THE EFFECT OF A WEIGHTED-VEST STRENGTH AND BALANCE TRAINING PROGRAM ON OBSTRUCTED WALKING IN POSTMENOPAUSAL WOMEN

by

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SUMMARY

Background: Age related declines in lower extremity strength have been associated with impaired mobility and changes in gait patterns, which increase the likelihood of falls. Since community dwelling adults encounter a wide range of locomotor challenges including uneven and obstructed walking surfaces, we examined the effect of a strength and balance exercise program on obstructed walking in postmenopausal women.

Objectives: This study examined the effect of a weighted-vest strength and balance exercise program on adaptations of the stance leg during obstacle walking in postmenopausal women. Methods: Eighteen women aged 44-62 years who had not engaged in regular resistance training for the past year were recruited from the St. Catharines community to participate in this study. Eleven women volunteered for an aerobic (walking), strength, and balance training program 3 times per week for 12 weeks while 7 women volunteered as controls. Measurements included: force platform dynamic balance measure of the center of pressure (COP) and ground reaction forces (GRFs) in the stance leg while going over obstacles of different heights (0, 5, 10, 25 and 30 cm); and isokinetic strength measures of knee and ankle extension and flexion. Results: Of the 18 women, who began the trial, 16 completed it. The EX group showed a significant increase of 40% in ankle plantar flexion strength \( (P < 0.05) \). However, no improvements in measures of COP or GRFs were observed for either group. Failure to detect any changes in measures of dynamic balance may be due to small sample size. Conclusions: Postmenopausal women experience significant improvements in ankle strength with 12 weeks of a weighted-vest balance and strength training program, however, these changes do not seem to be associated with any improvement in measures of dynamic balance.
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DEDICATION

To Dushan,
for providing wisdom when I needed direction,
strength when I needed support, and love
for all of the other times.
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LIST OF ABBREVIATIONS

%BF = relative body fat
1-RM = one repetition maximum
A/D = analogue to digitally
A/P = anterior-posterior direction
BIA = bioelectrical impedance analysis
BOS = base of support
COM = center of mass
CON = control group
COP = center of pressure
EX = exercise group
FFM = fat free mass
GRFs = ground reaction forces
HR = heart rate
M/L = medial-lateral direction
RPM = revolutions per minute
SE = standard error of the mean
SM = skeletal mass
T1 = before 12 weeks of training and control period
T2 = after 12 weeks of training and control period
V = vertical direction
Vo₂max = maximal oxygen consumption
CHAPTER 1

INTRODUCTION

1.1 PURPOSE

The purpose of this study was to examine the effects of exercise-induced strength gains on lower limb adaptations during obstructed walking in postmenopausal women.

1.2 RATIONALE

It is estimated that 1 of every 3 adults aged 65 and older fall each year (1). Falls are the leading cause of injury-related deaths and hospital admissions in elderly persons. Unintentional falls were more common in senior women and accounted for 71% of all injury admissions in Ontario (2). Falls are a major contributing factor to fractures (3;4) and are associated with considerable morbidity and mortality (5;6), reduced functioning (7), and increased institutionalization (8). In 1999/2000 the cost to treat fall-related injuries totalled $250 million in Ontario alone (9).

Falls are caused by a loss of balance and are more likely to occur in venues where there is poor lighting, uneven ground, cluttered pathways and obstacles or raised surfaces (10). Since normal aging is characterized by a decreased ability to maintain postural stability (11), environmental hazards can disturb postural regulation and increase the risk of falls. Maintaining postural stability requires the integration of the muscular, visual, vestibular and somatosensory systems (12). Unfortunately, aging is characterized by a decline in these systems which impairs postural stability and increases the risk of falls. As a result, any efforts to improve these systems may enhance postural stability and reduce the risk of falls. Since older women are at an increased risk of falling (2) and it is
expected that the elderly female population will continue to increase in coming decades, it is particularly important to establish ways to reduce the risk of falling in this group.

Recently, The North American Menopause Society has established exercise as one strategy for reducing falls and risk factors for falls in women (13). Several randomized clinical trials have demonstrated that regular physical activity can improve muscle strength (14-17), balance (18;19), functional performance (17) and reduce fall occurrence (18;20;21) in older adults. However, these studies have focused on the effects of exercise on measures of static balance and unobstructed level walking. Since community-dwelling adults encounter a wide range of environmental challenges such as unlevelled surfaces and cluttered pathways, it is important to examine the benefits of exercise on obstructed walking. The only study to investigate the effects of exercise induced strength gains on obstructed walking (22) showed that strength gains in the exercise group were accompanied by significant improvements in obstructed gait function. However, the results of the male and female subjects were grouped together, which masked the responses of the women to the exercise program. As a consequence, the positive results may have been due to increases brought about by the male subjects. In light of these findings further investigation is warranted to examine whether similar adaptations occur in postmenopausal women only.

1.3 **SPECIFIC OBJECTIVES**

In order to quantify the changes in strength and lower limb adaptations during obstacle walking, two groups (exercise and control) underwent dynamometry and gait analysis before (T1) and after 12 weeks (T2). The exercise group (EX) walked on a 200 metre track (intensity: 75% of age-predicted maximal heart rate) and performed strength and
balance exercises using a 20"- 12° angle wobble board three times a week for 12 weeks while wearing a weighted-vest. The vest was loaded as a percentage of body weight and was increased by 4% every 3 weeks up to a maximum of 15% of the subject’s body weight. The control group (CON) performed regular daily activities which did not include training of any kind. The specific objectives included:

- determining the magnitude of change in ankle and knee peak flexion and extension torque (N-m) at speeds of 60° s⁻¹ and 180° s⁻¹;
- assessing the magnitude of change in peak vertical (V), anterior-posterior (A/P), and medial-lateral (M/L) ground reaction forces (GRFs) of the standing leg during obstructed walking;
- calculating the change in anterior-posterior (A/P) and medial-lateral (M/L) center of pressure (COP) excursion of the standing leg during obstructed walking;
- investigating if exercise-induced strength gains correlate with lower limb adaptations during obstacle walking;
- evaluating the compliance of the exercise group to the prescribed exercise program.

1.4 HYPOTHESES

Strength and balance training with a weighted vest will elicit significant improvements in ankle and knee strength in exercisers compared with controls. These exercise-induced strength gains will be associated with significant decreases in peak V, A/P and M/L GRFs and increases in A/P COP excursion and reductions in M/L COP excursion.
2.1 Incidence of falls and fractures

Fall and hip fracture incidence rates increase exponentially with age. In Canada, O'Loughlin et al. (1) found an incidence rate of 29% in a 48-week prospective study of a random sample of 409 community-dwelling people aged 65 years and older. Similar rates have been found in the USA by Tinetti et al. (23) in a sample of 336 subjects aged 75 years and over (32%), and in Finland by Luukinen et al. (24) in 833 community-dwelling people aged 70+ years from five rural districts (30%). In the Randwick falls study (25), researchers found that the incidence of multiple or recurrent falls increase beyond the age of 65 years.

For adults 65 years and older, 60% of fatal falls happen at home, 30% occur in public places, and 10% occur in health care institutions (10). Women have been shown to fall more often than men (26) and as a result suffer more fractures than men so that fracture incidence in women become twice those of men (27). The three most common sites of fracture are the hip, spine, and distal forearm (28). There is a greater likelihood of falling the older an individual is. Also, if an individual has experienced a fall in the past there is a greater chance of experiencing a fall in the future (25). Figure 2.1 reveals the proportion of women who reported falling once, twice or three times in a 12-month period.
Figure 2.1 Proportion of older women who reported falling once, twice, three times or more in a 12-month period (Randwick Falls and Fractures Study) (25).

### 2.1.2 Consequences of falls and fractures

Unintentional falls are the leading cause of injury among emergency department visits and hospitalized cases in Ontario accounting for 65% of all trauma hospitalizations (Figure 2.2) (2). With advancing age fall rates increase exponentially. Falls are the leading cause of injury-related hospitalizations among seniors aged 65 years and over (29), and account for 85% of all injury admissions in Ontario (2). In senior women, unintentional falls account for 71% of all injury admissions in Ontario (2). Approximately half of falls result in minor injury and 5 to 25% result in serious injury such as fractures and sprains (30;31).
Falls are also a significant source of psychological distress. For older adults living in the community, the reported prevalence of the fear of falling ranged from 29% and 77%, tending to be greater in women than men with age (32;33). Fear of falling can limit physical activity and reduce functional abilities which can lead to reduced quality of life (7;34;35). Recently in a population-based study of 1064 persons aged 72 years and older, 19% reported restricting activities as a result of fear of falling (36).

In terms of morbidity and mortality, falls account for 57% of deaths due to injury in senior women and 36% of deaths among men (5). Of those who survive, many never recover and suffer from chronic pain, reduced activity levels that may lead to future falls, and a fear of falling (31;32;37). These consequences may result in lifestyle changes that have a negative impact on quality of life (38) and increase the likelihood of early
institutionalization as evident by the fact that 40% of all nursing home admissions can be directly attributed to seniors sustaining a fall (8). According to data from the 1994/1995 National Population Health Survey, seniors who reported an injurious fall were three times more likely to enter into care than those who did not report a fall (26).

Fractures are the most serious outcomes related to falls. It is estimated that 90% of hip fractures are a result of a fall from standing height (3;39). Falls are a major contributing factor to overall fracture occurrences in postmenopausal women (4). For example, distal forearm fractures are almost always a result of a fall where the individual has extended their arm to stop from falling (28). The majority of distal forearm fractures occur among women aged 65 years and older.

The statistics related to hip fractures are particularly disturbing. By age 50, women with an average lifespan of 80 have an 18% risk of hip fracture (40). Complications due to hip fractures result in death in up to 20 percent of cases, and disability in 50 percent of those who survive (6). Patients who suffer from hip fractures experience deterioration in functional status. For example, half of patients, who reported independence with dressing before fracture, regained this ability and only third of patients resumed independent transferring following recovery (41). Outcomes related to hip fracture include declines in physical capabilities (walking, bending, and reaching), loss of functional dependence, increased need for personal support, permanent institutionalization, diminished quality of life and deterioration of perceived health (6). Research has also demonstrated impairments in physical performance related to walking speed, range of motion, and daily activities such as cooking and shopping (42;42;43).
Since women are at a higher risk for falls and fractures, and it is expected that the female elderly population will increase in coming decades, it is of particular importance to establish ways to reduce the risk of falling in women.

