 (Time, $p = 0.004$) and figure 10 indicated that HCV was decreased at post-training stage. In addition, table 7 (Time*Group, $p = 0.004$), figure 11, and student's t-test revealed that HCV was decreased only in training group.

Table 7. ANOVA summary of HCV (2 factors: Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	7913.03	3956.52	2	9.4151	0.002
Subject[Group]					
Time	1398.05	1398.05	1	11.4541	0.004
Time*Group	1943.95	971.975	2	7.9633	0.004
Subject*Time[Group]					

Figure 10. HCV at pre- and post-training.

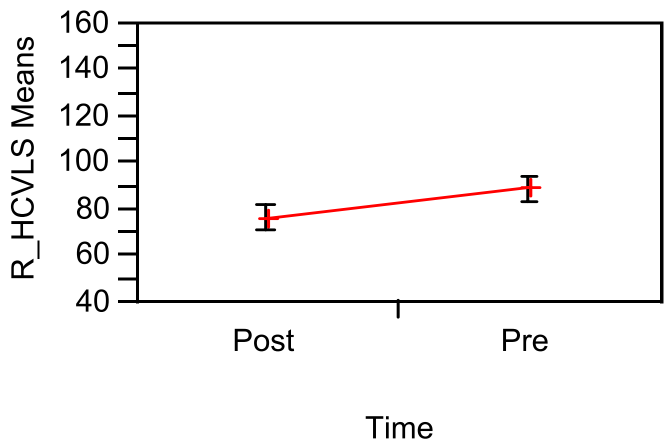
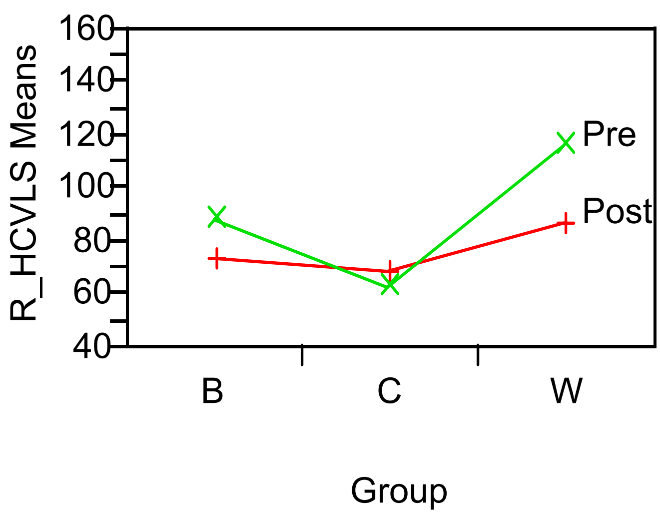


Figure 11. Interaction of Time x Group for HCV.



5.3.2. COM Velocity

Table 8 indicated that there was no significant main or interaction effect.

Table 8. ANOVA summary of Walking Velocity (2 factors: Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	16015.5	8007.75	2	6.6978	0.0083
Subject[Group]					
Time	287.291	287.291	1	2.0954	0.1683
Time*Group	42.686	21.343	2	0.1557	0.8572
Subject*Time[Group]					

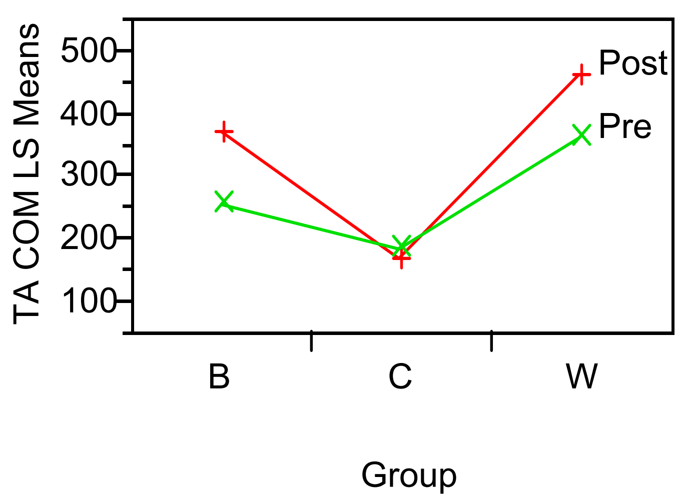
5.3.3. Transitional Acceleration of COM (TA COM) (cm/s^2)

Table 9, figure 12 and student's t-test indicated that, after 8 weeks, individuals in training groups walked with faster TA COM during heel contact phase of gait cycle, whereas, individuals in control group showed no change in TA COM (Time*Group, p = 0.02).

Table 9. ANOVA summary of TA COM (2 factors: Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	326446	163223	2	11.6474	0.0009
Subject[Group]					
Time	40477.9	40477.9	1	12.5707	0.002
Time*Group	31051.2	15525.6	2	4.8216	0.02
Subject*Time[Group]					

Figure 12. Interaction of Time x Group for TA COM.



5.3.4 Step Length

Table 10 indicated that there was no significant main or interaction effect.

Table 10. ANOVA summary of step length (Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	2063.69	1031.85	2	7.0169	0.007
Subject[Group					
Time	35.8482	35.8482	1	2.1772	0.16
Time*Group	11.2457	5.62286	2	0.3415	0.71
Subject*Time[Group]					

5.3.5 RCOF (Fx / Fz)

Table 11 (Time, p = 0.03) and figure 13 indicated that the RCOF was reduced after training. Furthermore, table 11 (Time*Group, p = 0.0005), figure 14, and student's t-test suggested that the reduction in RCOF was seen only in training groups.

Table 11. ANOVA summary for RCOF (Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	0.00058	0.00029	2	0.9659	0.40
Subject[Group]					
Time	0.00009	0.00009	1	5.7525	0.03
Time*Group	0.0004	0.0002	2	13.4118	0.0005
Subject*Time[Group]					

Figure 13. LS Means Plot of RCOF at pre- and post-training stages.

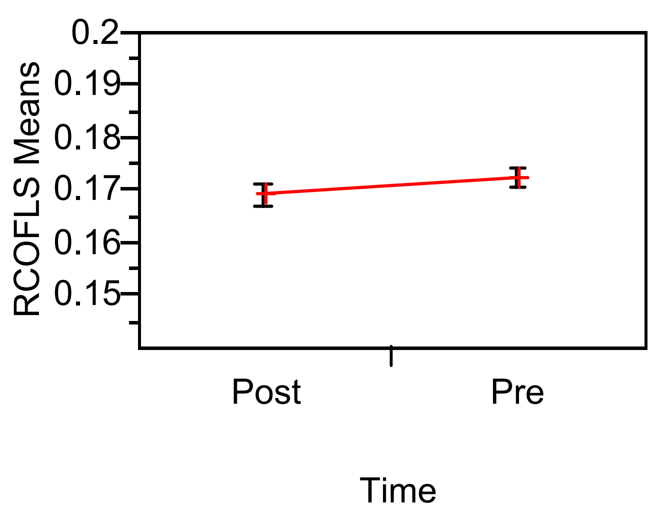
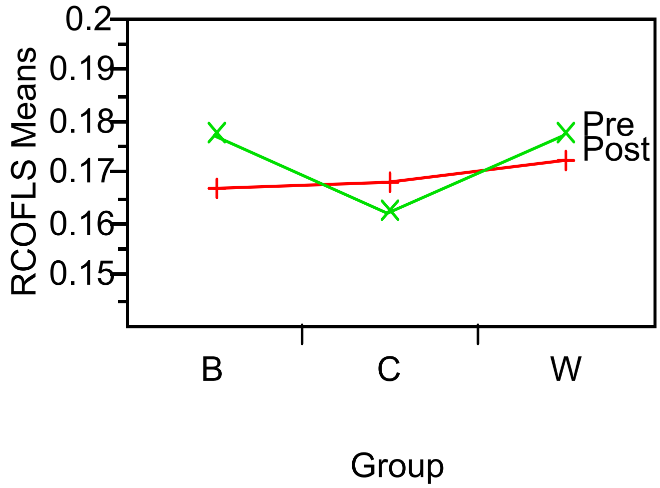


Figure 14. Interaction of Time x Group for the RCOF.



5.4. Detection and Recovery

5.4.1 Proprioception Sensitivity

2 × 2 ANOVA analysis (Table 12) indicated that proprioception sensitivity improved in all groups including the control group after 8 weeks. These results suggested that being active socially also could result in proprioception sensitivity improvements.

Table 12. Ankle (A) and Knee (K) Proprioception.

		Weight (N = 6)	Balance (N = 6)	Control (N = 6)	P (Time)	P (TM × Time)
A Plantar 10	Pre	3.4 ± 1.3	2.5 ± 2.1	4.2 ± 3.1		
	Post	1.5 ± 0.6	0.5 ± 0.1	3.2 ± 2.7	0.0004	0.54
A Dorsi 5	Pre	0.9 ± 0.4	0.9 ± 0.4	2.6 ± 1.8		
	Post	0.7 ± 0.3	0.4 ± 0.3	2.6 ± 1.7	0.09	0.4
K Ex 15	Pre	2.8 ± 1.9	3.8 ± 3.1	5.0 ± 5.1		
	Post	0.9 ± 0.4	2.3 ± 2.3	4.9 ± 5.3	0.002	0.1

5.4.2 Stability and Reaction

2 × 2 ANOVA analysis (Table 13) indicated that COP*area* (mm^2) and COP*distance* (cm) in training groups (balance and weight) exhibited a significant improvements in comparison to control group. These results suggested that balance and weight trainings play a role in improving somatosensory, especially, in detecting perturbations.

Table 13. Center of Pressure (COP).

		Weight (N = 6)	Balance (N = 6)	Control (N = 6)	P (Time)	P (TM × Time)
Area	Pre	109.7 ± 57.0	166.2 ± 167.2	209.9 ± 115.2		
	Post	70.7 ± 50.6	70.7 ± 80.7	181.9 ± 110.9	0.0034	0.0227
Distance	Pre	60.6 ± 33.8	76.2 ± 39.9	111.1 ± 75.5		
	Post	49.6 ± 16.5	55.4 ± 27.5	111.3 ± 90.4	0.0521	0.0123

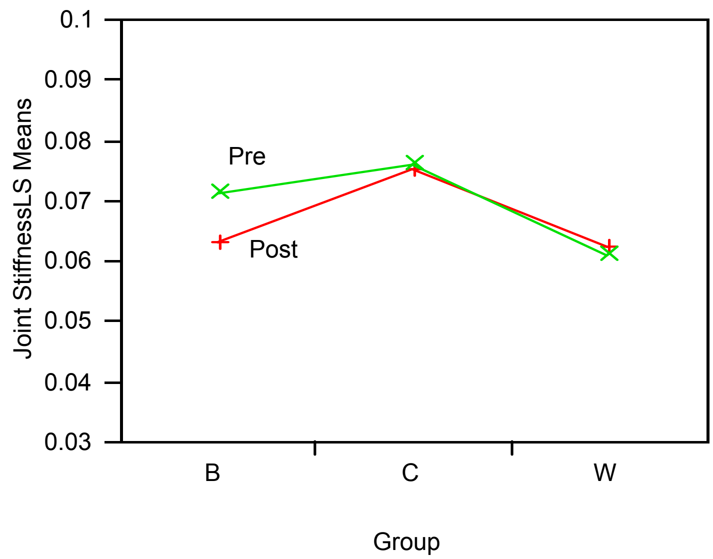
5.4.3 Joint Stiffness (JS)

Table 14 indicated that there was no main effect. There was an interaction effect in Time*Group (p= 0.03). Figure 15 and student's t-test suggested that only the balance training group exhibited a reduction in joint stiffness after 8 weeks. However, the data indicated that JS for balance training group did not differ from JS for weight training group.

Table 14. ANOVA Summary for Joint Stiffness.

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	0.00231	0.00115	2	1.8133	0.19
Subject[Group]					
Leg	0.00002	0.00002	1	1.1925	0.29
Leg*Group	0.0001	0.00005	2	3.1496	0.07
Subject*Leg[Group]					
Time	0.0001	0.0001	1	2.7300	0.11
Time*Group	0.00031	0.00015	2	4.1108	0.03
Subject*Time[Group]					
Leg*Time	0.00017	0.00017	1	2.0538	0.17
Leg*Time*Group	0.00005	0.00002	2	0.2821	0.75
Subject*Time*Leg[Group]					

Figure 15. Interaction of Time*Group.



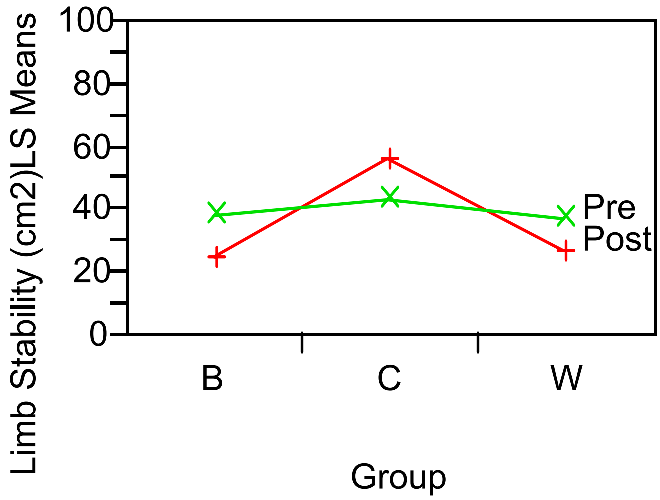
5.4.4 Limb Stability (LS)

Table 15 indicated that LS was different between dominant leg (29.24 cm^2) and non-dominant leg (46.06cm^2). There were interaction effects in Time*Group (p= 0.003). Figure 16 and student's t-test suggested that training groups exhibited better limb stability, whereas, control group did not show a difference after 8 weeks.

Table 15. ANOVA Summary for Limb Stability.

