The effects of a 12-week multifactorial exercise and balance training program on balance control in older adults

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Submitted in partial fulfillment of the requirements for the degree Master of Sciences in Applied Health Sciences (Kinesiology)

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ABSTRACT

The current thesis investigated the effects of a 12-week multifactorial exercise and balance training program on balance control in older adults. Participants completed a baseline testing session which included a series of questionnaires, anthropometric measures, and 18 stance and walking tests. Those who were randomly assigned to the exercise group participated in the 12-week training program while the comparison group was asked not to change anything in his/her lifestyle during the 12-week control period, but were invited to participate in the training program after his/her control period. The same testing protocol was repeated after the 12-week period. The results indicated that there were improvements in the time to complete the walking tests but no change in trunk sway in both the exercise and comparison groups. No changes in stance durations or trunk sway were observed. The findings suggest that the current training program showed no significant improvement in balance control in healthy older adults.

Key Words: trunk sway, balance, gait, multifactorial exercise, older adults
ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisor, Dr. Allan Adkin, for all of his hard work over the past 2 years. I really appreciated your “open door” policy and your willingness to sit down and explain concepts to me at length. I also very much appreciated your support through building my teaching dossier. Giving me the opportunity to lecture for your PEKN 2P05 class was an absolute pleasure and I thank you. Providing me with advice when I was searching for universities to do a PhD was paramount, your counsel was vital. Giving me many opportunities to present at conferences and gain experience has definitely grown me. Thank you again for taking me on as a student, it was an honour.

I would also like to acknowledge my committee members: Drs. Nota Klentrou, Kimberley Gammage and Craig Tokuno and my external committee member Dr. William Gage. Thank you so much for your time and your willingness to offer advice, I couldn’t have done this without you.

I would like to thank the participants from this study, other testers and the intervention staff for their time commitment. Without your contribution, this thesis would not be possible.

I would like to thank my roommates at 2 Larchwood and a special thanks to Todd Mahler for all their support, even though you may have not known exactly what I did everyday, you have still been supportive through this experience.

To all of my graduate student friends, all of our social events, laughs, and unforgettable memories have definitely made this experience enjoyable.
I would also like to extend my sincerest gratitude to my parents, my brothers Dave and Mike, my sister Marie, and my boyfriend Aaron. I value all of your time spent with editing my thesis and being there for me throughout this process, it was very much appreciated. You continue to be encouraging and supportive, and for that I am so grateful.

To everyone listed above, I have learned so much over the past 2 years and your continued help and support has made this experience a memorable one. Thank you
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CHAPTER 1: LITERATURE REVIEW

1.1 Canada’s Aging Population

The percentage of Canadians over the age of 65 has increased primarily due to the post-World War II baby boom coupled with subsequent declines in birth rates (Health Canada, 2002). In fact, it is estimated that “baby boomers” constitute nearly one-third of the Canadian population (Rawson & Saad, 2010), and that the projected number of adults over the age of 65 will increase by 43% between the years 2000 to 2020 (Anderson & Hussey, 2000). This shift in population will further strain Canada’s health care system, as, historically, older adults have had a high demand for health care services (Turcotte & Schellenberg, 2006).

1.2 Falls in Older Adults: Impact on Canada’s Health Care System

Falls and related consequences in older adults are a major health care issue. An estimated one third of those aged 65 and older experience one or more falls every year (Gillespie et al., 2009), especially in the medial-lateral or side-to-side direction (Maki, Holliday, & Topper, 1994). Almost 50% of older adults suffer a minor injury from a fall, and approximately 5% to 25% suffer a serious injury, such as a fracture or a sprain from a fall (Alexander, Rivara, & Wolf, 1992). Nearly 62% of injury-related hospitalizations are caused by falls in older adults (Canadian Institute for Health Information, 2004). Although falls have direct physical consequences, other changes in behaviour and lifestyle are associated with falls (King & Tinetti, 1995). For example, falls have been associated with functional impairment (Kiel, O’Sullivan, Teno, & Mor, 1991; Tinetti & Williams, 1998), activity restriction (Kosorock, Omenn, Diehr, Koepsell, & Patrick,
1992), fear of falling (Howland et al., 1993), premature institutionalization (Dunn, Furner, & Miles, 1993), and mortality (Baker & Harvey, 1985) in older adults. As families are often unable to provide homecare support, 40% of all nursing home admissions occur as a result of falls in older adults (Tinetti & Williams, 1998). Therefore, it is estimated that a 20% reduction in falls would translate to approximately 7500 fewer hospitalizations and 1800 fewer permanently disabled older adults, which would account for a savings of $138 million annually in Canada (SMARTRISK, 1998). This emphasizes the importance of research dedicated to fall prevention in older adults in order to decrease the associated burden on the health care system, especially given Canada’s current aging population.

1.3 Falls in Older Adults: A Multifactorial Problem

The prevention of falls remains a difficult challenge due to multiple task, environmental, and individual factors that may interact to cause a fall. Examples of task factors that increase the likelihood of falling are stepping over an obstacle, climbing a ladder, or simultaneously performing a cognitive or motor task while maintaining balance (i.e., dual tasking). Impaired balance during dual tasking has been observed in older adults (Maki, Zecevic, Hamid, Kirshenbaum, & McIlroy, 2001). Furthermore, those who are unable to maintain a conversation while walking, and subsequently must stop walking to hold a discussion, are more likely to fall (de Hoon et al., 2003).

Examples of environmental factors that contribute to falls include both home and outdoor hazards. Approximately 60% of all fatal falls occur in the home (Bloem, Steijns, & Smits-Engelsman, 2003); some examples of indoor hazards include loose carpets,
slippery floors, clutter, dimly lit rooms, and low toilet seats. Outdoor hazards include irregular or raised sidewalks, absent or poorly secured handrails, and traffic lights that do not allow for sufficient time to cross the street.

Examples of individual factors that may contribute to falls include age-related changes to the balance control system, which includes the deterioration of neural and musculoskeletal systems (Maki & McIlroy, 2003). Visual impairment (Tromp et al., 2001), decreased vestibular function (Ochs, Newberry, Lenhart, & Harkins, 1985; Sloane, Baloh, & Honrubia, 1989), decreased vibratory sense (Whanger & Wang, 1974), changes in muscular strength (Aniansson, Grimby, & Genberg, 1978; Whipple, Wolfson, & Amerman, 1987), and decreased joint flexibility (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995; Lewis & Bottomley, 1990) may increase the risk of falling. Impaired balance can increase the risk of falls, fractures and functional dependence among older adults (Duncan, & Studenski, 1992; Maki, Holliday, & Topper, 1991; Tinetti & Ginter, 1988; Woollacott, Shumway-Cook, & Nasher, 1986). Taken together, these findings suggest that there are age-related effects on the control of balance which can contribute to falls.

The interaction between task, environmental, and individual factors makes it difficult to predict when falls will occur. For example, carrying groceries while talking and navigating through a challenging environment may be difficult for an older adult placing him/her more at risk of falling; however this same scenario may be quite simple for a younger adult. Strategies to improve balance control and/or reduce task and environmental demands may assist in preventing falls in older adults. This thesis focuses
on using exercise and balance training to modify the individual constraint of age-related changes to the balance control system.

1.4 Balance Control System

Balance is an important requirement for the successful performance of many of our daily activities. The control of balance involves the complex interaction of multiple systems. Horak (2006) describes the systems approach to understanding balance as an interaction of biomechanical constraints, movement strategies, sensory strategies, orientation in space, control of dynamics, and cognitive processing. Without an understanding of the systems approach to balance, one may assess balance using one test and prescribe a single balance or exercise program to prevent falls. For example, if the performance on the Timed-Up-and-Go (TUG) determined that an older adult required strength training due to difficulty getting out of the chair, participating in strength training in isolation may not address other age-related deteriorations such as a reduced ability to perform dual-tasking activities; however solely examining this single balance test would only provide information on certain deteriorations in the balance control system. The systems approach encompasses the variety of balance systems that are involved during standing, walking and daily activities. Horak (2006) also outlines that the age-related changes in these balance systems vary across older adults. For some older adults, sensory loss in the feet due to neuropathy may result in an increased reliance on visual information (Horak & Hlavacka, 2001), which may result in instability in the dark. Other older adults may compensate for sensory loss by dependence on an assistive device (Dickstein, Peterka, & Horak, 2003); this strategy may serve to be helpful in the dark but
may be cumbersome when quickly stepping to the side to recover balance due to a postural disturbance (Zettel, McIlroy, & Maki, 2002). With ageing comes the increased likelihood of reliance on one of more of these subcomponents which suggests that balance should be examined under a wide variety of balance tests and trained on each subcomponent as there are individual differences among older adults. A summary of the six important subcomponents of the systems approach is provided.

1.4.1 Biomechanical Constraints

Balance can be defined as the process by which the body’s center of mass (COM) is controlled with respect to its base of support (BOS), or the area of the body that is in contact with the support surface, whether it is stationary or moving (Shumway-Cook & Woollacott, 2001). Horak (2006) suggests that the size and quality of the BOS (i.e., the feet) are the most important biomechanical constraints. Changes in the BOS from size, strength, range of motion, and control of the feet will affect balance (Tinetti, Speechlev, & Ginter, 1988). For example, changes in the orientation of the BOS such as standing on two legs to standing on one leg will increase the biomechanical constraints placed on the system. Mastery of one-legged stance is especially important as it occurs during 20-40% of walking during the swing phase and it has been suggested that one-legged stance is especially important for activities of daily living such as walking up stairs (Lichtenstein, Shields, Shiavi, & Burger, 1990). Longer one-legged stance is also correlated to faster walking speeds (Ringsberg, Gerdhem, Johansson, & Obrant, 1999).

Muscle strength is also an important biomechanical constraint as falls have been linked to muscle weakness. For example, Sieri and Beretta (2004) found that older men who have fallen have greater deficits in ankle plantar-flexor strength and power and older
women who have fallen have greater deficits in knee extension strength and power as well as decreased walking speed.

1.4.2 Movement Strategies

There are three main strategies to recover balance: an ankle, hip and stepping or reaching strategy. The ankle strategy shifts the body’s COM by rotating the body about the ankle joints with minimal hip or knee movement. This strategy typically occurs in response to small perturbations on a firm, wide surface capable of resisting ankle rotational torques. The hip strategy repositions the COM by flexing at the hips. This strategy typically occurs in response to fast, large perturbations and when the support surface is compliant. The hip strategy cannot be used on slippery surfaces (i.e., icy surfaces) since hip sway transmits horizontal shear forces to the surface. When the ankle and hip strategies are inadequate, the stepping or reaching strategy is used. It typically occurs in response to very fast or large perturbations. Individuals at risk for falling tend to select a combination of a stepping or reaching strategy and a hip strategy compared to healthy older adults who would tend to choose an ankle strategy (Maki, Edmondston, & McIlroy, 2000). The appropriate selection of a postural strategy depends on the size of the stability limit and the area over which each strategy could be used depends on individual differences, environmental characteristics, and the nature of the postural task (McCollum & Leen, 1989).

Postural adjustments are also frequently seen prior to a destabilizing force, and are called anticipatory postural adjustments (APAs). APAs help to maintain stability before voluntary movement in anticipation of the destabilization of a movement of a limb. Without APAs, all perturbations to the COM would be managed on a crisis by crisis basis
such as during unexpected perturbations, which consequently may lead to an increased risk of falling. Frank, Patla, and Brown (1987) compared the voluntary APAs of young versus older adults and found that both age groups displayed APAs; however older adults displayed longer latencies and also showed more co-contraction compared to young adults. Moreover, individuals with poorly coordinated responses show postural instability in response to external disturbances whereas those with poorly coordinated APAs show postural instability during voluntary movements (Horak, Frank, & Nutt, 1996).

1.4.3 Sensory Strategies

The control of balance is also influenced by the amount of sensory information available. Sensory information from the visual, somatosensory, and vestibular inputs must be integrated when overcoming complex sensory environments. In general, a healthy person standing on a firm BOS in a well-lit area relies on 10% vision, 70% somatosensory and 20% vestibular information (Peterka, 2002). However, the relative contribution of each system must be reweighted in different contexts. For example, when standing on an unstable surface, there is an increased dependence on vision and vestibular inputs to remain upright (Peterka, 2002). The ability to reweight sensory information is important for all populations, but becomes increasingly difficult for those with compromised sensory systems as they may become more at risk for falling (Horak, 2006).

A comprehensive study by Gill and colleagues (2001) examined balance under various stance, stance-related and gait tasks in different visual (eyes open, eyes closed) and sensory (vestibular, proprioceptive) conditions in young (15-25 years), middle aged (45-55 years) and older adults (65-75 years). They found all three age groups experienced increases in trunk sway as the various sensory systems were challenged in
these four unperturbed two-legged standing conditions: eyes open on firm surface, eyes closed on firm surface, eyes open on foam surface, and eyes closed on foam surface (Gill et al., 2001). The eyes closed condition proved to be more difficult (i.e., greater sway amplitude) than the eyes open condition for all two-legged tasks, and the foam support condition proved to be more challenging than the firm support surface among all age groups. Some have suggested that proprioceptive information is the most important sensory information available (El-Kashlan, Shepard, Asher, Smith-Wheelock, & Telian, 1998; Shumway-Cook, & Horak, 1986; Whipple, Wolfson, Derby, Singh, & Tobin, 1993), however Gill et al. (2001) found that the age related effects were less significant on a foam support than with eyes closed on a firm surface, suggesting that visual and vestibular inputs are more important than proprioceptive inputs for the control of standing (Gill et al., 2001). This has also been confirmed as reduced proprioceptive input from the ankles influences stabilizing responses to postural perturbations less than reduced vestibular or visual inputs (Allum, Bloem, Carpenter, & Honegger, 2000; Allum & Honegger, 1998; Allum & Shepard, 1999). The role of vision and vestibular inputs may be more important for older adults compared to young adults due to a decreased accuracy from lower-leg proprioceptive inputs (Blaszczyk, Hansen, & Lowe, 1993; Ring, Nayak, & Isaacs, 1989; Teasdale, Stelmach, & Breunig, 1991), but also due to a slowing of the conduction velocities of proprioceptive sensory signals due to age-related effects (Perrin, Jeandel, Perrin, & Béné 1997).

1.4.4 Orientation in Space

Horak (2006) delineates that the ability to orient the body in space with respect to gravity, the support surface, environment, and internal references is important for
balance. Automatic control processes orient the body in space in healthy individuals. For example, when standing on a wobble board, the body is constantly orienting itself in space in accordance to the tilting of the support surface. When in the dark, healthy individuals can maintain upright posture within a 0.5° angle as a result of the integration of multiple neural systems (Karnath, Ferber, & Dichgans, 2000). An inaccurate representation of upright posture renders an individual unstable, which may be attributed to the misalignment of perceived versus actual upright posture.

1.4.5 Control of Dynamics

Dynamic balance is the ability to maintain an upright posture while either the COM or the BOS are moving or the COM is moving outside the BOS (Woollacott & Tang, 1997). During the initiation stage of walking, the major role of the central nervous system is to destabilize the body by causing the COM to move ahead of the foot to commence forward progression of the body (Mann, Hagy, White, & Liddell, 1979). During steady-state walking, the COM is continuously moving beyond the BOS and re-establishing a new BOS with each step. In addition to gait being inherently unstable, perturbations may arise from self-initiated movements of the limbs or trunk, such as picking up an object that was heavier than expected while walking, as well as external forces such as being bumped in a crowd while walking (Patla, Frank, & Winter, 1990).

Lateral stability is controlled by lateral trunk control and lateral placement of the feet (Bauby & Kuo, 2000). The age-related declines in balance are emphasized in the medial-lateral direction such that an increase in sway in this direction translates to an increased risk for falls (Campbell, Borrie, & Spears, 1988). In fact, older adults tend to show increased postural sway during stance and stance related tasks (Gill et al., 2001),
decreased time to hold a one-legged stance (Gill et al., 2001), longer time to complete adaptive gait tasks (Gill et al., 2001), wider stride width (Helbostad & Moe-Nilssen, 2002), and decreased sway during gait tasks (Gill et al., 2001) compared to younger adults. These classic characteristics of the age-related changes in balance adopted by older adults may increase the BOS in order to increase overall stability, but this comes at the cost of kinetic efficiency, increasing the metabolic cost of walking (Mian, Thom, Ardigò, Narici, & Minetti, 2006).

1.4.6 Cognitive Processes

Dual tasking involves the performance of multiple actions simultaneously. The limited attention capacity theory suggests that the capacity for attention is drawn from a pool of resources; if capacity is exceeded, performance decreases on one or more of the tasks (Just & Carpenter, 1992). Given that one can concentrate on only a certain amount of information at one time, the ability to process information is limited. Even upright posture requires a certain amount of attention as shown with increased reaction times when seated compared to standing (Horak, 2006).

Dual tasking in combination with static and dynamic postural control may have detrimental effects on gait (Dault, Geurts, Mulder, & Duysens, 2001; Yardley et al., 2001). More specifically, attention switching, which is the ability to switch attention resources from task to task, that usually occurs during balance is impaired in older adults. Thus impaired attentional dynamics may contribute to impaired stability (Maki, Holliday, & Topper, 2001). Individuals with balance impairments may experience a limited availability of cognitive processing of a secondary task due to the increased need to prioritize balance, which can be called an increased dual task interference effect.
This summary of the 6 systems underlying balance described by Horak (2006) shows the importance of designing an exercise and balance training program incorporating a wide variety of balance challenges and assessing the impact of this training program using a variety of stance and walking tests.

1.5 Physical Activity in Older Adults

Older adults represent the most sedentary sector of the adult population. In fact, 57% of Canadian adults aged 65 and older are physically inactive (Canadian Community Health Survey, 2008). Physical activity tends to decrease with age, especially with those aged 65 and older (Canadian Community Health Survey, 2008; Statistics Canada, 1999). The effects of physical inactivity may lead to loss of bone and muscle strength, decreased cardiovascular and respiratory fitness, lack of flexibility and increased risk of chronic disease (Warbuton, Nicol, & Bredin, 2006). Inactivity is also a significant risk factor for functional decline and disability among older adults (Stuck et al., 1999; World Health Organization, 2000).

In contrast, regular physical activity may lead to many positive health outcomes for older adults. Some of the known positive outcomes include: maintenance of functional ability, increased independence and autonomy, improved psychological health, and reduced risk of chronic conditions such as arthritis, cardiovascular disease, diabetes, colon and breast cancer, osteoporosis, hypertension, anxiety, stress-related conditions, depression, obesity, back pain, unintentional injuries, and falls (Bassey, 2000; 2005). Regular physical activity is also recommended to maintain muscle strength, coordination,
joint function and flexibility, as well as functional and cognitive capacity as these tend to
decrease with age (Baker, Atlantis, & Singh, 2007).