2.1.3 Economic costs of falls

Given the consequences of falls and fall-related injuries it is not surprising that the cost of treating falls places a considerable burden on health care resources. Elderly people who report having an injurious fall are significantly more likely to use health care services in the following year (26). An estimated basic cost for fall-related injuries in Canada in 1994 amounted to $2.8 billion (44). In 1999/2000 falls were the most expensive trauma to treat accounting for 62% of all hospital costs amounting to more than $250 million in Ontario alone (Figure 2.3)(9). Unintentional falls in seniors aged 65 and older accounted for 79% of total hospital costs (9). The total cost to treat falls in males 65 years and older totalled $65 million, while the cost to treat falls in women of the same age category totalled $155 million (Figure 2.4). In 1999/2000 the average total cost to treat one case of unintentional fall was estimated at $6,998 (9). Lengthy hospital stays and chronic care account for the majority of these costs. For example, the length of stay for admissions due to falls were estimated at 15.4 days in adults aged 65 and older (9). As the population ages, and the total number of fall-related injuries rise, these cost will continue to escalate. Therefore, developing effective strategies aimed at fall prevention in the elderly will be a major focus of the Canadian health care system.
Unintentional falls
Motor vehicle collision
Other incidents
Fire & flames
Attempted suicide
Foreign bodies
Pedal cycle incidents
Underdetermined intent
Incidents with other road vehicles
All other causes

Figure 2.3 Total hospital costs by cause of injury in Ontario 1999/2000 (CIHI).

Figure 2.4 Total hospital costs of unintentional falls by age group and gender in Ontario 1999/2000 (CIHI).
2.2 CAUSES OF FALLS

Falls are almost always caused by a combination of personal (intrinsic) and environmental (extrinsic) factors. Although the presence of a particular risk factor may not guarantee a fall, research has shown that the presence of more than one risk factor greatly increases the risk for falls (45).

2.2.1 Extrinsic factors

Previous studies have found that extrinsic factors are responsible for 42-55% of all falls in community-dwelling adults (46;47). Extrinsic factors can disturb the different levels of postural regulation and cause a fall (48). For example, factors related to ground surfaces such as smooth or rough textures (49), the presence of an obstacle (50), wear of the floor covering (51), snow, ice and wetness (50) have been shown to increase the risk of falling.

Lighting is also a major factor involved in falls, especially when the light is too bright or insufficient (52). Interestingly, Campbell et al, (53) showed that temperature, especially cold temperatures increase the likelihood of falls, particularly in older women.

2.2.2 Intrinsic factors

Due to the fact that most falls are caused by a loss of balance, impairments in postural stability has been identified as the most important intrinsic risk factor for falls (54;55). Other impairments that increase fall risk include decreased lower extremity strength, decreased range of motion, cognitive impairment, sensory impairments, visual deficits, and decreased reaction time (24;39;56). Strength deficits in the hip, knee, and ankle increase fall risk (56;57). Robbins et al. (1989) reported that fallers, both community-
dwelling and institutionalized, have more hip weakness, and use more prescription drugs than non fallers (57).

Recently, Krueger et al. (58) identified history of falls, living in a long-term care facility, chronic illness, and altered mental state as the most important risk factors for falls. Medications can also increase the risk of falls in all elderly regardless of their living situation. Studies have shown that sedative use increases fall risk in both community-dwelling and institutionalized elderly (23). Using four or more medications may also increase a person’s risk for falls (57). Due to medications associated with certain diseases fall risk increases. For example, research has shown that a history of chronic lung disease, arthritis, Parkinson’s disease, and stroke has been shown to increase fall risk (59;60).

Gait impairments that identify fallers include increased trunk sway, inability to increase speed of walking, and more path deviations (56). Lord et al. (56) were able to discriminate fallers with more than one fall by the amount of postural sway present when the subject was standing on foam with eyes open.

2.3 BALANCE

2.2.1 Static Balance

Postural stability

Control of postural sway during standing requires continual muscle activity usually of the calf muscles and an integrated reflex response to visual, vestibular and somatosensory inputs (12). Aging is characterized by a decline in these systems, which contributes to increased postural sway. Research has shown that older persons exhibit greater sway than younger individuals and a number of studies have reported age-associated increases
in standing postural sway after the age of 30 years (61-63). There is no consensus regarding gender differences in sway; however, some studies report greater postural sway in women compared with men (64), while others have reported no differences (65;66).

Factors that are highly correlated with increased sway include reduced leg muscle strength (11;67), reduced peripheral sensation (68;69), poor near visual acuity (11;70) and slowed reaction time (11;71). A number of cross-sectional studies have reported significantly greater postural sway in subjects with a history of falling compared to non-fallers (72;73). In addition, prospective studies have shown that postural sway is a predictor of the risk of falling during follow-up periods (74-76).

Investigations of standing postural sway have also included standing tests, which alter foot positions and thus provide greater challenge on the postural control system. Investigators have evaluated in detail the effect of foot positioning on postural stability using force plates (77-79). Increases in postural sway were apparent during the more challenging conditions as result of the reduced size of stability limits.

Postural stability during leaning tasks

Early studies conducted by Hasselkus and Shambes (80) have shown that older women exhibit greater sway during leaning conditions compared to young women. Similarly, King et al. (81) studied the ability of women aged 20-91 to reach as far forward and backward as possible while standing in order to establish age-related differences in functional base of support. The authors found a decreased base of support was evident after the age of 60 and declined about 16% per decade thereafter.

Similarly, Duncan et al. (82) developed the functional reach test in order to assess postural stability during forward leaning. The authors reported significant age-related
declines in functional reach (82) and smaller mean reach in older subjects compared to younger subjects (66). Subsequent investigations have shown that functional reach is highly correlated with performance in activities of daily living (83) and is a significant predictor of falls in older subjects (84).

2.2.2 Dynamic Balance

Dynamic balance is an essential component of successful human locomotion and involves both reactive and anticipatory postural adjustment strategies (85). During reactive postural adjustments, automatic co-ordinated movements of the muscles are produced after the body encounters unpredictable forces, thus ensuring balance recovery. Conversely, during anticipatory strategies, activation of postural adjustments occurs prior to postural disturbances (86) This enables one to minimize balance disturbances and prevent the loss of balance during normal walking (87;88).

2.2.3 Factors of Balance

Maintaining balance requires the integration of sensory information regarding the body’s position, and the ability to generate forces to control movements (89). Thus, human balance depends on the interaction of sensory, motor, and integrative systems. The sensory system includes vision, vestibular function and somatosensation, which provide information about the position of the body relative to its surroundings. The musculoskeletal system is comprised of body segments, muscles and joints. Integrating these two systems requires higher-level neurological processing which enables the body to plan and respond to changes in the environment. A hierarchical model for the central control and organization of movement has been proposed by Allen and Tsukahara (90)
involving two levels of organization. The first involves planning and programming which includes the basal ganglia and the neocerebellum; the second involves the execution of the movement, which includes the integration of the motor cortex and the periphery. Knowledge of the central control of postural orientation and equilibrium is sparse and current evidence suggests that the spinal cord alone is not capable of producing the organized equilibrium.

Normal aging is associated with changes in the function of the musculoskeletal and sensory systems which contribute to postural instability (61;91). As a consequence, the aging process produces measurable deficits in tasks involving the maintenance postural stability.

**Attention**

It has been proposed that a slowing of central cognitive processing is primarily responsible for the impairment in balance performance seen with increasing age. Several investigators have examined attentional demands of postural control using a dual-task paradigm (92-96). In general, these studies show that tasks considered to be highly automated, require some degree of attention, and that static tasks require less attention than do dynamic tasks. This may be of particular importance since most women suffer falls in the home (97) perhaps as a result of increased attentional demands of dynamic activities such as housework. Recently, Marsh & Geel (98) employed a dual-task paradigm to determine the attentional demands of several postural control tasks in 16 older women and 14 young women. The authors showed that compared to the younger women, the older women had slower verbal reaction time and required more cognitive resources to maintain simple eyes open standing posture. This evidence has significant
implications for older women who may be at risk for falls and who may be performing tasks which require greater attention.

*Sensation*

Control of dynamic balance requires the integration of information from somatosensory, vestibular, and visual systems in order to provide a coherent interpretation of the body's orientation (99). This process occurs at the subconscious, involuntary level, and produces automatic postural adjustments. Sensory information can be divided into both exteroception (vision and hearing) and proprioception (skin receptors, muscle spindles, golgi tendon organs, joint and vestibular receptors).

In 1851, Romberg was the first to recognize that the elimination of visual input increases postural sway in humans. Since then, research has shown that visual acuity, level of illumination, and location and size of the visual stimulus within the visual field affect postural stability as well (100). Many researchers have found that various visual functions such as visual acuity, contrast sensitivity, glare sensitivity, dark adaptation, accommodation and depth perception decline significantly with age, especially beyond age 40 (101;102). Of all the visual functions, visual acuity has received the most attention in relation to falls and fall-related injuries.

In a large cross-sectional study, Ivers et al. (103) found that impaired visual acuity was associated with a history of falls. Similarly, Nevitt et al. (59) showed impaired depth perception and demonstrated that poor visual acuity was a risk factor for recurrent falls in older men and women. Conversely, Brocklehurst et al. (104) and Robbins et al. (57) have found no association between visual acuity and falls in subjects 65 and older.
Information from a number of systems including mechanoreceptors in the skin, pressure receptors in deep muscle, muscle spindles, golgi tendon organs, joint and vestibular receptors, integrate in order to provide information about postural orientation, perturbations in balance and in triggering rapid responses to regain postural equilibrium.

Research has demonstrated age-related declines in vestibular reflexes (105) and vibration sense (106). These age-related declines are caused by decreases in the number of nerve fibres in the vestibular nerve, which results in reduced vestibular excitability (107). Several studies have shown age-related declines in vibration sense in all parts of the body with greater age-related declines occurring in the lower limbs compared to the upper limbs (108;109). Poor vibration sense of the lower limbs suggests that an individual may have a decreased ability to detect obstacles or changes in standing or walking surfaces and as a result may be at an increased risk for falls.

In a prospective study comparing fallers with non-fallers, Lord et al. (56) reported that fallers had reduced vibration sense and impaired lower limb proprioception. In a previous study the same group (74) demonstrated that impaired lower limb proprioception is highly correlated with multiple falls in the elderly.

Using dynamic posturography, Speers et al. (110) reported increased postural sway in the elderly and proposed that these declines were due to a decreased ability to detect small motions in standing surfaces. As a result, the authors suggest that these age-related sensory changes may contribute to unsteadiness in the elderly.

**Strength**

The age-related losses observed in skeletal mass are directly related to decreases in muscle strength and are considered to be a major contributing factor to the loss of
functional dependence and frailty in many older adults (111;112). In both sexes, muscle strength reaches peak values between 20 and 30 years of age, after which strength begins to decline 10-15% per decade until it levels off in the seventh and eighth decade where individuals have about 50% of the strength of younger adults (113;114). Although the exact mechanisms underlying age-related losses in strength have not been elucidated, the underlying mechanism is believed to be related to decreases in muscle mass (115). The absolute strength of women ranges form 40-60% of that of men (116), which can be directly attributed to higher absolute skeletal mass in men. After expressing strength in relation to kilograms of body weight these differences disappear.