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	5118.53	2559.26	2	4.0054	0.04
Subject[Group]					
Leg	5089.26	5089.26	1	16.5430	0.0010
Leg*Group	16.252	8.126	2	0.0264	0.97
Subject*Leg[Group]					
Time	204.034	204.034	1	1.4747	0.24
Time*Group	2297.78	1148.89	2	8.3039	0.003
Subject*Time[Group]					
Leg*Time	56.3906	56.3906	1	0.9540	0.34
Leg*Time*Group	39.0526	19.5263	2	0.3303	0.72
Subject*Time*Leg[Group]					

Figure 16. Interaction of Time*Group.



5.4.5 Correlations between limb stability and joint stiffness

The results (figure 17) indicated that limb stability could not be predicted by joint stiffness at pre-training stage. However, the results (figure 18) suggested that limb stability improved as joint stiffness became smaller (Rsquare = 0.13, p = 0.03) at post-training stage.

Figure 17. Bivariate Fit of Limb Stability (cm^2) By Joint Stiffness at pre-training stage.

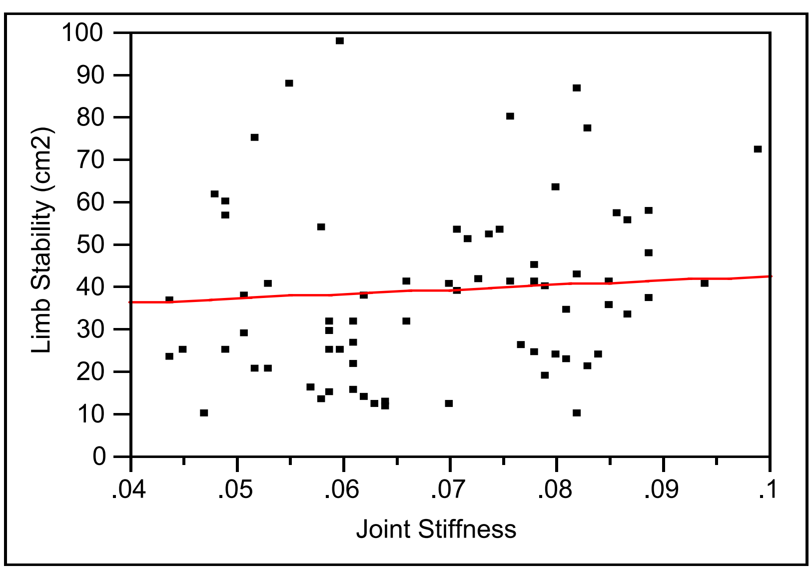
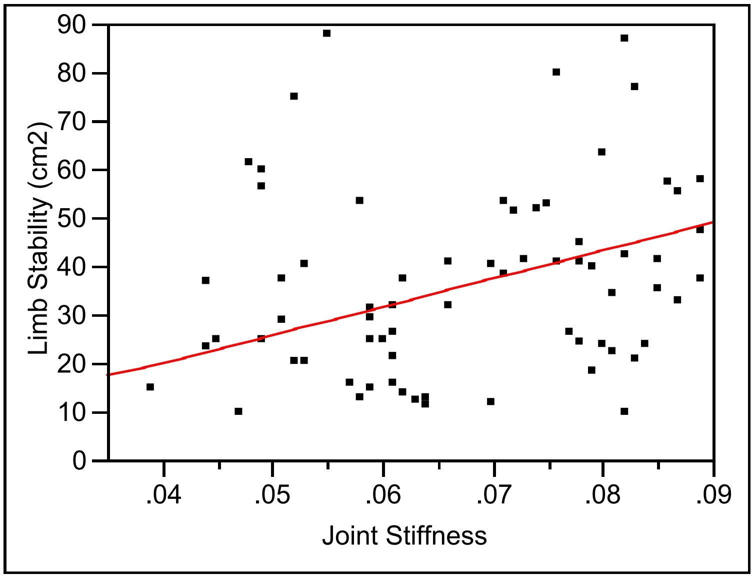


Figure 18. Bivariate Fit of Limb Stability (cm^2) By Joint Stiffness at post-training stage.



5.5 Slip severity (mm)

5.5.1 SD 1

Table 16 indicated that that there was no significant main or interaction effect.

Table 16. ANOVA summary for SD 1 (2 factors: Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	92.834	46.417	2	0.0046	0.99
Subject[Group]					
Time	49.9342	49.9342	1	0.0350	0.85
Time*Group	1697.03	848.517	2	0.5939	0.56
Subject*Time[Group]					

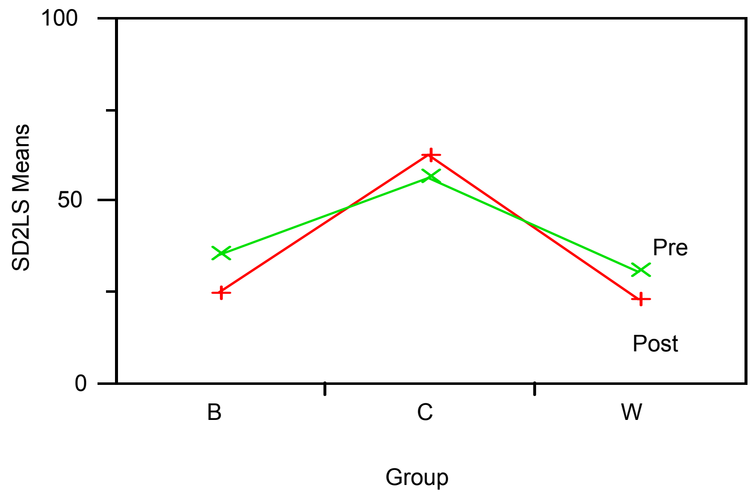
5.5.2 SD 2

Table 17 (Time, $p = 0.02$) and figure 5-10 indicated that, after 8 weeks, training groups showed a reduction in SD 2, whereas, control group showed no change in SD 2 (Time*Group, $p = 0.001$).

Table 17. ANOVA summary for SD 2 (2 factors: Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	7786.2	3893.1	2	1.5314	0.24
Subject[Group]					
Time	130.246	130.246	1	5.9547	0.02
Time*Group	489.816	244.908	2	11.1969	0.001
Subject*Time[Group]					

Figure 19. Interaction of Time x Group for SD 2.



5.5.3 PSHV

Table 18 indicated that there was no significant main or interaction effect.

Table 18. ANOVA summary for PSHV (Time x Group).

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	1.077e7	5387274	2	3.5549	0.0545
Subject[Group]					
Time	538613	538613	1	0.9689	0.3406
Time*Group	419046	209523	2	0.3769	0.6923
Subject*Time[Group]					

5.6 Fall frequency and Fall Prediction

In balance training group or weight training group, 4 individuals in each group who fell in the pre-training stage recovered from slips and 2 individuals in each group who recovered from slips in the pre-training stage recovered from slips after 8 week training. In control group, 5 individuals who fell in the pre-training stage fell again and 1 individual who recovered from a slip again recovered after 8 weeks. These results with consistent gait characteristics suggested that older individuals with training showed more chance to recover from slips.

5.6.1 Effects of leg strength on the likelihood of slip-induced falls

To avoid excessive data analysis, two representative strengths at ankle and knee joints were shown to fit the logistic regression model. Isokinetic 30 at ankle ($p = 0.13$) and isokinetic 30 at knee ($p = 0.40$) at pre-training stage had no effect on the likelihood of slip-induced falls. However, at post-training stage, ankle and knee strengths had significant effects on the likelihood of slip-induced falls (Figure 20 and 21). Logistic regression analysis (Figure 20 and 21) suggested that individuals with stronger legs had much more chance to recover from falls.

Figure 20. Logistic Fit of F(1)/R(0) By Isokinetic R Knee 30 Ex at post training ($p = 0.001$, $R^2 = 0.44$).

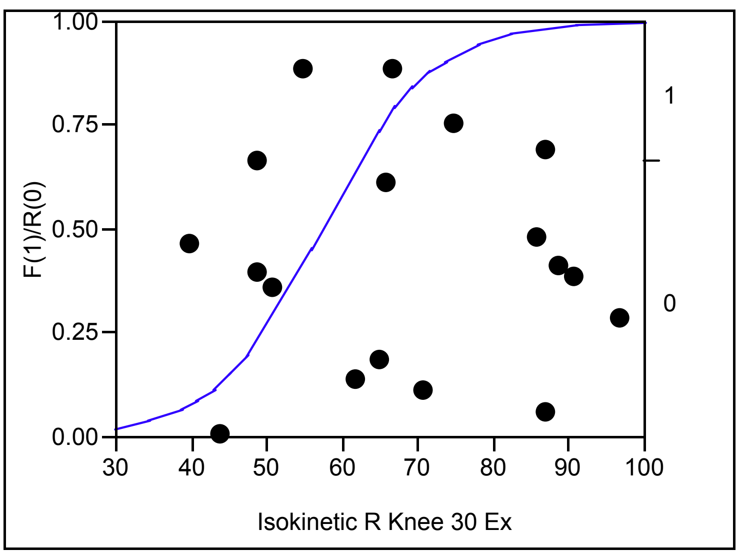
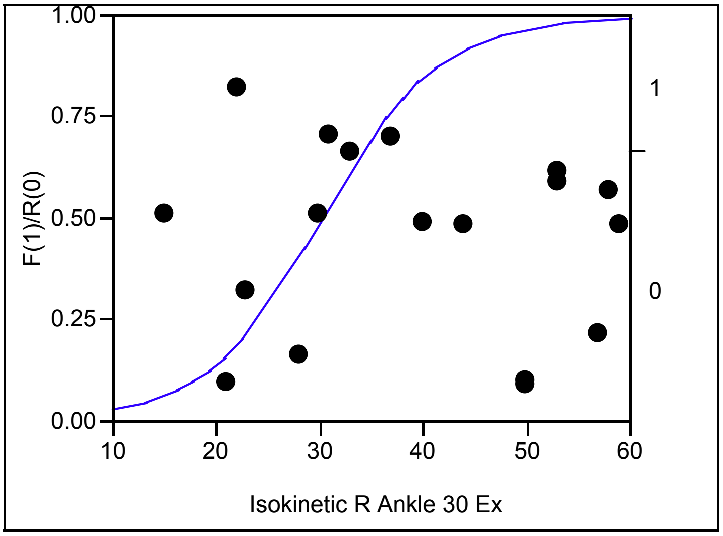


Figure 21. Logistic Fit of F(1)/R(0) By Isokinetic R Ankle 30 Ex at post-training ($p = 0.001$, $R^2 = 0.45$).



5.6.2 Effect of proprioception sensitivity on the likelihood of slip-induced falls

Simple logistic regression analysis indicated that proprioception sensitivity at pre-training stage had no effect on the likelihood of slip-induced falls. However, at post-training stage, proprioception sensitivity had significant effects on the likelihood of slip-induced falls (figure 22, 23, and 24). Logistic regression analysis (Figure 22, 23, and 24) suggested that individuals with better proprioception sensitivity had more chance to recover from falls.

Figure 22. Logistic Fit of F(1)/R(0) By Ankle Plantarflexion at post-training (P = 0.009, R^2 = 0.29).

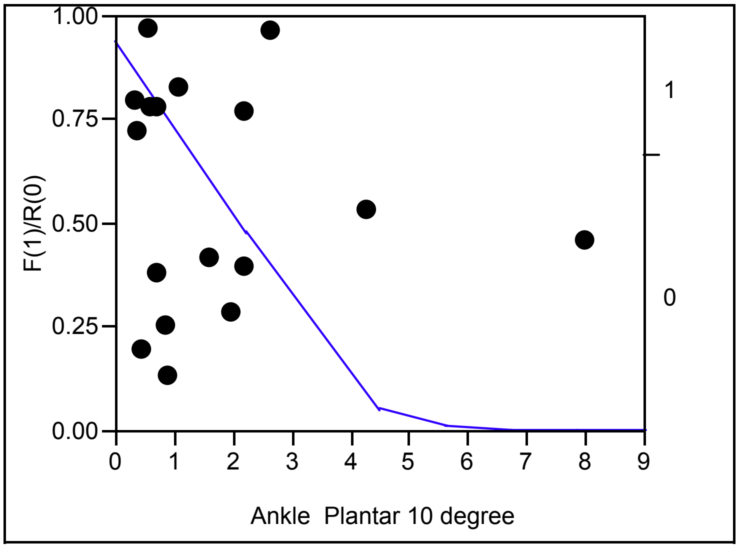


Figure 23. Logistic Fit of F(1)/R(0) By Ankle Dorsiflexion at post-training (p = 0.0053, R^2 = 0.34).

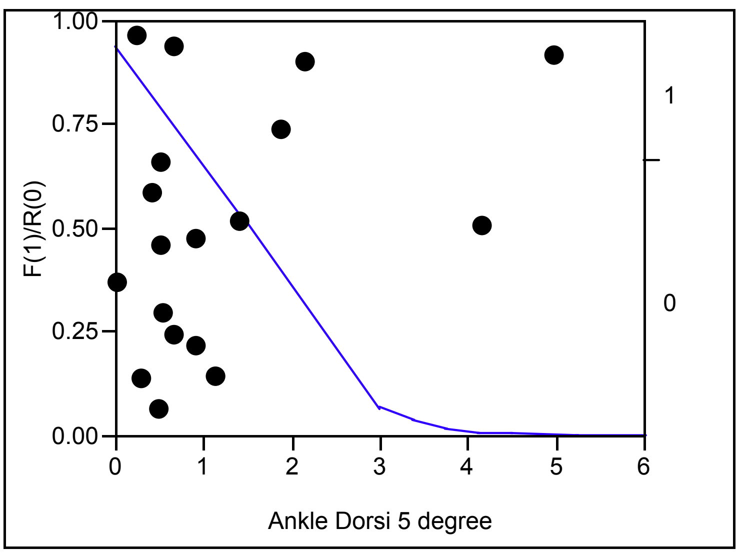
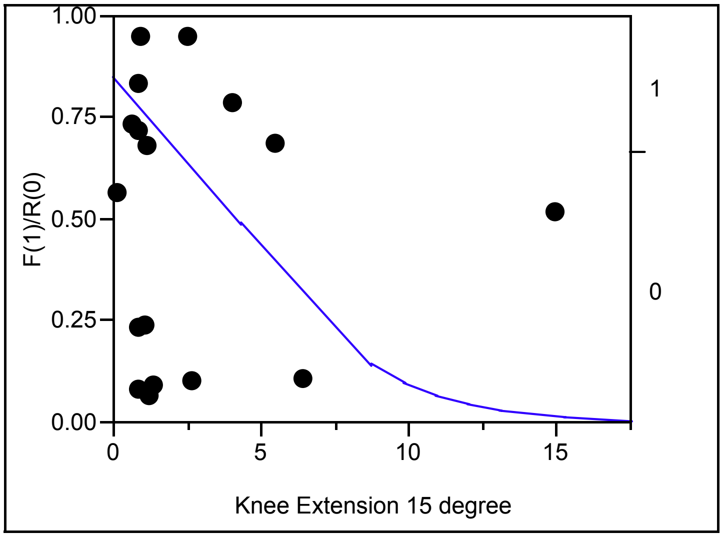


Figure 24. Logistic Fit of F(1)/R(0) By Knee Extension at post-training (p = 0.04, R^2 = 0.17).



