The Effect of Training Older Adults in Tai Chi and Compensatory Stepping on Balance Control

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The Effect of Training Older Adults in Tai Chi and Compensatory Stepping on Balance Control

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Presented to the Department of Kinesiology and Physical Education

At Wilfrid Laurier University

in fulfillment of the thesis requirement for the degree of

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Waterloo, Ontario

August 2015
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Abstract

**Introduction:** In Canadian society, there is a growing prevalence of older adults and one of the main problems facing this generation today is the risk of falling. Tai Chi (TC) is a martial art that has demonstrated improvements in balance control. It uses a series of fluid movements that engage head, neck and trunk rotation while simultaneously reducing base of support. In addition, it has been demonstrated that training older adults by administering unpredictable perturbations to challenge balance better equips them to react successfully in response to balance perturbations. This study aims to determine the potential balance specific benefits of a 10-week exercise intervention combining elements of TC/Compensatory stepping among older adults.

**Methods:** Eleven (11) older adult volunteers aged 65+ participated in a TC/compensatory stepping exercise class delivered 2x/week for one hour. Fifty five (55) minutes of each class were devoted to practicing TC and 5 minutes for compensatory stepping training. Compensatory stepping training involved the delivery of controlled manual perturbations in either the anterior/posterior or medial/lateral direction. Measures of functional balance included the Berg Balance Scale (BBS) and Timed-Up-And-Go (TUG). Balance confidence was measured using the Activities-Specific Balance Confidence Scale (ABC). Medilogic pressure insoles and Optotrak technology were used during quiet standing, static self-perturbation and gait termination trials to measure balance via maximum excursion, range and root mean square (RMS) values of the centre of pressure (COP) and centre of mass (COM) individually and their interaction. The intervention group underwent testing at baseline, 5 weeks, 10 weeks and 12 weeks post-intervention. A control group of 8 older adult volunteers were tested at the same 0, 5, and 10-week intervals.
**Results:** Significant improvements in balance confidence were demonstrated from baseline to week 10 for the intervention group as denoted by scores on the ABC, whereas the control group showed no significant change in balance confidence over time. Functional balance, as measured by the BBS and TUG, also showed significant improvements from baseline to week 10 for the intervention group, where performance was shown to decrease after 12 weeks post-intervention.

The intervention group showed significant improvements for measures of quiet standing with eyes open from baseline to week 10 for the intervention group in the categories of anterior-posterior (AP) net COP range and root mean square (RMS), and COM RMS as well as medial-lateral (ML) COP RMS and COM range. The control group did not show any significant changes over time. When eyes were closed, the intervention group saw decreases in AP COP net range and RMS and COM RMS, ML net COP and COM range from baseline to week 10. The control group also demonstrated decreases in AP COP and COM RMS from baseline to week 10. The intervention group demonstrated decreases across time for arm raise perturbation in AP COP and COM range and RMS, as well as the maximum difference between the COP and COM. ML decreases were noted for the intervention group in COP and COM range and for the control group in COM RMS. Lastly, decreases across time for gait termination measures were found for the intervention group in AP net COP range, ML net COP RMS and COM RMS. The control group decreased in ML COP and COM RMS over time.

**Discussion and Conclusion:** The intervention group demonstrated significant improvements across time in balance confidence and functional balance as measured by the Activities-Specific Balance Confidence Scale, the Berg Balance Scale and the Timed-Up-and-Go. Inconsistent, yet
significant improvements were observed for the intervention group primarily across AP measures of COP and COM range and RMS during quiet standing, arm raise perturbations and gait termination, however some improvements were also found in the ML direction. It is thought that much of these balance improvements were due to an increase in core strength and strength about the ankle joint as well as sensory uptake information from the bottom of the feet brought about by specific balance challenging motions in Tai Chi training. Compensatory stepping training is likely to have enhanced individual’s ability to respond more successfully when faced with an unexpected perturbation.
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<td>Activities-Specific Balance Confidence Scale</td>
</tr>
<tr>
<td>AP</td>
<td>Anterior-Posterior</td>
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<tr>
<td>APA</td>
<td>Anticipatory Postural Adjustment</td>
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<td>BBS</td>
<td>Berg Balance Scale</td>
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<tr>
<td>BOS</td>
<td>Base of Support</td>
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<td>CNS</td>
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1. Introduction