Interestingly, some researchers have shown that muscle strength in women declines from an earlier age and at a greater rate compared to men (117). However, despite this finding some researchers have shown a greater age-related loss in strength in men compared to women. Recently Sinaki et al. (118) conducted a study designed to examine age and gender differences in muscle strength in 70 men and 72 women aged 20-89 years of age. Interestingly, the authors reported greater age-related loss in back extensor strength in men compared to women. Although men had a greater age-related loss in muscle strength, reduced strength was related to a higher incidence of back pain, falls and fractures in women (118). Pearson et al. (119) found that 14% of community-dwelling women aged 75 years were unable to exert enough force with the calf muscle to support their body weight. This would indicate that these women would be at an increased risk of falling due mainly to their inability to perform everyday tasks such as climbing stairs, which requires them to transfer their weight from leg to leg. Therefore,
muscle weakness of the lower limbs has significant implications for risk of falling, and every effort to reduce the risk in women should be made.

Recently, the term “muscle quality” has been used to describe specific tension referring to the strength per unit of muscle mass, and is considered to be a better indicator of muscle function than strength alone (112). Although there is no consensus regarding gender differences and muscle quality some researchers have found no difference in muscle quality between older and younger women (120), while some have reported age-associated declines in muscle quality in men (121;122). In order to further describe these age-related and gender differences in muscle quality Lynch et al. (123) studied muscle quality of the arm and leg in 502 men and women aged 19-93. The authors found the following: 1) age-associated differences in arm muscle quality was greater for men than women, 2) muscle quality of the leg was higher in the arm for both men and women, 3) the decline in leg muscle quality was greater for women than men. These gender differences may be related to altered muscle fibre contractile function. For example, men were found to have significantly greater whole muscle cross-sectional area than women (124). Another possible explanation for gender differences in muscle function may be estrogen. For example, research has shown that women experience a 15% loss in muscular strength during the perimenopausal years which occurs in addition to age-related losses in strength (125). Therefore, implementing exercise interventions designed to improve strength in early postmenopausal women is of particular importance.

It is well established that aging is associated with declines in skeletal mass (SM). Gallagher et al. (126) measured upper and lower body SM and total appendicular SM using dual energy x-ray absorptiometry in a sample of 148 women and 136 men between
20-29 years of age. Men had significantly greater total appendicular SM than women and exhibited greater age-related losses in total appendicular SM than women (14.8% versus 10.8% respectively). Similarly, Jansen et al. (127) used whole body magnetic resonance imaging to assess losses in SM in 268 men and 200 women aged 18-88 years. The authors found that men had significantly more SM in comparison to women in both absolute and relative terms. These gender differences were greater for the upper body (40%) than the lower body (33%). However, despite greater SM, men had greater losses in SM with aging compared with women. Although men had greater losses in SM with aging, sarcopenia poses a greater risk in women because they tend to live longer than men do and have higher rates of disability (112).

2.2.4 Balance during Normal Gait

During locomotion, several different variables of postural orientation and balance are controlled simultaneously. The trajectory of the centre of mass (CoM) is controlled primarily by foot placement and travels along the medial border of the stance foot (128). Although CoM is rarely within the base of support, its trajectory is controlled to maintain balance.

Walking consists of repetitive and reciprocal movements that coordinated to a pattern involving the extremities and the trunk. There are two phases involved with walking. The swing phase, during which the foot is lifted and swung forward, and the stance phase when the foot is planted on the ground and moves backward relative to the trunk following one another (129). These movements are caused by coordinating motions of the ankle, knee and hip. Given that aging is associated with declines in both the sensory function and muscle strength, it is not surprising that gait patterns will change
with age and may be associated with decreased postural stability and falling (130). A number of studies have investigated the difference in gait patterns between younger and older individuals. Most studies have reported that older individuals walk more slowly than younger persons (76;131-133), which has been found to be directly related to shorter stride length (76;134;135) and increased time in double support (when one leg is about to begin the swing phase and the other leg has just finished it) (76;85;136).

Certain changes in gait patterns may predict falling in older people and some researchers consider gait velocity a valid measure of postural stability. Several studies have reported significantly slower gait velocity in subjects with a history of falling compared to those without a history of falls (72;73). In a large prospective study using 183 community-dwelling women, Lord et al. (76) found that slower gait velocity predicts falls.

Gait variability is an alternative approach to assessing gait changes associated with impaired postural control. One study has found that greater variability in stride, stance, and swing time are predictive of falls in older people (137).

**Balance during obstructed walking**

Since most falls are often caused as a result of tripping (97;138), it is necessary to study balance control mechanisms during walking in hazardous environments such as in the path of obstacles. Just as in normal walking, obstructed walking requires that balance control mechanisms take place before the body encounters a potential threat. This involves the early detection of potential hazards and the implementation of postural and locomotor adjustments prior to contact with the hazard. In this sense the visual system and attention are important aspects to early detection of potential threats to balance.
Once balance threats are recognized, complex sensorimotor integration occurs and modification of the walking behaviour is carried out (86). Identifying and understanding these modulations in walking during obstructed gait can provide us information about how to prevent falls.

Chen and colleagues (139) were one of the first groups to test obstacle avoidance in younger and older adults and found that foot placement during obstacle walking was shown to play a critical role in successful negotiation of obstacles. Using obstacles of 0, 25, 51 and 152 millimetres in height with a 4 metre approach, the authors found that older subjects employed a more conservative stepping strategy by having a slower crossing speed, shorter step length and smaller distance between the obstacle and the next heel strike. The authors argue that this conservative strategy serves to reduce the risk of toe-contact with obstacle as well to minimize the motion of the body’s center of mass (COM) in order to achieve more control. However, in the event of contact with the obstacle the older subjects would have less time to recover. In addition the authors found that although none of the older subjects fell, 25% stepped on the obstacle itself suggesting that age is associated with difficulty in negotiating raised surfaces and foot targeting.

Similarly, Patla et al. (87) examined the strategies for going over obstacles by manipulating obstacle height, cue time, and location of the obstacle. In these experiments the authors found that the healthy young subjects given adequate cue time were able to successfully modify their limb trajectory to go over obstacles of 2cm and 8cm. However, the high obstacle-late cue presented the greatest challenge as seen by the lower success rates. The authors also observed two strategies when going over higher obstacles. The first strategy involves providing an upward bias to the swing-leg by causing an elevation
null
in the body's COM and an increase in the V GRFs of the stance limb. The second strategy involves elevating the swing limb higher by flexing at the various joints. In particular, hip, knee, and ankle flexion increases as obstacle height increases. Since inadequate limb elevation during obstacle walking can increase the risk of tripping, this second strategy allows for large clearances of obstacles and represents greater safety.

Since stepping over obstacles of increasing height can make the body more unstable by moving the body's COM beyond the base of support (BOS), it is therefore important to measure the movement of the center of pressure (COP) and COM during obstacle walking. Using six healthy young subjects, Chou et al., (140) examined the effect of increasing obstacle height on the motion of the whole body's COM and subsequently the interaction with the COP. The authors found significant increases ($P = 0.043$) in the whole body's COM in both the anterior-posterior and vertical directions and a greater anterior-posterior distance between the COM and the COP during higher obstacle stepping. This data provides further evidence of the postural challenges of obstacle walking by emphasizing the instability it causes. As a result, it is necessary to investigate if certain factors such as lower limb strength can reduce the challenge that higher obstacles pose.

Initial data from our laboratory showed that peak ankle plantar torque at speeds of 60 and 180 degrees/second were negatively correlated with M/L GRF and M/L impulse (see Appendix 13) in postmenopausal women (172). The direction of this correlation revealed that those women with greater ankle strength used much less force in the medial lateral direction to negotiate obstacles of 30 cm in height. These findings warrant
further investigation to examine whether an exercise program designed to improve ankle strength can improve measures of dynamic balance.

2.4 EXERCISE INTERVENTIONS TO REDUCE FALLS RISK

Exercise can play a major role in preventing the risk of falls and reducing the modifiable risk factors associated with falls. One meta-analysis conducted by the Frailty and Injuries: Co-operative Studies of Intervention Techniques (FICSIT)(141) combined various forms of exercise with other interventions and found that individuals in the exercise groups had an estimated 10% lower risk of falling than the controls. However, not all exercise programs have been found to prevent falls. In the FICSIT meta-analysis, interventions classified as resistance, endurance or flexibility training did not significantly affect fall rates. Although exercise programs may be useful in modifying key risk factors for falls, some exercise programs may provide more benefit in terms of fall prevention and as a result it is important to discuss the different categories of exercise.

2.4.1 Resistance/strength training

Since age-associated declines in muscle mass and strength are risk factors for falls, it is of particular importance to examine the impact of resistance training on improving strength and reducing the incidence of falls. Recent reviews have shown that resistance training has profound effects on the musculoskeletal system and contributes to the maintenance of functional abilities through improvements in muscle mass and muscle strength, which can lead to reduced falls and fractures (142;143).
A number of randomized controlled trials have shown that resistance training can substantially increase muscle strength in community-dwelling adults aged 60 years and older. In a one-year circuit training study Pyka et al. (144) showed that prolonged moderated to high intensity resistance training increased muscle strength and muscle mass. Similarly, McCartney et al. (14) demonstrated that a twice-weekly 42-week program increased strength in women aged 60-80 years for at least 12 months. However, the authors revealed that the greatest gains were seen during the first 3 month of training. These gains have been demonstrated even with a reduced exercise frequency of only one resistance training session per week (15).

Using magnetic resonance imaging, Tracy et al. (145) evaluated the effects of resistance training on total quadriceps muscle volume, and found a 12% increase for both men and women aged 65-75 years of age. In order to see if the benefits of exercise could translate into improved functional performance, Carmeli et al. (146) studied the effects of a 12-week strength and cardiorespiratory training program on 28 men and women aged over 80 years. The authors confirmed the positive effects of strength and endurance training on functional performance in older people. Similarly, Schlicht et al. (147) demonstrated that 8 weeks of intense strength training improved maximal walking speed in men and women aged 60 years and over.