5.6.3 Effects of postural stability on the likelihood of slip-induced falls.

Simple logistic regression analysis indicated that COP area (p = 0.26) and COP distance (p = 0.26) at pre-training stage had no effect on the likelihood of slip-induced falls. However, at post-training stage, postural stability had significant effects on the likelihood of slip-induced falls (Figure 25 and 26). Logistic regression analysis (Figure 25 and 26) suggested that individuals with better postural stability had much more chance to recover from falls.

Figure 25. Logistic Fit of F(1)/R(0) By Area (mm2) at post-training ($p < 0.0001$, $R^2 = 0.77$).

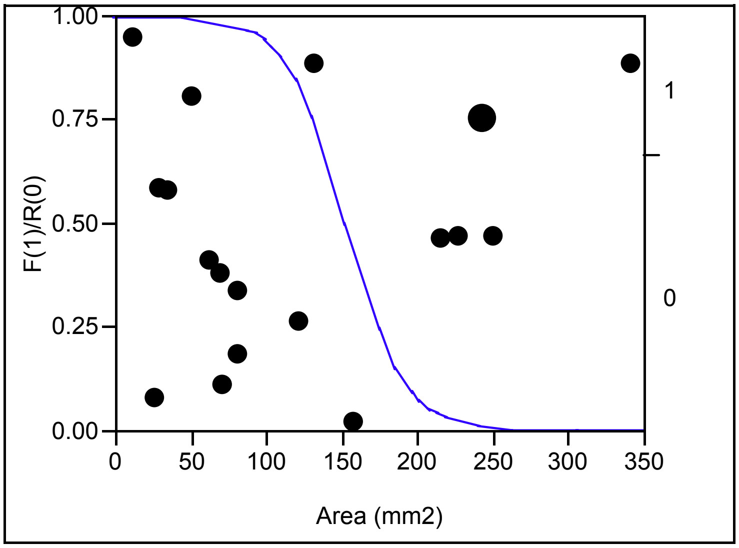
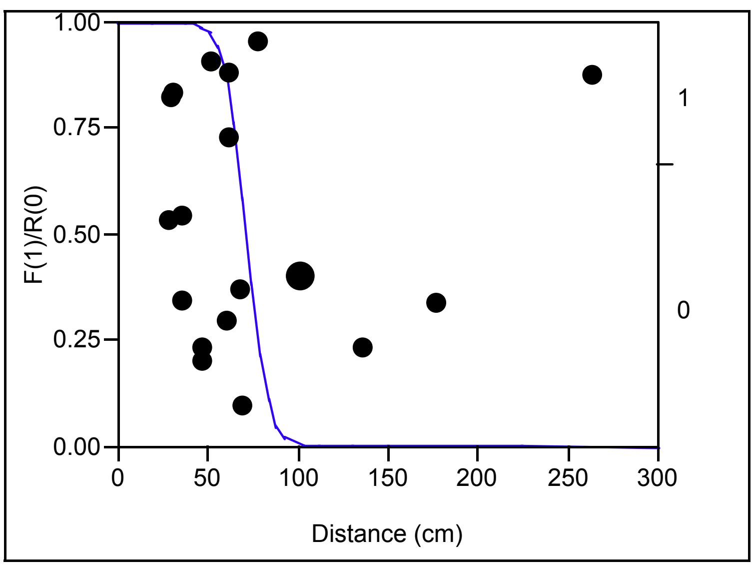


Figure 26. Logistic Fit of F(1)/R(0) By Distance (cm) at post-training ($p < 0.0001$, $R^2 = 0.69$).



5.6.4 Effects of JS and LS of the slipping leg on the likelihood of slip-induced falls.

Simple logistic regression analysis indicated that JS ($p = 0.21$, $R^2 = 0.07$) and LS ($p = 0.24$, $R^2 = 0.06$) at pre-training stage had no effect on the likelihood of slip-induced falls. However, at post-training stage, JS and LS had significant effects on the likelihood of slip-induced falls (Figure 27 and 28). Logistic regression analysis (Figure 27 and 28) suggested that individuals with better postural stability had much more chance to recover from falls.

Figure 27. Logistic Fit of F(1) / R(0) By Joint Stiffness of dominant leg at post ($p = 0.0001$, $R^2 = 0.65$).

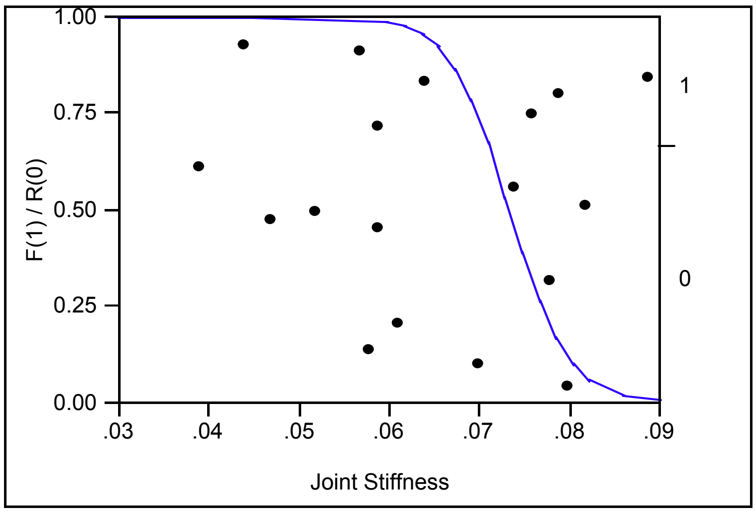
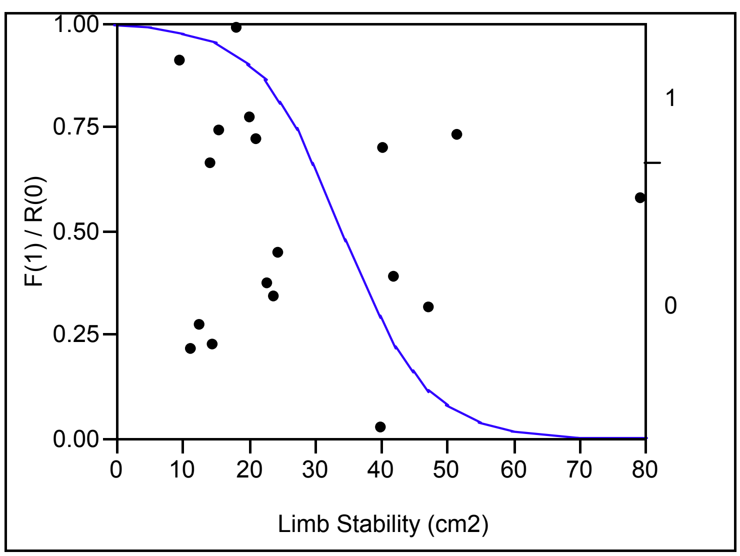


Figure 28. Logistic Fit of F(1) / R(0) By Limb Stability (cm2) of dominant leg at post ($p = 0.0006$, $R^2 = 0.51$).



5.6.5 Effects of JS and LS of the supporting leg on the likelihood of slip-induced falls.

Simple logistic regression analysis indicated that, at pre-training stage, individuals with higher JS had higher likelihood of slip-induced falls (p = p = 0.01, $R^2 = 0.27$), whereas, LS (p = 0.78, $R^2 = 0.0003$) had no effect on the likelihood of slip-induced falls. However, at post-training stage, JS and LS both had significant effects on the likelihood of slip-induced falls (Figure 29 and 30). Logistic regression analysis (Figure 29 and 30) suggested that individuals with lower JS and LS had much more chance to recover from falls.

Figure 29. Logistic Fit of F(1) / R(0) By Joint Stiffness of non-dominant leg at post (p = 0.0008, $R^2 = 0.49$).

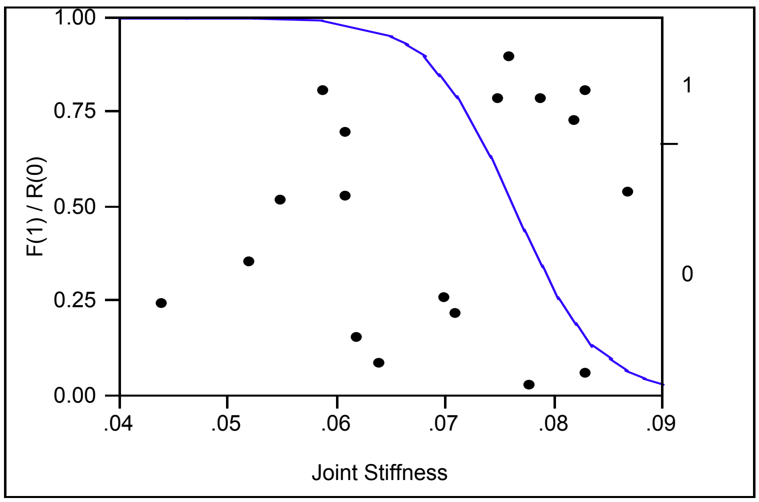
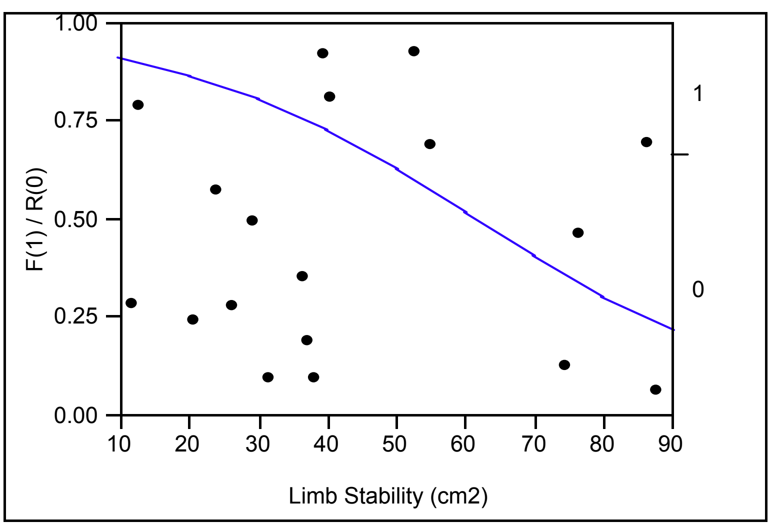


Figure 30. Logistic Fit of F(1) / R(0) By Limb Stability (cm2) of non-dominant leg at post (p = 0.04, $R^2 = 0.16$).



5.7 Gait Asymmetry

5.7.1 HCV

Table 19 indicated that HCV was different between dominant leg (70.82 cm/s) and non-dominant leg (88.98 cm/s), and was different between pre- (88.96 cm/s) and post-training (70.84 cm/s). Also there were interaction effects in Time*Group (p= 0.01) and Leg*Time (p = 0.001). Figure 31 and student's t-test suggested that training groups showed decreased HCV, whereas, control group did not show a difference after 8 weeks. Figure 32 and student's t-test suggested that non-dominant leg's HCV decreased more in comparison to dominant leg's HCV after 8 weeks.

Table 19. ANOVA Summary for HCV.

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	4068.07	2034.03	2	1.3400	0.29
Subject[Group]					
Leg	5939.88	5939.88	1	35.2416	<.0001
Leg*Group	366.398	183.199	2	1.0869	0.36
Subject*Leg[Group]					
Time	5916.29	5916.29	1	12.5894	0.002
Time*Group	5912.26	2956.13	2	6.2904	0.01
Subject*Time[Group]					
Leg*Time	1365.75	1365.75	1	15.6403	0.001
Leg*Time*Group	489.644	244.822	2	2.8037	0.09
Subject*Time*Leg[Group]					

Figure 31. Interactions of Time*Group.

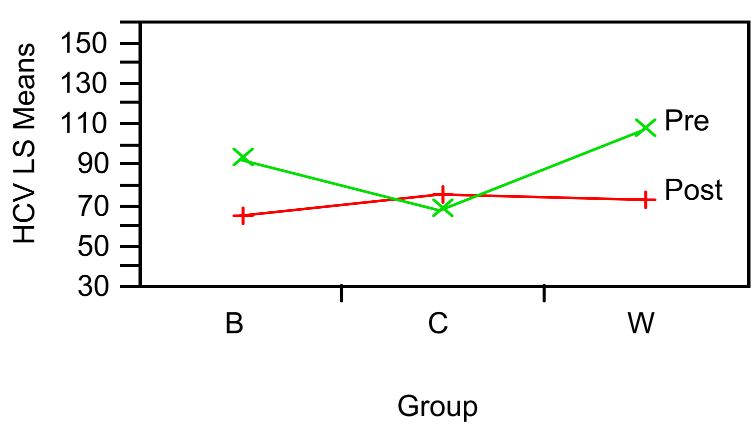
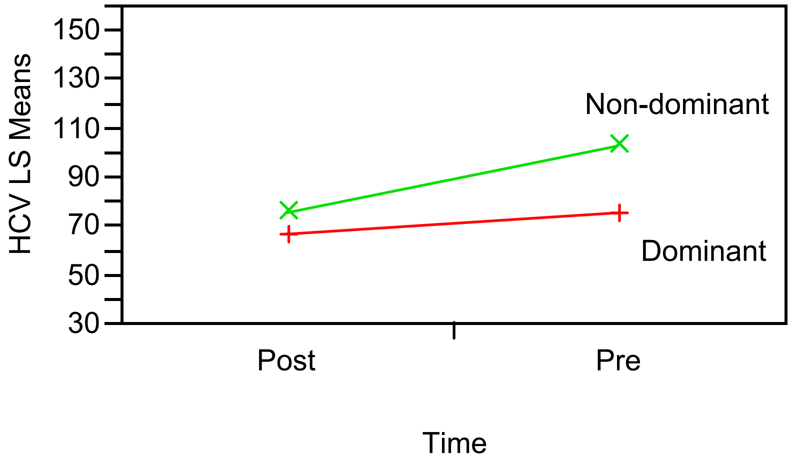


Figure 32. Interactions of Leg*Time.