1.1 Aging and Falling

There is a great increase in the proportion of older adults in today’s society, a trend largely accounted for by an increase in life expectancy, a decreasing fertility rate and the aging of the baby boomer population (defined as individuals born between the years 1946 and 1960) (Statistics Canada, 2011). According to the 2011 Canadian census, 15% of the Canadian population was 65 years and older and this was the age group with the greatest rise in population. This 29.1% growth is only expected to increase given that the first of the baby boomer generation reached age 65 years of age in 2011 (Statistics Canada, 2011). As the elderly population increases, the health of these individuals is of growing concern within the healthcare community and current research should therefore be devoted to assisting the healthy aging of this demographic (Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011). Independent living for an older adult is influenced greatly by their ability to ambulate freely while avoiding a fall. There is need for a universal definition of falling, however the World Health Organization defines a fall as “inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest on furniture, wall or other objects” (World Health Organization, 2007, p. 1).

The 2009/2010 Canadian Community Health Survey estimates that approximately 20% of seniors living in the community experience a fall at least once per year (Stinchcombe, Kuran, & Powell, 2014). With age, the body undergoes significant changes that increase the risk of falling such as poor functional balance, delayed postural reflex onset latencies (Lin & Woollacott, 2002), slower step reaction times (Rogers, Johnson, Martinez, Mille, & Hedman, 2003), and impaired mobility (Steffen, Hacker, & Mollinger, 2002). Falls may have a detrimental
chain effect upon the health of older adults and although few falls lead to immediate serious injury, for some, a single fall may lead to a loss in confidence followed by activity restrictions and an overall decrease in physical activity (O’Loughlin, Robitaille, Boivin, & Suissa, 1993). This study is the most recent detailing the direct relationship between falling, and loss of confidence and further limiting physical activity. Results of a longitudinal study conducted among 409 community dwelling older adults in Montreal, Canada, indicated that those who had a history of falls were more likely to have experienced multiple falls throughout the study. Phone interviews were conducted once every 4 weeks over a 48-week period to collect information about fall incidence as well as a number of daily activities including physical activity level, alcohol consumption, hospitalization and days spent in bed. It was evident that those who participated in regular physical activity were less likely to experience multiple falls (O’Loughlin et al., 1993). This study makes it clear that frequency of falling is of concern among older adults and displays evidence that physical activity levels influence their incidence.

The need for effective fall prevention programs is further recognized after analyzing the effects of age on the nervous and musculoskeletal system. Sensory afferent nerves receive information about muscle and body position and the central nervous system (CNS) processes these signals to create motor outputs, or movement responses. Systems work together as a whole to conduct movement through integration and signalling that cause muscles to contract. With age, the ability of the nervous system to transmit, process and receive signals declines, resulting in less efficient, slower and imprecise muscular reactions. Changes in an older adult’s ability to effectively integrate sensory information often results in difficulty performing tasks requiring speed, such as recovery from challenged balance that if unsuccessful, may lead to a fall (Christensen, Payne, & Wughalter, 2003; Rogers et al., 2003).
Numerous sensory systems including the visual, vestibular and somatosensory, become impaired with advanced age. It has been suggested that loss of peripheral sensation is reported so frequently without diagnosable disease that it has become accepted as a natural part of the aging process. Together, the sensory systems provide information about the body in relation to itself and its surroundings to maintain stability (Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989; Perry, Santos, & Patla, 2001; Rosenhall, 1973). The visual system is a used to gather information about the body’s position in extrapersonal space and is a very important tool for guided movement. Deterioration in the sensitivity of spatial information and a decreases in both vertical and horizontal fields of view may be due to a number of different factors such as eye disease or simply degradation of retinal cells. Lack of accurate visual cues may lead to an increased risk of falling among older adults (Manchester et al., 1989; Woollacott & Shumway-Cook, 1990).