To date a majority of the studies on resistance training focus on older women, few studies have attempted to examine the effect of resistance training on strength and balance of younger postmenopausal women. Nelson et al. (148) showed that a 1 year twice-weekly high-intensity strength training program was effective at improving muscle mass, strength and balance in 20 women aged 50-70 years. In a more recent study, Shaw
et al. (149) examined the effects of a 9-month resistance training program on strength and power and other indices of falls. Of the 44 women recruited, 22 women (aged 50-75 years) participated in a weighted-vest resistance training program. The authors reported significant increases in lower body muscle strength (16-33%), muscular power (13%), as well as improvements in lateral stability in the exercise group. Unfortunately, a majority of these training studies measure balance in static situations. Since a majority of falls occur during walking, turning or on stairs ((31;59), it is important to assess changes in dynamic balance after strength training.

Lamoureaux and colleagues (22;150) are the only researchers to have examined the effect of exercise-induced strength gains on measures of dynamic balance. Sixteen men and 29 women aged older than 62 years were randomly selected to participate in 24 weeks of progressive resistance training (n = 29) or serve as controls (n = 16). 1-RM strength as well as kinetic and kinematic data during obstacle walking were measured at baseline and at the end of the study. The authors reported significant strength increases ranging from 197-285% with training. Significant improvements in the peak vertical and anterior-posterior ground reaction forces as well as kinematic data were observed after training. However, because the data from the males and females were grouped together it is impossible to examine what effect the exercise program had on the strength and dynamic balance of the female subjects. As a result further studies are warranted to determine if similar improvements in strength and dynamic balance can be achieved with a training using only female subjects.
2.4.2 Balance and strength training

To date, several randomized controlled trials have shown that strength and balance training interventions are effective in reducing the incidence of falls. Robertson et al. (20) demonstrated a reduction in falls by 46% in 240 community-dwelling men and women aged 75 years and older participating in exercise. In one study by Campbell et al. (18) 233 community-dwelling women aged 80 and over participated in an exercise intervention designed to improve strength and balance and reduce falls. The authors reported improved physical functioning through increased strength and balance which translated into less falls.

It is important to note that all of these randomized controlled trials have involved older men and women (75 years +), it remains unclear whether fall rates can be reduced in a younger population as well. In a recent meta-analysis, Robertson et al. (151) pooled individual-level data from four fall intervention trials in nine cities in New Zealand. The authors concluded that a program of muscle strengthening and balance training was effective at reducing the frequency of falls in only those subjects 80 years and older. To explain this, some researchers have suggested that small gains in strength and balance may provide greater benefit to older individuals who may be at a critical threshold for risk of falls (152). Since younger postmenopausal women may not yet be at a critical threshold where daily activities are sufficient to cause falls; it has therefore been suggested that fall prevention programs be established early and sustained throughout the aging years (152).

Although not all strength and balance training programs have reported reduced fall incidence, improvements in factors associated with falls have been reported.
Recently in a randomized controlled trial Hauer et al. (17) reported improvements in strength and functional performance as well as fall-related behavioural and emotional restrictions during 3 months of strength and balance training in 57 geriatric female patients aged 75-90. Using 80 community-dwelling women aged 65-75 years of age, Carter et al. (153) demonstrated that a twice-weekly 40-minute program of supervised strength and balance training improved static and dynamic balance and strength.

2.4.3 Endurance training

To date a majority of interventions aimed at improving indices of falls have focused only on resistance/strength training and/or balance training. Although endurance training is not commonly discussed as one method for reducing falls, loss in aerobic capacity are related to difficulties in walking and transition which may lead to decreased functional abilities (154) and increased risk of falls (89). Therefore, improvements in oxygen consumption may lead to increased functional capacity and decrease the risk of falling.

A form of endurance training such as aerobic dance involving sagittal stepping and straddling movements, which have been shown to improve balance and agility (155), may be an effective way to prevent falls in older individuals. Recently, Shigematsu et al. (21) conducted a controlled dance-based aerobic exercise program designed to improve indices of falls in 38 women aged 72-87 years. The authors found that the exercise group had significantly greater single-leg balance with eyes closed, functional reach, and improvements in locomotion/agility compared to controls.

In another study, Buchner et al. (156) reported that an endurance and strength training program led to increases in aerobic capacity and had a protective effect of risk of falling. In a walking study conducted by Rooks et al. (157), 131 community-dwelling
adults showed improved tandem and single-leg stance and improved stair-climbing speed after meeting 3 times a week for 10 months.

**2.4.4 General exercise**

Another form of exercise which has been found to have an effect on fall rates is Tai Chi. In an individual FICSIT trial, Wolf et al. (158) randomly assigned 200 men and women (mean age 76.3) to either 15 weeks of computerized balance training or Tai Chi program. The authors reported that the rate of multiple falls was substantially reduced (47.5%) in subjects who participated in the Tai Chi training. Other reported benefits of Tai Chi training in older adults are improved muscular strength and endurance (159) co-ordination and balance (19) and reduced postural sway (160).

Recently, water-based exercises have become increasingly popular activities for older adults. The combination of the buoyancy and resistance makes this a particularly attractive activity because it creates an environment that requires high levels of energy expenditure while minimizing the compressive forces on joints. Recently, in a randomized clinical trial, Takeshima et al. (16) showed that a 12-week water-based exercise program significantly improved strength in knee extension (8%), knee flexion (13%), and back extension (6%) in women aged 60-75 years.
CHAPTER 3

METHODOLOGY

3.1 SUBJECTS

A total of 18 women aged (44-62) from the surrounding St. Catharines community agreed to participate in this study after being informed about possible risks. Eleven women volunteered for the exercise group (EX) and 7 women volunteered for the control group (CON). Only postmenopausal women (no menses > than 1 year) with no resistance-training background, asthma, cardiovascular disease, hormone replacement therapy and musculoskeletal disorders were invited to participate. Participants’ characteristics for the CON and EX groups at T1 and T2 are shown in Table 3.1.

Informed consent and Brock University Research Ethics Board approval were obtained at the start of the study (Appendix 2).

Table 3.1 Pre- and post-test Participant characteristics for the control and exercise groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Controls (n=7)</th>
<th>Exercisers (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>Age (years)</td>
<td>53.4 ± 2.1</td>
<td>N/a</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.2 ± 2.3</td>
<td>N/a</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.5 ± 4.0</td>
<td>74.0 ± 4.0</td>
</tr>
<tr>
<td>Relative body fat (%)</td>
<td>40.9 ± 2.2</td>
<td>40.6 ± 2.2</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>30.9 ± 3.2</td>
<td>30.5 ± 3.2</td>
</tr>
<tr>
<td>Fat free mass (kg)</td>
<td>43.5 ± 1.0</td>
<td>43.5 ± 1.0</td>
</tr>
<tr>
<td>VO2max (ml•min⁻¹•kg⁻¹)</td>
<td>32.8 ± 3.1</td>
<td>31.3 ± 2.1</td>
</tr>
</tbody>
</table>

Data are means ± SE. * Denotes a significant group-by-time interaction for repeated measures ANOVA (P < 0.05).
3.2 INTERVENTION

Subjects volunteered in a 12-week weighted vest supervised exercise program consisting of walking, strength, and balance training 3 times weekly. Each session consisted of 5 minutes of warm-up, 20 minutes of walking (intensity: 75% of age-predicted max HR), 15 minutes of lower body strength training (squats, lunges, leg lifts, calf raises) (Appendix 3), 15 minutes of balance training with a 20”-12” angle wobble board, 5 minutes of abdominal and back training, and 5 minutes of cool-down and stretch.

The loading of the vests was calculated using a percentage of the subject’s body weight. In order to familiarize the subjects with the weighted vest, the vest was worn with no weights during the first week. After the first week, the initial load of the vest was 3% of the subject’s body weight. Thereafter, the weight of the vest was increased by 4% of the subject’s body weight every 3 weeks. Figure 3.1 shows the loading schedule for the weighted vests.

![Figure 3.1 Loading schedule of the weighted vests]
3.3  MEASUREMENTS

3.3.1 Anthropometric and body composition assessment

Subject’s body mass (kg) and height (cm) were assessed at the start of the study (T1) and the end of the study (T2) the 12 weeks of training and control period. Each subject’s fat free mass (FFM), and relative body fat (%BF) was determined using Boelectrical Impedence Analysis (BIA, RJL Systems, Milford, CT, USA) as previously described (161-164).

3.3.2 Maximal oxygen consumption

Subjects in both groups were administered a continuous incremental exercise test for the determination of maximal aerobic consumption (VO2max) at T1and T2. VO2max was directly measured on a Monark cycle ergometer at a cycling rate of 80 rpm by an AEI metabolic cart (Pittsburgh, PA, USA). All subjects began cycling at 50 W, with increments of 20 W every 1 min to volitional fatigue. During the test, heart rate was monitored using a Polar heart rate monitor. The criteria used to verify the achievement of VO2max were: a respiratory gas exchange ratio >1.1, and a plateau of VO2 with increasing power output. VO2max was calculated by dividing the absolute value in millilitres by the subject’s FFM. As a result VO2max was expressed as ml•min⁻¹•kg⁻¹ FFM.

3.3.3 Strength

At T1 and T2 Knee extension and flexion and ankle plantar and dorsi flexion was measured unilaterally using 2-speeds (60° s⁻¹ and 180° s⁻¹) using a medical isokinetic system (Biodex dynamometer, Medical Systems, Shirley, NY). Each subject performed a practice session (3 repetitions of knee extension and flexion and ankle plantar and dorsi flexion) at speeds
of 60° s\(^{-1}\) and 180° s\(^{-1}\). Following the practice, the subjects then performed 3 maximal voluntary contractions at speeds of 60° s\(^{-1}\) and 180° s\(^{-1}\) for knee extensors (quadriceps femoris), knee flexors (hamstrings, gracilis, sartorius, popliteus), ankle plantar flexors (soleus, gastrocnemius, peroneus longus, peroneus brevis, tibialis posterior), and ankle dorsi flexors (tibialis anterior, extensor digitorum longus, extensor hallucis longus, peroneus tertius).

All tests were performed in a seated position with a solid back support and straps placed at the level of the chest, pelvis, and left thigh to stabilize the trunk and hip joints. Calibration of the machine was completed before each testing day and was performed using standard weights placed on the lever arm. Peak torque (the single highest torque output of the joint produced by muscular contraction as the limb moves through the range of motion) was obtained from the greatest single value of 3 maximal efforts. The average total time required to complete this test was approximately 20 minutes.

Previous research has shown peak torque to be an accurate and highly reproducible variable to measure. Valovich et al. (165) demonstrated intra-class correlation coefficients for peak torque to be 0.99.

### 3.3.4 Gait analysis

The experimental tasks consisted of walking unobstructed (0 m) and with obstacles (width: 0.2 m; depth: 0.05 m) of six different heights (0.005 m, 0.010 m, 0.025 m, 0.030 m) placed in the pathway at the location of mid-swing of the stride taken in the middle of the walkway. Participants were presented with blocks of trials consisting of different obstacle heights in a randomized order. Three successful trials were collected for each
obstacle height. The participants were asked to walk at their preferred walking speed with comfortable running shoes.