5.7.2 RCOF

Table 20 showed ANOVA summary for RCOF. Table 20 indicated that the RCOF was different between dominant legs (0.160) and non-dominant legs (0.169), and was different between pre- (0.172) and post-training (0.157). There were interaction effects in Time*Group ($p = 0.003$) and Leg*Time ($p = 0.0004$). Figure 33 and student's t-test suggested that training groups showed decreased RCOF, whereas, control group did not show a difference after 8 weeks. Figure 34 and student's t-test suggested that non-dominant leg's RCOF was decreased significantly more after training while dominant leg's RCOF was not decreased as much.

Table 20. ANOVA Summary for RCOF.

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	0.00069	0.00035	2	1.0337	0.37
Subject[Group]					
Leg	0.00149	0.00149	1	7.5814	0.01
Leg*Group	0.00017	0.00009	2	0.4342	0.65
Subject*Leg[Group]					
Time	0.00433	0.00433	1	33.4753	<.0001
Time*Group	0.00224	0.00112	2	8.6630	0.003
Subject*Time[Group]					
Leg*Time	0.00138	0.00138	1	20.9461	0.0004
Leg*Time*Group	0.00004	0.00002	2	0.3112	0.73
Subject*Time*Leg[Group]					

Figure 33. Interaction of Time * Group

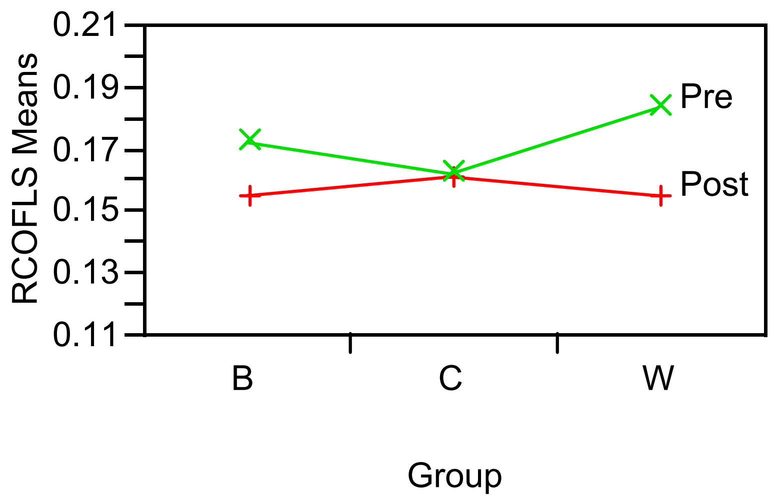
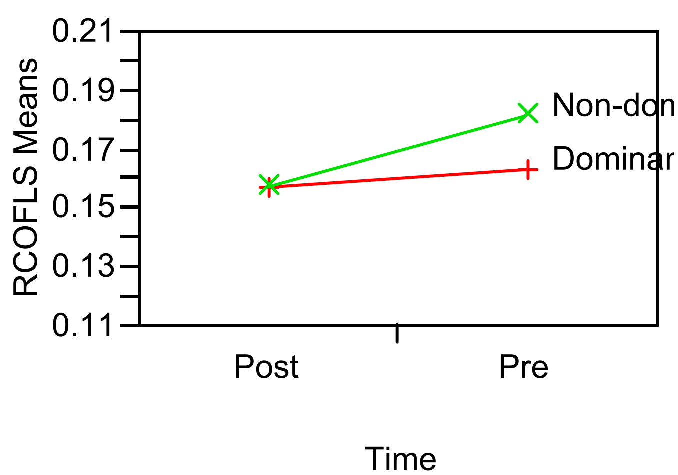


Figure 34. Interaction of Leg * Time



5.7.3 PFx

Table 21 indicated that PFx was different between dominant leg (78.46 N) and non-dominant leg (99.55 N), was different between pre- (95.57 N) and post-training (82.43 N). There were interaction effects in Time*Group (p= 0.01) and Leg*Time (p = 0.05). Figure

35 and student's t-test suggested that training groups showed decreased PFx, whereas, control group did not show a difference after 8 weeks. Figure 36 and student's t-test suggested that non-dominant leg's PFx as well as dominant leg's PFx decreased after 8 weeks. In addition, there was an interaction of Leg*Time*Group ($p = 0.05$).

Table 21. ANOVA Summary for PFx.

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	155.439	77.7196	2	0.0692	0.93
Subject[Group]					
Leg	8008.08	8008.08	1	16.6024	0.001
Leg*Group	481.117	240.558	2	0.4987	0.61
Subject*Leg[Group]					
Time	3110.53	3110.53	1	18.4251	0.0006
Time*Group	2062.09	1031.04	2	6.1073	0.01
Subject*Time[Group]					
Leg*Time	199.167	199.167	1	4.3150	0.05
Leg*Time*Group	330.555	165.277	2	3.5808	0.05
Subject*Time*Leg[Group]					

Figure 35. Interaction of Time * Group.

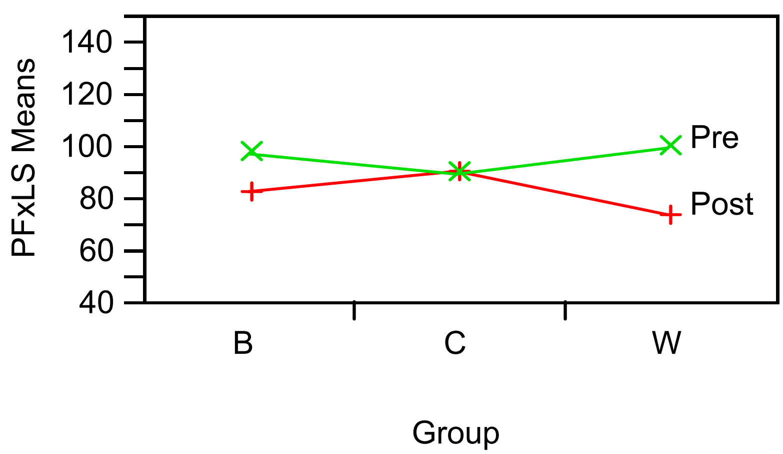
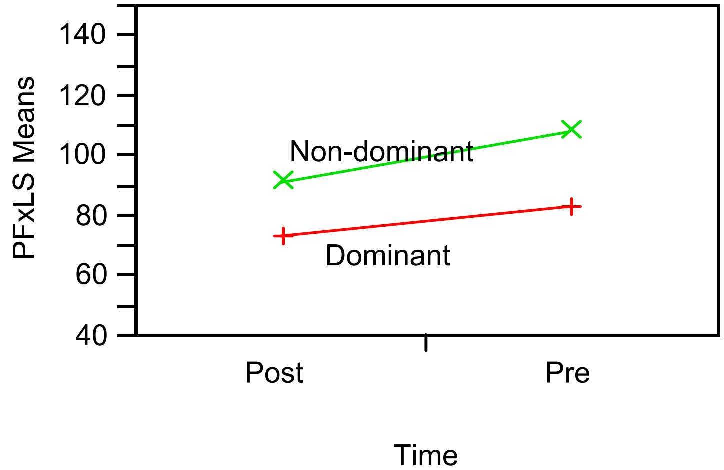


Figure 36. Interaction of Leg*Time.



5.7.4 PFz

Table 22 indicated that PFz was different between dominant leg (824.38 N) and non-dominant leg (806.23 N) and there was no interaction.

Table 5-22. ANOVA Summary for PFz.

Source	SS	MS Num	DF Num	F Ratio	Prob > F
Group	235473	117737	2	1.7691	0.2043
Subject[Group]					
Leg	5935.39	5935.39	1	10.2934	0.0059
Leg*Group	1451.07	725.536	2	1.2583	0.3125
Subject*Leg[Group]					
Time	1500.39	1500.39	1	1.3847	0.2576
Time*Group	4722.43	2361.22	2	2.1791	0.1476
Subject*Time[Group]					
Leg*Time	14.1321	14.1321	1	0.0353	0.8535
Leg*Time*Group	23.3189	11.6594	2	0.0291	0.9713
Subject*Time*Leg[Group]					

5.8 Effects of Training on Psychosocial Factors

The results indicated that, after 8 weeks, participants from all groups (balance, weight, and control) were less afraid of falling in the next year (Time, p = 0.0006; Group x

Time, p = 0.76), were more confident of leaving residence (Time, p = 0.001; Group x Time, p = 0.16), and more active (Time, p = 0.006; Group x Time, p = 0.97) (Table 24). No significant treatment effects were found.

After 8 weeks, the results indicated that participants answered that they visited their family or friends more often, attended a concert, movie, lecture, or sport event more often, and did house-works more often. Nonetheless, their participation in social activities such as attending other group meetings, playing card, bingo, or board game with other people, and attending church, did not increase after 8 weeks in all groups (see Table 23). There were no interaction effects on any of the questionnaires indicating that weight, balance, and control groups all improved. These results suggested that although participants' physical activity levels improved (i.e. question 2, 4, and 8), their socialization activity levels did not improve (i.e. question 1, 3, 5, and 6) within 8 weeks.

Table 23. ANOVA of Psychosocial Factors between pre- and post- trainings;
S-Question: questions in regard to level of independency and level of social involvement (social aspect)
P-Question: psychological factors in regard to fear of falling and level of curtailment (psychological aspect)

		Weight (N = 6)	Balance (N = 6)	Control (N = 6)	P (Time)	P (Group x Time)
S-Question 1 (frequency)	Pre	6.67 ± 3.01	4.33 ± 2.16	6.17 ± 2.79	0.35	0.15
	Post	7.00 ± 3.29	6.67 ± 3.14	6.17 ± 2.79		
S-Question 1 (duration)	Pre	2.17 ± 0.75	1.67 ± 0.82	2.50 ± 1.87	0.25	0.46
	Post	2.00 ± 0.89	2.67 ± 1.86	3.00 ± 0.89		
S-Question 2 (frequency)	Pre	1.83 ± 1.33	2.17 ± 1.17	2.00 ± 1.26	0.001	0.61
	Post	4.00 ± 3.16	3.16 ± 1.86	3.17 ± 0.75		
S-Question 2 (duration)	Pre	1.67 ± 0.52	2.17 ± 1.94	2.00 ± 1.26	0.10	0.83
	Post	2.00 ± 0.63	2.83 ± 1.72	2.33 ± 1.75		
S-Question 3 (frequency)	Pre	1.83 ± 1.47	1.67 ± 1.75	0.67 ± 0.82	0.39	0.07
	Post	2.67 ± 2.42	1.00 ± 0.63	1.17 ± 0.98		
S-Question 3 (duration)	Pre	2.17 ± 1.17	2.33 ± 1.21	1.33 ± 1.51	0.03	0.25
	Post	2.67 ± 1.86	2.50 ± 1.64	2.67 ± 1.97		

The table continues…

S-Question 4 (frequency)	Pre	0.83 ± 0.41	0.83 ± 0.75	0.17 ± 0.41	0.03	0.09
	Post	1.50 ± 0.84	1.50 ± 1.22	0.00 ± 0.00		
S-Question 4 (duration)	Pre	1.67 ± 1.03	1.33 ± 1.03	0.50 ± 1.22	0.001	0.04
	Post	2.67 ± 0.52	2.67 ± 1.37	0.00 ± 0.00		
S-Question 5 (frequency)	Pre	0.50 ± 0.84	1.00 ± 0.89	0.67 ± 0.52	0.17	0.61
	Post	0.17 ± 0.41	0.67 ± 0.52	0.67 ± 0.52		
S-Question 5 (duration)	Pre	0.83 ± 1.33	2.00 ± 1.67	1.50 ± 1.22	0.39	0.48
	Post	0.17 ± 0.41	2.00 ± 1.55	1.50 ± 1.22		
S-Question 6 (frequency)	Pre	1.50 ± 1.38	1.17 ± 0.75	2.33 ± 2.94	0.1	0.25
	Post	1.67 ± 1.63	1.00 ± 0.89	2.25 ± 2.67		
S-Question 6 (duration)	Pre	2.00 ± 1.67	1.67 ± 1.03	2.33 ± 1.63	0.55	0.70
	Post	2.00 ± 1.67	2.00 ± 1.90	2.33 ± 1.63		
S-Question 7 (frequency)	Pre	0.83 ± 0.98	0.83 ± 1.17	0.17 ± 0.41	0.12	0.37
	Post	1.00 ± 1.10	1.00 ± 1.10	1.17 ± 1.83		
S-Question 7 (duration)	Pre	6.67 ± 0.82	6.17 ± 1.33	3.17 ± 2.86	0.28	0.26
	Post	8.67 ± 2.88	6.67 ± 0.82	4.33 ± 3.08		
S-Question 8 (frequency)	Pre	6.67 ± 0.82	6.17 ± 1.33	3.17 ± 2.86	0.05	0.59
	Post	8.67 ± 2.88	6.67 ± 0.82	4.33 ± 3.08		
S-Question 8 (duration)	Pre	4.83 ± 0.98	3.83 ± 1.60	2.33 ± 2.07	0.001	0.91
	Post	5.17 ± 1.33	3.83 ± 1.33	2.00 ± 1.10		
P-Question 2	Pre	1.88 ± 1.35	2.43 ± 1.78	3.30 ± 1.96	0.0006	0.76
	Post	1.22 ± 1.12	0.10 ± 0.17	2.33 ± 1.79		
P-Question 3	Pre	0.68 ± 0.33	0.43 ± 0.35	1.68 ± 1.46	0.001	0.16
	Post	0.10 ± 0.24	0.10 ± 0.17	0.52 ± 0.38		
P-Question 4	Pre	1.25 ± 0.99	1.33 ± 1.49	2.13 ± 1.49	0.006	0.97
	Post	0.22 ± 0.35	0.32 ± 0.55	1.27 ± 1.44		

6. Discussion

The injury process associated with slips and falls includes three phases: 1) slip initiation, 2) slip detection, and 3) fall recovery. Slip initiation can originate from the personal, environmental, and biomechanical conditions that dictate whether a given walking step will result in secure foot placement or if the foot will accelerate away from the base of support. Slip detection and fall recovery describe components of the neuro-musculo-skeletal control system which orchestrates an individual's attempt to arrest a fall. Impact occurs if recovery fails. Musculoskeletal injuries may occur during slipping and/or at impact.