The vestibular system provides feedback about the linear and angular acceleration of the head. Woollacott and colleagues demonstrated that both young and older adults’ sway patterns are greatly impaired when the accuracy of sensory information is impaired. A review of the vestibular system across the lifespan reported overwhelming evidence that the specific cell structures of the vestibular system degenerate across time, and are unfortunately unable to regenerate. Therefore the integrity of this system is fully dependent upon an ability to maintain structural organization within their environment (Babin & Harker, 1982). In 2004, a study was conducted in an attempt to understand the incidence of vestibular dysfunction in older adults admitted to an emergency accident clinic with an unexplainable fall (a fall occurrence where there is no known cause). Results showed that 80% of older adults who experienced an unexplainable fall did in fact present with symptoms of vestibular impairment (Pothula, Chew,
Lesser, & Sharma, 2004). Therefore is it important to recognize the crucial role the vestibular system plays in balance control and how impairments may lead to falls in older adults (Kristinsdottir, Jarnlo, & Magnusson, 2000; Pothula et al., 2004).

The somatosensory system provides information regarding the motion of the body as it relates to its other segments and its support surface. Perry, McIlroy and Maki (2000) used hypothermic anesthesia to decrease the cutaneous sensation on the bottoms of the feet of healthy young adults to investigate compensatory stepping reactions in response to moveable platform perturbations. This technique can be used to simulate the effects of age related loss of cutaneous sensation on the soles of the foot of older adults. Such decreases in sensation suggest a mechanism in which older adults may have difficulty preventing a fall. The results depicted that due to this decrease in cutaneous sensation, participants, unable to detect a shift in balance in a timely manner, delayed onset of backward stepping as the centre of mass (COM) approached the posterior limit of the base of support (BOS). It was also found that there was an increase in multi-step balance recovery reactions in the forward direction. These results indicated that due to a loss of cutaneous sensation, these individuals found it more difficult to successfully and efficiently recover from perturbations. Comparing this purposeful decrease in somatosensory perception to that of somatosensory loss in an older population would suggest that similar stepping reactions are to be expected if faced with a somatosensory perturbation (Perry, McIlroy, & Maki, 2000). Altogether, the age related compromise in multiple sensory systems requires an intervention program targeted towards improving the various impairments since they are so closely related to balance control.

In addition to nervous system challenges, the muscular system is detrimentally affected by aging, and is associated with difficulty with balance, coordination and agility. Sarcopenia, the
age-related loss in muscle mass, is among the changes that make older adults more susceptible to falling, as well as more likely to take multiple steps in attempt to recover challenged balance (Maki & McIlroy, 1997). Reduced efficiency of the musculoskeletal system can be attributed to a decrease in the number, size and type of muscle fibers. Without training, muscle fibres also begin to respond more slowly to nerve stimulation and overall muscle mass decreases due to atrophy (Brunner et al., 2007).

A study conducted by Kuptniratsaikul et al. in 2011 revealed that participation in a simply designed balance exercise program can improve balancing abilities as well as decrease the rate of falls for elderly individuals with a history of falling. A limitation of this study was that the nature and frequency of any falls that occurred in the 12 months prior to participation was not detailed. Participants included community-dwelling elderly individuals over the age of 50 who had experienced a fall within the last 12 months. Scores on the Berg Balance Scale (BBS), the Timed-Up and Go (TUG) test, the functional reach test and the chair test were evaluated at baseline, 3, 6, 9 and 12 months. The exercise regime required participants to perform 10-20 repetitions of 7 simple exercises including tandem walking, marching, and stepping over a bench (about 20 minutes of exercise) a minimum of three days per week. Following the one year of deliberate exercise, 49% of participants had not fallen during the course of the study. A significant increase in balance abilities was found for the TUG, BBS, chair stand and functional reach (Kuptniratsaikul et al., 2011).