Ground reaction forces (GRFs) were measured using two OR6-6 force plates (Advanced Medical Technology Inc (AMTI), Waterdown, MA, USA) which were placed after a 3-step approach. The signals from the AMTI transducers were amplified 4000X and digitized using AMTI MiniAmp MSA-6 amplifiers. GRFs in the anterior-posterior (A/P), medial-lateral (M/L), and vertical (V) direction as well as the moments around each axes were collected. The 12 signals were digitized using a 16 bit analogue to digital converter (A/D) (NI PCI-6014, National Instruments) at a frequency of 1200Hz (Appendix 4). The software used for data acquisition was Mr. Kick (v. 1.12d). Using Mr. Kick, the voltages from the force plates were manually processed to obtain peak amplitude and the area under the curve for the A/P, M/L, and V directions. Area under the curve was calculated between heel contact and mid stance in order to extract M/L, A/P, and V impulses.

Once the data was reduced, the following voltage output calculation was used to obtain “converting factors” for each of the 12 channels:

\[ V_o = 0.000001 \times S \times V_{exc} \times G \times \text{Input} \]

\[ V_o \] = the output voltage from the amplifier used

0.000001 = volts/micro-volt, units for sensitivity

S = the sensitivity

\[ V_{exc} \] = the bridge excitation voltage

G = the amplifier gain

Input = the input force or moment
Once the “converting factors” for the M/L, A/P, and V directions were calculated, they were multiplied by the raw voltages (acquired by Mr. Kick) to obtain the forces. The force data were then normalized by dividing by N-weight to compare magnitudes across subjects. From the normalized and smoothed force-time data, peak braking forces in the V and A/P directions were computed. Using the data collected on GRFs and moments around each axes, center of pressure (COP) excursion in the medial-lateral and anterior-posterior directions as well as stance time were calculated using MATLAB (the MathWorks, Inc., Natick, MA, USA). The forces were downsampled to 300Hz and filtered with a 4\textsuperscript{th} order Butterworth Zero-phase shift filter using Winter’s method (166). Appendix 5 shows the MATLAB syntax equations used to calculate these measures.

Previous research has shown the reliability of force platform intra-class correlation coefficients for both propulsive and braking forces to be 0.73 at fast speeds and 0.88 for slower movements (167).

3.4 COMPLIANCE

Exercisers were instructed to complete an exercise training log (Appendix 6) after every training session. A check mark was used to signify if the participant completed the five components of each training session. The five components consisted of a warmup and stretch, walking 20 min at the prescribed training heart rate (75% of age-predicted heart rate max), strength training, balance training, cooldown and stretch. Several lines for comments were available for participants to document any unusual symptoms during exercising or reasons for not completing the training session. Compliance was calculated by summing all of the subjects’ completed training sessions then dividing the available
number of classes for the 12 weeks (34) which was multiplied by the total number of participants (9, excluding dropouts).

3.5 **STATISTICAL ANALYSIS**

An independent-samples T test was used to determine differences between the two groups (CON and EX) at the start of the study (week 0) for the COP excursions, GRFs, and participants’ characteristics. A one-way Analysis of Variance (ANOVA) using repeated measures was used to investigate between-group (CON and EX) and within-group (pre-test and post-test) effects and group-by-time interactions. When appropriate, Bonferroni post-hoc comparisons were conducted to determine differences between the within-group measures. An alpha level of $P < 0.05$ was chosen as the criterion for significance. In order to examine the variability between the CON and EX groups for GRFs and COP excursion, average coefficients of variation were also determined and analyzed using repeated measures ANOVA. All statistical analyses were conducted using the Statistics Package for Social Sciences (SPSS 11.5 for Windows, SPSS Inc., Chicago, IL, USA).
CHAPTER 4

RESULTS

4.1 EXERCISE COMPLIANCE AND PHYSICAL CHARACTERISTICS

During the course of the exercise program, 2 women dropped out for reasons not related to the study. The exercise compliance rate was 79.7%. In the final analysis the CON group consisted of 7 women and the EX group consisted of 9 women.

At the start of the study (T1) there were no significant between-group differences in participants' characteristics. After 12 weeks significant decreases in mean relative body fat ($F(1,14) = 6.26, P = 0.03$) and fat mass ($F(1,14) = 5.16, P = 0.04$) were observed in both the CON and EX groups. From T1 to T2 the EX group showed a significantly greater improvement in FFM compared to controls ($F(1,14) = 5.62, P = 0.03$) (see Table 3.1).

4.2 STRENGTH

Appendix 7 shows an example of a peak muscle torque trace using the Biodex. With the exception of knee flexion strength (60° s⁻¹) there were no significant between-group differences at T1 for any of the 7 strength measures. Pre- to post-test means as well as the mean percentage change for the 8 strength measures are shown in Table 4.1. From T1 to T2 the EX group showed a significantly greater improvement of 40% in mean ankle plantar flexion strength (60° s⁻¹) compared to 16% increase in the CON group ($F(1,14) = 4.76, P = 0.05$).
Table 4.1 Pre- and post-test strength measures for the control and exercise groups

<table>
<thead>
<tr>
<th>Measure</th>
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<th>Exercisers (n=9)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>% change</td>
<td>T1</td>
<td>T2</td>
<td>% change</td>
</tr>
<tr>
<td>Ankle</td>
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<td></td>
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<tr>
<td>Plantar flexion 60°.s⁻¹</td>
<td>47.3 ± 7.4</td>
<td>51.3 ± 6.4</td>
<td>16.0 ± 9.8</td>
<td>37.8 ± 2.8</td>
<td>52.2 ± 4.7*</td>
<td>40.2 ± 13.1</td>
</tr>
<tr>
<td>Dorsi flexion 60°.s⁻¹</td>
<td>12.3 ± 1.1</td>
<td>13.2 ± 1.4</td>
<td>8.4 ± 8.6</td>
<td>12.4 ± 1.1</td>
<td>13.0 ± 0.7</td>
<td>9.4 ± 8.5</td>
</tr>
<tr>
<td>Plantar flexion 180°.s⁻¹</td>
<td>30.9 ± 3.2</td>
<td>29.8 ± 3.8</td>
<td>-3.7 ± 9.9</td>
<td>27.9 ± 2.4</td>
<td>30.6 ± 3.2</td>
<td>9.8 ± 8.2</td>
</tr>
<tr>
<td>Dorsi flexion 180°.s⁻¹</td>
<td>10.9 ± 2.3</td>
<td>12.9 ± 3.0</td>
<td>29.9 ± 34.4</td>
<td>10.6 ± 1.0</td>
<td>10.3 ± 1.4</td>
<td>5.9 ± 14.8</td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension 60°.s⁻¹</td>
<td>93.4 ± 8.8</td>
<td>83.2 ± 7.2</td>
<td>-8.6 ± 8.9</td>
<td>102.8 ± 11.6</td>
<td>102.0 ± 12.0</td>
<td>1.5 ± 9.7</td>
</tr>
<tr>
<td>Flexion 60°.s⁻¹</td>
<td>62.1 ± 5.9</td>
<td>59.0 ± 4.6</td>
<td>-0.9 ± 10.3</td>
<td>81.1 ± 8.1</td>
<td>74.9 ± 8.0</td>
<td>-5.3 ± 9.1</td>
</tr>
<tr>
<td>Extension 180°.s⁻¹</td>
<td>54.3 ± 7.4</td>
<td>46.5 ± 6.9</td>
<td>-14.4 ± 7.8</td>
<td>61.9 ± 7.2</td>
<td>61.2 ± 7.4</td>
<td>9.3 ± 18.4</td>
</tr>
<tr>
<td>Flexion 180°.s⁻¹</td>
<td>50.0 ± 5.8</td>
<td>39.2 ± 5.2</td>
<td>-19.9 ± 10.3</td>
<td>56.7 ± 6.6</td>
<td>55.2 ± 6.0</td>
<td>3.7 ± 12.1</td>
</tr>
</tbody>
</table>

Data are means and mean percentage change ± SE. * Denotes a significant group-by-time interaction for repeated measures ANOVA (P < 0.05).
4.3 GROUND REACTION FORCES (GRFs)

Figure 4.1 depicts obstacle walking in the stance leg and the corresponding V GRFs, impulses and COP excursion.

Figure 4.1 Example of V GRFs and COP excursion in relation to obstacle walking
At T1 there were no significant between-group differences for any of the GRFs. Changes in M/L, A/P, and V peak braking forces as a function of obstacle height at T1 and T2 are shown in figure 4.2. A one-way Analysis of Variance (ANOVA) using repeated measures revealed a significant main effect for obstacle in the A/P ($F(4,11) = 7.04, P = 0.01$) and V ($F(4,11) = 5.41, P = 0.01$) directions. However, the group-by-time interaction did not reach statistical significance ($F(1,14) = 0.10, P = 0.76$ and $F(1,14) = 0.10, P = 0.76$ respectively). An analysis of the changes in M/L peak braking forces at T1 and T2 revealed no significant main effects or interactions. Post-hoc analysis using Bonferroni comparisons for the mean differences of the 5 obstacle heights for A/P and V peak braking forces are shown in Appendices 8 and 9.

Figure 4.3 illustrates the changes in M/L, A/P, and V braking impulses as a function of obstacle height at T1 and T2. Significant increases in the magnitude of A/P ($F(4,11) = 20.74, P = 0.00$) and V ($F(4,11) = 13.21, P = 0.00$) braking impulse across obstacles were observed at T1 and T2. However, the group-by-time interaction did not reach statistical significance ($F(1,14) = 0.00, P = 0.967$ and $F(1,14) = 0.33, P = 0.57$ respectively). An analysis of the changes in M/L braking impulse at T1 and T2 revealed no significant main effects or interactions. Post-hoc analysis using Bonferroni comparisons between the mean differences of the 5 obstacle heights for V and A/P braking impulse are shown in Appendices 10 and 11.
Figure 4.2 Mean ± SE M/L, A/P and V peak braking force as a function of obstacle height (panels A, B and C respectively) for the CON and EX groups at T1 and T2.
Figure 4.3 Mean ± SE M/L, A/P and V braking impulse as a function of obstacle height (panels A, B and C respectively) for the CON and EX groups at T1 and T2.
4.4 CENTER OF PRESSURE (COP) AND STANCE TIME

At T1 there were no significant between-group differences in stance time. However, at T1 significant between-group differences between 10 cm ($T=2.64, P<0.02$) and 25 cm ($T=2.97, P<0.01$) were observed for M/L COP excursion.