Current guidelines stress multifactorial physical activity prescription for older
adults, including strengthening exercises, cardiovascular, flexibility and balance training
as these modalities are the most documented and have demonstrated positive health
effects when prescribed in isolation (Baker et al., 2007). Previous research has shown
that frequent or occasional leisure-time physical activity is associated with remaining
healthy in older adulthood (Shields & Martel, 2006). Recommendations suggest that
older adults should participate in moderate physical activity 5 days per week or vigorous
intensity activity 3 days per week (Nelson et al., 2007). Research has also consistently
linked increases in exercise with improved functional independence. For example, Sato,
Kaneda, Wakabayashi and Nomura (2009) found that there was a significant correlation
between the physical functioning portion of the Short-Form-36 (SF-36), which is a
measure of health-related quality of life, and the Functional Independence Measure (FIM)
questionnaire ($r=0.301$, $p<0.05$) from baseline to 12 months, using a difference score, of
twice per week attendance at an aquatics intervention in frail older adults. Other research
has also demonstrated significant improvements in the physical functioning portion of the
SF-36 in the exercise group (baseline mean: 88, standard deviation: 12; post mean: 89.3,
standard deviation: 9.7) compared to the comparison group (baseline mean: 82, standard
deviation: 17; post mean: 80.2, standard deviation: 14.8) after a 6-month, 3 times per
week multifactorial training program in those aged 70 years and older (Cress et al., 1999).

It is well recognized that exercise interventions can improve balance in healthy
individuals (Howe, Rochester, Jackson, Banks, & Blair, 2007). Many studies have shifted
to exercise and balance training to improve physical fitness and strengthen the resistance against fall-related injury. Exercise has been shown to reduce the occurrence of falls in the home in older adults (Day et al., 2002; Robertson, Gardner, Devlin, & Campbell, 2001). Other research has found that it is not effective at reducing falls in general in the elderly population (Barnett, Smith, Lord, Williams, & Baumand, 2003). Despite this finding, recent work has shown through a review that exercise interventions should include a balance training component to reduce fall risk in older adults (Sherrington et al., 2008).

Sherrington et al. (2008) also recommend that the exercise training is moderate to highly challenging, of sufficient dose including training at least 2 hours per week summing to over 50 hours in total, ongoing for a lasting fall prevention effect, targeted to older adults at risk and not at risk for falls, performed at home or in a group, not singularly comprised of a walking program, offering the option of strength training as it may provide further benefits, and providing referrals to other risk factors for falls such as cataract surgery. Further, a meta-analysis outlining several studies suggests that training programs appear to have an indirect effect on balance measures such as the TUG, single leg stance, walking speed, subjective balance measures and the BBS (Howe et al., 2012). However, Howe et al. (2012) suggested that there is insufficient evidence to conclude the effects of a training program on clinical balance outcomes, which expresses the need for further investigation.

In sum, regular aerobic, resistance (Singh, 2002), balance (Hain, Fuller, Wil, & Kotsias, 1999; Lord, Ward, Williams, & Strudwick, 1995; Wolfson et al., 1996) and flexibility training (Alter, 1988; Pollock, et al., 1998) have the potential to lessen the
impact of age-related changes on balance. To determine the impact of balance and exercise training on balance control and functional mobility, examining various forms of exercise is necessary. It is also important to investigate the combination of multifactorial exercise prescription on balance control in older adults as limited research focuses on this area.

1.5.1 Balance Training Interventions

Balance training interventions have shown mixed findings with some improving balance control and reducing the risk for falls (Fong & Ng, 2006; Gatts & Woollacott, 2007; Hackney & Earhart, 2008; Ramachandran, Rosengren, Yang, & Hsiao-Wecksler, 2007; Sihvonen, Sipila, & Era, 2004; Tsang & Hui-Chang, 2006; Wallmann, Gillis, Alpert & Miller, 2009; Wolf, Barnhart, Ellison, & Coogler, 1997; Yang, Verkuilen, Grubisich, Reed, & Rosengren, 2006) and others not showing effects on balance (Barnett et al., 2003; Gatts & Woollacott, 2007; Weerdesteyn et al., 2005). To challenge the balance control system, standing balance exercises can be progressed to dynamic balance exercises such as challenging the sensory system with various tactile obstacles, challenging the BOS during walking activities such as tandem walking (heel-to-toe walking), or perturbing the COM or BOS during a balance activity. A variety of methods of balance training exist, and various forms of balance training research in older adults such as dance classes, balance education, vibration training, computerized balance training, as well as tai chi are outlined below. It is important to note that the diverse training programs train different aspects of the balance control system.

Senior jazz dance has shown improvements on static balance in women over the age of 50 (Wallmann, et al., 2009). They found that once per week attendance for 15
weeks of a jazz dance class had benefits for static balance using the 6 Sensory Organization Test conditions. These conditions consist of 1) normal vision, fixed support 2) no vision, fixed support 3) sway-referenced vision, fixed support 4) normal vision, sway-referenced support 5) no vision, sway-referenced support 6) sway-referenced vision, sway-referenced support. Significant differences between baseline, midway through the intervention, and post intervention for all conditions were found except for normal vision, fixed support and no vision, fixed support (conditions 1 and 2). Insignificant findings in conditions 1 and 2 may be attributed to the lack of complexity of the tasks. A similar study examining folk dance in older adults showed that after an 8 week intervention, improvements were observed in the chair stand time, 6 minute walk, stair climbing and the Berg Balance Scale (BBS) in the folk dancing group compared to the comparison group (Eyigor, Karapalt, Durmaz, Ibisoglu, & Cakir, 2009).

In contrast, educational balance sessions including various topics such as polypharmacy, memory loss, bereavement, sleep disturbances, falls, and other issues of importance to the group (Wolf et al., 1997), have shown to have little to no improvements on balance and are often times used for the purposes of a comparison group. For instance, Wolf and colleagues (1997) found no significant improvement in balance after the educational factors were discussed. Similarly, Gatts and Woollacott (2007) found that the educational sessions showed improvements only on the Functional Reach test with no improvements in the TUG or the BBS test performance. Although changes in balance control are not typically observed during educational training programs, Bouwerm Walker, Tydahl, and Culham (2003) did find improvements in balance confidence.
Whole body vibration, which provides vibration signals to the body, has shown some beneficial effects on balance in community-dwelling older adults. For as little as 3 minutes, 3 days per week for 3 months, whole body vibration in the medial to lateral direction showed improvements in movement velocity and maximum point excursion compared to the comparison group (Cheung et al., 2007). A similar study examining whole body vibration in the medial to lateral direction showed improvements in the time to complete the TUG, 5 chair stands test, as well as on the Tinetti balance test which consists of a series of both standing and walking balance tasks completed by the participant and rated subjectively by the examiner (Furnass & Maschette, 2009). These improvements were shown in those who completed the whole body vibration 2 and 3 times per week but no improvements were shown for those who completed whole body vibration once per week or not at all.

Other programs such as computerized balance training, which uses force transducers to detect changes in the COM when adjusting weight to a moving cursor displayed on a monitor, have also shown improvements in standing balance. Wolf et al. (1997) found that computerized balance training showed improvement in standing balance measures and no improvement in the educational group or the tai chi group after 15 weeks of 1 hour per week instruction. However, these findings have limitations as the computerized balance training group was tested with the same instrumentation as in the intervention. This could have led to learning or practice effects as familiarization with the instrumentation may be a primary factor for the enhanced postural stability. The older adults who participated in the balance training program showed significantly less trunk sway when standing with toes up, with eyes open or closed, than the tai chi group.
and comparison group; however, there were no differences between groups for quiet standing with eyes open or closed (Wolf et al., 1997). In a similar study examining the effects of a 4-month intervention using computerized force platform with visual feedback in frail older women, standing leans were examined (Sihvonen et al., 2004). It was found that a 35% improvement in the stability limit parameter during standing leans was observed in those who received balance training and visual feedback compared to the comparison group. The balance trained group also showed decreases in pitch velocity in a semi-tandem stance with both eyes open and closed compared to controls. Therefore, it is unknown which standing balance tasks may be predictive of balance control and falls in older adults.

Tai chi is another well documented method of improving balance. It was traditionally a Chinese martial art fixated at defence training; yet present day balance interventions utilize this technique to also improve overall health. Tai chi has shown to significantly reduce tripping, significantly increase use of a heel-strike, control stepping strategy (swing leg and foot trajectory and end position), significantly reduce medial cross-step distance of the swing leg during gait recovery, increase COM anterior-posterior (AP) motion during heel strike (Gatts & Woollacott, 2007) and improve TUG scores compared to the control group (Frye, Scheinthal, Kemarskaya, & Pruchno, 2007). Results from Gatts and Woollacott (2007) showed that the elderly in the tai chi intervention showed an increase in COM-center of pressure (COP) AP separation at heel strike suggesting improved ability to tolerate unsteadiness, support increased mechanical loading at the hip and greater confidence in the ability to recover balance when stepping onto a moving surface.
Tai chi has also shown benefits to individuals with Parkinson’s disease. After as few as 5 days of tai chi, Parkinson’s patients showed an improvement in balance measures such as the BBS, Unified Parkinson’s Disease Rating Scale, TUG, tandem stance test, six minute walk, and backward walking (Hackney & Earhart, 2008). There were also improvements in satisfaction with tai chi as well as well-being; however, no improvements with forward walking or one-leg stance tasks were found (Hackney & Earhart, 2008).

Long term tai chi has shown benefits of smaller increases in postural sway in the AP direction in response to perturbations (Tsang & Hui-Chang, 2006), and this effect has not been seen in those who practiced tai chi for shorter durations such as 3 months (Fong & Ng, 2006). Furthermore, Ramachandran and colleagues (2007) found that tai chi practitioners show more cautious strategies by using slower gait speeds and shorter and slower steps than controls. They also use a wider base of support during preferred stance when in an upright position compared to controls and older adults (Yang et al., 2006). Ramachandran et al. (2007) also found that tai chi practitioners spend significantly longer time in single leg support while crossing an obstacle.

To reiterate, there are mixed findings with regards to the effects of balance training on balance control in older adults as the training programs and outcome measures are broad. A meta-analysis reported that there is weak support for the improvement of balance shown in some types of balance training programs in older adults (Howe et al., 2012). Specifically, balance training has shown positive effects on the TUG, two-legged stance time, one-legged stance time, gait speed, the BBS, ML stability during stance, limits of stability, and the sensory organization test. However, no differences were found
for one-legged stance time with eyes closed, the functional reach, tandem walking, or AP stability during stance.

1.5.2 Strength Training

Strength training has shown positive effects on overall physical fitness as well as balance (Lord, Ward, & Williams, 1995). This type of exercise refers to activities involving moving or lifting some type of resistance such as weights, or elastic bands, at a level that requires physical effort. While the integration of upper and lower extremity muscles should be incorporated, muscles in the lower-body (ankles, hips, leg extensors and flexors) are chiefly important for mobility and independence (Singh, 2002). Incorporating a strength training component into an exercise program targeting fall prevention is important (Day et al., 2002; Hauer et al., 2001; Robertson, Campbell, Gardner, & Devlin, 2002) as studies have highlighted that falls are associated with leg weakness (Skelton, Kennedy, & Rutherfort, 2002).

Age-related declines in muscle mass, strength, and bone density can be mitigated through strengthening exercises commenced in middle or old age (Mazzeo et al., 1998; Nelson et al., 1994). Aside from the well-known effects of resistance training such as increases in strength and the muscle fibre area (Beniamini, Rubenstein, Faigenbaum, Lichtenstein, & Crim, 1999; Carral & Pérez, 2007), this type of exercise may also pose gains in other age-related physiological impairments such as balance (Nelson, et al., 1994), aerobic capacity (Beniamini, Rubenstein, Faigenbaum, Lichtenstein, & Crim, 1999; Carral & Pérez, 2007), flexibility (Beniamini, Rubenstein, Faigenbaum, Lichtenstein, & Crim, 1999; Carral & Pérez, 2007) as well as performance based tests of functional limitations such as gait velocity, the ability to rise from a chair, and stair
climbing power (Fiatarone et al., 1990; 1994; Fisher, Pendergast, & Calkins, 1991; Pu et al., 2001; Nelson et al., 1997; Sauvage et al., 1992).

Inconsistencies exist with regards to the effectiveness of strength training regimes as some show improvements and others do not (Howe et al., 2012). A meta-analysis showed that strength training programs elicited improved TUG test performance, single leg stance time with eyes open, functional reach and an increase in walking speed; however there were no differences between exercise and comparison groups for the sensory organization test, stability limits, single leg stance time with eyes closed, walking backwards, tandem walking, fastest walking speed, or BBS scores (Howe et al., 2012). One strength training program in older adults showed that progressive resistance training for 3-6 months increased muscle strength by 40-150%, and increased total body lean mass by 1-3 kg or muscle fibre area by 10-30% (Singh, 2002). Other research showed that a 12-week dynamic resistance training elicited slower gait velocity, enhanced balance and improved ability to walk backward; however, these post-test measures were not significantly different from the comparison group (Topp, Mikesky, Wigglesworth, Holt, & Edwards, 1993). Strengthening exercises have shown beneficial effects on both on land and in water. Avelar, Bastone, Alcântara, and Gomes (2010) showed that after 40 minutes, twice per week for 6 weeks, both strengthening exercises on land and in water showed improvements on the Dynamic Gait Index (DGI) and on the BBS. Others contend that strength training does not elicit changes in balance as after 3 months of resistance training in community-dwelling older adults (Wolfson et al., 1996). Similarly, Buchner and colleagues (1997) found that a short term exercise program of 24-26 weeks in mildly deficient strength and balance participants may not have restorative effects in
gait, balance and physical health status; though, beneficial effects were seen on fall rates and health care use. Some strength gains were exhibited in a strength training group compared to an educational group, but improvements in balance or gait were not significantly different in the strength training group from the educational group (Brouwer et al., 2003).

Strengthening exercise has shown improvements in stance-related tasks. For example, significant improvement in postural sway was found in those who participated in a 6-month resistance training program and those who participated in a 6-month agility training program (Liu-Ambrose et al., 2004). The older women who were in the agility training group, and those in the resistance training group showed a decrease total sway amplitude compared to the flexibility training group when standing on foam for 30s.

Other research examining balance in seated upper and lower body strengthening exercises (twice per week attendance over a 7-month period) in frail older adults showed improvements in a chair-stand time compared to those in the reminiscence group, which was primarily a social time with music (McMurdo & Rennie 1993). The exercise group also showed improvements in flexibility and grip strength, whereas the reminiscence group incurred deterioration.

1.5.3 Aerobic Training

Aerobic activity has also shown positive effects on physical health as well as balance. These activities refer to the continuous movement of large muscle groups and are maintained for a minimum of 10 minutes (U.S. Department of Health and Human Services, 1996). Some examples include: biking, swimming, walking and daily activities such as vacuuming, and sweeping.
Aerobic exercise has shown confounding effects on the improvement of balance or gait; however, it has shown to have positive effects on reducing fall risk and health care use in older adults (Buchner et al., 1997), and therefore is important to incorporate into an exercise program for older adults as it provides the greatest protection against adverse effects of chronic diseases associated with aging (Cress et al., 2004). Although there are benefits to low-intensity activities, a progression from low to moderate intensity exercise elicits further benefits of physical activity (Cress et al., 2004). Furthermore, low to moderate intensity aerobic activities such as walking, standing, and stationary cycling at 60% maximal exercise capacity have been associated with improvements in cardiovascular efficiency (Naso, Carner, & Blankfort-Doyle, 1990; Stamford, 1973) and mobility tasks such as walking or standing on a chair (Schnelle, MacRae, Ouslander, Simmons, & Nitta, 1995).

A meta-analysis suggests that interventions focused on walking, there were no differences between the exercise and control groups on the TUG, single leg stance with eyes open or closed, narrow stance with eyes open or closed sway, or in AP or omnidirectional tilt board scores, but there were improvements in the exercise group for the functional reach test, two-legged stance time, stability scores during standing with eyes open, tandem stance time, tandem walking over 10 feet, tandem stance eyes closed, and gait speed (Howe et al., 2012). Howe et al. (2012) also report that there were no differences for interventions including cycling between exercise and comparison groups for any primary or secondary outcome measures. Some suggest that aerobic training can improve static balance (Brooke-Wavell, Athersmith, Jones, & Masud, 1998; Buchner et al., 1997; Roberts, 1985); while others believe that it cannot (Paillard, Lafont, Costes-
Salon, RiviÃre, & Dupui, 2004). For example, research has shown improved balance control in older adults who participated in speed skating at least once per week to sedentary older adults (Lamoth & van Heuvelen, 2012). Those who were participating in speed skating showed to have better standing postural control as reflected by less sway in the anterior-posterior direction on standing with eyes open, eyes closed as well as dual tasking. In fact, the older adult speed skaters showed a shift in the continuum towards that of younger adults’ postural control. Other studies contend that aerobic training does not elicit changes in balance control. Paillard et al. (2007) examined older men and compared those in a brisk walking group who participated 5 times per week for 45-60 min for a 12-week training program to a comparison group. They found no differences between groups on static balance or spatio-temporal gait such as walking speed, stride length, or double limb support; but did find improvements in lateral balance with eyes open and an increase in maximal oxygen uptake ($\text{VO}_{2\text{max}}$). Furthermore, it was suggested that changes in balance control were not observed as the older adults examined in this study were very healthy.

The ability to avoid obstacles while walking in daily life is an important skill, especially for older adults. Previous work focused on sensorimotor adaptation training, which entailed changing visual scenes in the treatment group, on a treadmill has shown positive effects on obstacle avoidance (Buccello-Stout et al., 2008). Buccello-Stout et al. (2008) showed that after a 4-week intervention of twice per week attendance of 20 minutes of treadmill training while viewing a rotating visual scene that provided a perceptual-motor mismatch, participants elicited superior performance on the obstacle
course by moving quicker and obtaining fewer penalties than the comparison group who was trained on the treadmill while viewing a static screen.

Other research by Cress et al. (1995) found that gait speed was the strongest independent predictor of self-reported physical function in 417 community-dwelling older adults and 200 nursing home residents. The ability to increase or decrease gait speed above or below the usual pace is important and suggests the potential to adapt to varying environments and task demands such as crossing the street or avoiding obstacles (Steffen, Hacker, & Mollinger, 2002). Average gait speeds for healthy older adults over the age of 60 range from 0.60-1.45 m/s for comfortable walking speeds (Blanke & Hageman, 1989; Bohannon, 1997; Elble, Thomas, Higgins, Colliver, 1991; Himann, Cunningham, Rechnitzer, & Paterson, 1988; Ferrandez, Pailhous, & Durup, 1990; Hageman & Blanke, 1986; Murray, Kory, & Clarkson, 1969; Oberg, Karszna, & Oberg, 1993; Ostrosky, VanSwearingen, Burdett, & Gee, 1994) and from 0.84-2.1 m/s for fast walking speeds (Bohannon, 1997; Murray, Kory, & Clarkson, 1969; Oberg, Karszna, & Oberg, 1993; Ferrandez, Pailhous, & Durup, 1990; Elble, Thomas, Higgins, & Colliver, 1991; Himann, Cunningham, Rechnitzer, & Paterson, 1988). Many researchers have found older adults to have slower average walking speeds than young adults, with older adults walking 71% to 97% slower than younger adults (Bohannon, 1997; Hageman & Blanke, 1986; Murray, Kory, & Clarkson, 1969; Oberg, Karszna, & Oberg, 1993; Ostrosky, VanSwearingen, Burdett, & Gee, 1994; Elble, Thomas, Higgins, & Colliver, 1991; Finley, Cody, & Finizie, 1969; Winter, Patla, Frank, & Walt, 1990). Older adults have the capacity to increase walking speed from 21% to 56% above normal gait speed when instructed to walk as fast as possible or very fast (Bohannon, 1997; Elble, Thomas,
Higgins, & Colliver, 1991; Ferrandez, Pailhous, & Durup, 1990; Himann, Cunningham, Rechnitzer, & Paterson, 1988). Therefore, the incorporation of walking in aerobic training regimes among older adults is important for reducing the risk for falls in older adults (Sherrington et al., 2011).