Research also clearly indicates that physical activity is a powerful intervention for preserving and enhancing functional capacity of the CNS (Christensen et al., 2003). This study in particular provides the most recent findings specific to physical activity and the preservation of CNS functional capacity. Participants from vigorous, moderate and low physical activity groups
were tested and compared on the basis of both physical function (VO$_2$ max, percentage of fat, sum of skinfolds and body weight) and psychomotor function (coincidence anticipation timing, simple reaction time, and choice reaction time). Results indicated that increased levels of physical activity were related to improved psychomotor performance and superior physiological outcomes (Christensen et al., 2003).

Based on the understanding that the decline in movement ability is multifaceted, it is therefore important that an intervention program designed to combat and reduce the effects of aging also includes a variation of exercises in order to target the multitude of effects. Effective exercise programs aimed at preventing falls and improving balance control should be designed and implemented to minimize the incidence of falls in the elderly population (Holland, Tanaka, Shigematsu, & Nakagaichi, 2002; William W.N. Tsang & Hui-Chan, 2004).

Tinetti et al. in 1994 investigated the effect of implementing a multi-factorial approach to modifying risk factors for falls in the elderly including balance impairment and muscle weakness. By identifying specific risk factors associated with falling (eg. muscle weakness, use of multiple medications, balance impairment etc.), this approach targeted modifiable factors and trained older adults in attempt to counteract physical threats to balance control. Intervention strategies included specific gait training, balance exercises, and strength exercises for those with gait, balance and muscular impairment respectively. Others received modified medication dosages in conjunction with participant’s primary physician. It was evident that those who had received training specific to falling risk factors, showed a significant decrease in the incidence of falls compared to the control group (Tinetti et al., 1994). Therefore it is important to recognize that by tailoring an intervention program to the specific risk factors associated with falling, researchers can hope to reduce those risks and in turn reduce the risk of falling among elderly
participants. Tinetti and colleagues suggested that this risk-reduction strategy is an excellent intervention approach that could be useful for seniors both in the community and in long term care facilities (Tinetti et al., 1994).

The aim of this intervention was to address the physical risk factors associated with the problem of falls in the elderly population by targeting and training the often-impaired muscles and sensory systems associated with the risk of falling. The program combined a low impact ancient Chinese martial art, known as Tai Chi Qigong (TC), with compensatory stepping training in order to maximally benefit the older adults and better prepare them to respond successfully when balance is challenged in the future.

1.2 Older adults and Tai Chi Qigong

Qigong, considered to be the root of all traditional Chinese medicine, has developed into many forms, including several exercise practices (Rogers, Larkey, & Keller, 2009). The ancient practice of Tai Chi has typically been performed as a martial art and has recently been found to have beneficial effects on balance and posture in the elderly. The practice of TC integrates breathing exercises combined with slow-body movements in an upright posture as a physiotherapeutic approach to balance training (Fong et al., 2014). This form of exercise uses a series of fluid yet individual, dance-like movements that engage head, neck and trunk rotation while simultaneously reducing base of support and challenging balance (Tse & Bailey, 1992; Wolf, Coogler, & Xu, 1997). TC incorporates gentle movements of low vigor, the type of exercise best suited to the elderly population (D. Q. Xu, Hong, & Li, 2008). Numerous beneficial outcomes have been studied among Tai Chi practicing elderly individuals that demonstrate maintenance and even improved balance control (Frye, Scheinthal, Kemarskaya, & Pruchno,
The first researchers to explore the beneficial effects were Tse and Bailey in 1992, who found that when comparing 9 individuals who had participated in Tai Chi for 1-20 years previously (6 men, 3 women aged 65-84) against 9 who had never practiced (6 men, 3 women aged 66-86), on five tests of balance, that the Tai Chi participants performed significantly better on 3 of the tests (Tse & Bailey, 1992). No baseline measures were recorded since participants were recruited for a one-time balance measurement only and experience of the Tai Chi practitioners varied. All participants were of Chinese decent, independent ambulators, and self-reported to be healthy, meaning they were free of any medical problems affecting mobility or diseases with a primary balance disorder (eg. Parkinsons disease, multiple sclerosis, or residual effects from a previous stroke).