With advancing age, components of the neurological, muscular, and skeletal systems and the ability to integrate these systems continue to degrade. As a result, older adults become more susceptible to slips and recovery becomes more difficult. It is obvious that intervention strategies must be developed and employed to reduce the likelihood of slip-induced falls for older adults. In the present study, intrinsic changes associated with aging such as gait adaptation and musculoskeletal and sensory degradation were evaluated, and an 8-week weight or balance training routine was implemented to assess the effects of the training on the initiation, detection, and recovery processes of slips and falls.

6.1 Slip Initiation

The objective of the present study was to determine if an 8-week neuromusculoskeletal training regimen would alter the gait characteristics of the elderly so as to lessen the risk of a dangerous slip while walking.

Conducting the slip-induced fall experiment at a participant's preferred walking speed required a very sophisticated and controlled experimental set-up. Therefore, extra observations were required before and during the experiment to make sure that participants were walking at their preferred walking speed without noticing the slippery surface. Each participant's natural walking speed was observed before the experiment started. All participants indicated discomfort due to the fall arresting rig and safety harness which initially caused them to walk slower than their natural walking speed. However, once they became familiar with the equipment and the surroundings, they resumed their normal pace. This process usually took about 15-25 minutes. During the experiment, it was important that the participants remained unaware of any changes in the floor surface. To ensure this, participants were asked to engage in simple tasks to divert their attention from the floor. For this particular experiment, they were asked to count a dot on a TV screen that had been placed at eye level. This diversion allowed for the observation of spontaneous slip accident as the participants maintained their natural walking speed. The experiments were said to be "successfully controlled" if both HCV and step length were no different while walking on a dry surface than while walking on a slippery surface. It was found in the present study that participants did not notice a change in the floor surface before proceeding to walk on the slippery floor. These results further indicate that participants were walking at their preferred walking speed throughout the experiment.

The results from the present study suggest that, aside from walking velocity and step length, older adults' gait characteristics (i.e. HCV and TA COM) were altered after 8 weeks of training. In addition, the RCOF in training groups was reduced. These results were similar to those found in the literature (Schlicht et al., 2001; Sipila et al., 1996) which described the effectiveness of exercise training on altering gait characteristics. Although, most of these studies failed to indicate a clear relationship between strength gain and alterations in gait characteristics (Buchner et al., 1997; Singh, 1997). Further, these studies did not evaluate the effects of exercise training on risk factors of slips and falls while walking at the preferred walking speed over a slippery surface. HCV as well as TA COM were suggested to be related to the likelihood of slip-induced falls due to their mechanical effects on alterations in horizontal shear forces at the heel contact phase. As neuromusculoskeletal systems continue to degrade, older adults have difficulty developing rapid torque at specific joints (Hakkinen and Hakkinen, 1991). Hamstring muscles (Lockhart and Kim, 2005) and ankle plantar-flexor muscles (Thelen et al., 1996) are especially problematic. With advancing age, the proportion of slow twitch muscle fibers (type 1) increases while the proportion of fast twitch muscle fibers (type 2) decreases (Doherty et al., 1993; Lexell, 1995). These age-related alterations in muscle fiber type have been suggested to contribute to the inability to generate explosive forces (Doherty et al., 1993; Lexell, 1995). Furthermore, a study by Lockhart and Kim (2005) reported that the ability to generate adequate forces in hamstring muscles could play a role in reducing heel contact forces (i.e. horizontal shear force). The present study suggests that strength improvements in hamstring muscle groups (knee flexors) played a role in reducing the forward leg momentum right before the heel contact, and strength improvements in ankle plantar-flexor muscles play a role in pushing off the whole body center-of-mass in the forward direction after heel contact. Reducing forward leg momentum and accelerating the whole body in the forward direction are critical components to avoiding dangerous slips caused by high RCOF at the heel contact phase of the gait cycle. Older adults in training groups were able to reduce heel contact velocity and to increase TA COM resulting in a reduction of the RCOF. Moreover, it was noteworthy to see improvements in slip propensity (i.e. slower HCV and faster TA COM) among older adults in training groups without observing alterations in fundamental gait characteristics such as walking velocity and step length. Walking velocity and step length (Lockhart and Kim, 2005; Gronqvist, 1989) were suggested to influence the likelihood of slips due to their effects on the horizontal shear force component at the heel contact phase of the gait cycle. It was generally suggested that older adults exhibited slower gait and shorter step length because they wanted to maintain safer gait characteristics. However, older adults fell more (Lockhart et al., 2003; Lockhart and Kim, 2005) than their younger counterparts. These findings may indicate that slower gait and shorter step length should not be referred to as a safer gait. It may be more appropriate to refer to slower gait and shorter step length as an aging gait or a pathological gait. The present study suggests that older adults with neuromusculoskeletal training are able to walk normally, but are able to reduce the likelihood of slips by altering only HCV and TA COM.

In the present study, slip severity, evaluated by SD 2, decreased after 8 weeks in both training groups although SD 1 and PSHV did not change. After training, participants in the training groups were able to recover from the initial slip (i.e. no difference in SD 1, but significant reductions in SD 2). These results suggest that exercise training would influence recovery mechanisms. Also, the difference seen in TA COM in the present study further supports the idea that training has an effect on recovery mechanisms. A study by Lockhart et al. (2003) and Lockhart and Kim (2005) reported that younger adults were exposed to severe slips more frequently than older adults, however, younger adults fell less often than older adults. The authors in those studies suggested that fewer falls for younger adults was due to the fact that they exhibited faster TA COM than older adults. The present study found similar results when participants in training groups recovered more frequently and exhibited enhancements in TA COM. No such changes were observed in the control group. These results suggested that the training played a role in improving a mechanism contributing to the forward progression of the whole body COM after heel contact. Authors in the present study found that all fallers at the pre-training stage fell backward in a similar manner. The upper body (i.e. head, trunk, and arms) twisted backward while lower body (i.e. slipping foot) continuously moved forward. However, non-fallers who fell at the pre-training stage exhibited a forwardly progressing upper body motion while slipping when they recovered from slipping. These video analyses further support the fact that a faster TA COM plays an important role in recovering from slipping. The present study suggests that, in order for the elderly to recover effectively or efficiently from a dangerous slip, it is advantageous to have the whole body center of mass progress forward after heel contact is made.

6.2 Slip Detection and Slip Recovery

The objective of the present study was to determine whether 8 weeks of balance or weight training would improve proprioception sensitivity, postural stability, ankle joint stiffness, and limb stability to reduce the likelihood of slip-induced falls. Understanding the effects of balance or weight training on the likelihood of slip-induced falls may help identify intervention strategies for the elderly.

6.2.1 Effects of neuromusculoskeletal training on proprioception and postural stability.

In the present study, after 8 weeks of training, the individuals in the control group (social activity group) show improvement in ankle and knee isometric and isokinetic strengths as did the individuals in the training group. Strength improvement seen in the social activity group was a very interesting outcome because the authors expected to see significant strength improvement in the balance and weight training groups but not, in the control group. These results demonstrated that elderly who are socially active may also be benefit from improved strength. In addition, these results suggest that a reduction in strength with advancing age could not only be due to physiological aging, but to a lack of socialization as well. Control group met three times a week. In order to attend these social meetings, participants had to leave their residence and, in many cases, had to drive. During the social meetings, they had to walk in picnic areas, shopping malls, or museums. These kinds of activities were not a controlled physical training, nonetheless, they resulted in improved leg strength after only 8 weeks. These results indicate that older adults should be as active as possible to maintain their mobility.

Proprioception sensitivity for ankle plantarflexion and knee extension also improved in all groups including the control group. These results indicate that, in addition to improved leg strength, being socially active can provide stimulation for proprioceptive system and delay its degradation with advancing age. Despite the improved ankle plantarflexion proprioception sensitivity, however, the dorsiflexion sensitivity did not show significant improvement after 8 weeks. This was due to the fact that the range of motion of dorsiflexion for the elderly was too small. For most participants, 5° of dorsiflexion was almost at the end of rotation. This factor may contribute to boosting proprioceptive sensitivity level in dorsiflexion direction.

Postural stability was found to improve only for those individuals in the training group. These results were somewhat confusing given that strength and proprioception sensitivity improved in all groups including the social activity group (control group) after 8 weeks. This suggests that, in order for the elderly to improve postural stability, formal physical training such as balance or weight training is necessary. Although, simply being active may be enough to delay degradations in strength and proprioception sensitivity as one ages.

For adequate postural stability, many different mechanisms are required to work synchronously to keep the center of mass within the base of support. Harmonious responses among the proprioceptive, skeletal muscle, and central nervous systems are the major elements in maintaining stable upright posture. Although social activities could play a role in improving strength and proprioceptive sensitivity at ankle and knee joints, it could not play a role in enhancing postural stability. The results from the present study suggest that only formal physical training such as weight or balance training could enhance the integration of these three systems.

6.2.2 Relationships between proprioception sensitivity and postural stability and the likelihood of slip-induced falls

Previous studies (Lipsitz et al., 1991; Lord et al., 1991; Lord et al., 1994; Robbins et al., 1989; Wolfson et al. 1995) suggested that the frequency of falls increases as age increases due to neuromusculoskeletal degradations. However, most of these studies never evaluated the likelihood of falls while walking on a slippery surface. For example, some studies (Arfken et al., 1993; Cumming et al., 2000; Friedman et al., 2002) counted the number of falls within a period of time and evaluated in risk factors for these falls. Other studies (Deshpande et al., 2003; Thelen et al., 1996; Mills and Barrett 2001) evaluated statistical differences in the risk factors for falls between younger adults and older adults and suggested the differences as risk factors for falls among older adults. The present study is unique in that its objective is to evaluate the risk factors associated with slip events for elderly individuals. Falls or recoveries while walking on a slippery surface were identified for each participant, and a logistic regression was performed to predict the likelihood of slip-induced falls by quantifying these risk factors (proprioception sensitivity, postural stability, and strength).

In order to perform activities correctly and to avoid falls, intact coordination and performance among sensory inputs (proprioception, somatosensory, and vestibular system), neural controls (motor control), and muscle force development are required. However, degradations in sensory systems, neural controls, and muscle strength start to accelerate at the age of 50, and these changes have been suggested to be major contributions to falls among older adults (Judge, 2003; Wolfson, 2001) due to impaired postural control (Horak et al., 1989; Manchester et al., 1989; Thelen et al., 1998; Woolacott M., 1986). As a prevention strategy, strength training such as balance or weight training has been introduced to improve postural control (Jeandel and Vuillemin, 2000) and to enhance mobility (Chandler et al., 1998).

In agreement with previous studies (Stelmach and Worringham, 1985; Thelen et al., 1998; Teasdale et al. 1991; Wolfson et al. 1995), when proprioception sensitivity, postural stability, and strength were enhanced due to training, participants in training groups had a better chance of recovering from the slip-event. Generally, after 8 weeks, individuals in the training group generally exhibited improvement in all of these risk factors. Individuals in the control group exhibited improvements only in leg strength and in proprioception sensitivity. The number of falls occurring among the training group decreased during the post-stage evaluation whereas the same number of falls was observed for the control group. During a dangerous slip event, the slipping leg is sliding away from the body and the majority of the body weight is shifted toward the supporting leg. Therefore, to turn this event into a recovery, an individual must first sense the changes in body position relative to normal position. The individual must then employ their neural control systems and generate adequate muscle force to resist the fall. In the present study, the ability to sense changes in ankle or knee joint position played a large role in helping participants recover from slip events. These results indicate that proprioception sensitivity, postural stability, and strength played a major role in reducing the likelihood of slip-induced falls.

6.2.3 Effects of training on Joint Stiffness (JS) and Limb Stability (LS)

The results from the present study suggested that only the balance training group exhibited decrements in JS. The results indicated that, after training, the JS (0.063) of the balance group did not differ from the JS (0.062) of the weight training group although the JS (0.075) of control group was different than the JS of either the weight or balance training group. The JS of the weight training group at the pre-training stage was 0.061. Based on that, the authors speculated that JS between 0.062 and 0.063 would be an optimal range for the elderly in the present study after 8 weeks of training. Many studies evaluated JS and suggested that it was an important indicator for pathological gait, aging gait, postural instability, and gait instability. However, no study has clearly stated the usefulness of this measure in developing intervention strategies. Therefore, studies should be performed to assess the optimal range of JS for the elderly while walking to further advocate the importance of the joint stiffness measure.

In agreement with a previous study (Salsich and Mueller, 2000), JS was mainly improved due to improvements in flexibility rather than improvements in ankle plantarflexor strength. In the present study, decrements in JS in the balance group after 8 weeks of training were generally a result of an increased range of motion from foot flat to heel off. These results suggest that balance training would help improve the range of motion at ankle joints. Reduced flexibility at the ankle joint was suggested to contribute to the increased risk of falls among the elderly (Gehlesen and Whaley, 1990). The effects of balance training on JS in the present study definitely suggested that balance training played a role in improving flexibility at the ankle joint. Better flexibility led to the lower JS, in turn, decreased the risk of falls for the elderly.