1.5.4  Flexibility Training

Flexibility activities promote a greater range of motion around the joint, and an increase in muscle length beyond routine daily activities. Stretching can include both dynamic and static stretches. Dynamic stretching refers to the full range of motion of the muscle about the joint such as arm circles. Static stretching is the lengthening of muscles across the joint and held for a period of 10-30 s at a time (Nelson et al., 2007).

Flexibility is important to ensure adequate range of motion to complete activities of daily living that require increased flexibility. For example, Schenkman, Morey, and Kuchibhatla (2000) examined a spinal rotation test, which measures the ability to rotate in a chair and look behind the body. They found that decreased spinal rotation resulted in increased functional limitations, as measured by the functional reach, the number of steps and the time to complete a 360° turn, and the time to complete a 10 m walk and a supine to standing test in community-dwelling older adults. Despite its importance, the effects of flexibility training on balance are mixed. Morey et al. (1999) examined aerobic training versus aerobic training plus spinal flexibility and found no differences between groups on functional balance measures such as the functional reach test. Liu-Ambrose et al., (2004) examined community-dwelling older women with low bone mass after a 6-month flexibility training program and found no improvements in standing balance.
Additionally, the influence of physical activity on flexibility is not clear. Some research has shown that an 8-week program of active stretching in elderly women living in a residential community resulted in marked improvements in range of motion compared to the comparison group (Gallon et al., 2011). This is also consistent with other literature that has examined active stretching (Cristopoliski, Sarraf, Dezan, Provensi, & Rodacki, 2008). Other literature examining flexibility has shown improvements on functional balance tests such as the TUG (Batista et al., 2009). Increases in active range of motion following high-intensity progressive resistance training have been observed in frail older adults (Fiatarone et al., 1994), depressed older adults (Stavrinos et al., 1999), and cardiac rehabilitation patients (Beniamini, Rubenstein, Faigenbaum, Lichtenstein, & Crim, 1999). However, low-intensity resistance training (Stavrinos, et al., 1999) and aerobic training (Fatouros et al., 2002) have shown little to no effects on flexibility in older adults. In fact, the health benefits of flexibility training are not well established and these exercises are commonly used as a placebo activity (Frankel, Bean, & Frontera, 2006).

However, flexibility has been shown to decline markedly from physical inactivity (Warbuton, Nicol, & Bredin, 2006), and age (Laukkanen et al., 1994; Bassey, Morgan, Dallosso, & Ebrahim, 1989; Gehlsen & Whaley, 1990). Some research has shown that flexibility exercises have shown improved joint range of motion and function, enhanced muscular performance, and increased tendon flexibility (American College of Sport and Medicine, 1998), which stresses the importance of its inclusion in training programs, especially for older adults.
1.5.5 Multifactorial Interventions

Multifactorial exercise interventions refer to the incorporation of multiple combinations of different types of exercise. Largely, these types of programs have shown to provide greater improvements in balance and overall health, specifically in older adults (e.g., Day et al., 2002). Although a relationship between falls and impaired balance exists (Thorbahn & Newton, 1996), studies have shown mixed results when examining the effects of exercise and balance interventions on balance, falls and physical functioning (Brown & Holloszy, 1991; Crilly, Willems, Trenhold, Hayes, & Richardson 1989; Fiatrone et al., 1990; Hu & Woollacott, 1994; Lichtenstein, Shields, Shiavi, & Burger, 1989; Province et al., 1995; Roberts, 1989; Topp, Mikesky, Wigglesworth, Holt, & Edwards, 1993). A meta-analysis examining multifactorial interventions has reported that these types of programs improve performance on the TUG, BBS, functional reach, tandem walking, duration for the single leg stance with eyes open and eyes closed, and gait speed (Howe et al., 2012). However, no differences have been revealed for two-legged stance sway with eyes open or closed, sensory organization test, stability limits, DGI, tandem stance or for maximum walking speed (Howe et al., 2012). These mixed results may stem from the inconsistencies in the literature of the quantity of exercise used in the interventions (e.g., exercise type, exercise frequency, or exercise intensity) makes determining the direct contribution of each of the exercise and balance components difficult. Therefore, it is important to determine the effectiveness of these programs on balance control in older adults.

A recent Australian study assessing community-dwelling older adults examined the effectiveness of a multifactorial intervention in those 70 and older. They sub-divided
the population into eight groups either alone or in combination including: exercise, home hazard management, treatment of visual problems, exercise and home hazard management, exercise and treatment of visual problems, treatment of visual problems and home hazard management, all three interventions, and controls. They analyzed the direct effects of each of the conditions and found that the combination of the 3 conditions was the most effective at reducing falls (Day et al., 2002). They also found that exercise was the only effective condition in isolation; however it was less effective than the multifactorial contributions.

Another recent study examined older men participating in a multifactorial exercise regime while on a vibration board including exercises such as squats, lunges and standing on one leg compared to another multifactorial program including aerobic, resistance and flexibility exercises compared to a comparison group (Bogaerts, Verschueren, Delecluse, Claessens, & Boonen, 2007). Results showed significant improvements in both multifactorial groups in isometric strength, explosive strength and muscle mass compared to the comparison group. Although balance was trained during the interventions, it was not an outcome measure.

Another multifactorial training program incorporating strength training 3 days per week, aerobic exercises twice per week and balance exercises once per week for a total of 3 days per week of exercise for 10 weeks found improvements in strength averaging 39% improvement for the exercise group and a 21% improvement for the comparison group (Baker et al., 2007). No aerobic gains were shown in the either group as measured by the 6 minute walk test. Many of the balance measures such as stair climbing power and chair
climbing speed improved in both exercise and comparison groups similarly, which suggests that the comparison group may have exhibited a learning effect.

Multifactorial interventions have been shown to decrease the rate of falls. In one study, the multifactorial exercise intervention included exercise components such as flexibility, balance, coordination, aerobic capacity and muscle strength (Barnett, Smith, Lord, Williams, & Baumand, 2003). This exercise intervention showed that there was a decrease in the rate of falls for the exercisers, such that falls were 40% lower than that of the comparison group. This study also found improvements in balance. Barnett et al. (2003) found that this multifactorial intervention was effective at improving balance on 3 of the 6 balance tests administered including standing on a firm surface with eyes open and closed as well as leaning balance in the exercise group compared to the controls.

Other studies have also shown improvements in balance resulting from a multifactorial exercise intervention. Weedesteyn and colleagues (2006) examined the effects of the Nijmegen Falls Prevention Program in community-dwelling older adults. The exercise program consisted of 5-weeks of twice per week attendance with the first session focused on balance, gait, and coordination training on an obstacle course which simulated activities of daily living, and the second session focused on walking exercises such as walking in crowded areas with varying speeds and practicing fall techniques in the AP and medial-lateral (ML) directions. They found no difference in standing balance; however they did find improvement in one-leg stance duration and weight shifting tasks post intervention in both the exercise group the comparison group. They also found larger improvements in the treadmill obstacle avoidance test in exercisers compared to controls which may be explained by improved cognitive control of stepping
(Weerdesteyn et al., 2006). Although the program was of short duration, the exercise program was effective in reducing the fall frequency by 46% compared to the controls.

Balance improvements were also observed in a study by Lord, Ward, Williams, and Strudwick (1995). They examined 197 community-dwelling older women in a 12-month exercise program consisting of a warm up, conditioning exercises including aerobic, strengthening, balance, flexibility, and hand-eye foot-eye coordination, and relaxation activities. They found a significant decrease in sway amplitude on all standing balance tasks, but greater improvements in the tests that stressed stability for the exercisers compared to controls from baseline to the midpoint of the study as well as after 12 months. They also found a significant improvement in strength, neuromuscular control and reaction time. Fall frequency also significantly decreased for the exercisers who attended 75% or more of the exercise classes compared to the exercisers who attended less than 75% of the classes and controls. Interestingly, most of the improvements seen from this study were reported after 22 weeks of the study, with small improvements observed between 22 weeks and 12 months after baseline. This suggests that shorter multifactorial programs may also elicit improvements in balance and fall risk.

Multifactorial exercise has shown minimal improvements in gait speed. Buchner and colleagues (1997) examined older adults with mild deficits in balance and strength and examined the effects of a multifactorial exercise program targeting resistance training, and aerobic training for 24-26 weeks, and found no to very minimal effects on gait, which is consistent with previous findings (Brown & Holloszy, 1991). They did find that there was a 4% improvement in gait speed and a 3% improvement in stair
climbing speed in the exercise group compared to the controls; however this was clinically irrelevant.

Multifactorial exercise has shown improvements in mobility in older adults. After a 32-week multifactorial intervention with twice per week attendance including balance and strength training components in older women, gains in muscular strength were observed for all maximal strength tests for both legs as well as the 30 s chair stand test (Marques et al., 2011). Improvements in the 30 s chair stand test suggest that functional mobility increased through exercise which may lead to enhanced functional independence.

Multifactorial interventions have shown to be feasible and effective at reducing falls in older adults (Nelson et al., 2004). Incorporating multiple types of exercise has shown to have a superior impact on reducing the risk for falls compared to any type of exercise in isolation as most falls result from multiple risk factors (Chang et al., 2004). Additionally, the skills acquired through multifactorial exercise may better translate to activities of daily living than any single type of exercise in isolation. Furthermore, the continued use of these programs may provide insight into developing innovative interventions to reduce falls and fear of falling among older adults (Wolf et al., 1997). This explains the rationale behind the use of this type of exercise to improve balance and functional ability.

Despite this evidence, not all exercise interventions have been successful at improving balance (Gillespie, Gillespie, Cumming, Lamb, & Rowe, 2001; Province et al., 1995). For example, some studies have shown improvements on standing balance on a firm surface (Barnett Smith et al., 2003), while others found significant differences only
in standing balance tests that stressed stability (Lord, Ward, Williams, & Strudwick, 1995). Another study combining aerobic and resistance exercise in older adults showed no improvements in balance or gait as measured by walking speed, time to tandem walk 9 m, reaction time or the functional reach; however marked improvements were shown for strength and endurance (Cress et al., 1999). This suggests that, due to the specificity of training, improvements in balance were not observed as participants were not trained on balance. Because some studies include participants who already have a low risk of falling, it may be difficult to observe balance improvements in this type of population (Glasgow, Vogt, & Boles, 1999; Robertson, Gardner, Devlin, & Campbell, 2001; Tinetti, et al., 1994).

A meta-analysis suggests that in general, a challenging training program consisting of training programs of 3 days per week summing to a total number of at least 50 hours has the potential to show benefits to balance in older adults (Howe et al., 2012). However, the large body of literature on training programs in older adults suggests that the improvement in balance is not robust (Howe et al., 2012). This is because many studies have poorly reported the results, plausibly because significant findings were not found which increases the risk for exaggerated effect sizes. Howe et al. (2012) also suggested that it is difficult to draw an accurate conclusion of the impact of training on balance as multiple outcome measures have been used. Therefore, there is insufficient evidence to form a conclusion of the impact of training on balance in older adults.

In conclusion, many different types of programs incorporate a wide variety of interventions including but not limited to: balance training through dance, education, vibration, tai chi, resistance training programs both on land and in water, aerobic training
programs, flexibility training programs, and multifactorial programs that use a combination of training. The large number of outcome measures also exists such as measuring sway, COP on the force plate, kinematic measures, duration such as with the TUG, as well as subjective measures such as the DGI and BBS. There also exists a range of objectives to these training programs such as to improve strength, aerobic capacity, functional mobility, and balance confidence as well as decreasing the risk for falls. The focus of this thesis is to examine the effects of a multifactorial exercise and balance training program on balance control in older adults. Although other physiological, psychological or functional changes may occur as suggested by the literature, the aim of this thesis is to examine the changes in balance control.
CHAPTER 2: RATIONALE, PURPOSE, AND HYPOTHESES

2.1 Rationale

Falls and their consequences remain an important health care issue for older adults. Approximately one-third of older adults suffer at least one fall each year (Gillespie et al., 2009). The consequences of these falls can range from serious injury (i.e., fracture; Tinetti, Speechley, Ginter, 1988), to the development of an anxiety or fear related to falling (Tinetti, Mendes de Leon, Doucette, & Baker, 1994). Furthermore, a fall can generate substantial changes in behaviour including changes to how balance is controlled, loss of muscle strength, and reduced participation in daily activities (Tinetti et al., 1994). These changes in behaviour can lead to a negative cycle that results in more falls and further impacts these behaviours eventually leading to reduced quality of life, hospitalization, and loss of independence (Tinetti et al., 1994).

One important factor that may elevate fall risk is changes in balance control strategies. In particular, changes in trunk control with age have been noted across a number of different types of balance tests (Gill et al., 2001). That is, older adults generally showed greater trunk sway during the standing tests and less trunk sway during the walking tests compared to young and middle aged adults (Gill et al., 2001). One way to counter these changes in balance control in older adults is to participate in an exercise and balance training program (Howe et al., 2012). The efficacy of a number of different types of programs has been explored; some programs have shown success in improving balance and reducing the risk of falling (Barnett et al., 2003), while others have not shown these gains (Lord, Ward, Williams, & Strudwick, 1995). Limitations with these studies are related to the training program used, with many programs focusing on the
effects of one type of training program (e.g., strength, balance) on these outcomes (Howe et al., 2012). As well, limitations may arise as to the type of balance tests that are assessed as many focus on a single type of balance test (such as standing or walking or performance on a standard balance assessment tool such as the BBS or TUG test) (Howe et al., 2012).

As the control of the trunk is critical for adequate whole body stability during many daily activities (Femia, Zarit, & Johansson, 1997) and with this type of control influenced by age (Goutier, Jansen, Horlings, Küng, & Allum, 2010), it is important to determine if a multifactorial exercise and balance training program can improve trunk control in older adults. The method by which trunk sway was measured provides for added flexibility in the types of stance and walking tests that were assessed. This converging evidence may provide greater insight into how an exercise and balance training program can impact trunk control across a wider variety of tests. This information on the effects of exercise and balance training on multiple components of the balance control system may provide greater insight into the efficacy of the training program and also improve treatment strategies for fall prevention in older adults.

2.2 Purpose

The purpose of this thesis was to investigate the effects of a 12-week multifactorial exercise and balance training program on balance control in older adults. Two research questions were addressed with respect to the type of dependent measures used to assess balance control (i.e., trunk sway and duration).
2.2.1  *Research Question 1*

Did a 12-week training program improve trunk sway during stance and walking tests in older adults? To answer this question, trunk pitch (forward-backward) and roll (side-to-side) sway measures at the baseline and 12-week testing session were compared between exercise and control participants for each stance and walking test.

2.2.2  *Research Question 2*

Did a 12-week training program improve the time to complete stance and walking tests in older adults? To answer this question, total test duration at the baseline and 12-week testing session was compared between exercise and control participants for each stance and walking test.

2.3  *Hypotheses*

The following hypotheses were associated with each of the research questions.

2.3.1  *Hypotheses for Research Question 1*

It was hypothesized that a significant interaction effect between participant group (exercise, control) and time (baseline, 12-week) would be observed for trunk sway measures. In general, it was expected that stance and walking performance would improve in the exercise group following the training program while there would be no change in these measures in the comparison group. However, it was expected that these changes would not be global. That is, changes in either trunk pitch and roll sway would depend on the specific stance or walking test examined. For example, tests that challenge roll stability would show improvement in this direction only (e.g., walking 8 m while rotating the head) while tests that challenge pitch stability would show improvements in
this direction only (e.g., the get-up-and-go). As well, the direction of these changes (i.e., increased or decreased trunk sway) would also be test-dependent. For example, increased trunk sway would reflect improvement on some tests (i.e., walking tests) while decreased trunk sway would reflect improvement on other tests (i.e., standing tests).

2.3.2 Hypotheses for Research Question 2

It was hypothesized that a significant interaction effect between participant group (exercise, control) and time (baseline, 12-week) would be observed for test duration measures. It was expected that test duration measures would show improvement in the exercise group following the exercise and balance training program while there would be no change in these measures in the comparison group. The direction of these changes (i.e., shorter or longer duration values) would depend on the stance or walking test examined. Shorter durations would reflect improvement on walking tests while longer durations would reflect improvement on stance tests.
CHAPTER 3: METHODOLOGY

3.1 Participants

The current thesis examined a subset of data from a pool of participants involved in a larger ongoing study. One hundred and ten older adults were selected from this pool of participants. Inclusion criteria for this thesis consisted of individuals who were 65-79 years of age, had no self-reported musculoskeletal, neurological, or sensory deficits that interfered with balance, were able to walk independently without using a mobility device, were living independently within the community, and were able to travel to Brock University.

3.1.1 Assignment to Exercise and Comparison Groups

Participants were randomly assigned to an exercise group (n=62) or a comparison group (n=48). Participants were informed of the group to which they had been assigned at the baseline testing session. The exercise group was offered a free 12-week training program with free parking at Brock University as an incentive to participate in the study. A description of the training program is presented below in Section 3.4. The comparison group had the option to enter into the training program after the completion of the 12-week control period.

Participants in the exercise group were tested at baseline as well as after the 12-week training program. Participants in the comparison group were tested at the baseline and 12-week testing session. During the 12-week interval, participants in the comparison group were asked not to change any aspect of his/her lifestyle, and participants in the exercise group were asked not to change any aspect of his/her lifestyle other than
participating in the training program. Characteristics of participants are presented in the results section 4.2.

3.2 Experimental Protocol

Before each testing session began, participants read and signed an informed consent form (see Appendix A) approved by the Brock University Research Ethics Board (REB# 07-276) (see Appendix B). As part of the larger study, participants provided demographic information, completed 14 questionnaires presented in a random order (e.g., Activities-specific Balance Confidence [ABC] scale [see Appendix C], Godin Leisure-Time Physical Activity questionnaire [see Appendix D]), had anthropometric measures taken, performed a series of stance and walking tests, and completed fitness, strength, and flexibility tests during each testing session. This thesis examined selected demographic measures, anthropometric measures, fall history, ABC scale, Godin questionnaire, and the TUG test at baseline, as well as performance on the stance and walking tests at baseline and 12-week testing sessions.