Changes in stance time as a function of obstacle height at T1 and T2 are shown in Figure 4.4. Stance time increased significantly across obstacles from T1 and T2 in both the CON and EX groups ($F(4,11) = 55.12, P=0.00$). However, there were no significant group-by-time interactions for stance time ($F(1,14) = 0.023, P = 0.88$). Post-hoc analysis using Bonferroni comparisons between the mean differences of the 5 obstacle heights for stance time is shown in Appendix 12.

![Figure 4.4](image_url)  
**Figure 4.4** Mean ± SE stance time as a function of obstacle height for the CON and EX groups at T1 and T2.
Figure 4.5 shows the changes in M/L and A/P COP excursion as a function of obstacle height at T1 and T2. Using repeated measures ANOVA revealed a significant main effect for time for M/L COP excursion ($F(4,11) = 8.08, P = 0.01$). However, the group-by-time interaction reached near significance ($F(1,14) = 4.22, P = 0.06$). An analysis of the changes in A/P COP excursion at T1 and T2 revealed no significant main effects or interactions.

Figure 4.5 Mean ± SE M/L and A/P COP excursion as a function of obstacle height (panels A and B respectively) for the CON and EX groups at T1 and T2.
4.5 CORRELATIONS

In order to determine if changes in ankle plantar flexion strength ($60^\circ \text{s}^{-1}$ and $180 \text{ s}^{-1}$) were related to measures of GRFs at T2 in the EX group (for 30 cm obstacle height), bivariate correlations were performed. This analysis revealed no significant correlations ($P < 0.05$). Figure 4.6 shows the correlations between changes in peak ankle plantar flexion torque $60^\circ \text{s}^{-1}$ and changes in M/L impulse at the 30 cm obstacle height for the EX group. The correlation and significance was -0.496 and 0.175 respectively. The strength of this correlation was calculated by the coefficient of determination ($r^2$). An $r^2$ of 0.25 was calculated suggesting a moderate strength relationship exists between these two variables where 25% of the variance is explained.

![Figure 4.6](image)

**Figure 4.6** Correlation between changes in peak ankle plantar flexion torque $60^\circ \text{s}^{-1}$ and changes in M/L impulse at the 30 cm obstacle height for the EX group.
4.6 VARIABILITY

The EX group showed a decrease in the coefficient of variation for stance time compared with an increase that was observed in the CON group. However, the time-by-group interaction did not reach statistical significance ($F(1,14) = 1.80, P = 0.20$). Similar results were seen for the coefficient of variation in A/P COP excursion, with the EX group decreasing and the CON group increasing. Again, the group-by-time interaction did not reach statistical significance ($F(1,14) = 1.95, P = 0.18$). Statistical analyses of the coefficient of variation for the other dependent variables revealed no significant main effects or interactions.
CHAPTER 5

DISCUSSION

5.1 INTRODUCTION

The purpose of this study was to determine if exercise-induced strength gains improved measures of dynamic balance during obstacle walking in a group of postmenopausal women. The measures of dynamic balance included: V, A/P and M/L GRFs; and COP excursion in the A/P and M/L directions. The main findings of this study can be summarized into the two major points:

1) The EX group showed significant improvements in ankle plantar flexion strength ($60^\circ \text{s}^{-1}$) compared with the CON group.

2) Exercise-induced strength gains in the ankle were not associated with improvements in GRFs or COP excursion.

5.2 STRENGTH

The training program resulted in a significant ankle strength increase of 40% in the EX group. These results are in agreement with previous research. To date, the study by Shaw & Snow (149) is the only study to examine the effect of a weighted-vest strength training program on indices of falls (leg strength, leg power and lateral stability). Twenty-two women between the ages of 50-75 years were selected from a group of 44 to participate in a weighted-vest exercise program 3 times a week for 9 months. Exercise classes were 60 minutes in duration and consisted of mild stretching and lower-body resistance exercises (squats, chair raises, lunges, and toe raises). Similar to the current study, Shaw & Snow (149) tested muscle strength using an isokinetic dynamometer. The
authors reported significant increases in lower body muscle strength ranging from 16-33% with training. The current study observed similar strength gains in the ankle with only 12-weeks of training, which indicate that exercise programs of short durations (12 weeks) can elicit significant improvements in strength similar to longer duration training programs (9 months). However, since the current study was unable to show significant improvements in all measures of strength with exercise, these results appear contradictory. One explanation for the current study findings is the relatively short duration of training. The exercisers in the study by Shaw & Snow (149) attended classes for nine months suggesting that a longer duration of study may be required to elicit significant improvements in the strength of the lower body.

Recently Bemben and colleagues (168) demonstrated that 6-months of either a high-load (HI) or high repetition (HR) training program increased lower body strength (30%) and hip strength (37-40%) in younger postmenopausal women aged 41-60 years. Because the subjects performed the strength exercises using isotonic resistance training equipment they were able to narrow the range of movement and focus on specific muscles. Despite their success at producing improvements in strength, programs that use exercise machines require specialized equipment, close supervision, and participant travel which can make implementation difficult.

In the study by Shaw & Snow (149) the weighted vests were loaded initially at 5% of body weight and then increased to a maximum of 10% of body weight over 9 months of training. This load was enough to produce significant improvements in strength. Based on these results, it was agreed that the vest should be loaded to a maximum of 15% of body weight. None of the subjects reported any musculoskeletal
issues prior to the start of the study, however, during the course of training several subjects complained of knee and/or shin pain which seemed to coincide with increases in the load of the weighted-vest. Perhaps, higher loads (> 15% body weight) are needed to elicit greater improvements in strength. However, the difficulty with this is that there is an increased likelihood of musculoskeletal injuries and higher chance of drop-out. In order to provide the optimal training stimulus while minimizing exercise barriers, a more thorough investigation of strength training programs using uncomplicated equipment is necessary.

In the present investigation, compliance to the exercise program was high; 79%. These results are in agreement with other studies which have shown high compliance rates of 80-90% (149;169).

5.3 GROUND REACTION FORCES, CENTER OF PRESSURE, AND STANCE TIME

After 12 weeks of training, no significant changes in GRFs or COP were observed. These results are in conflict with previous research. The study by Lamoureux et al. (22) was the only investigation to examine the effects of strength training on balance and postural control during obstacle avoidance in older adults. Sixteen men and 29 women older than 62 years were randomly assigned to either a control or exercise group. The exercisers underwent 24-weeks of progressive resistance training targeting five muscle groups (iliopsoas, gluteus maximus, quadriceps, hamstrings, and gastrocnemius) using custom-designed pin-loaded weight machines. The intensity was set at 60% of one repetition maximum (1-RM) at week 0 and then was increased to 85% of 1-RM by week 24. The exercises were performed at a volume which ranged from two and five sets and
five and eight repetitions. The authors reported increases in peak V and A/P braking and propulsive forces which were interpreted as improvements. However, since the authors reported the results of the men and women together it becomes difficult to determine the effect of the training on the female subjects only, hence may explain the findings.

Another explanation for the lack of significance in our study may be related to age differences in the populations. In the study by Lamoureux and colleagues (22) all of the subjects were older than 65 years. Since strength declines significantly with age, the participants had a much larger margin for improvement compared with the subjects of the current study. Further investigations using younger and older postmenopausal women, would be necessary to address questions of age-related adaptations to strength and obstacle walking.

In the study by Lamoureaux et al. (22) the authors reported an increase in obstacle crossing time velocity in the experimental group. Since increasing speed across the force platform can cause significant increases in the amplitude of GRFs, increased crossing time velocity and not strength may explain the improvements seen in GRFs in the experimental group. By controlling for the crossing speed the authors may eliminate any improvements reported in the GRFs of the experimental group.

The stance phase or “support phase” begins when the forward limb makes heel contact with the floor and ends when the same limb reaches toe off. In the current study stance time of the standing leg increased significantly during obstacle crossing. This suggests that women spent increasingly more time in the support phase of the gait cycle. Although previous studies have shown a reduced obstacle crossing speed during bilateral obstacle walking (139;170), the current study is the first to show reduced obstacle
crossing speeds during unilateral obstacle walking. The results of the current study provide further evidence for the challenges that obstacle walking posed to the postural system in postmenopausal women.

Previous data from our group showed significant correlations between peak torque of the ankle at speeds of 60° s\(^{-1}\) and 180° s\(^{-1}\) and M/L GRF and impulse (Appendix 13; 172). Therefore, in an attempt to examine the relationship between the changes in ankle peak torque and M/L GRFs and impulse following exercise training, correlations were conducted. Although there were no significant correlations, a moderately strong relationship between changes in ankle peak torque (60° s\(^{-1}\)) and M/L impulse was observed. However, only 25% of the variance could be explained by this relationship. Upon examining the changes in peak torque, it was revealed that one subject actually decreased in ankle strength after the training. As a result, they were excluded from the analysis. After conducting a second correlation without this subject a very strong relationship between changes in peak ankle torque and M/L impulse was shown. Approximately 70% of the variance could now be explained. This is the first study to correlate changes in peak torque with changes in GRFs following a 12-week weighted vest strength and balance program. The results suggest that this type of exercise training can improve ankle strength which may translate into enhanced postural control while negotiating obstacles. Future investigations to further elucidate the relationship between changes in strength and changes in GRFs following exercise training are needed.

\section*{5.4 LIMITATIONS}

Due to sample size (n = 16) parameter measures with large variances made it difficult to detect significant differences between the CON (n = 7) and EX (n = 9) group. This
increased the likelihood of making a type II error (accepting that there are no significant differences between the CON and EX group when in fact there really is). In addition, questions arise regarding the ability of the study’s small sample to adequately represent a subset of the population.

The duration of the study could be another limitation. In order to see significant improvements in the measures of strength and dynamic balance a longer training program 6 months or more may be required.

Since a majority of the women cited “weight loss” as their motivation for volunteering for this study, this may have been another limitation. For example, some of the women may have initiated other weight loss strategies such as performing additional exercise and/or restricting food intake while participating in this program.

5.5 **CONCLUSIONS**

The present study sought to examine the effects of a weighted-vest strength and balance training program on strength and dynamic balance in postmenopausal women. The following conclusions can be made regarding the objectives found in section 1.3:

1) 12 weeks of a weighted-vest strength and balance training program resulted in a high compliance rate in postmenopausal women.

2) Strength and balance training with a weighted vest for 12 weeks can elicit significant improvements in ankle plantar flexion strength at speeds of $60^\circ$ s$^{-1}$.

3) This type of training was not successful at improving knee extension and flexion strength.
4) After 12 weeks of a weighted-vest strength and balance program, a reduction in M/L COP excursion was observed, however the changes were not significantly different between the CON and EX groups.

5) Exercise-induced strength gains do not result in increases in peak V, A/P, and M/L GRFs or reductions in A/P and M/L COP excursion after 12 weeks of a weighted-vest strength and balance training program in postmenopausal women.