Limb stability in the present study was a fundamental measure which represented the entire sum of gait instability or variability for the elderly. Limb stability measured in the present study indicated an outcome of all the combined factors that may contribute to gait instability or variability while walking. Limb stability has not clearly been investigated despite the fact that many studies evaluated gait variability, strength, or joint stiffness in an attempt to explain limb stability. However, these parameters only represent a portion of limb stability. These parameters can not entirely represent dynamic limb stability. Older adults are known to adapt to safer gait in order to avoid falling (Hausdorff et al., 1997; Maki, 1997). Despite this adaptation, falls are still a major concern for them. This suggests that safer gait does not entirely mean "SAFE" while walking. Studies (Buzzi et al., 2003; Hausdorff et al., 1997) reported that older adults exhibited unstable joints or gait in comparison to younger adults and, further, these studies suggested that these local instabilities seen among the elderly contributed to high frequency of falls among the elderly. The present study desired to test if these gait instabilities could be improved through exercise training and, in addition, to evaluate the asymmetry of gait stability between the dominant leg and non-dominant leg. The results indicated that limb stability improved only in the training group.

In the present study, improvements in LS correlated to decreases in JS at the post-training stage whereas LS could not be predicted by JS at the pre-training stage. These results suggest that JS provides important information about limb control as was suggested by Salsich and Mueller (2000). Improved flexibility, as noted by a smoother rate of joint movement throughout its range of motion, and improved limb stability in the present study suggest that limb control was mainly derived from the contractile capability of ankle plantarflexor muscles (Lamontagne et al., 2000; Salsich and Muller, 2000) which became stronger after training. The ability for ankle plantarflexor muscles to control or stabilize the ankle joint throughout forward progression of the COM represents limb control as well as limb stability. Better limb stability most likely indicates smaller variability in the medio-lateral COM. Therefore, improved limb stability stems from smoother sinusoidal progression of the COM which, in turn, suggests a smoother rate of change in joint moments throughout the range of motion. Improvements in limb stability in training groups further support the idea that training can facilitate improvements in limb control mechanisms among older adults.

6.2.4 Asymmetrical gait

In agreement with previous suggestions (Allard et al., 1996; Barr et al., 1987; Law, 1987; Rosenrot et al., 1980; Stefanyshyn et al., 1980), LS of the dominant leg was different from LS of the non-dominant leg. Results indicated that the dominant leg had better LS in comparison to the non-dominant leg. Limb dominance can take place when one side is preferred to the other side in activities such as kicking. To date, no study has suggested a relationship between limb dominance and limb stability although many studies (Vanden-Abeele, 1980; Rosenrot, 1980 ; Matsusaka et al., 1985) have suggested a relationship between limb dominance and gait asymmetry in the lower limbs. The results from the present study suggest that progressing body forward over dominant leg is much safer as was indicated by a smaller variability when compared to the non-dominant leg. Furthermore, results in the Time x Group interaction indicated that LS improved due to training. These results suggest that limb dominance plays a role in gait stability and that the effects of limb dominance could be minimized by exercise training.

6.2.5 Relationships between JS and LS and the likelihood of slip-induced falls.

JS and LS are suggested to alter with advancing age (Hausdorff et al., 2001; Ho and Bendrups, 2002). Further, falls among the elderly are suggested to be related to JS and LS (Hausdorff et al., 2001; Ho and Bendrups, 2002). However, no study has tested the effects of JS and LS of the elderly when actual slip events are introduced. The present study is unique in that the effects of JS and LS were evaluated during actual slip events. Balance or weight training contributed to changes in JS and LS while no changes were observed for the control group. These findings made a strong argument for the role of JS and LS in postural instability in older adults. The results from the present study suggest that JS and LS of the dominant leg play a significant role in recovering from slip-induced falls, and JS and LS of the non-dominant leg contributes to recovery as well. This study also suggests that the ability to produce adequate ankle force at any ankle joint angle (i.e. JS) plays a significant role in the recovery from a slip-event. During dangerous forward slips as introduced in the present study, the ankle of the dominant leg was forced to rotate in the plantarflexion direction as the foot was sliding away from the knee, hip, and upper body. At the same time, the ankle of non-dominant leg was forced to rotate in the dorsiflexion direction as the foot was progressing toward the knee, hip, and upper body. Fallers demonstrated either an inability to produce the required forces to resist the plantarflexor rotation at the ankle joint of the slipping foot or an inability to produce the required forces to resist dorsiflexor rotation at the ankle joint of the supporting foot. In order to recover from a dangerous slip, individuals must resist or overcome these subsequent actions (i.e. rotations) at the ankle joints. These capabilities were further demonstrated by improvements in JS after training in the present study. As previously suggested in the present study, training contributed to improvements in flexibility resulting in a reduced JS. This further suggests that individuals in training groups were able to produce the same or more force at the ankle joint. These improvements in the ability to produce adequate muscle force at various ankle angles would contribute to a reduction in the likelihood of slip-induced falls.

LS also played a role in recovering from the slip-events in the present study. At the pre-training stage, the likelihood of falls was not influenced by LS while at the post-training stage, LS had a significant effect on the likelihood of slip-induced falls. During normal walking, stability indicated the capability to coordinate all three systems such as sensory inputs, central processing, and muscle force development. It was important to notice that LS could be improved by training. Improvements in the capability of integrating sensory, neural, and skeletal muscle played a significant role in recovering from the dangerous slip event.

6.3 Effects of Training on Gait Asymmetry and Relationships between Gait Asymmetry and Slip-initiation

It has been suggested by many studies, although it is still in debate, that the lower limbs of normal people behave asymmetrically while walking (Sadeghi et al., 2000). Various studies (Allard et al., 1996; Barr et al., 1987; Law, 1987; Rosenrot et al., 1980;

Stefanyshyn et al., 1980) reported that spatial-temporal and kinematic behaviors between dominant legs and non-dominant legs were statistically different. Furthermore, some studies indicated that kinetic characteristics such as anterior-posterior and medio-lateral components of ground reaction forces were also statistically different (Herzog et al., 1988 and 1989; Devita et al., 1991). However, a few studies have questioned the effects of limb asymmetry on the likelihood of slip-initiation and on the risk of falls for older adults.

Slip severity would increase as the difference between the Required Coefficient of Friction (RCOF) and available dynamic COF of the floor surface increases (Hanson et al., 1999, Redfern and Andres, 1984). Thus, RCOF at the shoe-floor interface (indication of the constant available dynamic COF) predicts the slip-initiation severity (Irvine, 1986; Perkins and Wilson, 1983) and also the risk of falling for older adults. Gait instability for the elderly is indicated as a risk factor for falls because it indicates a lack of limb coordination in producing smooth rhythmical motion, and, further, it implies deterioration in the ability of individuals to walk in a repetitive and stable manner. Older adults are known to exhibit an unsteady gait (i.e. wobbling in medio-lateral direction of the whole body center of mass) which disperses the smooth rhythmical transition across the terrain.

A study has indicated that limb asymmetry seen in kinematic (heel contact velocity) and kinetic parameters (horizontal ground reaction force) influences the slip severity during healthy older adult gait. The present study investigated whether the dominant leg's slip-initiation severity would differ from the non-dominant leg's slip-initiation severity. The study suggested that more severe slips would occur for the non-dominant leg than for the dominant leg due to a higher RCOF. This higher RCOF may be an outcome of higher heel contact velocity.

Balance or weight training has been suggested to improve leg strength, but the effects of leg strengthening on the outcomes of fall accidents are still not clear. The present study assumed that the slip severity on the non-dominant leg would be reduced if neuromusculoskeletal training was performed. The objective of this study was to determine whether neuromusculoskeletal training could minimize asymmetrical gaits and could reduce slip severity among the elderly for both dominant and non-dominant legs.

In agreement with previous findings (Campbell et al., 1999; Gardner et al., 2002), the present study found that an exercise training program was effective in gaining strength for the elderly. The training groups showed much greater gain in knee strength in comparison to the control group. Strength gain for the elderly was credited for improvements in proprioceptive sensitivity and, more significantly, for improvements in postural stability. The improvements in postural stability in the previous study may be due to a significant role of training in improving neural recruitment patterns (Fiatarone et al, 1990) while standing quietly. The improvements in neural recruitment patterns could primarily be attributed to enhanced coordination of the sensory, skeletal muscle, and central nervous systems. The results from the present study further support this idea: proper actions of lower muscles contribute to lowering HCV and PFx, eventually, the RCOF.

The results from the present study suggested that, after 8 weeks of training, the non-dominant leg's HCV decreased much more than the dominant leg's HCV. In addition, HCVs of both legs were decreased significantly due to training. It was suggested that reducing forward leg momentum (i.e. HCV) was highly correlated to hamstring muscle strength (Inman et al., 1981; Lockhart and Kim, 2005; Winter, 1991). In agreement with previous studies (Inman et al., 1981; Lockhart and Kim, 2005; Winter, 1991), after strength gains in leg muscles (i.e. isokinetic flexor strength) which contribute to reducing forward leg momentum, HCV was decreased in both legs. However, presently, the decrements in the non-dominant leg (from 102.40 cm/s to 75.56 cm/s) were significantly more than decrements in dominant leg (from 75.53 cm/s to 66.11 cm/s). These findings suggest that neuromusculoskeletal training could play a role in reducing HCV and, ultimately, in symmetrizing lower limbs.

It was indicated by the previous studies (Grönqvist et al., 1989; Lockhart et al., 2003) that horizontal shear force was an important indicator for the RCOF since RCOF is determined by a ratio of F_h (horizontal shear force) over F_v (vertical force) (Redfern and Andres, 1984). The results from the present study suggested that the horizontal shear force was reduced in both legs although a greater reduction was observed in the non-dominant leg. The reductions in the horizontal shear force at the heel contact phase could have been influenced by the slower HCV found among individuals in the training groups. HCV was found to influence horizontal shear force (Lockhart et al., 2003). The authors in previous study (Lockhart et al., 2003) suggested that, given the constant contact time (t) and mass (m) associated with the heel contact phase of gait cycle (Irvine, 1986), the impulse-momentum relationship demonstrates proportional increments in horizontal shear force as HCV increases. Furthermore, greater reductions of horizontal shear force seen after training in non-dominant leg (from 107.78 N to 91.31 N) in comparison to dominant leg (from 83.37 N to 73.55 N) suggest that balance or weight training could play a significant role in symmetrizing behavior between the two lower limbs while walking. The outcomes of balance or weight training in the present study would have presented as improvements in the integration of the neuromusculoskeletal system. Many studies (Manchester et al. 1989; Teasdale et al. 1991; Woollacott et al. 1986) suggested that at an older age, due to musculoskeletal degradations, individuals exhibit difficulties in integrating sensory inputs, central processing, and skeletal muscle responses and, therefore, show gait instability.

Previous studies (Perkins, 1978; Hanson et al., 1999; Redfern and Andres, 1984) have suggested that alterations in the RCOF become critical when walking over a slippery surface. There would be more dangerous slips if the difference between the RCOF and available dynamic coefficient of friction on a floor became inflated. Therefore, many studies evaluating the likelihood of slips employed the RCOF to indicate slip-propensity. In the present study, the RCOF became smaller only in training groups. Smaller RCOF with slower HCV and smaller PFx in the present study undoubtedly suggests that training has a large effect on reducing slip-propensity in training groups.

In the present study, chance of a slip-induced fall was greater during the heel contact phase of the non-dominant leg. The authors thought that these results were due to the fact that the non-dominant leg aged faster than the dominant leg. However, greater improvements seen in the non-dominant leg in comparison with the dominant leg suggests that the risk of a dangerous slip could be reduced by introducing an exercise training program for the non-dominant leg. Still, higher risk of slip remained in the non-dominant leg in comparison with the dominant leg after 8 week training. The authors recommended that longer or more intense exercise training routine would result in lowering the likelihood of slip-induced falls for the elderly and that particular exercise routines that help strengthen the non-dominant leg more effectively would result in reducing the likelihood of slip-induced falls for the elderly in overall.

6.4 Effects of 8-week balance training or weight training for the elderly on fear of falling measures and social activity levels

The present study was conducted to evaluate the effects of balance or weight training on psychosocial factors of older adults. Due to the nature of this study, much of the information in this discussion comes from anecdotal data. However, the goal of the study was to evaluate the psychosocial factors objectively.

After 8 weeks, all groups including the control group indicated that they were less afraid of falling and more confident about being active. However, none of the groups showed increased participation in social activities. These results indicated that, after 8 weeks of training or social meeting, they were more physically active although their social activity level did not improve. The authors found out that local community centers provide activities for seniors, but, these activities are not offered regularly and therefore do not provide adequate socialization. With more support from the local community, the participants could have had more opportunity to socialize. Local community programs mostly offer the senior citizens trips to zoos, parks, or museums. However, these trips not only require the elderly to drive to the center, but can also be very costly for those who are retired. For those elderly who can not drive, family support then plays a very important part in their level of social activity. As mentioned, these activities are not interactive enough for them to socialize as a group since these trips are not offered regularly. The authors suggest that providing a regular socially-interactive activity such as bingo, card games, or board games would play a significant role in improving socialization among older adults.

In addition to community and family support, self-efficacy among older adults could play a significant role in their participation in social activities. Even if the local community offers regular social activities and a family member offers to drive, the elderly would not benefit unless they could motivate themselves to attend. As indicated by a study (McAuley et al., 2003), what plays a definite role in motivating older adults to participate in regular activities is not clear. A combination of self-efficacy, social support, and family support may maximize socialization (McAuley et al., 2003). The 8-week exercise training program in the present study may not have been sufficient to dramatically impact the subjects' level of self-motivation and to encourage continued socialization among these older adults.

The study suggests that providing a sufficient level of social activity for seniors could improve their psychosocial factors and play a role in reducing their incidence of falls.

The present study indicated that the fear of falling for all groups including the control group (social group) decreased after eight weeks. Participants reported being more active and independent engaging in activities like going out to movie theaters, shopping malls, or museums and spending more time cleaning up their closets or houses.