3.2.1 Demographic and Anthropometric Measures

Demographic and anthropometric measures used to describe the exercise and control groups as well as the dropouts from each group (i.e., those who did not complete the 12-week testing session) were age (years), sex, fall history (frequency), height (cm), weight (kg), the ABC scale, Godin questionnaire and TUG. Adherence was examined by assessing the mean number of sessions attended out of a total of 36 sessions for the exercise group and exercise dropouts. Fall history referred to the self-reported number of falls that had occurred within the last 12 months. The ABC scale is a 16-item questionnaire that assesses the confidence in one’s ability to perform 16 daily activities.
without falling on a scale from 0% (no confidence) to 100% (complete confidence) (Powell & Myers, 1995). The ABC has a 2 week test-retest reliability of ICC=0.92 and internal consistency Cronbach’s alpha of 0.96 (Liu-Ambrose et al, 2004). The Godin Leisure-Time Physical Activity Questionnaire assesses weekly frequencies of mild, moderate, and vigorous physical activities performed for at least 15 minutes with the total weighted score calculated in the metabolic equivalent of the task (MET) (Godin & Shephard, 1985). The Godin has a correct two-way classification of 69% of the participants (Godin & Shephard, 1985). The TUG is a functional balance measure and was assessed by asking the participants to get up from a chair without using the arm rests, walk 3 m as quickly as they could at his/her own pace without running, turn around, and walk back to the chair and sit down without using the arm rests (Podsiadlo & Richardson, 1991). This task was timed using a stop watch and an average time of the three trials was used for analysis. The TUG has shown to be reliable and correlate with other measures such as the BBS ($r=-0.81$), gait speed ($r=-0.61$) and Barthel Index of activities of daily living ($r=-0.78$). These measures were selected to examine if the exercise and comparison groups were similar at the baseline testing session and that changes due to the training program were not due to differences in age, fall history, balance confidence, leisure time activity, or functional mobility.

### 3.2.2 Stance and Walking Tests

Table 1 presents the series of 18 stance and walking tests that were completed by each participant. The balance tests administered challenge a number of the different balance systems outlined by Horak (2006). All tests were performed once during each testing session and were performed in bare feet in order to standardize performance
across participants. To quantify balance performance during the stance and walking tests, trunk movements were recorded using angular velocity transducers (SwayStar System, Balance International Innovations GmbH, Switzerland). Participants wore the lightweight device which was attached to an elasticized motorcycle belt and placed on the lower back at the lumbar level of L2-L3 (Figure 1). This device also calculated the total test duration (s) for each stance and walking test. This series of tests was modified from different series of tests that have been used in the past to successfully reveal age-related (Gill et al., 2001) and pathology-related (Allum & Adkin, 2003; Adkin, Bloem, & Allum, 2005) differences in trunk sway.

Standing balance was assessed under different combinations of vision (i.e., eyes open or closed), base-of-support (i.e., two or one-legged stance), and support surface (i.e., firm or foam) conditions (see tests 1-7; Table 1). The removal of vision (i.e., eyes closed), reduction of the base of support (i.e., one-legged stance) and change in support surface (i.e., foam) were introduced to provide an increased challenge to balance.

Figure 1. A participant is shown performing a stance test (left) and obstacle avoidance test (right) while wearing the trunk sway monitoring device.
Table 1. The series of stance and walking tests completed during each testing session. Performance on only 13 of the 18 tests was examined; performance on the tests highlighted with shading was not examined.

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Standing on foam requires the participant to rely on the vestibular and visual systems (i.e., when eyes are open) to compensate for the reduced proprioceptive information from the feet to control balance (Jeka, Kiemel, Creath, Horak, & Peterka, 2004). The dimensions of the foam used were 142 cm in length by 60 cm in width by 7.5 cm in depth.

For each of these seven tests, participants were instructed to stand as still as possible with his/her arms at his/her sides for a maximum duration of 30 s. Depending on the test, additional instructions were also provided. For eyes open tests, participants were required to fixate on a target located 2.18 m in front of him/her at eye level for the duration of the test. For eyes closed tests, participants started by fixating on this target and then were asked to close his/her eyes and then the test began. For all two-legged tests, stance width was defined by the participant’s foot length. For all one-legged tests, participants selected his/her preferred leg on which they would stand. Participants then adopted the one-legged stance position and then the test was begun; the transition from two-legged standing to one-legged standing was not examined. The test was terminated in the event of a loss of balance, support required from the spotter, change in the base-of-support (e.g., taking a step when standing on two legs or placing the elevated leg down when standing on one leg), or opening the eyes.

Stance-related tests, including forward-backward and side-to-side stability limit tests and tandem walking tests, were assessed (see tests 8-12; Table 1). For each stability limit test, participants fixated on a target located 2.18 m in front of him/her at eye level for the duration of the test and stance width was defined by the participant’s foot length. For the forward-backward stability limit test, participants started by standing as still as
possible and then were instructed to move the body as far forward as comfortable, return to his/her original position, move the body as far backward as comfortable, and return to his/her original position. For the side-to-side stability limit test, the same procedure was followed except participants moved to the left and right. Participants were instructed to accomplish these tests by keeping his/her arms at his/her sides and moving only about the ankle joints and not the hip joints.

The tandem stance tests were performed under different combinations of vision (i.e., eyes open or closed), and support surface (i.e., firm or foam) conditions. The dimensions of the foam used were 447 cm in length, 60 cm in width and the 7.5 cm in depth. Participants were instructed to begin the test in a tandem step position (i.e., heel of one foot placed directly in front of the toes of the other foot), walk a maximum of 15 tandem steps, and then come to a two-footed stop. The steps were counted for the participant by the spotter and the spotter instructed the participant when to terminate the test. Data collection stopped immediately in the event of a loss of balance, support required from the spotter, step-out of the tandem step or opening the eyes.

Walking was assessed under different combinations of vision (i.e., eyes open or closed) and voluntary head movement (i.e., pitch or roll) conditions (see tests 13-18; Table 1). Each of these walking tests was performed on a firm support surface over a distance of 8m. Participants were instructed to begin the test in mid-stance, with one foot on the ground and the other foot in mid-step behind the heel ready to initiate walking when instructed. Participants were instructed to walk at a preferred pace and come to a two-footed stop after walking 8 m. For the test requiring alternating head roll movements, participants were instructed to turn his/her head to the left when his/her left
foot stepped forward and turn his/her head to the right when the right foot stepped forward during walking. For the test requiring alternating head pitch movements, participants were instructed to move his/her head up and down in synchrony with step cadence, which matches the head movements with step movements.

In addition, adaptive walking was assessed using an obstacle avoidance test and walking initiation from a seated position was assessed using a modified get-up-and-go test. For the obstacle avoidance test, four foam obstacles were placed 1 m apart on the 8 m travel path. The dimensions of the obstacles were 10.5 cm in length, 62 cm in width, and 7.5 cm in height. The adaptive strategy used to step over the obstacles depended upon the preference of the participant. For the modified get-up-and-go test, participants were seated on a backless chair (44 cm high) with arm rests. Participants were instructed to get out of the chair, walk 3 m and come to a two-footed stop. Participants were instructed not to use the arm rests when getting out of the chair; however they could push off his/her thighs to assist him/her in getting out of the chair. If the arm rests were used, the participant could retry the test up to three times, and if they could not get out of the chair without using the arm rests, this test was noted as incomplete and was not used for analysis.

After an examination of the data, it was determined to investigate performance on only 13 of the 18 tests; tests that were not examined are shaded in Table 1. The tests of leaning forward-to-backward about the ankles (i.e., pitch lean) and leaning left-to-right about the ankles (i.e., roll lean) were not examined primarily due to inability or inconsistency between participants in executing the tests only about the ankles. The tests of walking a maximum of 15 tandem steps on a firm support surface with eyes open and
with eyes closed and on a foam support surface with eyes open were not examined due to inconsistency in identifying test failures and inability to differentiate between time to complete the test compared to time to failure on the test.

3.3 Dependent Measures

Balance performance was assessed by calculating total test duration (s) and calculating trunk sway measures for each stance and walking test. Peak-to-peak range excursions in pitch and roll directions for both trunk angular displacement (°) (with respect to reset angular positions of zero displacement at the start of each trial) and trunk angular velocity (°/s) were calculated for each stance and walking test (see Figures 2-5 for a depiction of trunk angular sway and trunk velocity for standing on one leg on a firm support surface with eyes open test, and the modified get-up-and-go test). Representative profiles for a single participant for the tests of standing on one leg on a firm support surface with eyes open and the modified get-up and go are presented in Figures 2-3 and 4-5, respectively.

Trunk mounted angular velocity sensors are able to quantify a wide range of stance and walking tests which makes it an invaluable tool to improve standard clinical test protocols (Allum & Adkin, 2003). Trunk sway has shown to be a useful and reliable tool for detecting changes in balance with age and pathology (e.g., Gill et al., 2001; Allum & Adkin, 2003; Adkin, Bloem, & Allum, 2004). It has also been shown to demonstrate consistency over time in a healthy comparison group and is able to detect changes over time in patients with a unilateral vestibular disorder (Allum & Adkin, 2003).
Some of the advantages to trunk sway are that there is no influence of gravity (unlike force-plate measures that need to zeroed), data are not blocked by external objects or limb movement, (unlike motion analysis), it is not affected by confined spaces or external light sources, measures do not depend on support surfaces (unlike force-plate data), it has a high sampling rate (>100Hz), and measures are independent of subject height after the age of 25 (Allum & Carpenter, 2005). The lightweight technology of the trunk sway system allows the detection of subtle changes in trunk velocities and accelerations over long time periods in real-life environments (Aminian & Najafi, 2004; Najafi et al., 2003; Paraschiv-Ionescu, Buchser, Rutschmann, Najafi, & Aminian, 2004). Thus, the device allows balance to be assessed on a variety of stance and walking tests.

There are a number of limitations of the trunk sway system that should be acknowledged. Specifically, Allum and Carpenter (2005) outlined these issues and they include: noise, drift, temperature (in inexpensive devices), and angular changes relative to start position instead of absolute position relative to a fixed coordinate system are measured (unlike motion analysis). Noise can be circumvented by using various filtering techniques, and the relative angular changes can be overcome by additional sensors to measure acceleration and limb position (Hogeman, Honegger, Kupper, & Allum, 2005; Najafi, Aminian, Loew, Blanc, & Robert, 2002). Additionally, the straps that hold the trunk sway system may impede movement or change motion of the body, and the larger and heavier sensors of the trunk sway system may also contribute to a decrease in natural movements compared to active or reflective markers (Allum, & Carpenter, 2005). Other issues arise when major changes of the sensor’s axes of rotation occur which can lead to difficulty computing total angular changes with respect to the starting position. Lastly,
Figure 2. A representative trunk angular sway profile for one participant during the performance of the standing on one leg on a firm support surface with eyes open test. Pitch angle is depicted in the dotted grey and roll angle is depicted in black.

Figure 3. A participant’s trunk velocity is shown performing the standing on one leg on a firm support surface with eyes open test. Pitch velocity is depicted in the dotted grey and roll velocity is depicted in black.
Figure 4. A participant’s trunk angular sway is shown performing the modified get-up-and-go test. Pitch angle is depicted in the dotted grey and roll angle is depicted in black.

Figure 5. A participant’s trunk velocity is shown performing the modified get-up-and-go test. Pitch velocity is depicted in the dotted grey and roll velocity is depicted in black.
because the trunk sway measurement system detects angular changes, it cannot adequately ascertain whether the trunk movement is occurring as a result of movement in the ankle, knee, hip or a simultaneous combination of the three (Adkin, Bloem, & Allum, 2004).

3.4 Multifactorial Exercise and Balance Training Program

3.4.1 Clearance for Participation in Physical Activity

Prior to being allowed to start the training program, participants provided information to confirm that they could safely increase his/her levels of physical activity. Participants were required to complete the Physical Activity Readiness Questionnaire (PAR-Q; Appendix E; Canadian Society for Exercise & Physiology, 2002) during the first testing session. Participants responded “Yes” or “No” to seven questions which assessed the ability of the participant to increase physical activity levels. As the PAR-Q is only applicable for adults up to 69 years of age, participants over the age of 70 were required to obtain a doctor’s note in order to participate in training program, regardless of his/her responses on the PAR-Q. If participants 69 years of age and under answered “Yes” to any of the seven questions, they were required to obtain a doctor’s note permitting his/her participation in the training program. If participants answered “No” to all of the questions, it was considered safe for the participants to engage in physical activity.

3.4.2 Summary of Multifactorial Exercise and Balance Training Program

Once cleared for physical activity, participants were asked to exercise 1 to 1.5 hours per day, 3 days per week for a 12-week period in the Exercise Intervention
Laboratory at Brock University. Participants could complete the training program in the laboratory at any of the following times: Monday, Wednesday, or Friday from 8:00 am to 11:30 am and 5:00 pm to 6:30 pm, or Tuesday, Thursday, or Saturday, from 8:00 am to 10:30 am. Supervising trainers were third and fourth year Physical Education and Kinesiology undergraduate students, and Applied Health Science graduate students. Student trainers were certified in Cardiopulmonary Resuscitation (CPR), and the laboratory was equipped with a first aid kit, along with a phone in case of emergency. Student trainers created a welcoming environment for the participants by providing encouragement and positive reinforcement. The equipment in the laboratory consisted of treadmills, elliptical trainers, recumbent and upright bikes, weight machines, mats, benches, stability balls, step platforms, hand weights, weighted bars, bands, medicine balls, and balance equipment (e.g., half foam rollers, wobble boards, balance pods).

Each participant received a logbook with an identification number to track the exercises that were completed during each training session. The logbook contained a list of the exercises that the participant was to complete as well as the seat heights, weights, sets and repetitions associated with each exercise. Progress was tracked by an indication in the log book of the completed exercises, as well as the number of repetitions of the exercise that were completed. Participants were encouraged to leave notes in his/her logbooks with questions or comments that would be answered by a trainer. The log books were kept in a locked room located in the laboratory.

3.4.3 Orientation to Multifactorial Exercise and Balance Training Program

Each participant attended an orientation session before initiating the training program. This session was used to introduce the exercise equipment, to provide
instructions regarding the proper technique for performing each exercise, and to explain the appropriate physiological sensations that should be associated with each exercise. At this time, proper adjustments of the equipment and exercise intensities were determined for each participant. After a demonstration of the proper form for each exercise, participants performed each exercise under supervision to determine if the exercise was completed correctly. Next, individualized starting weights were determined for each exercise. Each participant had a logbook with the appropriate seat heights, starting weights, and number of repetitions to be performed. Participants’ age-related heart rate maximum (i.e., 220-age) as well as his/her target heart rate zone (55-85% of age-related heart rate maximum) were calculated and included in the logbook. At the conclusion of the orientation, participants were free to ask any clarification questions.

3.4.4 Multifactorial Exercise and Balance Training Program Sessions

Once the participants completed the orientation session, they commenced the training program by attending three times per week at his/her convenience. Upon arrival, participants asked student trainers for his/her logbooks with his/her identification number written on the front. The training program consisted of approximately 20 minutes of cardiovascular activity, 30-45 minutes of upper and lower body strengthening activities, 10-15 minutes of a balance obstacle course, and 5-10 minutes of stretching. The training program was progressive such as increasing the weight for the resistance exercises, more difficult activities on the obstacle course, and increasing the speed on the treadmill. Each exercise component of the training program is outlined below.
3.4.5 Balance Training

The balance obstacle course included a variety of unstable objects, such as texturized balance pods, wobble boards, BOSUs, balance disks, and half foam rollers. Both static and dynamic balance activities with different visual conditions were supervised by student trainers. The trainers’ responsibilities were to spot the older adults during these activities and facilitate progressive balance activities. To challenge the participants, cognitive and physical tasks were performed while balancing on the obstacle course (i.e., counting backwards by sevens while carrying an object on the balance pods). The student trainers were innovative in modifying the participants’ balance regimens. Some of the activities of the balance training included hand-eye, and foot-eye coordination during balance, center of mass (COM) perturbations on the balance pods, base of support (BOS) perturbations on a BOSU ball, carrying a medicine ball while standing on one leg, stepping over obstacles while moving a medicine ball around the midline of the body, and touching toes while maintaining the stability of a wobble board.

During the balance portion of the training program, participants completed three cycles of the balance obstacle course which lasted approximately 10-15 minutes. In addition to the balance obstacle course, participants were required to perform three sets of pitch leans (forward and backward swaying from the ankles) and roll leans (side-to-side swaying from the ankles). Based on the tenets of the systems approach to balance assessment and training, the balance part of the program was designed to train multiple subcomponents of the balance control system.
3.4.6 Aerobic Exercise

The participants’ aerobic exercise involved low to moderate intensity. For this study, aerobic exercise was defined as the continuous movement of the legs and arms on cardiovascular equipment. Participants were given a selection of aerobic machines to choose from, including treadmills, recumbent bikes, upright bikes, and elliptical trainers, and were asked to accumulate approximately 20-30 minutes on any of these machines. Participants were asked to exercise at 55-85% of his/her age-related heart rate maximum (220-age) which was measured by heart rate monitors.

3.4.7 Resistance Exercise

The progressive strength training regimen involved exercises for the upper body and lower body. The program was designed to strengthen and condition all major muscle groups. One set of 15 repetitions of exercises such as the seated chest press, seated row (upper back), triceps pushdown, shoulder press, lat pull-down, leg press, calf raises, and squats against the wall with a stability ball were performed each session. Additionally, the abdominal exercises that were performed were one set of crunches, oblique twists, and opposite arm/leg raises. The exercise regimen was slightly modified in the last 6 weeks of the program to incorporate more functional activities by incorporating exercise bands, weighted bars, and hand weights on unstable surfaces such as exercise balls, BOSUs, and balance disks. Core exercises became increasingly difficult when appropriate by performing them on a stability ball, or by adding a medicine ball. For strengthening exercises, once 15 repetitions were easily performed, trainers increased the weight by the smallest possible increments. Exercises were individualized for each participant by considering both health status and individual capabilities. When a
participant could not perform a task for certain reasons (e.g., medical reasons), an alternate activity was provided.

3.4.8 Flexibility Exercise

Participants performed stretches in a standing or seated position. Stretching sessions lasted between 5-10 minutes, and all muscle groups were stretched for 20-30 s. All stretching exercises were designed to increase the full range of motion of all major muscle groups. The following muscles/muscle groups were stretched: biceps, triceps, shoulders, chest, upper back, lower back, abdominals, quadriceps, hamstrings, gluteus, calves, and inner thigh.

3.5 Statistical Analyses

To determine if the assumption of normal distribution was met, central tendency, skewness, kurtosis, and outliers were screened for normality. Variables were screened for normality by examining skewness and kurtosis values. Significance was determined by dividing the skewness or kurtosis statistic by the standard error of the skewness or kurtosis statistic. Data were log transformed if skewness scores were greater than or less than $z=\pm 1.96$ (Cramer & Howitt, 2004). Univariate outliers were identified using standardized scores ($z$-scores). A $z$-score that was greater than or equal to $\pm 3.29$ ($p<0.001$, two tailed test) was flagged as a potential outlying value and inspected to determine if it needed to be replaced with the next closest value in the range (Tabachnick & Fidell, 2007). The relationship between dependent measures was assessed using bivariate correlations calculated by group and by time. Pearson correlations were calculated to examine the relationship between total test duration, trunk pitch angle, trunk
roll angle, trunk pitch angular velocity and trunk roll angular velocity for each stance and walking test. Correlations that were too highly correlated ($r=0.9$) could be considered to be redundant (Tabachnick & Fidell, 2007); this analysis could reduce the number of dependent variables that need to be examined. To determine if the assumption of equal cell size was met, the sample sizes of the comparison group were compared to the exercise group. The assumption of independent random sampling was addressed in terms of random sampling and random assignment into groups. The assumption of homogeneity of variance was assessed using the Levene’s test for each dependent variable for the exercise and comparison groups at baseline.