5.6 RECOMMENDATIONS FOR FUTURE WORK

The results of this study and others like it, suggest that lower extremity strength can be greatly improved with the proper training stimulus and program duration. Future studies should examine the effect of varying training frequency (2, 3, or 5 days a week), exercise load (low, med, or high), study duration (long vs. short), and different methods of weight training (machine vs. body weight) on strength and balance measures. This would allow researchers to determine the optimal balance of these factors and provide recommendations for clinicians and fitness instructors to prescribe exercises for increasing balance and reducing falls in women.

Since it remains unclear which mechanisms are responsible for balance changes during exercise, further research involving strength and other training programs are necessary to identify this link. Future studies may include different types of training such as aerobic or flexibility exercise. This may provide further insight into the mechanisms responsible for adaptations in postural balance and control during dynamic situations.

A more extensive examination using kinematic data would be necessary to address questions of adaptations during obstacle walking. This would allow researchers to identify flexion at the different angles and would allow for the calculation of muscle
power. An additional force platform after the obstacle would allow researchers to analyze the standing leg further. This would address questions regarding time spent in single and double support during the stance phase of the standing leg while crossing obstacles.

Because of the age-related declines in strength and balance, it necessary to further investigate how younger and older postmenopausal women respond to strength and balance training and adapt to dynamic situations.

In addition to the physical benefits of exercise, physical activity can improve self-esteem and heighten self-confidence (171). Since fear of falling can limit physical activity and reduce functional abilities which can lead to reduced quality of life (7), it would be interesting to examine the psychological impact of a strength and balance training program in younger postmenopausal women.
References


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null


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Appendices

APPENDIX 1: Brock University Research Ethics Board Approval

APPENDIX 2: Consent form

APPENDIX 3: Examples of exercises performed

APPENDIX 4: Schematic drawing of force plate set-up

APPENDIX 5: Matlab syntax for calculating COP

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APPENDIX 8: Pairwise comparisons of the mean difference ± SE between five obstacle heights for peak vertical braking force

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APPENDIX 10: Pairwise comparisons of the mean difference ± SE between five obstacle heights for vertical braking impulse

APPENDIX 11: Pairwise comparisons of the mean difference ± SE between five obstacle heights for anterior-posterior braking impulse

APPENDIX 12: Pairwise comparisons of the mean difference ± SE between five obstacle heights for stance time

APPENDIX 13: Correlations between peak ankle plantar flexion at speeds of 60 and 180 degrees/second and M/L GRF and impulse at T1 for all 16 subjects
APPENDIX 1: Brock University Research Ethics Board Approval

DATE: March 13, 2003

FROM: Joe Engemann, Chair
Senate Research Ethics Board (REB)

TO: Nota Klentrou, Physical Education
Michael Ladouceur, Physical Education & Kinesiology
Jill Slack

FILE: 02-165, Klentrou/Ladouceur/Slack

TITLE: Changes in dynamic balance correlate with changes in lower limb strength following a 12-week weighted vest exercise program in postmenopausal women

The Brock University Research Ethics Board has reviewed the above research proposal.

DECISION: Accepted as clarified.

This project has been approved for the period of March 13, 2003 to August 31, 2003 subject to full REB ratification at the Research Ethics Board's next scheduled meeting. The approval may be extended upon request. The study may now proceed.

Please note that the Research Ethics Board (REB) requires that you adhere to the protocol as last reviewed and approved by the REB. The Board must approve any modifications before they can be implemented. If you wish to modify your research project, please refer to www.BrockU.CA/researchservices/forms.html to complete the appropriate form REB-03 (2001) Request for Clearance of a Revision or Modification to an Ongoing Application.

Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Principal Investigator, the safety of the participants and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-Council. Policy Statement requires that ongoing research be monitored. A Final Report is required for all projects, with the exception of undergraduate projects, upon completion of the project. Researchers with projects lasting more than one year are
required to submit a Continuing Review Report annually. The Office of Research Services will contact you when this form REB-02 (2001) Continuing Review/Final Report is required.

Please quote your REB file number on all future correspondence.
APPENDIX 2: Brock University Research Ethics Board Approval
BROCK UNIVERSITY DEPARTMENT OF APPLIED HEALTH SCIENCES

TITLE: CHANGES IN DYNAMIC BALANCE CORRELATE WITH CHANGES
IN LOWER LIMB STRENGTH FOLLOWING A 12-WEEK WEIGHTED VEST
EXERCISE PROGRAM IN POSTMENOPAUSAL WOMEN

RESEARCHERS: Panagiota Klentrou Ph.D., Dr. Michel Ladouceur, Ph.D., Dr. Kelly
Lockwood Ph.D., and Jill Slack MSc. candidate

NAME OF PARTICIPANT: ____________________________

This training study will examine the changes in dynamic balance and strength during a
12-week weighted vest exercised program in post-menopausal women. I understand that
after initial screening I will be assigned to either the exercise group or the control group.
If I am in the exercise group I will be required to attend a one-hour exercise sessions 3
times per week for 12 weeks. The weighted vest will be worn during all exercise
sessions. The weight of the vest will be increased slowly over the 12 weeks so that by
the end of the 12 weeks you will be wearing a maximum of 10 percent of the your body
weight in the vest. I understand that if I am assigned to the control group (no exercise), I
will not be participating in any exercise for 12-weeks. I understand that both groups will
also be required to undergo an initial history, measures of psychological well-being and
physical examination complete with blood work, fitness measurements and gait analysis.
I understand that both groups will be required to repeat these specific tests again at the
end of the 12-week period, which results in a total time commitment of 14 weeks.
Fitness tests will include muscle strength, aerobic fitness, body fat and weight
measurements. The gait analysis will require that I wear reflective markers that will
allow the researchers to record joint angles via video cameras. I will also be required to
walk on a walkway equipped with sensors for measuring the forces that I generated with
my body during walking.

If I decide to participate in this study, I understand that I must be aware that the following side
effects are possible:

1. Muscle soreness/ Body fatigue- Participants may experience slight muscle
soreness/fatigue within 24 hours of testing as a result of the maximal effort that is
required for the bike and strength testing. If muscle soreness/fatigue is experienced,
it should dissipate within 48 hours.

2. Skin irritation/ Bruising/ Fainting- Individuals may experience slight skin irritation/
bruising around the sites used for withdrawing blood. In addition, some individuals
may experience slight skin irritations due to allergies form adhesive tape. In the
event that someone may be allergic to adhesive tape, the individual may not be
eligible to continue on in the study. On rare occasions, some individuals may
experience fainting during blood withdrawals. To minimize this risk, only a small
amount (20 ml) of blood will be taken while the participant is in a seated reclined
position.
I understand that all tests and exercises will take place at Brock University. I understand that my participation in this study is completely voluntary and I may withdraw from the study at any time and for any reason without penalty or prejudice. I understand that there will be no payment for my participation.

I understand that there is no obligation to answer any question or participate in any aspect of this study that I consider invasive, offensive or inappropriate.

I understand that all personal data will be kept in strict confidence, where only the investigators of the study will have access. All information will be coded so that my name is not associated with my answers. Data will be kept for a minimum of 5 years after publication. After this time all data will be destroyed by confidential shredding after 5 years.

Participant Signature_________________________ Date_________________________

This study is research for a MSc. Thesis and has been reviewed by, and received Ethics clearance through, the Office of Research Ethics, Brock University (File #02-165). For more information please contact the Research Ethics Officer at 905-688-5550 x 3035.

If you have any questions or concerns about your participation in the study, you may contact Jill Slack at 905-688-5550 ext 4901 or Dr. Panagiota Klentrou at 905-688-5550 ext. 4538 or Dr. Michel Ladouceur 905-688-5550 ext. 4905.

Feedback about the use of the data collected will be available during the month of August 2003, in Welch Hall Room #17. A written explanation of group and individual results will be provided for you upon request.

Thank you for your help! Please take one copy of this form with you for further reference.

I have fully explained the procedures of this study to the above volunteer.

Researchers Signature_________________________ Date_________________________
APPENDIX 3: Examples of exercises performed

- Gastrocnemius
- Inner Thigh
- Soleus
- Hamstrings
- Quadriceps
Strengthening Exercises

Squats

Back Extensions

Lunges

Abdominal/Obliques

Outer Thigh
Balance Exercises

Standing (eyes open and closed)

Squat one arm (eyes open and closed)

Standing one leg

Tossing and catching ball

Squat (eyes open and closed)
APPENDIX 4: Schematic drawing of force plate set up
APPENDIX 5: Matlab syntax for calculating COP excursion

% This program is for the calculation of the COP
% Made by Michel Ladouceur, PhD and Kelly Krahn, CPT
% July, 2003
%
% Setting up the calibration function of the forceplates based
% on the equation from AMTI
% \( V_0 = 0.0000001 \times \text{sensitivity} \times \text{Excitation Voltage} \times \text{Amplifier Gain} \)
% FP1 is AMTI SN:4297
% FP2 is AMTI SN:4296
% FP3 is AMTI SN:4295
%
Sens_Fz_FP1 = 0.0861;
Sens_Fy_FP1 = 0.3407;
Sens_Fx_FP1 = 0.3427;
Sens_Mz_FP1 = 1.6937;
Sens_My_FP1 = 0.7902;
Sens_Mx_FP1 = 0.7867;

Sens_Fz_FP2 = 0.0860;
Sens_Fy_FP2 = 0.3408;
Sens_Fx_FP2 = 0.3428;
Sens_Mz_FP2 = 1.7035;
Sens_My_FP2 = 0.7863;
Sens_Mx_FP2 = 0.7836;

Cal_Fz_FP1 = 1 / (0.000001 * Sens_Fz_FP1 * 10 * 4000);
Cal_Fy_FP1 = 1 / (0.000001 * Sens_Fy_FP1 * 10 * 4000);
Cal_Fx_FP1 = 1 / (0.000001 * Sens_Fx_FP1 * 10 * 4000);
Cal_Mz_FP1 = 1 / (0.000001 * Sens_Mz_FP1 * 10 * 4000);
Cal_My_FP1 = 1 / (0.000001 * Sens_My_FP1 * 10 * 4000);
Cal_Mx_FP1 = 1 / (0.000001 * Sens_Mx_FP1 * 10 * 4000);

Cal_Fz_FP2 = 1 / (0.000001 * Sens_Fz_FP2 * 10 * 4000);
Cal_Fy_FP2 = 1 / (0.000001 * Sens_Fy_FP2 * 10 * 4000);
Cal_Fx_FP2 = 1 / (0.000001 * Sens_Fx_FP2 * 10 * 4000);
Cal_Mz_FP2 = 1 / (0.000001 * Sens_Mz_FP2 * 10 * 4000);
Cal_My_FP2 = 1 / (0.000001 * Sens_My_FP2 * 10 * 4000);
Cal_Mx_FP2 = 1 / (0.000001 * Sens_Mx_FP2 * 10 * 4000);
% Generate the force vectors