In agreement with previous studies (Chandler et al., 1996; Lawrence et al., 1998; Myers et al., 1996; Tinetti et al., 1988), adults were found to develop the fear of falling as they age due to the dreadful outcomes (i.e. injuries) of falling. In addition, whether they have fallen or not, older people who fear falls restrict the activity of their daily living (ADL) and curtain other physical and social activities. Unfortunately, curtailing activities often leads to a decrease in physical capability and depression due to lack of socialization. In turn, this facilitates a more rapid physiological aging in comparison to active older adults (Chandler et al., 1996). The fear of falling among the elderly in the present study could have compromised socialization as measured by CHAMP questionnaires (Arfken et al., 1994; Howland et al., 1998). In agreement with previous studies (Arfken et al., 1994; Chandler et al., 1996; Howland et al., 1998; Li et al., 2002), all groups exhibited a greater tendency to leave their residency after completion of 8 weeks of regular meetings. The results in the present study found that all groups exhibited improvements in proprioception sensitivity as well as strength, although strength improvements were primarily found in exercise training groups. These results further support the idea that older adults who participate in regular activities have better physical and psychological health (McAuley and Rudolph, 1995; Spirduso, 1995; ACSM, 1998). Everyone who participated in the present study reported that they became physically and psychologically healthier after 8 weeks.

In order to remain healthy and active individuals, older adults need to carry out independent daily activities such as cooking, showering, gardening, going up and down stairs, driving, and shopping (Judge et al., 1996). However, older adults with the fear of falling tend to restrict their daily activities (Chandler et al., 1996; Arfken et al., 1994; Howland et al., 1998; Silverton and Tideiksaar, 1989) because most falls among older adults do, in fact, stem from their daily activities. Performing such activities requires precise coordination and integration of movements such as walking, standing, reaching, turning, bending, picking, and sitting (Nevitt et al. 1991; Vellas et al. 1993). Family support and self-efficacy toward exercises have been suggested to be an important factor that assists and facilitates the elderly to remain active (Duda and Tappe, 1989; Dzewaltowski, 1989; Howland et al., 1998). In the present study, the elderly, after being active for 8 weeks while attending exercise training or regular social meetings, indicated that they were less afraid of falling. Further, all participants reported that they spent more time doing independent daily activities independently after 8 weeks.

6.4.1 Effect of strength and balance training for older adults on the quality of life in context of falls

Mortality and morbidity among older adults decrease as fitness level increases (Paffenbarger et al., 1993; Sandvik et al., 1998). Further, it is said that people with better health habits live longer and experience a better quality of life in their later years (Vita et al., 1998). Falls are a major cause of death and disability among older adults (Braun, 1998). To improve the quality of life among older adults, their incidence of falling needs to be decreased. As previously discussed, a fall is an outcome of an amalgamation of physiological, psychological, and social factors. However, one common factor that may be used to decrease the incidence of falls is to improve the physical and functional capability of older adults. The present study suggests that the improvements of physical and functional capabilities of older adults should eventually decrease negative psychological and social factors such as the fear of falling and the curtailment of daily and social activities that influence the occurrence of falls.

Currently, most interventions to minimize fall accidents among older adults have been focused on the improvement of lower extremity strength (Neil, 1994) and balance (Judge J., 2003). An exercise training program is found to be effective in lessening the degeneration of physical capabilities contributing to a reduction in fall rates (Campbell et al., 1999; Gardner et al., 2002). One advantage of strength and balance training among older adults is that it plays a significant role in improving neural recruitment patterns resulting in strength gain (Fiatarone et al, 1990). Moreover, strength gain by exercise training plays a role in the improved coordination of other fixator muscles necessary for body support during daily tasks such as cooking, gardening, reaching for an object, and walking. Gaining more coordinated contractions between agonist and antagonist muscle groups leads to a greater net force generation for the impending movements (Jones et al., 1989; Rutherford and Jones, 1986; Sale 1988). Simply, the above studies (Fiatarone et al, 1990; Jones et al., 1989; Rutherford and Jones, 1986; Sale 1988) suggest that exercise training results in improving postural control while performing daily tasks.

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7. Summary and Conclusion, Limitation, Future Research, Contribution, and Design Recommendation

7.1 Summary and Conclusion

7.1.1 Effects of Training on the Likelihood of Slip-induced Falls

The injury process associated with slips and falls includes three phases: 1) slip initiation, 2) slip detection, and 3) fall recovery. Slip initiation describes the personal, environmental and biomechanical conditions that dictate whether a given walking step will result in secure foot placement or if the foot will accelerate away from the base of support. Slip detection and fall recovery describe components of the neuro-musculo-skeletal control which represent the kinematic control sequence while the individual attempts to arrest the fall. Musculoskeletal injuries may occur during slipping and/or at impact if recovery fails.

Older adults are at a higher risk of slip-induced falls because the ability to integrate the neuro-musculo-skeletal system degrades with age. Intervention strategies to improve the integration must be discovered and employed to reduce the likelihood of slip-induced falls for older adults. Moreover, the effects of intervention strategies on the likelihood of slip-induced falls must be validated. In the following, the effects of an eight week weight or balance training program for older adults on the initiation, detection, and recovery processes of slips and falls.

<u>Slip Initiation</u>

Friction demand (i.e. the RCOF) is closely related to heel contact dynamics and the whole body transitioning at the time of the heel contact phase of gait cycle (Lockhart et al., 2003 and Lockhart and Kim, in press). The RCOF is suggested to increase as heel contact velocity (HCV) increases or transitional acceleration of the whole body center of mass (TA COM) decreases due to their effects on the variation in horizontal ground reaction force while walking. Proper activations of hamstring muscles and gastrocnemius muscles are important in reducing the HCV and in improving TA COM while walking, respectively. This, in turn, contributes to reductions in the likelihood of slip-induced falls. Thus, an objective of the present study was to evaluate the effects of weight or balance training on the risks of slips and, further, on the likelihood of slip-induced falls. Both weight and balance training programs were found to be effective in gaining ankle plantarflexor (i.e.

gastrocnemius muscle) and knee flexor (i.e. hamstring muscle) strengths for older adults. In conclusion, improvements in the ankle plantarflexor and knee flexor strengths accounted for improvements in transitional acceleration of COM and for the reduction in HCV, respectively. As a result, training played a critical role in reducing slip-propensity among older adults.

Detection and Recovery while Slipping

Intact integration of sensory, muscular, and skeletal systems are necessary in order to detect postural disturbance (Thelen et al., 1998) such as slipping and in order to recover from slipping. Neuromusculoskeletal training such as weight or balance training contributes to improvements in the integration of sensory, muscular, and skeletal systems. Proprioception sensitivity contributes to reflex muscle contraction providing dynamic joint stability while slipping, and muscular strength contributes to the appropriate level of force generation while slipping. Measures of postural stability, joint stiffness, and limb stability represent an ability to integrate the neuromusculoskeletal system while walking and slipping. Therefore, the objectives of the present study were to perform neuromusculoskeletal training for older adults and to evaluate the effects of the training on the sensory system (i.e. proprioception sensitivity), the muscular system (i.e. muscular strength), and the integration of the neuro-musculo-skeletal systems (i.e. postural stability, joint stiffness, and limb stability).

Postural stability, which required integration of the neuro-musculo-skeletal systems, improved only in training groups. This indicated that only the formal exercise training enhanced the ability to integrate these three systems. Additionally, improvements in postural stability after training accounted for the reduction in the likelihood of slip-induced falls. Of course, the ability to integrate these systems played a critical role in recovering from dangerous slips. Older adults in either balance or weight training program improved leg strength. Improvements in leg strength and its positive relationship to the likelihood of slip-induced falls indicated that the ability of leg muscles to produce explosive force at the ankle and knee joints while slipping contribute to reducing the likelihood of slip-induced falls. In addition, improvements in postural stability through training and its positive relationship to the likelihood of slip-induced falls indicated that increased ability to integrate neuro-musculo-skeletal systems while slipping accounted for reducing the likelihood of slip-induced falls.

Joint stiffness is an important indicator for smooth forward progression of the whole body (Mickelborough et al., 2004). The ability of the ankle muscles to generate appropriate ankle joint torque throughout the ankle's range of motion while walking indicates the quality of single limb support. Limb stability also is an important indicator for limb control since larger variability of limb stability while walking indicates unstable gait and, ultimately, fall-prone gait. The present study indicated that training accounted for improvement in joint stiffness (JS) and limb stability (LS) although joint stiffness was improved only in the balance training group. However, a high correlation between JS and LS after training indicates that JS took a part in controlling limb stability. For example, the forward progression of the whole body COM became smoother by improvements in JS. Furthermore, non-fallers after training possessed better JS and LS. Ability of the ankle muscles to produce explosive force at any ankle angle and the ability to integrate the neuromusculoskeletal system while slipping accounted for reductions in the likelihood of slip-induced falls. In conclusion, training improved both JS and LS contributing to a reduction in the likelihood of slip-induced falls among older adults. In addition, limb dominance played a role in gait stability. Therefore, transitioning the whole body on dominant legs was safer than non-dominant legs. More importantly, the study concluded that only the formal training could help reduce the likelihood of slip-induced falls among older adults, although being social active could lead to improvements in sensory sensitivity as well as muscular strength.

7.1.2 Gait Asymmetry and the Effects of Training on Gait Asymmetry

Limb asymmetry in terms of kinetics (i.e. ground reaction forces) and kinematics (i.e. joint angular velocity) is suggested (Sadeghi et al., 2000). However, no study has reported the effects of gait asymmetry on the slip-propensity. Therefore, an objective of the study was to evaluate relationships between limb asymmetry and the likelihood of slip-initiation. The present study suggested that limb asymmetry played a significant role in the slip-propensity among 18 participants. Slip propensity while transitioning the whole body on non-dominant legs was higher than dominant legs. These results may be due to muscular strength difference between dominant legs and non-dominant legs. Therefore, a study to evaluate the effect of weight or balance training on the slip-propensity was performed. In conclusion, the difference in the slip-propensity between two limbs was minimized due to training. This indicated that training could play a role in symmetrizing two limbs contributing to lowering the risks of slips among older adults.

7.1.3 Effects of Neuromusculoskeletal Training on Psychosocial Factors

Falls are a result of a complex integration of psychosocial and physical factors. Psychosocial factors are directly related to physical factors. Improvements in either of these two elements will inevitably improve the other as well. Therefore, the objective of the study was to evaluate the effects of neuromusculoskeletal training on the psychosocial behavior of older adults. After 8 weeks of participating in either training or social activities, all groups exhibited less fear of falling and more confidence about leaving their residency. Moreover, all groups were more independently active although their social involvement level did not improve. These results indicated that being involved with any activity contributed to changes in older adults' psychosocial behavior. Being active was the main key to becoming more confident and less fearful of falling although exercise training was proven to be more effective in actually improving their physical capability. There were some unexpected results when evaluating the social aspects of older adults after training. The experimenter expected that independence would be correlated with level of social involvement. Level of social involvement could have possibly been improved if 1) the local community provided more regular activities for seniors, 2) the local community center was close to their home, 3) the local community or family members could provide transportation for them.

Although both exercise training programs were effective in improving ankle and knee strength, being socially active also led to some improvements in leg strength. Also, being socially active resulted in improvements in proprioception sensitivity. The social group met three times a week and encouraged participants to engage in social activities. In order for them to participate in these activities, they had to be physically active during the meeting performing tasks that required them to reach, turn, stand, and walk. As a result, being socially involved may have led to improvement in some muscular strength as well as proprioception sensitivity.

In conclusion, being either socially active or physically active played a role in alterations in the psychosocial behavior of older adults, but, being either socially active or physically active did not play a role in alterations in the level of social involvement.

7.2 Limitations and Suggestions for Future Study

There were many limitations in the present study. Some limitations in the present study come from the threats to external validity. Statistical power of 0.65 was accepted for the present study since the number of drop-outs could not be anticipated. The training program had to begin as soon as possible when people were gathered for the introductory meeting. The experimenter could not postpone the program to wait for additional participants to join. In fact, most participants would have dropped out if training was postponed for additional participants. Therefore, the experimenter had no choice but to start the program, immediately. This low power (0.65) could have led to the unexpected results seen in some of the ankle and knee strength measures as well as measures of proprioception sensitivity. In some ankle and knee strength measures, treatment was found to be ineffective across the groups. Likewise, treatment was also found to be ineffective for measures of proprioception sensitivity. These findings may have been significant if statistical power was set higher than the current allowed level (0.65). *In the future, higher statistical power should be used so that the probability of a statistical significance test rejecting the null hypothesis for a specified value of an alternative hypothesis will be appropriate.*

Additionally, an inability to balance out gender across the groups was a limitation in the present study. As discussed earlier, the study had to start quickly once the introductory meeting was held. The experimenter was not able to postpone the program until the preferred number of participants was admitted since the volunteers had to schedule in advance hours for the social activities or exercise training sessions. Seventeen females and one male participated in this study. Therefore, it was not possible to balance the gender effect. This could cause problems when generalizing the results of the present study to all female and male adults over 65 years old. *In the future, study should either balance out gender or investigate the gender effects of this training.*

A large age range is a limitation for the present study. All participants were aged 65 and older and came from Montgomery County, Virginia. Still, participant age ranged from 66 to 82 in the present study. This large range of age could decrease the possibility for generalization of the results. *In the future, the age range should be minimized or participants should be distributed among narrow age groups such as 55-59, 60-64, 65-69, and 70-74, etc.* This could be more difficult but could improve the study's generalizability. Their educational level may have influenced their ability to adapt to training programs or to bring bias against the experiment. In other words, one group's learning curve over training and consequent slip performance may have been different from the other group. For example, one individual seemed to learn slower in terms of training procedures whereas another person seemed to learn faster. One individual seemed to be concerned about the walking experiment more than other individuals. Sometimes, many questions or concerns regarding the slip-induced fall experiment were posed to the experimenter, but, in other case, only one or two questions were asked.

Some limitations in the present study stem from the threats to internal validity. When treating multiple groups with different training programs, all the groups must be comparable to each other because one group may respond differently to a particular dose than the other. Descriptive statistics (i.e. mean and standard deviation) indicated that height, weight, and age across the three groups were not significantly different. These similarities in physical figures minimized the threat to internal validity. Still, their education level, attitude, personality, motor ability, and mental ability were not statistically evaluated to indicate if those groups were comparable. These factors may influence measures while walking or slipping and responding to questionnaires. *Ideally, in the future, more comparable individuals should be tested to minimize the selection bias.* In order to select comparable individuals for the study, interviews or questionnaires that may help categorize each individual should be developed before randomly distributing each individual into different groups.