In order to provide a description of the sample, descriptive statistics (mean and standard deviation values) were calculated for demographic and anthropometric variables at baseline for the exercise and comparison groups. Descriptive statistics were calculated for falls within the 12-week duration, the Godin, the ABC, and the TUG to determine if there were changes in these measures after the 12-week period between groups.

To determine if the descriptive statistics were similar between the exercise and comparison groups at baseline, separate ANOVA procedures were conducted for all demographic and anthropometric measures. As well, to determine if the exercise group showed changes within the 12-week period, and to verify if comparison group did not partake in lifestyle alterations within the 12-week period, separate 2 x 2 repeated measures ANOVA (RM-ANOVA) procedures were also completed for the Godin, the ABC and the TUG with the between-subject factor of group (exercise, control) and the within subject factor of time (baseline, 12-week). The significance level was set to $p<0.05$. 

Descriptive statistics (mean and standard error of the mean values) were also calculated for total test duration, trunk pitch and roll angle and angular velocity for each stance and walking test for the exercise and comparison groups. The dependent measures for each stance and walking test were submitted to a one-way ANOVA and analyzed at baseline for both the exercise and comparison groups to determine if the groups were different at baseline. If exercise and comparison groups were different at baseline, the baseline variable(s) were entered as a covariate in a one-way ANOVA to account for pre-existing participant variability. Based on the number of analyses conducted (n=53), the Bonferroni correction adjusted the significance level to \( p<0.0009 \).

For each stance and walking test, duration, trunk pitch angle and velocity, and trunk roll angle and velocity values were submitted to separate 2 x 2 RM-ANOVA procedures. Each analysis included the between-subject factor of group (exercise, control) and the within subject factor of time (baseline, 12-week). To answer Research Question 1, a total of 44 RM-ANOVAs were conducted so significance level was adjusted to \( p<0.0011 \). To answer Research Question 2, a total of nine RM-ANOVAs were conducted so the significance level was adjusted to \( p<0.0056 \). RM-ANOVAs for duration were not examined for the four standing on two legs tests as each participant was capable of standing for 30 s for each condition. Follow-up t-tests were conducted for any significant interaction effects between participant group and time to determine where the differences existed. Significance level for these analyses was set to \( p<0.05 \). Trends for an interaction effect and main effect for group and time were examined using a \( p<0.05 \).
3.5.1 Statistical Analyses for the Dropouts

Similar analyses were also performed for the dropouts including screening for normality, outliers, and descriptive statistics. Separate one-way ANOVA procedures were conducted between the exercise group and exercise dropouts at baseline and between the comparison group and comparison dropouts. Trends for main effects were examined using a $p<0.05$. 
CHAPTER 4: RESULTS

4.1 Data Screening

A data set was generated from the demographic, anthropometric, ABC, Godin, and TUG measures collected at baseline. Trunk sway and duration measures for each baseline stance and walking test were obtained from the software program for the trunk monitoring system (Swaystar, Balance International Innovations GmbH) at the baseline and 12-week testing sessions. Data were then entered into the quantitative data analysis software program Statistical Package for the Social Sciences (SPSS) version 18.0. Using this data set, data screening and analysis were completed in several stages.

4.1.1 Outliers

Outliers are extreme scores that may influence the results of the statistical analysis (Tabachnick & Fidell, 2007). The data were screened for univariate outliers for each group at both baseline and 12-week testing session. Univariate outliers were identified using standardized scores (z-scores), and z-scores that were greater than or equal to ±3.29 ($p<0.001$, two tailed test) were flagged as potential outlying values and visually inspected to determine if the outliers should be replaced with the next closest value in the range (Tabachnick & Fidell, 2007). For example, for the standing eyes open test at the 12-week testing session for the comparison group, a z-score of 3.72 with a roll angle score of 2.07° was replaced with 1.68° as this value was the next closest in the range and this better reflects the balance performance of the sample. To give another example, for the test of walking 8m on a firm support surface while vertically pitching the head in synchrony with each step, an outlying value was identified for pitch velocity at baseline in the comparison group (z-score=4.04; 184.13°/s). This value was replaced with 144.27°/s.
which better reflects the mean value at baseline for the exercise group. After the values were replaced, z-scores were calculated. This protocol was repeated until all z-score values were within the normal distribution range. Outliers occurred for both exercise and comparison groups at both baseline and 12-week testing sessions across all balance tests. There were no consistent patterns for outlying values across tests (e.g., the same participant generating outlying values for different tests, or a single test generating many outlying values). There were 69 instances in which an outlier was identified and replaced.

4.1.2 Normality of Sampling Distribution

Each dependent variable was assessed for normality by examining skewness and kurtosis values by group and by time. Significance was determined by dividing the skewness or kurtosis statistic by the standard error of the skewness or kurtosis statistic. Data were log transformed if skewness or kurtosis scores were greater or less than $z=\pm 1.96$ (Cramer & Howitt, 2004). To ensure that the dependent variable was being compared on the same scale, if one dependent variable was skewed or kurtotic, log transformations were performed by group and by time. Most of the dependent measures were skewed or kurtotic, which did not represent a normal distribution. To correct for this, log transformations were performed to meet this assumption, which is consistent with previous literature (e.g., Gill et al., 2001). Each dependent variable was examined after the log transformations were completed to determine if a normal distribution was met. The log transformations were successful in generating normal distributions. Log transformations were not required for the exercise or comparison group at the baseline or 12-week testing session for the following tests with their associated measures: walking with eyes open for pitch angle and pitch velocity, walking over obstacles for duration,
and the modified get-up-and-go for roll angle, pitch angle and pitch velocity. Further analyses were conducted on the original data if it was not skewed and the data that required log transformations.

4.1.3 Homogeneity of Variance

Each dependent variable was assessed by group and time for homogeneity of variance using the Levene’s test. If the Levene’s statistic was $p<0.001$, homogeneity of variance would be violated and statistics for the row equal variances not assumed in SPSS would be reported to alter the degrees of freedom by rounding to the next whole number (Gastwirth, Gel, & Miao, 2009). All Levene’s statistics were not significant.

4.1.4 Multicollinearity

Multicollinearity was checked to determine if variables were too highly correlated ($r\geq0.9$); for example, variables that contained a combination of two or more variables are considered redundant (Tabachnick & Fidell, 2007). Pearson bivariate correlations by group and by time were completed to test for multicollinearity in order to determine if the number of univariate ANOVAs could be reduced. Correlations ranged from $r=0.01$ to $r=0.84$, therefore the variables were not considered redundant.

4.2 Descriptive Statistics

One hundred and ten older adults were sampled from the larger study. There were 31 dropouts (i.e., those who did not complete the 12-week testing session) (exercise: $n=16$; control: $n=15$) showing a 27% dropout rate for the exercise group, a 31% dropout rate for the comparison group and an overall dropout rate of 28% which is consistent with previous literature (e.g., Boshuizen, Stemmerik, Westhoff, & Hopman-Rock, 2005). After
accounting for these dropouts, the final number of participants was 79 (exercise: \( n=46 \); control: \( n=33 \)). Table 2 presents the demographic and anthropometric measures taken at baseline testing for the exercise and comparison groups and those who dropped out of the exercise and comparison groups. Table 2 also presents the 12-week data from falls that occurred within the 12-week period, the ABC scores, TUG performance and Godin scores in the exercise and comparison groups. The age for those in the exercise group ranged from 65-79 years and 65-77 years for the comparison group. For the exercise group, there were 14/46 fallers including eight single fallers and six recurrent fallers. For the comparison group, there were 7/33 fallers, four of which were single fallers and three of which were recurrent fallers. For the exercise dropouts, 4/16 fell with one single fal ler and three recurrent fallers. For the comparison dropouts, 5/15 fell with three single fallers and two recurrent fallers. A significant main effect for time emerged for the TUG \((F_{(1,75)}=5.077, p=0.027)\) showing a decrease in duration for both exercise and comparison groups from the baseline to 12-week testing session.

Table 2 also presents the demographic and anthropometric measures for the exercise and comparison dropouts. There was a significant difference in weight \((F_{(1,60)}=5.234, p=0.026)\) between the exercise group and the exercise dropouts with the exercise dropouts weighing more than the exercise group. No significant main effects were shown for any of the other measures.

### 4.2.1 Power and Effect Size Estimate

Post hoc power analyses and estimates of effect sizes are given in a range across all balance tests for each dependent variable for both exercise and comparison groups, where \( P \) represents power and the associated \( \eta^2 \) represents the effect size. The ranges
Table 2. Descriptive statistics by group and time. Mean and standard deviation values (in brackets) with the respective range below are given.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Exercise Group (n=46)</th>
<th>Comparison Group (n=33)</th>
<th>Exercise dropouts (n=16)</th>
<th>Comparison dropouts (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>M=18, F=28</td>
<td>M=12, F=21</td>
<td>M=2, F=14</td>
<td>M=3, F=12</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>70.76 (4.94) 65-79</td>
<td>69.64 (3.11) 65-77</td>
<td>69.44 (3.88) 65-78</td>
<td>71.80 (4.84) 65-79</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.75 (8.47) 148.50-180.00</td>
<td>165.40 (8.16) 149.00-186.50</td>
<td>162.59 (7.74) 154.50-183.50</td>
<td>163.73 (9.44) 151.50-181.50</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.21 (15.94) 46.00-120.7</td>
<td>73.82 (12.31) 47-95</td>
<td>85.51 (19.89) 56.80-130.9</td>
<td>73.27 (12.44) 50.00-91.80</td>
</tr>
<tr>
<td>Adherence (# of sessions)</td>
<td>31.43 (6.06) 13-36</td>
<td>16.38 (7.68) 3-29</td>
<td>86.23 (13.12) 36.25-100.00</td>
<td>86.33 (11.24) 63.13-100.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fallers</th>
<th>Baseline 12-week</th>
<th>Baseline 12-week</th>
<th>Baseline</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABC (%)</td>
<td>86.23 (13.12) 36.25-100.00</td>
<td>89.03 (10.28) 62.38-100.00</td>
<td>89.30 (10.45) 60-100</td>
<td>91.25 (8.68) 64.38-100</td>
</tr>
<tr>
<td>TUG (s)</td>
<td>7.65 (1.56) 5.26-12.29</td>
<td>7.21 (1.59) 4.81-13.55</td>
<td>7.20 (1.11) 5.47-10.44</td>
<td>7.10 (1.24) 4.57-11.62</td>
</tr>
<tr>
<td>Godin</td>
<td>32.39 (25.67) 0-102</td>
<td>35.29 (20.34) 6-85</td>
<td>36.29 (22.33) 0-91</td>
<td>36.73 (20.18) 6-102</td>
</tr>
</tbody>
</table>

Note: M=male, F=female
for the exercise group are to follow: duration ($P=0.059-0.905$, $\eta^2=0.002-0.220$), roll angle ($P=0.07-0.434$, $\eta^2=0.004-0.081$), roll velocity ($P=0.061-0.391$, $\eta^2=0.002-0.080$), pitch angle ($P=0.176-0.704$, $\eta^2=0.024-0.126$), and pitch velocity ($P=0.051-0.298$, $\eta^2=0.000-0.045$). The ranges for the comparison group are to follow: duration ($P=0.076-0.955$, $\eta^2=0.012-0.308$), roll angle ($P=0.091-0.564$, $\eta^2=0.012-0.130$), roll velocity ($P=0.056-0.685$, $\eta^2=0.002-0.165$), pitch angle ($P=0.051-0.808$, $\eta^2=0.000-0.210$), and pitch velocity ($P=0.051-0.554$, $\eta^2=0.000-0.127$).

4.3 Hypothesis Testing

In order to answer the two main research questions, two subsequent sets of analyses were conducted. The exercise and comparison groups were not different in terms of trunk sway and duration scores at baseline for all the stance and walking tests (all $p$’s$>0.0038$).

4.3.1 Research Question 1

Trunk sway measures (i.e., roll angle, pitch angle, roll velocity, and pitch velocity) for each of the 11 balance tests were examined for a significant interaction effect of group by time and for main effects of group and time. Trunk sway was not examined for the standing on one leg on a firm support surface with eyes closed or standing on one leg on a foam support surface with eyes open due to the increased variability in performance of the tests.

4.3.1.1 Standing on Two Legs Tests

There were no significant interaction or main effects observed for standing on two legs on a firm support surface with eyes open, standing on two legs on a firm support surface with eyes closed, standing on two legs on a foam support surface with eyes open, or standing on two legs on a foam support surface with eyes closed.
surface with eyes closed, standing on two legs on a foam support surface with eyes open, or standing on two legs on a foam support surface with eyes closed for any of the trunk sway measures (all \( p' > 0.0011 \)). Table 3 presents the mean and standard error of the mean values for all two-legged tests for the trunk sway measures.

4.3.1.2 Standing on One Leg Tests

There were no significant interaction or main effects observed for the standing on one leg on a firm support surface with eyes open for any of the trunk sway measures between exercise and comparison groups (all \( p' > 0.0011 \)). Table 4 presents the mean and standard error of the mean values for trunk sway measures for standing on one leg on a firm support surface with eyes open.

4.3.1.3 Walking Tests

No significant interaction or main effects were observed for any of the six walking tests for trunk roll angle, pitch angle, roll velocity, or pitch velocity (all \( p' > 0.0011 \)). Tables 5 and 6 present the mean and standard error of the mean values for all the walking tests for the trunk sway measures.

The results for the walking 8m on a firm support surface with eyes open revealed a trend for a main effect for time for roll angle (\( F_{(1, 78)} = 4.276, p = 0.042 \)) and roll velocity (\( F_{(1, 78)} = 4.367, p = 0.04 \)). Trunk roll sway was increased at the 12-week compared to baseline testing session.

A trend for a significant interaction effect for pitch angle (\( F_{(1, 77)} = 7.893, p = 0.006 \)) for the comparison group only was found for the test of walking over four obstacles on a firm support surface with eyes open. Trunk pitch angle increased at the 12-week compared to baseline testing session for the comparison group.
Table 3. Mean and standard error of the mean raw values for the trunk sway measures for all two-legged standing tests by group and time. RA=Roll Angle, RV=Roll Velocity, PA=Pitch Angle, PV=Pitch Velocity. 2LEO= Standing on two legs with eyes open, 2LEC=Standing on two legs with eyes closed, 2LEOF= Standing on two legs with eyes open on foam, 2LECF= Standing on two legs with eyes closed on foam.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Measures</th>
<th>Exercise Group</th>
<th>Comparison Group</th>
<th>Exercise Group Dropouts</th>
<th>Control Group Dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>12-week</td>
<td>Baseline</td>
<td>12-week</td>
</tr>
<tr>
<td>2LEO</td>
<td>RA (°)</td>
<td>0.70 (0.04)</td>
<td>0.80 (0.05)</td>
<td>0.85 (0.06)</td>
<td>0.76 (0.05)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>1.41 (0.07)</td>
<td>1.48 (0.09)</td>
<td>1.58 (0.11)</td>
<td>1.53 (0.10)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>1.70 (0.11)</td>
<td>1.77 (0.10)</td>
<td>2.07 (0.15)</td>
<td>2.11 (0.14)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>3.23 (0.17)</td>
<td>3.24 (0.19)</td>
<td>3.63 (0.27)</td>
<td>3.58 (0.27)</td>
</tr>
<tr>
<td>2LEC</td>
<td>RA (°)</td>
<td>0.76 (0.05)</td>
<td>0.84 (0.05)</td>
<td>0.85 (0.06)</td>
<td>0.82 (0.07)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>1.58 (0.11)</td>
<td>1.74 (0.12)</td>
<td>1.77 (0.13)</td>
<td>1.74 (0.16)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>1.83 (0.08)</td>
<td>2.13 (0.13)</td>
<td>2.03 (0.14)</td>
<td>2.12 (0.18)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>3.71 (0.19)</td>
<td>3.88 (0.22)</td>
<td>4.12 (0.30)</td>
<td>4.14 (0.27)</td>
</tr>
<tr>
<td>2LEOF</td>
<td>RA (°)</td>
<td>1.39 (0.10)</td>
<td>1.40 (0.07)</td>
<td>1.33 (0.11)</td>
<td>1.44 (0.11)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>3.51 (0.24)</td>
<td>3.12 (0.20)</td>
<td>3.35 (0.27)</td>
<td>3.34 (0.30)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>2.25 (0.11)</td>
<td>2.39 (0.12)</td>
<td>2.41 (0.14)</td>
<td>2.63 (0.17)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>5.12 (0.35)</td>
<td>4.86 (0.29)</td>
<td>4.97 (0.32)</td>
<td>5.18 (0.35)</td>
</tr>
<tr>
<td>2LECF</td>
<td>RA (°)</td>
<td>1.68 (0.13)</td>
<td>1.64 (0.13)</td>
<td>1.71 (0.16)</td>
<td>1.46 (0.11)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>4.27 (0.35)</td>
<td>3.90 (0.31)</td>
<td>4.94 (0.56)</td>
<td>3.78 (0.36)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>2.81 (0.14)</td>
<td>3.08 (0.18)</td>
<td>3.31 (0.24)</td>
<td>2.90 (0.18)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>7.43 (0.53)</td>
<td>7.04 (0.50)</td>
<td>7.74 (0.60)</td>
<td>6.87 (0.61)</td>
</tr>
</tbody>
</table>
Table 4. Mean and standard error of the mean raw values for the trunk sway measures for standing on one leg on a firm support surface with eyes open by group and time. RA=Roll Angle, RV=Roll Velocity, PA=Pitch Angle, PV=Pitch Velocity, 1LEO= Standing on one leg with eyes open.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Measures</th>
<th>Exercise Group</th>
<th>Comparison Group</th>
<th>Exercise Dropouts</th>
<th>Comparison Dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>12-week</td>
<td>Baseline</td>
<td>12-week</td>
</tr>
<tr>
<td>1LEO</td>
<td>RA (°)</td>
<td>7.98 (0.74)</td>
<td>6.97 (0.72)</td>
<td>6.38 (0.74)</td>
<td>7.17 (0.69)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>26.57 (2.44)</td>
<td>23.71 (2.30)</td>
<td>28.23 (3.20)</td>
<td>25.01 (2.40)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>5.62 (0.43)</td>
<td>4.70 (0.43)</td>
<td>5.66 (0.54)</td>
<td>5.36 (0.35)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>24.06 (1.80)</td>
<td>22.09 (2.03)</td>
<td>28.29 (2.98)</td>
<td>24.18 (2.17)</td>
</tr>
</tbody>
</table>
Table 5. Mean and standard error of the mean raw values for the trunk sway measures for all walking tests by group and time. RA=Roll Angle, RV=Roll Velocity, PA=Pitch Angle, PV=Pitch Velocity. WEO=Walking with eyes open, WO=Walking over obstacles, WR=Walking while rotating the head.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Measures</th>
<th>Exercise Group</th>
<th>Comparison Group</th>
<th>Exercise Dropouts</th>
<th>Comparison Dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>12-week</td>
<td>Baseline</td>
<td>12-week</td>
</tr>
<tr>
<td><strong>WEO</strong></td>
<td>RA (°)</td>
<td>6.07 (0.21)</td>
<td>6.23 (0.19)</td>
<td>5.72 (0.25)</td>
<td>6.11 (0.21)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>57.62 (3.13)</td>
<td>58.64 (2.87)</td>
<td>54.11 (2.06)</td>
<td>62.64 (3.96)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>9.51 (0.38)</td>
<td>8.89 (0.33)</td>
<td>8.75 (0.41)</td>
<td>9.04 (0.44)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>72.0 (3.57)</td>
<td>77.26 (3.86)</td>
<td>73.04 (4.13)</td>
<td>77.98 (5.29)</td>
</tr>
<tr>
<td><strong>WO</strong></td>
<td>RA (°)</td>
<td>7.86 (0.29)</td>
<td>7.53 (0.30)</td>
<td>7.17 (0.31)</td>
<td>7.63 (0.33)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>68.43 (3.40)</td>
<td>66.12 (2.77)</td>
<td>66.34 (3.52)</td>
<td>72.93 (4.31)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>13.42 (0.63)</td>
<td>12.99 (0.64)</td>
<td>11.85 (0.49)</td>
<td>13.32 (0.55)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>120.64 (7.40)</td>
<td>115.03 (6.58)</td>
<td>109.59 (6.77)</td>
<td>120.50 (7.67)</td>
</tr>
<tr>
<td><strong>WR</strong></td>
<td>RA (°)</td>
<td>9.16 (0.34)</td>
<td>9.18 (0.50)</td>
<td>8.44 (0.42)</td>
<td>7.83 (0.37)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>64.03 (2.97)</td>
<td>60.30 (2.62)</td>
<td>59.38 (2.67)</td>
<td>63.43 (3.10)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>9.77 (0.30)</td>
<td>10.12 (0.50)</td>
<td>9.07 (0.55)</td>
<td>9.51 (0.39)</td>
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<tr>
<td></td>
<td>PV (°/s)</td>
<td>76.43 (3.46)</td>
<td>76.51 (3.61)</td>
<td>73.80 (4.63)</td>
<td>75.25 (4.45)</td>
</tr>
</tbody>
</table>
Table 6. Mean and standard error of the mean raw values for the trunk sway measures for all walking tests by group and time. RA=Roll Angle, RV=Roll Velocity, PA=Pitch Angle, PV=Pitch Velocity. WP=Walking while pitching the head, WEC=Walking with eyes closed, GUG=Modified get-up-and-go.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Measures</th>
<th>Exercise Group</th>
<th>Comparison Group</th>
<th>Exercise Dropouts</th>
<th>Comparison Dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>12-week</td>
<td>Baseline</td>
<td>12-week</td>
</tr>
<tr>
<td>WP</td>
<td>RA (°)</td>
<td>7.62 (0.31)</td>
<td>7.39 (0.28)</td>
<td>7.23 (0.35)</td>
<td>7.88 (0.36)</td>
</tr>
<tr>
<td></td>
<td>RV (°/s)</td>
<td>59.96 (2.59)</td>
<td>60.23 (2.28)</td>
<td>55.95 (3.02)</td>
<td>64.13 (3.53)</td>
</tr>
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<td></td>
<td>PA (°)</td>
<td>11.32 (0.43)</td>
<td>10.33 (0.35)</td>
<td>10.17 (0.49)</td>
<td>10.69 (0.53)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>79.93 (3.46)</td>
<td>83.38 (3.46)</td>
<td>73.11 (3.99)</td>
<td>74.67 (3.47)</td>
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<tr>
<td>WEC</td>
<td>RA (°)</td>
<td>6.47 (0.28)</td>
<td>6.29 (0.22)</td>
<td>6.73 (0.36)</td>
<td>6.64 (0.33)</td>
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<tr>
<td></td>
<td>RV (°/s)</td>
<td>51.17 (2.26)</td>
<td>52.81 (2.04)</td>
<td>53.78 (2.73)</td>
<td>58.10 (3.12)</td>
</tr>
<tr>
<td></td>
<td>PA (°)</td>
<td>10.07 (0.42)</td>
<td>9.12 (0.38)</td>
<td>9.62 (0.46)</td>
<td>9.18 (0.42)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>71.13 (4.02)</td>
<td>71.46 (3.19)</td>
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<td>71.80 (4.01)</td>
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<tr>
<td>GUG</td>
<td>RA (°)</td>
<td>6.82 (0.23)</td>
<td>7.01 (0.28)</td>
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<td>6.81 (0.32)</td>
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<td>RV (°/s)</td>
<td>64.18 (3.32)</td>
<td>68.19 (3.31)</td>
<td>58.77 (3.50)</td>
<td>61.52 (3.43)</td>
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<td></td>
<td>PA (°)</td>
<td>47.97 (1.21)</td>
<td>46.95 (1.17)</td>
<td>45.77 (1.39)</td>
<td>46.71 (1.19)</td>
</tr>
<tr>
<td></td>
<td>PV (°/s)</td>
<td>200.80 (6.57)</td>
<td>208.10 (6.03)</td>
<td>208.10 (6.03)</td>
<td>199.59 (7.40)</td>
</tr>
</tbody>
</table>
4.3.2 Research Question 2