Since this original project, many have explored how TC can be used as a mechanism for fall prevention for the elderly and found that it does indeed make a significant positive difference in balance and postural control (Nnodim, Strasburg, & Nabozny, 2006; William W.N. Tsang & Hui-Chan, 2004; Wolf, Barnhart, et al., 1997). Specifically, the practice of Tai Chi has led to significant reduction in fall incidence, improved single limb support time, balance perturbation recovery, joint range of motion and muscle strength (Wolf et al., 1997). Much of these improvements are attributed to the nature of the Tai Chi movements themselves. Since Tai Chi involves constant weight shifting, lowering the body’s COM, and emphasizes maintenance of vertical posture while the head and neck are held in an extended position, it requires precise control over the mechanisms responsible for accurate balance control (Wong & Lan, 2008). Accurate balance control is a combination of coordinated joint and muscle actions working
together to maintain upright posture and a tight regulation of one’s own COM within the BOS (Lugade, Lin, & Chou, 2011).

Functional stability is related to a person’s ability to maintain controlled balance throughout activities of daily living (Wong & Lan, 2008). When examining the gait patterns performed in Tai Chi movements, it was found that the COP significantly increased in the anterior-posterior (AP) and medial-lateral (ML) directions compared to normal gait. Since Tai Chi practice also incorporates one-legged movements, it requires greater muscular activation and control to maintain balance (D. Xu, Hong, & Li, 2004). Therefore, this improved activation, gained through Tai Chi practice, may aid in managing unexpected perturbations encountered in daily life and in turn reduce the amount of falls experienced by Tai Chi practitioners. Li and colleagues (2004) examined this hypothesis by implementing a 6-month Tai Chi intervention program using the 24-form Yang style, among two hundred and fifty six healthy, physically inactive older adults between the ages of 70-92. Researchers defined ‘healthy’ as those who were independent ambulators, free of chronic disease that would limit participation in low-moderately intense physical activity, having no cognitive impairments and clearance from a physician for participation. Participants were randomly assigned to either a Tai Chi intervention program or a stretching control group. At baseline, 42% of participants assigned to the Tai Chi group had experienced one or more falls in the 3 months prior to entry into the study, compared to 31% of those assigned to the stretching control. Measures of functional balance included the BBS, dynamic gait index and functional reach. Throughout the intervention, the number of falls experienced by the participants was recorded. At the end of the 6-month period, the Tai Chi intervention group experienced a significantly lower proportion of falls (28%) compared to the stretching control (46%) as well as significantly superior performance on all measures of
functional balance. After another 6-month follow-up period, the participants from the Tai Chi intervention group maintained a significantly lower rate of falls compared to the control group. From this study, it is important to garner that Tai Chi intervention had demonstrated improved functional balance in older adults and with subsequent reductions in fall incidence (Li et al., 2005).

In contrast to using the 24-form Yang style Tai Chi intervention, Wolf and colleagues (1997) reduced the 108 forms of Tai Chi into 10 increasingly complex forms. Their main objective was to compare the effects of a 15-week Tai Chi intervention program with a computerized balance training program as well as to an educational control group (Wolf et al., 1997). The computerized balance training consisted of system that provides feedback information to participants as they stand on a platform and instructed through a series of movements including maintaining a steady centre of mass and targeting to follow appropriate displacements. The educational group met weekly for one hour with a gerontological nurse / researcher to discuss topics of interest to older adults such as coping with bereavement, sleeping disorders, pharmacological management or cognitive deficits. Participants were assessed using the Chattecx Balance System during 4 postural conditions: quiet standing and eyes open, quiet standing and eyes closed, toes up and eyes open and toes up and eyes closed. Results did not reveal a significant improvement in stability for those who had completed the Tai Chi portion or the educational portion, and rather a significant improvement in stability for those trained with the computerized balance was depicted. Although computerized balance training did show greater improvements in postural stability, it was recognized that Tai Chi delayed the onset of an initial fall or multiple falls and that Tai Chi participants had a decrease in fear of falling after the
intervention program (Wolf et al., 1997). A limitation of this study was that it did not detail how fear of falling was measured.