Outside events may have also influenced participants' performance during the course of the experiment. The experimenter attempted to monitor each individual's activities throughout eight weeks. However, it was not possible to control their daily lives which may have consisted of performing heavy housework or taking on home improvement projects. These activities could have led to an improvement in strength although it was not intended to do so. This may have led to the unexpected results such as improvements in some ankle and knee strength measures in the control group.

In addition, experimental bias may have played a role in the outcomes of dependent measures. One instructor mostly instructed balance and weight training classes, whereas, the other instructor mostly instructed control group (social group). Differences in the styles of the instructors may have influenced the outcomes of dependent measures. In addition, the instructor's bias may have played a role in encouraging trainees. For all training sessions, the instructor was at the site to monitor the programs. However, with the instructor's presence, the trainees may have felt pressured to perform the activity harder than they normal could. Practically, few people can afford to hire personal trainers to be available to monitor them all the time while exercising. Most people just go to a gym and work out without trainers. This may have enhanced the effects of weight or balance training on dependent measures. In the future, a training group with their own personal trainers should be compared to training groups with one instructor in terms of their physical improvements before and after training.

Another limitation comes from the laboratory setting. Although the experimenter assessed participants' natural gait speed before entering to the Locomotion Research Laboratory and attempted to compare their natural gait speed to a simulated gait speed while wearing the fall- arresting-harness, their gait speed while actually wearing the harness would not have been their natural gait speed. The fall-arresting rig may have influenced their natural gait characteristics contributing to alterations in slip or fall-related factors. Also, with the fall-arresting harness on, their reaction mechanisms during slipping may be different from their natural reaction mechanisms. Another laboratory setting bias could come from the introduction of IRB to participants before entering the walking trials. The IRB clearly stated that slippery surfaces would be introduced while walking although the occurrence of slippery floor surface change was not indicated.

There was a limitation when designing the questionnaire to evaluate the psychosocial aspects of older adults. The present study used a pre-evaluated method called "CHAMPS" questionnaires. Eight questions were drawn out of CHAMP questionnaires, which would assess the level of independence and level of social involvement. The

CHAMPS questionnaire was designed mainly to evaluate physical activity level for under-active older men and women. Although, many of the questions drawn for the present study may still be suitable for evaluating social characteristics of normal healthy older adults. Still, the sensitivity of questions measuring social activity level may have been improved if the questionnaire was more suitable for measuring social activity level among independently living older adults. *In the future, in order to evaluate the social aspect of a sample in the local community, a more careful method should be developed to more sensitively evaluate social behavior.* For example, an experimenter should assess social characteristics of the independently living older adults in the community in which the sample population resides. Then, a more suitable questionnaire could be developed that specifically targets the sample population and more accurately assesses social activity level.

For biomechanical analysis, reliability of the instrumentation must be considered. Although two identical force platforms were used to measure ground reaction force characteristics of two different legs during a gait cycle, their sensitivity may have changed throughout 8 weeks. Also, motion analysis calibration may have changed throughout the experiments although the experimenter made every effort to standardize the instrument setting.

The present study only implemented weight or balance training for treatment. The present study did not include a group that performed both weight training and balance training simultaneously. It would have been interesting to see the additional effects of the integrated balance and weight training on dependent measures. In addition, most of the weight training for ankle muscles focused on exercising ankle plantarflexor muscles. However, the effects of training on strength and proprioception sensitivity of ankle dorsiflexor muscles were tested across the groups. These factors may have led to unexpected results such as no treatment effects found in ankle dorsiflexor muscle and proprioception sensitivity.

7.3 Future Research

The present study suggests that both weight and balance training are good intervention programs to reduce the likelihood of slip-induced falls among older adults. However, simultaneous balance and weight training has not been performed to further investigate the effects of an integrated training program (weight and balance) on the likelihood of slips and falls. Further studies should include balance plus weight training groups in addition to balance-only or weight-only training groups. For some participants, balance training will be introduced for the first half of the program and weight training will be introduced for the second half. For others, the orders of training will be reversed. Still a third group of participants will be introduced to balance and weight training alternately week by week.

The present study suggests that machine weight training can play a role in improving mobility, motor control, and strength contributing to reductions in the likelihood of slip-induced falls. The effects of free weight training on the likelihood of slip-induced falls have not been thoroughly examined. Furthermore, the effects of free weight training on the likelihood of slip-induced falls has not been compared to the effect of machine weight training on the likelihood of slip-induced falls. *In the future, an integration of free weight training and machine weight training will be implemented as a form of exercise, and biomechanical evaluations of the effects of these training programs on the likelihood of slip-induced falls will be performed.*

As indicated earlier, the results from the present study can only be generalized for healthy older adults between ages 66 and 82. It would be preferable to expand the sample age and divide participants into more specific age groups such as 50-54, 55-59, and 60-64. Currently, about 60 million people in the non-institutionalized population are age 55 and over. That is about 25% of the total US population. Furthermore, in the next 10 years, the baby boomers who are aged over 50 will be the largest population group. The well-being of this age group will be the primary goal of biomechanical research in the U.S. in the next 10 years. *Therefore, future studies will target those baby boomers who are entering their mid 50's and early 60's.*

The present study only utilized one of many balance training methods. As balance training in the present study has been found to be effective in improving older adult's physical mobility, any balance training can be assumed to play a similar role in improving older adults' physical mobility. However, scientific validations will be necessary to properly implement these balance training methods. Currently, only Tai-Chi, a form of martial art, has been suggested and used to improve balance for older adults although there are many forms of martial arts available. Besides Tai-Chi, Tae-Kwon-Do is a wellrecognized martial art in the U.S. Tae-Kwon-Do has been known to account for improvements in motor skills, muscle strength, and coordination. In addition to Tae-Kwon-Do, Yoga, a form of exercise training, is well known to improve motor skills, muscle strength and coordination. However, no study has been performed to evaluate the effects of Tae-Kwon-Do or Yoga on older adults' physical mobility, or more specifically, the factors contributing to the likelihood of slip-induced falls. *Tae-Kwon-Do and Yoga will be implemented as training regimen, in the future.*

Many scientists forget the impact of the psychosocial aspects of older adults in successful aging and improving their quality of life. The present study suggested that psychosocial factors improved after social activities such as weight training, balance training, and regular social meetings. These results suggest that social activities contribute to altering psychosocial behaviors of older adults. It has been suggested that depression and anxiety levels of a person could be relieved by exercise training. However, few studies have actually examined the effects of exercise training and social activity training on levels of either depression or anxiety. In order to evaluate this, older adults with a similar level of depression and anxiety will be randomly assigned to either an exercise training group or a social activity group. Then, the effects of each program will be assessed. The relationships between depression and anxiety, psychosocial characteristics, and training effects will also be assessed. This study will play a role in the well-being of the aging population.

Work-related injuries have been an important issue at work places that require manual labor. In 1996, The National Occupational Research Agenda (NORA), which is a collaborative program to stimulate innovative research in workplace safety and health, reported that the future of research primarily needs to target special workforces and significant work place injuries such as traumatic injuries. Slips and falls are major causes of traumatic injuries among the aging workforce. Currently, about 70 percent of people aged 55-59, 50 percent of people aged 60-64, and 17 percent of people aged 65 and over are in the civilian labor force. These percentages will become larger within the next 10 years. Therefore, to reduce fall-related traumatic injuries, it is important to identify the mechanisms that cause these falls. Falls may be inevitable due to the fatigue that occurs while performing manual labor. Fatigue is suggested to be related to a person's level of endurance as well as strength. Weight training and balance training has been suggested to improve to strength as well as endurance. Improvements in strength or endurance due to training may reduce fatigue likelihood. *Therefore, a future study should evaluate the relationships between central fatigue and the likelihood of slip-induced falls among the aging workforce (i.e. age 55-65). The study should also evaluate the effects of weight or balance training on central fatigability and the likelihood of slip-induced falls.*

Fall-related traumatic injury is a major type of injury identified by NORA. Still, intervention strategies to reduce these injuries are lacking. Most fall-related traumatic injuries are caused 1) when the muscles are generating excessive forces against unexpected disturbances such as slipping and falling and 2) when body segments or joints strikes against the ground or hard materials. To reduce these possible injuries, estimates need to be made of how much force is generated in each muscle during the unexpected slips and falls and how much impact is generated between the materials and body parts. Therefore, the future study utilizing either EMG or simulation (human muscle modeling) will be introduced to estimate the dynamic muscle forces while slipping and falling and to estimate the impact between the body part and materials such as a cement floor.

7.4 Major Contributions

7.4.1 Contributions to Science

Many studies have evaluated the effects of weight or balance training on fall mechanisms. However, the effects of weight or balance training on the slip initiation factors such as heel contact velocity and transitional acceleration of center of mass has not been reported thoroughly in literature. The experimenter also is not aware of any study that has attempted to predict the likelihood of slip-induced falls by biomechanical measures that were evaluated while walking on the actual slippery surface.

The second significant contribution of the present study is that this may be the first study to concern the relationships between limb asymmetry and slip initiation and likelihood of slip-induced falls. Moreover, this may be the first study to report the effects of weight or balance training on limb asymmetry.

The third significant contribution of the present study is that measures of limb variability were simplified by implementing a currently available mathematical technique (factor analysis). The significance of this unique measure is that the values from this measure can represent the sum of gait variability while walking. Hopefully, this simplified biomechanical measure will be a baseline for all the measures of limb variability.

The fourth significant contribution of the present study is that the study found that flexibility at ankle joint was improved due to balance training, but not to weight training. Most studies, which observed the effects of exercise training programs on gait characteristics, evaluated the spatial-temporal gait characteristics such as gait speed, step length, and swing time etc. However, in this study, musculoskeletal characteristics of musculoskeletal systems such as ankle joint stiffness after training were evaluated.

Finally, the present study may be the first to employ social activities for control group to eliminate commonly occurring additional treatments such as motivation, competition, and cooperation when an exercise group is formed. By introducing social activities for the control group, the study isolated and identified the effects of physical treatments on psychosocial characteristics and the biomechanical measures.

7.4.2 Contribution to the Community

More than 25% of older adults fall every year, and older adults and their family members fear their falls and fall-related injuries due to the associated high mortality rate. The Center for Disease Control (CDC) reported in 2003 that emergency departments treated more than 1.6 million seniors due to fall-related injuries and, among them, 373,000 were admitted to the hospital. Older adults are at a higher risk of falls due to age-related deficient gait characteristics and postural control, especially when facing unexpected external perturbations such as slippery surfaces. Falls among the elderly over 65 result in enormous economic and personal losses. To minimize economic and personal losses, tribometric techniques for assessing shoe/floor interactions were studied as well as postural control and the biomechanical responses of walking on slippery floor surfaces. Still, the elderly population is at a high risk of falling and, in fact, it is a major cause of hospitalization (CDC, 2003). However, reasons for slip-induced fall accidents are still not clear. Hopefully, the present study provides insight into not only the causes of slips and falls among the aging population but also the factors contributing to recovery from slips.

Additionally, this study should have shown the effectiveness of balance or weight training in improving mobility and, further, in reducing the likelihood of slip-induced falls in older adults. The goal of this research is to help the aging population and their families to identify an appropriate intervention strategy such as weight or balance training for reducing the likelihood of slip-induced falls and such as social activity meetings for improving psychosocial behavior.

7.5 Design Implementation and Recommendations

Either balance or weight training program should be considered for older adults 1) for improving ankle plantarflexor muscle strength and knee flexor muscle strength which play an important role in reducing the slip propensity and 2) for improving an ability to integrate neuro-musculo-skeletal systems which play a critical role in improving the likelihood of recovery while slipping.

Being involved with the exercise training programs contributes not only to improvements in physical capability but also improvements in psychosocial behavior among older adults. Proper implementation of balance or weight training will lead older adults to become more independent. In particular, people who live in professional care settings such as nursing home residents should participate in these kinds of exercise programs.

Older adults are at a higher risk when they transition their body on their non-dominant leg. Either weight or balance training will improve the non-dominant leg's strength contributing to a reduction in heel contact velocity and an increment in transitional acceleration of the whole body center of mass. This should lead to a reduction in the likelihood of slip-induced falls.

As indicated by the study, well-organized regular social activities contribute to as much improvement in psychosocial behavior and muscular strength as regular exercise training. Exercise training or social activities should be considered for those older adults who need to improve psychosocial behavior. However, for those older adults who may not wish to participate in an exercise training program, but, need to improve psychosocial behavior, regular social activity meetings only should be considered.

As an industrial engineer, a concern is to improve workers' health status while working. Exercise training programs for the well-being of older workers (both office and labor workforces) should be considered to reduce injuries associated with slips and falls and to improve an ability to integrate neuro-musculo-skeletal systems. Employing exercise training programs for middle-aged workers should be also considered due to the effects of the training programs on the psychosocial behavior and the physical capability such as muscular strength and flexibility. Companies should consider allowing workers to take a short break and perform weight lifting or balance exercises. A facility to perform either weight training or balance training should be considered to be within their building or close to the workers.

Reference 7

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Appendix 1. Falls and fear of falling measure

Question 1: Have you been fallen within the last 12 months? Falling includes unintentionally coming to rest on the ground or other level such as a chair. (Friedman et al., 2002)

□ **YES**

□ **NO**

Q2: How afraid are you that you will fall and hurt yourself in the next year?
(Mark (i.e. /) a point where it is applicable)

0--3--6

Not at all Very Afraid

Q3: Do you ever limit your activities, for example, what you do or where you go, because you are afraid of falling? (Howland et al., 1998) Please read next questions and mark.

You don't leave the residency because are worried that you might fall.
(Mark (i.e. /) a point where it is applicable)

0---3---6

Less Likely More likely

You stop doing things because you are worried that you might fall.
(Mark (i.e. /) a point where it is applicable)

0---3--6

Less Likely More likely