The measure of the time to complete the balance test was examined for nine of the balance tests for a significant interaction effect of group by time and for main effects of group and time. Duration for the standing on two legs tests was not examined as all participants successfully completed the test (i.e., stood for 30 s).

4.3.2.1 Standing on One Leg Tests

No significant interaction or main effects were observed for duration for the tests of standing on one leg on a firm support surface with eyes open, standing on one leg on a firm support surface with eyes closed, or standing on one leg on a foam support surface with eyes open (all \( p > 0.0056 \)). Table 7 presents the mean and standard error of the mean values for all the standing on one leg tests for the duration measure.

Standing on one leg with eyes open on foam showed a trend for a difference between exercise and comparison groups at baseline (\( F_{(1,68)} = 4.01, p = 0.049 \)). After controlling for duration at baseline as a covariate, there was a trend for a main effect for group (\( F_{(1,68)} = 8.822, p = 0.011 \)). Follow-up paired sample t-tests showed a trend for a difference between baseline and 12-week testing sessions in the exercise group only (\( t = -2.272, p = 0.029 \)). There was a trend for an increase in duration from the baseline to 12-week testing session in the exercise compared to the comparison group.

4.3.2.2 Walking Tests

A significant time main effect for duration was observed for walking 8 m on a firm support surface with eyes open (\( F_{(1,78)} = 15.387, p < 0.0001 \)), walking 8 m on a firm support surface while vertically pitching the head in synchrony with each step (\( F_{(1,77)} = 11.175, p = 0.001 \)), walking 8 m on a firm support surface with eyes closed
Table 7. Mean and standard error of the mean raw values for the duration measures for all one-legged stance tests by group and time. Dur=Duration. 1LEO= Standing on one leg with eyes open, 1LEC=Standing on one leg with eyes closed, ILEOF=Standing on one leg with eyes open on foam support.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Measures</th>
<th>Exercise Group</th>
<th>Comparison Group</th>
<th>Exercise dropouts</th>
<th>Comparison dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12-week</td>
<td>12-week</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>1LEO</td>
<td>Dur (s)</td>
<td>9.87 (1.15)</td>
<td>11.05 (1.53)</td>
<td>7.76 (1.71)</td>
<td>5.03 (1.07)</td>
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<td></td>
<td></td>
<td>11.34 (1.44)</td>
<td>13.90 (1.59)</td>
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<td></td>
</tr>
<tr>
<td>1LEC</td>
<td>Dur (s)</td>
<td>2.69 (0.23)</td>
<td>3.92 (0.72)</td>
<td>2.58 (0.59)</td>
<td>2.48 (0.52)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.91 (0.63)</td>
<td>3.80 (0.64)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1LEOF</td>
<td>Dur (s)</td>
<td>6.66 (1.03)</td>
<td>11.25 (1.86)</td>
<td>6.40 (1.64)</td>
<td>5.79 (1.89)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.77 (1.23)</td>
<td>9.91 (1.70)</td>
<td></td>
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</tr>
</tbody>
</table>
(\(F_{(1,78)}=12.885, p=0.001\)), and performing the modified get-up-and-go test \((F_{(1,71)}=23.865, p<0.0001)\). For each of these tests, there was a decrease in the time taken to complete the test for the 12-week compared to baseline testing session (Figure 5). No significant main effect for time was observed for the walking over four low obstacles on a firm support surface with eyes open or walking 8m on a firm support surface while horizontally while rotating the head in synchrony with each step tests (both \(p\)’s >0.0056). No significant interaction effect or group main effect was observed for duration for any of the walking tests (all \(p\)’s >0.0056). Table 8 presents the mean and standard error of the mean values for all the walking tests for the duration measure.

A trend for a main effect for time was observed for walking over obstacles \((F_{(1,77)}=7.037, p=0.01)\) and walking while rotating the head \((F_{(1,77)}=6.108, p=0.016)\) in the exercise and comparison groups. There was a decrease in the time taken to complete the test at the 12-week compared to baseline testing session.

4.3.3 Comparison of the Exercise Group and Exercise Dropouts and the Comparison Group and Comparison Dropouts

There was a trend for a difference between the exercise group and the exercise dropouts for roll angle for standing on two legs with eyes open at baseline \((F_{(1,60)}=9.437, p=0.003)\). The exercise dropouts showed a trend for greater roll angle than the exercise group. A trend for a difference was also found between the exercise group and the exercise dropouts for roll angle \((F_{(1,60)}=5.027, p=0.029)\), pitch angle \((F_{(1,60)}=9.271, p=0.003)\) and pitch velocity \((F_{(1,60)}=4.385, p=0.04)\) for standing on two legs with eyes closed. The exercise dropouts showed greater roll angle, pitch angle and pitch velocity compared to those in the exercise group at baseline. There were no other differences
Figure 5: Significant main effect for time for duration for walking 8 m with eyes open, walking 8 m while pitching the head, walking 8 m with eyes closed and the modified get-up-and-go tests. *** indicates $p \leq 0.0056$. 
Table 8. Mean and standard error of the mean raw values for the duration measures for all walking tests by group and time. Dur=Duration WEO=Walking with eyes open, WO=Walking over obstacles, WR=Walking while rotating the head, WP=Walking while pitching the head, WEC=Walking with eyes closed, GUG=Modified get-up-and-go.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Measures</th>
<th>Exercise Group</th>
<th>Comparison group</th>
<th>Exercise dropouts</th>
<th>Comparison dropouts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
<td>12-week</td>
<td>Baseline</td>
<td>12-week</td>
</tr>
<tr>
<td>WEO</td>
<td>Dur (s)</td>
<td>9.94 (0.29)</td>
<td>9.52 (0.34)</td>
<td>9.72 (0.23)</td>
<td>8.63 (0.37)</td>
</tr>
<tr>
<td>WO</td>
<td>Dur (s)</td>
<td>10.49 (0.33)</td>
<td>10.11 (0.35)</td>
<td>10.12 (0.28)</td>
<td>9.48 (0.35)</td>
</tr>
<tr>
<td>WR</td>
<td>Dur (s)</td>
<td>11.64 (0.49)</td>
<td>11.37 (0.50)</td>
<td>11.72 (0.58)</td>
<td>10.41 (0.47)</td>
</tr>
<tr>
<td>WP</td>
<td>Dur (s)</td>
<td>10.67 (0.38)</td>
<td>10.30 (0.42)</td>
<td>11.56 (0.51)</td>
<td>10.45 (0.51)</td>
</tr>
<tr>
<td>WEC</td>
<td>Dur (s)</td>
<td>13.71 (0.72)</td>
<td>12.52 (0.67)</td>
<td>12.25 (0.54)</td>
<td>11.41 (0.57)</td>
</tr>
<tr>
<td>GUG</td>
<td>Dur (s)</td>
<td>4.72 (0.14)</td>
<td>4.27 (0.15)</td>
<td>4.78 (0.18)</td>
<td>4.29 (0.15)</td>
</tr>
</tbody>
</table>
between the exercise group and the exercise dropouts or between the comparison group and the comparison dropouts for standing on two legs tests. Table 3 presents the mean and standard error of the mean values for all two-legged tests for the trunk sway measures.

There were no differences between any trunk sway measures between the exercise group and the exercise dropouts or the comparison group compared to the comparison dropouts when standing on one leg with eyes open. Table 4 presents the mean and standard error of the mean values for trunk sway measures for standing on one leg on a firm support surface with eyes open.

There was a trend for a difference between the exercise group and the exercise dropouts for roll angle \((F_{(1,60)}=4.990, p=0.029)\) for walking 8 m with eyes open at baseline. The exercise dropouts showed a greater roll angle than the exercise group. There was a trend for a difference between the comparison group and the comparison dropouts for roll angle \((F_{(1,46)}=4.577, p=0.038)\) and pitch angle \((F_{(1,46)}=4.709, p=0.035)\) for walking 8 m with eyes open at baseline. The comparison dropouts showed a greater roll and pitch angle than the comparison group. There was a trend for a difference between the exercise group and the exercise dropouts for roll angle \((F_{(1,58)}=8.340, p=0.005)\) for walking 8 m while rotating the head at baseline. The exercise dropouts showed a greater roll and pitch angle than the exercise group. There was a trend for a difference between the comparison group and the comparison dropouts for duration \((F_{(1,46)}=7.902, p=0.007)\) for walking 8 m with eyes closed at baseline. The comparison dropouts showed a greater duration than the comparison group. There were no other differences between the exercise group and the exercise dropouts or between the
comparison group and the comparison dropouts for trunk sway measures for the walking tests. Tables 5 and 6 present the mean and standard error of the mean values for all the walking tests for the trunk sway measures.

There was a trend for a difference for duration when standing on one leg with eyes open \((F_{(1,44)}=10.197, p=0.003)\) and standing on one leg on foam \((F_{(1,51)}=4.697, p=0.036)\) between the comparison group and the comparison dropouts. The comparison dropouts showed less duration compared to the comparison group. No other differences emerged between the exercise group and the exercise dropouts or between the comparison group and the comparison dropouts for duration for the standing on one leg tests. Table 7 presents the mean and standard error of the mean values for all the standing on one leg tests for the duration measure.

There were no differences between the exercise group and the exercise dropouts or between the comparison group and the comparison dropouts for duration for the walking tests. Table 8 presents the mean and standard error of the mean values for all the walking tests for the duration measure.
CHAPTER 5: DISCUSSION

This thesis investigated the effects of a 12-week training program on balance as assessed with trunk sway and duration measurements. It was expected that individuals who participated in the training program would show improvements in balance at the 12-week testing session, compared to the comparison group. Improvement in balance would be reflected by decreased trunk sway and longer duration for standing tests, as well as increased trunk sway and shorter duration for walking tests. It was also expected that no changes in balance would occur for individuals who did not participate in the training program between the 12-week testing session and the baseline testing session.

The results of this thesis showed that these hypotheses were not supported. No significant interaction effects were observed for trunk sway or duration measures for any of the stance or walking tests. The significant findings that were observed in this thesis were main effects for time (changes at the 12-week in comparison to the baseline testing session for test duration or the time to complete the test). These significant differences in test duration were isolated to the walking tests: a) walking 8m on a firm support surface with eyes open, b) walking 8m on a firm support surface while pitching the head with eyes open, c) walking 8m on a firm support surface with eyes closed and d) the modified get-up-and-go. The time taken to complete the test was significantly reduced at the 12-week compared to the baseline testing session. Improvements ranged from walking 6.2% to 8.0% faster at the 12-week compared to the baseline testing session for these tests. The remaining two walking tests showed similar improvements in duration for the 12-week compared to baseline testing sessions but these tests failed to meet the corrected significance level (walking 8m on a firm support surface over four obstacles with eyes
open: *p*=0.010; walking on a firm support surface while rotating the head with eyes open: *p*=0.016).

These time main effects demonstrate that the improvements in completing the walking tests were similar for the exercise group and comparison group. These results can be interpreted in several different ways. First, it can be interpreted that the training program had no effect on walking performance as both groups showed the same improvement over the 12-week time period between tests. The improvements observed in both groups for these walking tasks as well as the TUG may have been indicative of a learning effect and/or more comfort with the testing environment and experimental protocol. Second, the exercise group may have replaced his/her usual physical activity with the training program involved in this study. For example, if the exercise group normally walked in the morning, they may have stopped going for a walk as they were going to exercise in the training program, even though they were asked not to change anything in his/her lifestyle other than participating in the training program. This seems plausible with the lack of a significant increase in Godin scores for the exercise or comparison group. Furthermore, the improvements in the time to complete the walking tests in the comparison group are not likely attributed to lifestyle changes as there were no significant increases in Godin scores for this group. It is also unlikely that these improvements in both the exercise and comparison groups can be attributed to improvements in balance confidence as there were no significant differences shown from the baseline to 12-week testing session. Third, as previously noted, increased trunk sway occurs with increasing walking speeds (Goutier et al., 2010). Although the focus of the balance component of the training program was on improving COM control while
moving through the obstacle course and greater conscious control of balance has been linked to interference with its control (Wulf, McNevin, & Shea, 2001), the relationship between duration and trunk sway leading to smaller reductions in duration in the exercise group is unlikely. Because both exercise and comparison groups showed similar correlations between duration and trunk sway for the walking tests at both the baseline and 12-week testing session, it is improbable that the exercise group internalized improvement on the walking tests as being related to improved trunk stability. It may be more likely that both the exercise and comparison groups felt more comfortable with the testing protocol at the 12-week testing session compared to the baseline testing session which may have contributed to an increase in walking speed.

The lack of significant changes observed in the trunk sway measures across stance and walking tests in the exercise group may seem unexciting as multifactorial exercise is recommended and was implemented in the current thesis. However, these results are consistent with several research studies that have shown no effect of exercise and balance training on balance control (Barnett et al., 2003; Gatts & Woollacott, 2007; Weerdesteyn et al., 2005).

5.1 Characteristics of the Sample Population at Baseline

5.1.1 Characteristics of the Exercise and Comparison Groups at Baseline

The exercise and comparison groups were similar at baseline testing in terms of functional mobility, balance confidence, leisure-time physical activity and fall rates. The population examined in this thesis represents a relatively healthy population based on several measures compared to previous literature. For example, the mean from the
baseline TUG measure was approximately 7.4s, which was slightly faster than previous literature that reported scores ranging from 8-14.31s in older adults of similar age (Hatch, Gill-Body, & Portney, 2003; Schepens, Goldberg, & Wallace, 2010; Shumway-Cook, Brauer, & Woollacott, 2000; Steffen, Hacker, & Mollinger, 2002). Baseline balance confidence was also found to be representative of a healthier population as older adults in this thesis reported a mean of approximately 88% out of 100%; meanwhile, previous literature has reported a range of 78.9-84.7% (Hatch et al., 2003; Schepens, Goldberg, & Wallace, 2010). Balance confidence scores above 80% have also been shown to be indicative of highly functioning and usually physically active older adults (Myers, Fletcher, Myers, & Sherk, 1998). In total, there were approximately 25% of the participants who were fallers at baseline, which is slightly lower than previous literature has found with 30-35% of older adults being fallers (Prudham & Evans, 1981; Rubenstein, 2006). Leisure-time physical activity was higher among the older adults in this thesis (i.e., approximately 33 metabolic equivalent of the task [METs]), in comparison to previous literature (i.e., approximately 22.2 METs) which also examined older adults (Courneya, Nigg, & Estabrooks, 1998). Importantly, the exercise and comparison groups were similar in terms of trunk sway and duration scores at baseline for all the stance and walking tests.