FP1_Fz = sweep1(:,3)*Cal_Fz_FP1;
FP1_Fy = sweep1(:,4)*Cal_Fy_FP1;
FP1_Fx = sweep1(:,5)*Cal_Fx_FP1;
FP1_My = sweep1(:,7)*Cal_My_FP1;
FP1_Mx = sweep1(:,8)*Cal_Mx_FP1;
FP2_Fz = sweep1(:,9)*Cal_Fz_FP2;
FP2_Fy = sweep1(:,10)*Cal_Fy_FP2;
FP2_Fx = sweep1(:,11)*Cal_Fx_FP2;
FP2_My = sweep1(:,13)*Cal_My_FP2;
FP2_Mx = sweep1(:,14)*Cal_Mx_FP2;

FP1_Fz = downsample(FP1_Fz, 4);
FP1_Fy = downsample(FP1_Fy, 4);
FP1_Fx = downsample(FP1_Fx, 4);
FP1_My = downsample(FP1_My, 4);
FP1_Mx = downsample(FP1_Mx, 4);
FP2_Fz = downsample(FP2_Fz, 4);
FP2_Fy = downsample(FP2_Fy, 4);
FP2_Fx = downsample(FP2_Fx, 4);
FP2_My = downsample(FP2_My, 4);
FP2_Mx = downsample(FP2_Mx, 4);

% Filter the force vectors to 15 Hz with a Sampling Frequency of 1200 Hz
% Using Winter's method (1990) Butterworth 4th order Zero-phase shift filter

Fs = 300;
Fcutoff = 4;
Fc = Fcutoff/0.802;
wn = (Fc*2)/Fs;
[b,a] = butter(2,wn);

FP1_Fz_Filtered = filtfilt(b,a,FP1_Fz);
FP1_Fy_Filtered = filtfilt(b,a,FP1_Fy);
FP1_Fx_Filtered = filtfilt(b,a,FP1_Fx);
FP1_My_Filtered = filtfilt(b,a,FP1_My);
FP1_Mx_Filtered = filtfilt(b,a,FP1_Mx);
FP2_Fz_Filtered = filtfilt(b,a,FP2_Fz);
FP2_Fy_Filtered = filtfilt(b,a,FP2_Fy);
FP2_Fx_Filtered = filtfilt(b,a,FP2_Fx);
FP2_My_Filtered = filtfilt(b,a,FP2_My);
FP2_Mx_Filtered = filtfilt(b,a,FP2_Mx);
%Find Stance Duration
for n=30:3000
if FP2_Fz(n) > 20
    startstance = n;
    break
end
end

for n=startstance:3000
if FP2_Fz(n) > 20
    endstance = n;
end
end

% Manipulation of data in light of slippage
%sipstance = startstance + 30;
%
%for n=1:12000
%if n > startstance & n < slipstance;
%    FP2_Fy(n) = 0;
%end
%
%
% Calculate COP
%
FP1_Zoffset = -0.044836;
FP2_Zoffset = -0.043428;

for n=1:3000
FP1_COPx(n)=((FP1_My_Filtered(n)+(FP1_Zoffset*FP1_Fx_Filtered(n)))/FP1_Fz_Filtered(n))*(-1);
FP1_COPy(n)=((FP1_Mx_Filtered(n)-(FP1_Zoffset*FP1_Fy_Filtered(n)))/FP1_Fz_Filtered(n));
FP2_COPx(n)=((FP2_My_Filtered(n)+(FP2_Zoffset*FP2_Fx_Filtered(n)))/FP2_Fz_Filtered(n))*(-1);
FP2_COPy(n)=((FP2_Mx_Filtered(n)-(FP2_Zoffset*FP2_Fy_Filtered(n)))/FP2_Fz_Filtered(n));
end

% Filter the COP calculations
%
FP1_COPx_Filtered = filtfilt (b,a,FP1_COPx);
FP1_COPy_Filtered = filtfilt (b,a,FP1_COPy);
FP2_COPx_Filtered = filtfilt (b,a,FP2_COPx);
FP2_COPy_Filtered = filtfilt (b,a,FP2_COPy);

% Cropping of data for plotting and analysis
i=1;
for n=startstance:endstance
    FP2_COPx_stance(i) = FP2_COPx_Filtered(n);
    FP2_COPy_stance(i) = FP2_COPy_Filtered(n);
    i=i+1;
end

figure (1);
plot (FP2_COPx_stance,'r');
grid on;
hold;
plot (FP2_COPy_stance,'b');
legend ('FP2_COPx:red','FP2_COPy:blue');
grid on;
hold;
figure (2);
plot (FP2_COPy_stance,FP2_COPx_stance);
grid on;

stancetime = (endstance-startstance) / Fs
Xexcursion = max(FP2_COPx_stance) - min(FP2_COPx_stance)
Yexcursion = max(FP2_COPy_stance) - min(FP2_COPy_stance)
clear
APPENDIX 6: Exercise training log

Date:_______ Time:_______

Body Weight (lbs):_____ Weighted Vest Weight (lbs):_____

Target Heart Rate: __________
Heart Rate During Warm-up: __________
Heart Rate During Walking: __________
Heart Rate After Cool down: __________

Please check which activities you completed today

<table>
<thead>
<tr>
<th>Warmup &amp; Stretches</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking on Track</td>
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</tr>
<tr>
<td>Strength Training</td>
<td></td>
</tr>
<tr>
<td>Abdominal &amp; Back Work</td>
<td></td>
</tr>
<tr>
<td>Cool down &amp; Stretch</td>
<td></td>
</tr>
</tbody>
</table>

Comments:____________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
______________________________________________________________
APPENDIX 7: Example of peak muscle torque trace using the Biodex
# APPENDIX 8: Pairwise comparisons of the mean difference ± SE between five obstacle heights for peak vertical braking force

<table>
<thead>
<tr>
<th>Obstacle height (x)</th>
<th>Obstacle height (y)</th>
<th>Mean Difference (x-y) ± SE</th>
<th>P value</th>
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<td>24.2 ± 22.3</td>
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<td>-84.9 ± 23.5</td>
<td>0.03*</td>
</tr>
<tr>
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<td>-87.3 ± 26.1</td>
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<td>-109.1 ± 21.9</td>
<td>0.00*</td>
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<td>0.00*</td>
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<td>2.0 ± 20.1</td>
<td>1.00</td>
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<td>0.03*</td>
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<td>5</td>
<td>109.1 ± 21.9</td>
<td>0.00*</td>
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<tr>
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<td>82.9 ± 22.8</td>
<td>0.03*</td>
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<td>111.5 ± 24.2</td>
<td>0.00*</td>
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<td>85.3 ± 27.5</td>
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* Mean difference is significant at the 0.05 level
APPENDIX 9: Pairwise comparisons of the mean difference ± SE between five obstacle heights for peak anterior-posterior braking force

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<th>Obstacle height (x)</th>
<th>Obstacle height (y)</th>
<th>Mean Difference (x-y) ± SE</th>
<th>P value</th>
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<td></td>
<td>25</td>
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<td></td>
<td>30</td>
<td>-87.5 ± 20.9</td>
<td>0.01*</td>
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<td>0</td>
<td>1.2 ± 10.1</td>
<td>1.00</td>
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<td>10</td>
<td>-19.8 ± 11.0</td>
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<tr>
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<td>25</td>
<td>-81.7 ± 13.8</td>
<td>0.00*</td>
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<td>21.0 ± 9.5</td>
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<td>0.06</td>
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<td>0</td>
<td>82.9 ± 16.7</td>
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<td>5</td>
<td>81.7 ± 13.8</td>
<td>0.00*</td>
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<td>0</td>
<td>87.5 ± 20.9</td>
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<td>66.4 ± 20.4</td>
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* Mean difference is significant at the 0.05 level
APPENDIX 10: Pairwise comparisons of the mean difference ± SE between five obstacle heights for vertical braking impulse

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<th>Obstacle height (y)</th>
<th>Mean Difference (x-y) ± SE</th>
<th>P value</th>
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<td>25</td>
<td>-114.8 ± 16.6</td>
<td>0.00*</td>
</tr>
<tr>
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<td>-129.2 ± 21.1</td>
<td>0.00*</td>
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<td>0</td>
<td>30.8 ± 13.9</td>
<td>0.44</td>
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<td>-8.1 ± 7.5</td>
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<td>38.9 ± 10.3</td>
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<td>5</td>
<td>8.1 ± 7.5</td>
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<td>-90.3 ± 16.0</td>
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<td>114.8 ± 16.6</td>
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<td>84.0 ± 11.5</td>
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<td>0</td>
<td>129.2 ± 21.1</td>
<td>0.00*</td>
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<tr>
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<td>5</td>
<td>98.4 ± 15.3</td>
<td>0.00*</td>
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<tr>
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<td>90.3 ± 16.0</td>
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* Mean difference is significant at the 0.05 level
APPENDIX 11: Pairwise comparisons of the mean difference ± SE between five obstacle heights for anterior-posterior braking impulse

<table>
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<tr>
<th>Obstacle height (x)</th>
<th>Obstacle height (y)</th>
<th>Mean Difference (x-y) ± SE</th>
<th>P value</th>
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<td>10</td>
<td>-72.5 ± 11.8</td>
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<td>0.00*</td>
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<td>-181.3 ± 25.0</td>
<td>0.00*</td>
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<td>41.9 ± 13.3</td>
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<td>72.5 ± 11.9</td>
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<td>-81.6 ± 11.7</td>
<td>0.00*</td>
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<td>-108.8 ± 16.8</td>
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<td>154.1 ± 19.5</td>
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<td>0.00*</td>
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<td>181.3 ± 25.0</td>
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<td>139.4 ± 17.9</td>
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<td>0.00*</td>
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* Mean difference is significant at the 0.05 level
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APPENDIX 12: Pairwise comparisons of the mean difference ± SE between five obstacle heights for stance time

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<td>-0.13 ± 0.01</td>
<td>0.00*</td>
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<td>0.05 ± 0.00</td>
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<td>0.02 ± 0.01</td>
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<td>-0.06 ± 0.01</td>
<td>0.00*</td>
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<td>0.00*</td>
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<tr>
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<td>10</td>
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<tr>
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* Mean difference is significant at the 0.05 level
APPENDIX 13: Correlations between peak ankle plantar flexion at speeds of 60 and 180 degrees/second and M/L GRF and impulse at T1 for all 16 subjects (panels A, B, C and D respectively)