5.1.2 Characteristics of the Exercise and Comparison Groups Compared to the Dropouts

A meta-analysis including a variety of balance training programs in older adults reported a range of dropouts from 0-48% which is in line with the overall dropouts from this study (i.e., 28%) (Howe et al., 2012). It was found that the exercise group dropouts
weighed significantly more than the exercise group which may have been a contributing factor in the dropout status. A review suggests that those who are fitter at baseline and those who lead a physically active lifestyle adhere to training programs better than those who are unfit and physically inactive at baseline (Martin, & Sinden, 2001). Although it did not reach significance, it appears that those who dropped out of the exercise group showed slightly less balance confidence and less leisure-time physical activity scores which also may have led to dropping out of the program.

Adherence rates were markedly high for the exercise group with an overall 87% adhering to the program with 43% from the exercise group fully adhering to the program. A review of adherence rates in training programs among older adults suggests an average of 78% adherence which is slightly less than the current results (Martin, & Sinden, 2001). Simek, McPhate, and Haines (2012) suggest that there is a relationship between intervention factors and adherence rates such that programs including a balance component and a walking component show greater adherence rates than programs that do not include these factors. This may explain the increased adherence rates in the current training program. Those who dropped out of the training program showed an overall partial adherence of 45.5% which is much higher than previous literatures that reports 19% adherence (Buchner et al., 1997).

The trends for differences in trunk sway and duration measures at baseline across the balance tests for the exercise and comparison dropouts compared to those who adhered to the program may be a reason for dropping out of the program. This was shown through a trend for increased trunk sway during two-legged standing for the exercise dropouts only, shorter time to complete the standing on one leg tests for the
comparison dropouts only, and increased trunk sway during walking tests for both exercise and comparison dropouts. Gill et al. (2001) suggest that, due to the age-related changes to the balance control system, older adults show increased trunk sway during standing on two legs, and shorter time to complete one-legged standing compared to young adults. For the walking tests, potentially the exercise group had better control of his/her trunk sway compared to the exercise dropouts as the exercise dropouts displayed increased trunk sway. Furthermore, the exercise group dropouts may have found the training program too challenging and decided to withdraw from the program due to decrements in balance control. It is possible that the comparison group dropouts did not want have his/her balance tested again and decided to withdraw also due to balance decrements.

5.2 Balance Tests: Influence of a Multifactorial Exercise and Balance Training Program

5.2.1 Standing on Two Legs

The hypothesis that the exercise group would improve trunk sway on two-legged stance tests after completing the training program was not supported. Confounding results exist with regards to the effects of a training program on standing balance as previous training studies have reported a decrease in the amount of postural sway during standing balance after a training program (Barnett et al., 2003; Lichtenstein et al., 1989; Liu-Ambrose, Khan, Eng, Lord, & McKay, 2004; Wolf, Barnhart, Ellison, & Coogler, 1997), and other studies yielded no change (Barnett et al., 2003; Weerdesteyn et al., 2005) while others have shown an increase in the amount of postural sway during
standing balance after a training program (Lord et al., 1995; Lichtenstein et al., 1989; Wallmann, Gillis, Alpert, & Miller, 2009; Wolf, Barnhart, Ellison, & Coogler, 1997).

There also remains a lack of consensus in the literature on whether increased or decreased postural sway reflects improved balance. An example of this inconsistency was shown after 5-weeks of the Nijmegen Falls Prevention Program, which was a low-intensity exercise program focusing on falls, standing balance, balance confidence and obstacle avoidance. Standing balance and weight shifting tests did not provide clear evidence of improved automatic or voluntary control of posture after this exercise program (Weerdesteyn et al., 2006). Wolf and colleagues (1997) found similar results for a 15-week intervention with participants experiencing decreased numbers of falls and increased balance confidence, but a lack of training effects on basic control mechanisms of standing balance for both a tai chi exercise group and computerized balance training group. Further to this work, Hu and Woollacott (1994) have shown that standing tests that challenged the various sensory systems showed the most improvements after a training program such as standing with eyes closed or on foam (Hu & Woollacott, 1994). This finding did not emerge in the standing tasks that challenged the sensory systems in this thesis.

Although this study did not compare balance across different tests, it appears as though older adults had more difficulty with the conditions as shown through the increased trunk sway values for the tests that challenged the sensory systems. Studies have shown that during visual and proprioceptive conditions, there is an increase in trunk sway in older adults (Gill et al., 2001). In fact, we found an approximate two-fold increase in roll angle, roll velocity, pitch angle and pitch velocity from standing on two
legs with eyes open compared to standing on two legs with eyes closed on foam support which is consistent with previous literature (El-Kashlan, Shepard, Asher, Smith-Wheelock, & Telian, 1998; Shumway-Cook, & Horak, 1986; Whipple, Wolfson, Kerby, Singh, & Tobin, 1993). Contrary to the findings of Gill et al. (2001), it also appears that there was increased sway when standing on foam compared to standing with eyes closed as shown with the global increase in trunk sway values for each dependent measure. In fact, Hu and Woollacott (1994) found that the trained group did not significantly improve on tests that stressed the visual or vestibular systems but did improve when proprioceptive inputs were challenged when standing on two legs. This suggests that proprioception may have a greater influence on balance control than vision.

The trunk sway values of the two-legged standing tests at baseline are similar to previous research examining older adults. Gill et al. (2001) showed comparable roll angle, roll velocity and pitch angle values to the current research. The pitch velocity values reported in Gill et al. (2001) were slightly higher than the current research for the standing on two legs tests. Previous work examining standing on two legs with eyes closed on firm and foam support surface also show similar trunk sway values to the current study (Adkin, Bloem, & Allum, 2005). Other research examining an 80-year-old woman showed similar roll angle values but slightly higher pitch angle, roll velocity and pitch velocity values during standing on two legs with eyes closed on foam than the current research (Hegeman, Shapkova, Honegger, & Allum, 2007).

Taken together, the results of this thesis support several studies that have shown no effect of exercise and balance training on standing balance control (Barnett et al., 2003; Gatts & Woollacott, 2007; Weerdesteyn et al., 2005). It is possible that given the
relatively healthy nature of the population examined in the thesis that the standing on two legs tests were too simple and performance too variable to show improvement in the exercise group following the training program. It could also be argued that the training program did not specifically train two-legged standing balance control and that the training completed in the program did not transfer to improve balance control on this type of test.

5.2.2 Standing on One Leg

The time to hold one-legged stance tests an important variable when examining balance as 20-40% of walking is performed on one foot (Lichtenstein et al., 1990) and longer one-legged standing has been correlated to increased walking speed (Ringsberg, Gerdhem, Johansson, & Obrant, 1999). It has been suggested that one-legged stance is especially important for activities of daily living such as walking up stairs (Lichtenstein, Shields, Shiavi, & Burger, 1990). However, it has been suggested that one of the limitations of evaluating older adults on standing on one leg is that many cannot perform this test due to either a lack of muscle strength or a fear of performing the test (Thapa, Gideon, Fought, Kormicki, & Ray, 1994). The results of this thesis failed to show any significant differences in duration and trunk sway measures for the standing on one leg tests between the exercise and comparison groups. As reported in the literature review, there are confounding results with regards to the effects of a training program on one-legged stance. Some literature suggests that a training program improves one-legged standing (Islam et al., 2004) while other research shows no changes in the performance of this test (Schlicht, Camaione, & Owen, 2001). Other studies have shown mixed results with some individuals in the exercise group improving while others do not (Hu &
Woollacott, 1994) which suggests that the level of improvement in the exercise group is dependent on individual differences which may impact the variability of performance observed for these tests in the current thesis. This finding may provide support for the lack of significant findings for the one leg stance tests observed in this thesis. Although it did not reach the corrected significance level, there was a trend for participants in the exercise group to maintain one-legged stance for a longer duration compared to participants in the comparison group when standing on foam with eyes open ($p=0.011$). This trend could be explained by the nature of the training program. One of the primary goals of the balance obstacle course was to force individuals to adapt and become comfortable with single leg stance positions by requiring him/her to step to balance pods and step and walk along foam rollers. This type of training may have specifically improved the ability of the participants in the exercise group to stand on one leg when on a foam support surface. Although speculative, improvements in lower leg strength and proprioceptive inputs may have been responsible for the trend toward longer one-legged stance durations on a foam support surface in the exercise group. This trend for improvement observed in standing on one leg on a foam support surface in the exercise group may have clinical significance. As declines in standing balance are associated with falls (Tinetti, Speechley, & Ginter, 1988), standing balance is a valuable predictor for identifying individuals who are at risk for falls (Rogers, Rogers, Takeshima, & Islam, 2003).

Trunk sway values of baseline one-legged standing with eyes open in previous literature in older adults are similar to the current study. For example, Gill et al. (2001)
also showed slightly smaller roll angle, similar pitch angle and roll velocity, and slightly smaller pitch velocity values in older adults aged 65-75 years.

When examining duration scores of previous literature, it appears that this population could not hold this position for as long as similar populations have. For example, other studies examining standing on one leg with eyes open have revealed that those aged 60-69 years could hold this position for 22.5 s and the 70-79 years group could hold this position for only 14.2 s which is much less than both the exercise (baseline: M=9.9 s, 12-week: M=11.3 s) and comparison groups (baseline: M=11.1 s, 12-week: M=13.9 s) at the baseline and 12-week testing sessions (Bohannon, Larkin, Cook, Gear, & Singer, 1984). However, the exercise group did show a 12.4% improvement while the comparison group showed a 20.1% improvement.

In another example looking at standing on one leg with eyes closed, Schlicht, Camaione and Owen (2001) found that older adults could hold this position between 4.6-6.0 s, whereas the current population only held this position for between 2.7-3.9 s. Other researchers have shown that those aged 60-69 years could hold a one leg eyes closed position for 10.2 s and the 70-79 years group could only hold this position for 4.2 s which shows a drastic change in the age-related influence on balance (Bohannon et al., 1984). Gill et al. (2001) found similar results in those aged 65-75 years as they could hold this position for 8.9s. Although baseline values seemed to be low in this population, standing on one leg eyes closed showed a 31% improvement in the exercise group to a -3% decrement in duration for the comparison group.

For the test of standing on one leg on foam support, Gill et al. (2001) found that older adults could hold this position for approximately 12.5 s whereas in this thesis, the
exercise group at baseline could only hold this position for 6.7 s and the comparison group held this for 11.3 s. There was a trend for a difference between exercise and comparison groups at baseline ($p=0.049$) however a 32% improvement for duration was found in the exercise group compared to the -12% decrement in performance in the comparison group.

Given that the present study only examined standing on one leg in the various conditions for only one attempt in some cases, when comparing the methods of similar studies, they have all offered participants 5 attempts at holding the position (Bohannon et al., 1984; Schlicht, Camaione, & Owen, 2001) or the best duration of two trials (Gill et al., 2001), which may explain why participants in other studies are performing better on these tests due to decreased variability in the findings.

When comparing the trunk sway values of standing on one leg with eyes open in the current study to the work of Gill et al. (2001), roll angle, roll velocity and pitch angle and pitch velocity appear to be similar. As expected, global trunk sway values were much higher when standing on one leg compared to any of the standing on two legs tests. Gill and colleagues (2001) also showed that standing on one leg causes dramatic increases in sway compared to two-legged standing for older adults, middle aged, and young subjects. Also as expected, participants were much more unstable in the roll direction compared to the pitch direction in both angle and velocity when standing on one leg compared to two legs as standing on one leg decreases the medial-lateral base of support.
5.2.3 Walking Tests

Although many tests examine static postural control, most falls occur during walking when performing activities of daily living (Berg, 1989; Quail, 1994; Sheechely & Tinetti, 1990) under less than optimal sensory conditions such as dim lighting or unexpected environmental conditions (Lipsitz, Jonsson, Kelly, & Koestner, 1991; Patla, et al., 1990; Quail, 1994). This highlights the importance of the inclusion of walking tasks in the balance testing battery.

Trunk sway values of baseline walking in previous literature in older adults showed to be similar or slightly less compared to the current study. Gill et al. (2001) found similar roll angle and roll velocity, but slightly less pitch angle and pitch velocity for walking with eyes closed. Gill et al. (2001) also found less trunk sway values for walking while rotating the head and walking while pitching the head compared to the current study.

In general, a number of studies using different types of exercise and balance training have reported improvements in walking speed or shorter walking durations after a training program (Bohannon, 1997; Helbostad, Sletvold, & Moe-Nilssen, 2004; Schlicht, Camaione, & Owen, 2001; Shimada et al., 2009; Shumway-Cook, Gruber & Baldwin, 1997). The current study also showed similar self-selected walking speeds compared to previous research in older adults (Bohannon, 1997; Shimada et al., 2009; Shumway-Cook, Gruber & Baldwin, 1997). The results of the current thesis provide partial support for this research, in that the exercise group did show improvement after the training program. Unfortunately, the comparison group also showed these
improvements so the faster walking durations cannot be singularly attributed to the training program, or attributed to the program at all.

Increased trunk angle and velocity have been shown to emerge with faster walking speeds (Goutier et al., 2010). A trend for a time effect for increased roll angle ($p=0.042$) and roll velocity ($p=0.04$) together with an increased walking speed was reflected for the current thesis when walking with eyes open in both exercise and comparison groups. Similarly, a trend for an interaction effect for increased pitch angle ($p=0.006$) coupled with a decreased duration was also reflected for walking over obstacles for the comparison group only. It is logical that a trend for increased trunk sway values were shown with decreased time to complete the aforementioned walking tests (Goutier et al., 2010); however it is puzzling why the comparison group increased on sway measures while no changes were observed with the exercise group for the walking over obstacles test. It is possible that the exercise group may have had better control of his/her trunk sway when walking over obstacles, despite the decrease in duration as they may have exhibited increased consistency compared to the comparison group. Because part of the training program for the exercise group included walking over balance pods on the obstacle course, they may have exhibited more control over his/her COM when performing this test compared to simply walking with eyes open as normal walking which may not have been a very challenging test.

5.2.4 Effects of a Training Program on Balance Control

The overall results of this thesis show little benefit to balance control, which may be a result of the training program. The key components to overloading the system during a training program include frequency, intensity, type, and time. It is important to
note that the most important principle is overload and specificity. It is possible that this principle was not implemented during the training program. That is, the exercise group may not have loaded the system enough, even though the training program was designed for individual progress, it may have been too short or was not vigorous enough to show changes. Likewise, the multifactorial nature of the current training program may not have been specific enough to show changes in the balance tests. Similar to this, the balance tests also may not have been specific enough to show changes to the balance control system thus no significant findings were uncovered. Although no significant changes to balance control were found, it is possible that other changes that were not examined, such as a decrease in fall rates or a decrease in activity restriction occurred.

The current state of research investigating the effects of exercise and balance training on performance and control of stance and walking tests remains mixed. The pending question that arises is the reason why some training programs have been successful at improving balance and/or reducing falls and others have not. It has been suggested that those that have been unsuccessful in eliciting changes may be due to high drop-out rates, low adherence to the training program, non-randomization into exercise and comparison groups, variation in training programs, or the training program was not specific enough to show changes in the outcome measures, and the outcome measures selected (McMurdo, Millar, & Daly, 2000; Nowalk, Prendergast, Bayles, D’Amico, & Colvin, 2001; Shumway-Cook et al., 1997; Wolf et al., 1996). However, the current thesis did showed a high adherence rate of 87% and a modest overall dropout rate of 28%. Some successful studies that have shown improvements in balance control in older adults have targeted training to the sensory systems, the selection of motor strategies or
focusing on training the other subsystems involved in balance (Hu & Woollacott, 1994; Protas, Wang, & Harris, 2001; Rose & Clark, 2000). The current thesis targeted many of the systems that were suggested to show improvements in balance control using the balance obstacle course; however this thesis revealed minimal changes to balance control as assessed through trunk sway and test duration on stance and walking tests.

There are several strengths to the design of the current thesis which should have contributed to the expected improvements with the training program. However, there are also several limitations to the design of the current thesis that may have resulted in the lack of improvements that were observed after the training program. The strengths and limitations with respect to sample population, balance testing, the training program and the interaction between the sample population, balance testing and the training program will be discussed next.

5.3 Strengths and Limitations

5.3.1 Sample Population

The findings of this study are not generalizable to all older adults. The sample homogeneity restricts generalization to relatively healthy community-dwelling older adults, independent walkers, and highly motivated populations. The sample population volunteered to exercise 3 times per week, which is atypical for people from his/her community, and suggestive of his/her disproportionate motivation to lead healthy lifestyles. If this is the case, these results are not applicable to older adults who are not interested in starting an exercise program. This may also explain the lack of improvement with exposure to the training program as individuals may have had a high ceiling for
balance performance and thus improvements would be hard to detect compared to a more sedentary and inactive group.

In addition, some participants may have shown different age-related deficits in one or more of the subsystems of balance control outlined by Horak (2006). For example, the specific age-related deficit(s) may not have been global across participants as some individuals may have had deficits in cognitive processing while other individuals may have had deficits in sensory strategies. These differences may have led to some individuals performing well on some tests while others performed poorly on these tests. This may have increased the variability between the exercise and comparison groups, thereby resulting in the lack of significant differences after the training program. It might be recommended to look at individual performance across different balance tests to determine where deficits might exist, and determine if training specifically improved performance on these tests. Alternatively, a composite balance score may also provide insight into these findings. However, due to the multiple systems nature of balance, this has proved difficult to accomplish (Allum, Carpenter, & Adkin, 2001).

Additionally, the current study may have needed a larger sample size to show significant differences between groups. Studies examining the effects of a training program have included a range between 11-163 participants (Asikainen, 2006; Barnett et al., 2003; Baum, Jarjoura, Polen, Faur, & Rutecki, 2003; Helbostad, Sletvold, & Moe-Nilssen, 2004; Rosie & Taylor, 2007), and the participants included for this thesis were well within this range. However, when examining the post hoc effect sizes and power, these values range from very low to very high, suggesting that some of the balance tests and measures were of adequate size and others were not.
5.3.2 Balance Testing

Data for this thesis were obtained from a larger study conducted over the past 4 years. Inherent with this long testing interval is the large number of testers and spotters that were used to collect the baseline and 12-week data. Although training of testers was consistent through the study, this approach may have led to inter- and intra-tester variability. Some of the limitations associated with the different testers are listed next.

The inconsistent or inaccurate delivery of the instructions for the balance tests may have occurred between and within testers which may have had an effect on the results. This problem may have been exaggerated for more complex tests, which required additional instructions such as walking while rotating the head in synchrony with each step, as opposed to simpler tests such as standing with eyes open on a firm support surface for 30 s. Despite the perceived simplicity of this latter test, the stance width was defined by the participants’ foot length and slight variation may be been introduced from baseline to 12-week testing sessions. It is also possible that some testers allowed the participants to attempt a balance test an additional time in the event that they did not understand the instructions or if participants performed uncharacteristically poorly and requested a second opportunity. Other testers may have known the participant from the training program which may have made the participant feel more comfortable, which may have increased tester-participant familiarity. Additionally, some testers may have provided encouragement to participants during the testing session while others may not have, which could have possibly contributed to inconsistencies during testing. However, the advantage of having a larger ongoing study is that more participants have the opportunity to benefit from the program. By including more people in the study, there is
less of a chance that significant findings were not observed as a result of having a small sample size which reduces type I error.

Because the sample population was healthy, this may have rendered certain balance tests to be too simple. For example, all four standing tests showed a ceiling effect with duration as all participants could stand for 30 s. Conversely, some participants could not adequately complete highly complex tests, such as standing on one leg with eyes closed. One of the advantages to this study was the implementation of a wide variety of balance tests. By using multiple measures of trunk sway and duration across a number of stance and walking tests, this study was able to provide a more broader assessment of overall balance. Many assessment techniques have only assessed standing balance in the anterior-posterior direction; however it is well known that falls in older adults primarily occur in the medial-lateral direction (Maki, Holliday, & Topper, 1991). For this reason, trunk sway was assessed in both anterior-posterior and medial-lateral directions in order to provide a more thorough representation of his/her balance control. Thapa et al. (1994) have reported that the majority of falls occur during walking, which stresses the importance of implementing walking in balance assessment protocols. Due to the wide variety of tests examined and the inopportunity to perform multiple attempts of each test for the interest of time, understanding the variability in performance was limited between the exercise and comparison groups.

The experimenters were not subjected to a double-blind procedure. Thus, conscious or subconscious observer bias may have affected the results. Likewise, participants were not blind to the intervention or the control period. Participants in the exercise group may have felt pressure to perform, though it is interesting that the non-
blind procedure did not elicit demand characteristics, a phenomenon wherein participants behave in conformance with researcher expectations. Alternatively, participants may not have known what to expect during the baseline testing session, and sought to perform better at the 12-week testing session. However, due to the nature of training program, it is impossible to support a double-blind procedure.

The comparison group exhibited unexpected improvements in the 12-week testing session for the walking tests. These improvements may be the function of a learning effect as participants may have become familiar with the lab protocol at the 12-week compared to the baseline testing session. It is also possible that they modified certain aspects of his/her lifestyle in preparation for committing to exercise 3 times per week, such as improving eating habits, exercising more often, and even practicing balancing activities. It is important to report that the comparison group was not a true comparison group which has been noted as a limitation in many training studies (Howe et al., 2012). Participants in the comparison group were permitted to participate in the training program upon completion of the 12-week testing session, in accordance to the intention to treat principle to avoid dropout effects.

5.3.3 Training Program

As previously mentioned, each participant may have had deterioration in different combinations of the systems involved in balance control wherein the interaction of the six systems contributes to overall balance ability (Horak, 2006). To this end, some individuals may have benefited from certain aspects of the training program, while other participants may have experienced little to no changes in balance. Individual differences in the progression of improvement during the training program may have contributed to
increased variability and a lack of apparent results. More specifically, some participants may have shown marked improvements in strength training, but not as many improvements in aerobic or balance training. These improvements may not have been captured in the balance testing in the exercise group if a system that was improved was not examined. For example, dual tasking (i.e., cognitive processing system) was trained on the balance obstacle course in the training program; however dual tasking was not part of the testing battery. Therefore, it is possible that the exercise group improved in the systems that were not tested, which may have affected the results.

The principle of individual differences can also be applied to the possibility that some individuals in the exercise group may have been much more motivated to participate in exercise and may have put forth more effort compared to others. Conversely, perhaps others were not invested in the program and may not have completed the requirements set for him/her. It is also possible that the exercise group may have replaced his/her typical exercise routine with the training program, even though they were asked to engage in routine activities save for the training program. Individual differences can also relate to how much or how little of an effect the training program had on the participants. Those who did not regularly exercise prior to the study may have improved substantially more in comparison to those who did regularly exercise prior to the study; although, this was minimized as the exercise and comparison group had no significant leisure-time physical activity differences at baseline as shown by the Godin (Godin & Shephard, 1985).

While the training program was standardized for those in the exercise group, some variation in the exercises existed, including specific exercises, repetitions, and intensity
due to a range of ability and physical health limitations among participants. This can be seen as a benefit considering that the program was individualized for each participant depending on his/her capabilities.

Another strength of this training program was the high adherence rates among the exercise group. Because the exercise group had such a high adherence rate, the lack of significant differences in balance control is unlikely to be a function of adherence.

It is possible that the length of the training program, albeit 12-week period, may not have been long enough to elicit changes in balance control. Some studies that have examined the effects of longer training programs than that of the current thesis in mildly deficient strength and balance participants did not have restorative effects in walking, balance or physical health status (Buchner et al., 1997). However, a review of training programs for older adults suggested that the most effective programs at reducing falls are those that include at least 50 hours of highly challenging balance training and avoidance of brisk walking (Sherrington et al., 2008). The current training program requested that the participants exercise between 1-1.5 hours per week, 3 times per week for a 12-week period, therefore each participant exercised between 36-54 hours. However, the balance portion of the training program only included 15-20 minutes on the obstacle course, summing to a total of 9-12 hours of balance training over the course of the 12-week period. As suggested by Sherrington and colleagues (2008), there may have not been enough training allotted to balance which may be why changes were not shown. This review was focused on the reduction of falls, not on changes observed in balance control, but it is possible that the recommendation of 50 hours of highly challenging balance training be also appropriate for improving overall balance control in older adults. On the
contrary, a meta-analysis suggested that, in general, the most effective training programs that improved balance were challenging and ran 3 times per week for 3 months (Howe et al., 2012). This suggests that the training program implemented in the current thesis may or may not have been of adequate length.

5.3.4 Interaction of the Sample, Balance Testing, and Training Program

Cause and effect relationships pertaining to the training program are inconclusive due to the multifactorial design of the program. Variability in results can be explained by multiple experimental manipulations and external, confounding factors. For example, any independent or combination of the following constructs may have moderated improvements in balance: aerobic training, resistance training, flexibility training, balance training, the act of simply getting out of the house, social interaction, regular motivation and encouragement by trainers or peers. It is plausible that the lack of observed differences in the experimental group between the baseline and 12-week testing session could be attributed to the unspecific training program or interactions with other variables. Further, other measures that were not assessed could have improved as a result of the training program. That is, there may have been improvements in the risk for falls or activity restriction in the exercise compared to the comparison group.

Some emerging literature has found that specific interventions targeting specific variables show significant differences, whereas those that are more general do not show differences. For example, Hu and Woollacott (1994) found that a 10-day training program that specifically trained participants on the tests that were measured, significantly improved after the intervention. This thesis trained balance on a more general scale and this may have contributed to the insignificant findings. However, by
implementing a multifactorial training program, participants had the opportunity to benefit from a wide variety of exercises. Although other fitness related measures were not analyzed for this thesis, potentially the overall health and wellbeing of the participants involved in the training program improved. It is plausible that from the participation in a consistent training program, the exercise group benefited from improvements in aerobic capacity, muscle strength, and flexibility. Although the enjoyment of this training program was not measured, it is possible that due to the multifactorial nature of this study, participants may have enjoyed this type of training program more than a highly specific training program. In addition, with the use of a regularly updated activity board with community events, and increase in social interaction with peers, this study also may have contributed to improving adherence and overall enjoyment of the study as shown through the high adherence rates in the exercise group.

In addition, anecdotal evidence suggests that participants showed improvements in balance on the balance obstacle course over the course of this training program which was evidenced by the increase in challenging activities (e.g., dual tasking) that participants were performing at the conclusion of the 12-week period. However, it should be noted that this progression was highly individual. This anecdotal evidence may suggest that assessment of balance at baseline and 12-week testing sessions include a similar balance obstacle course to determine if the skills trained during the program were transferred to a different environment. This is especially salient as the training was designed to challenge flexibility of balance control strategies. This approach could provide insight into the benefit of the current training program in the participants’ performance of his/her daily activities.
A reduction in the ability to maintain balance control may be linked to higher risk of falling, increased dependency, illness and early mortality (Howe et al., 2012). After examining a healthy older adult population following a 12-week multifactorial training program, it is apparent that this type of exercise was not successful at improving balance as assessed through trunk sway and test duration. It remains unknown which types of training programs are optimal for improving balance in older adults.

5.4 Recommendations and Future Directions

Taking these strengths and limitations into consideration, some recommendations can be derived from this thesis. One recommendation is that participants should be assessed in the testing lab using a similar method as the one implemented in the training program. Perhaps training on the obstacle course did not transfer to the different aspects of balance that were examined in the testing portion of the thesis. Many of the different tasks that were trained on the obstacle course included dual tasking, reaching tasks as well as COM and BOS perturbations; however it is unknown how the tasks performed on the obstacle course transferred to the testing laboratory. Future studies should examine the utility of these methods of assessing balance control. It is possible that tests such as a retropulsion test, walking up and down stairs, and dual tasking tests may show that assessing balance using these methods would better discriminate between exercise and comparison groups as these types of tasks were trained on the obstacle course. Perhaps comparing the effects of balance control between obstacle course tasks and similar lower impact tasks may further unveil the usefulness of the obstacle course as an assessment tool. Weerdesteyn et al. (2006) found that training on an obstacle course did not elicit
changes in posturographic balance tests; however when they were assessed on the obstacle course, they did show improvements compared to the comparison group. This suggests that the testing should be more specific in order to show improvements in balance. Potentially, the exercise group would have shown improved performance on the obstacle course compared to the comparison group as a reflection of his/her balance specific training. It may also be reasonable to investigate the effects of this type of balance training on the ability to perform daily activities and future falls to determine the efficacy of the program.

It is recommended that multiple trials of each of the balance tests should be examined. Assessing the mean of each balance test performed at least three times may decrease the variability of the findings. Multiple trials on a balance test may provide understanding of the variability in performance that could provide better insight into the functioning of the balance control system. Although depending on the test, increased variability in performance may be viewed as positive (i.e., increased in flexibility in balance control strategy) while decreased variability may also be viewed as positive (i.e., similar test durations for one-leg stance).

Based on previous research, it is recommended that future training programs implement a moderate to high challenge to balance and it should provide a sufficient dose of exercise; in general, 3 times per week exercise over 3 months has shown to be effective (Howe et al., 2012). It is also recommended that a follow-up study be conducted to determine the ongoing effects of the program. It would be interesting to determine if the benefits of the training program (i.e., the shorter walking durations) persisted in the exercise compared to the comparison group. Although a generally
healthy population was investigated in this thesis further research should target lower functioning older adults to determine the impact of this type of program on these individuals.

5.5 Conclusion

This thesis was the first to investigate the effects of a training program on balance performance across a wide variety of stance and walking tests in healthy older adults living in the community. Although the thesis was not able to verify the effects of the training program for improving balance, strengths and limitations of the current approach were identified and recommendations were made for future research investigations. The results of this thesis reinforce the gap that remains between understanding the benefits of exercise and balance training on balance control in older adults. The results from the thesis contribute to the growing body of literature that suggests that physical activity may show no improvements in balance control in healthy older adults. Evidence has shown that in those who are inactive and/or have a balance disorder, there is a positive correlation between exercise and activities of daily living (Pitta et al., 2005); however the greater the exercise capacity, the weaker the correlation becomes, probably due to increased variability (Hayashi et al., 2012). This lends to the reasoning that exercise may be a contributing factor to balance but not a determining one. Therefore, further research is needed in this area to resolve the true effects of exercise and balance training on balance in older adults.
REFERENCES


SMARTRISK. The economic burden of unintentional injury in Canada. 1998.


SwayStar System, Balance International Innovations GmbH, Switzerland


APPENDIX A: Informed Consent

Date: Fall, 2010

Project Title: The effects of a physical activity intervention on body image, self-presentation concerns, balance confidence, and trunk sway in older adults.

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INVITATION
You are invited to participate in a study that involves research. The purpose of this study is to investigate the effect of a 12-week physical activity program on body image, concerns about how others think of us, balance confidence, and balance, in men and women 60 years of age and older.

WHAT’S INVOLVED
As a participant, you will be asked to participate in 3 phases of the study. In Phase 1, you will attend an initial testing session, in which you will be asked to fill out a series of questionnaires, complete a series of balance tests, and a series of fitness tests. Participation in this session will take approximately 2.5 hours of your time. Then, you will be randomly assigned to either the exercise group or a comparison group. Those in the comparison group are asked to lead his/her normal lives, with no changes to his/her lifestyles. Those in the exercise group will be asked to participate in a 12-week supervised exercise program. You will be asked to attend the exercise sessions 3 times per week at Brock University. Each session will last approximately 60-75 minutes. The exercise program will consist of a brief warm-up, 20 minutes of cardiovascular activity of your choice, strength training, balance training, and flexibility training, followed by a cool-down. At the end of 12-weeks, all participants will be asked to complete the same questionnaires, balance, and fitness tests as the start of the study. For Phase 2 you may be randomly asked to participate in a focus group. This group will be made up of either all men or all women, and is designed to get participants’ perceptions of the exercise program in which they participated. Each focus group will last approximately 1-1.5 hours, will be audio-taped, and will take place on the Brock University campus. In Phase 3, you will be asked to return to Brock one year after previous testing. You will again complete the same questionnaires, balance tests, and fitness tests as you did previously, to
examine the extent to which any changes have been maintained. Again, this session will take approximately 2.5 hours.

**POTENTIAL BENEFITS AND RISKS**

Possible benefits of participation include the benefits associated with physical activity. You will also receive information about your own fitness levels. There also may be risks associated with participation. For example, there is some risk of injury associated with any physical activity. There is also a risk of injury due to falling, especially during the balance exercises. All exercise and testing sessions will be supervised by qualified research assistants. The exercise program is designed for all fitness levels, and will progress gradually, at each individual’s own pace. In addition, the nature of some of the questionnaires may lead to some psychological discomfort. However, there are no known instances of any problems resulting from anyone completing these questionnaires. If you do experience any concerns, you may contact Dr. Gammage at the above number or email.

**CONFIDENTIALITY**

All information you provide is considered confidential; your name will not be included or, in any other way, associated with the data collected in the study. Furthermore, because our interest is in the average responses of the entire group of participants, you will not be identified individually in any way in written reports of this research. Given the format of the group exercise sessions, and the focus groups, we ask you to respect your fellow participants by keeping all information that identifies or could potentially identify a participant and/or his/her comments confidential. Data collected during this study will be stored in a locked filing cabinet in a locked storage room on campus. Data will be kept for 1 year following publication of results of the study, after which time all questionnaires will be shredded and audiotapes destroyed. Access to this data will be restricted to the investigators listed above, and his/her student research assistants.

**VOLUNTARY PARTICIPATION**

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled.

**PUBLICATION OF RESULTS**

Results of this study may be published in professional journals and presented at conferences. Feedback about Phase 1 of this study will be available following completion of this phase for all participants. At this time, you will receive feedback about the results of your individual fitness assessments, and the summary of the results of the study. You will receive this information via email or regular mail, as requested. Summaries of the focus group findings will be provided upon completion of all focus groups. Feedback about your one-year follow-up fitness tests and about the summary of these results will again be provided (via email or regular mail) upon completion of the entire study. At this time, you may contact us with any questions you may have about the interpretation of your results.
CONTACT INFORMATION AND ETHICS CLEARANCE
If you have any questions about this study or require further information, please contact the Principal Investigator using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (File #07-276). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.
Thank you for your assistance in this project. Please keep a copy of this form for your records.

CONSENT FORM
I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

Name: ________________________________

Signature: ______________________________ Date: ____________________________
APPENDIX B: Ethical Clearance

From: Research Ethics Board [mailto:reb@brocku.ca]
Sent: Monday, April 28, 2008 11:01 AM
To: Kimberley Gammage; Allan Adkin; Panagiota Klentrou
Cc: Michelle McGinn
Subject: REB 07-276 GAMMAGE - Accepted as Clarified

DATE: April 28, 2008

FROM: Michelle McGinn, Chair
Research Ethics Board (REB)

TO: Kimberley L. GAMMAGE, Physical Education and Kinesiology
    Allan Adkin, Nota Klentrou

FILE: 07-276 GAMMAGE

TITLE: The effects of a physical activity intervention on body image, self-presentation concerns, balance confidence, and trunk sway in older adults

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

DECISION: Accepted as Clarified

This project has received ethics clearance for the period of April 28, 2008 to January 9, 2010 subject to full REB ratification at the Research Ethics Board's next scheduled meeting. The clearance period 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 cleared by the REB. During the course of research no deviations from, or changes to, the protocol, recruitment, or consent form may be initiated without prior written clearance from the REB. The Board must provide clearance for any modifications before they can be implemented. If you wish to modify your research project, please refer to http://www.brocku.ca/researchservices/forms to complete the appropriate form 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 clearance 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 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 *Continuing Review/Final Report* is required.

Please quote your REB file number on all future correspondence.

MM/kw

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http://www.brocku.ca/researchservices/ethics/humanethics/
APPENDIX C: The Activities-specific Balance Confidence (ABC) Scale

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0%  10  20  30  40  50  60  70  80  90  100%

no confidence  completely confident

How confident are you that you can avoid a fall when you…

1. …walk around the house? ____%
2. …walk up or down stairs? ____%
3. …bend over and pick up a slipper from the front of a closet floor ____%
4. …reach for a small can off a shelf at eye level? ____%
5. …stand on your tiptoes and reach for something above your head? ____%
6. …stand on a chair and reach for something? ____%
7. …sweep the floor? ____%
8. …walk outside the house to a car parked in the driveway? ____%
9. …get into or out of a car? ____%
10. …walk across a parking lot to the mall? ____%
11. …walk up or down a ramp? ____%
12. …walk in a crowded mall where people rapidly walk past you? ____%
13. …are bumped into by people as you walk through the mall? ____%
14. …step onto or off an escalator while you are holding onto a railing? ____%
15. …step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%
16. …walk outside on icy sidewalks? ____%

(Powell & Myers, 1995)
APPENDIX D: Godin Leisure-Time Physical Activity Questionnaire

1. During a typical 7-Day period (a week), how many times on the average do you do the following kinds of exercise for more than 15 minutes during your free time (write on each line the appropriate number).

<table>
<thead>
<tr>
<th>Times Per Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) STRENUOUS EXERCISE (HEART BEATS RAPIDLY)</td>
</tr>
<tr>
<td>(e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)</td>
</tr>
<tr>
<td>b) MODERATE EXERCISE (NOT EXHAUSTING)</td>
</tr>
<tr>
<td>(e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)</td>
</tr>
<tr>
<td>c) MILD EXERCISE (MINIMAL EFFORT)</td>
</tr>
<tr>
<td>(e.g., yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)</td>
</tr>
</tbody>
</table>

2. During a typical 7-Day period (a week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?

<table>
<thead>
<tr>
<th>OFTEN</th>
<th>SOMETIMES</th>
<th>NEVER/RARELY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. □</td>
<td>2. □</td>
<td>3. □</td>
</tr>
</tbody>
</table>

(Godin & Shephard, 1997)
APPENDIX E: PAR-Q & You

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 65, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

**YES** | **NO**
---|---
1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

**YES to one or more questions**

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

**NO to all questions**

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live activity. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

**DELAY BECOMING MUCH MORE ACTIVE.**

- If you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better, or
- If you are or may be pregnant — talk to your doctor before you start becoming more active.

**PLEASE NOTE:** If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

**Informed Use of the PAR-Q.** The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity and in doubt after completing this questionnaire consult your doctor prior to physical activity.

**No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.**

**NOTE:** If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

**NAME:**

**DATE:**

**SIGNATURE OF PARENT or GUARDIAN (for parents under the age of majority)**

**WITNESS:**

**Note:** This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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continued on other side.