Since 1997, further studies have confirmed that Tai Chi practitioners do display a decreased fear of falling, but also demonstrate improved balance and postural control compared to non-practitioners (Tsang & Hui-Chan, 2008). Tai Chi intervention programs have become a highly recommended form of fall intervention since it is low-cost, can be easily implemented, and practiced in nearly any location. It is ideal for elderly individuals since it is low impact, gentle and reduces risk of falling (Tsang & Hui-Chan, 2008).

1.3 Older adults and Compensatory Stepping

Regulating the relationship between COM and BOS is the primary goal in maintaining upright posture and a steady balance. It is therefore important that older adults remain active in order to ensure they are better prepared to react efficiently when balance is challenged. It is known that in order to maintain upright, balanced posture, that the individual’s COM must be controlled within their BOS (Maki & McIlroy, 1997). There are two main strategies used as reactive balance recovery, should COM be at risk of going beyond the BOS limits. The first class is fixed support strategies, the second of which is change-in-support strategies, distinguishable respectively by whether the limbs remain in a fixed position on the ground or whether the limbs are moved to adjust the base of support (Maki & McIlroy, 1997). This study used Tai Chi exercise and manually delivered perturbations as a mechanism to train older adults and improve control in balance recovery limb movements during change in support strategies.

Contrary to popular belief, research demonstrates that change in support reactions are not a last resort movement, but often initiated well in advance of the COM reaching its outer limits within the BOS (Maki & McIlroy, 1997). Compensatory reactions become an important
component in fall prevention because, in contrast to controlling balance throughout voluntary action, it is often the unexpected perturbations, and an inability to successfully respond that results in a fall (Maki et al., 2008). There is a notable difference in neural control between volitional stepping and action taken to recover from postural perturbation. For example, assessing lateral stability during forward and backward stepping, anticipatory postural adjustments (APA) are mechanisms that shift an individual’s COM towards the standing limb before the stepping foot is lifted. APAs in compensatory steps are typically absent (Maki & McIlroy, 1997). It is therefore necessary to train older adults to respond to unexpected perturbations rather than simply in volitional movements since the neuromechanics behind each reaction is so different.

There is sufficient literature to support that training older adults in volitional steps is beneficial for evoking an improved reaction time upon a given cue. Rogers and colleagues (2003) demonstrated perturbation based training has the ability to significantly reduce the time that an older adults needs to initiate a step. Twelve (12) young adults and 8 healthy older adults (independent ambulators, free of a history of cardiopulmonary, musculoskeletal, neurological, any other major systemic medical problem, or a history of falls) participated in a 3-week stepping training regime. Participants were randomly assigned to a group that was trained to take a voluntary step (in response to a small non-destabilizing waist pull), or a group trained to take a step in response to a large, destabilizing, waist-pull perturbation. Before beginning the training, a baseline measure of reaction time and step initiation time was taken by asking participants to take a step as fast as possible after delivery of an auditory cue. These values were compared to measures taken after the completion of the training. Results showed that for those who participated in perturbation based training, there was a significantly greater improvement in the
time needed to initiate a voluntary step. This provides evidence that perturbation based training is effective in improving successful stepping initiation reactions. However, few studies have examined the effectiveness of using manual or platform induced perturbations to train older adults in effective change in support reactions.

Mansfield and colleagues (2010) however, used a platform perturbation-based training protocol to investigate change-in-support reactions in older adults. The program was intended to target impairments in compensatory stepping reactions seen with age (Mansfield, Peters, Liu, & Maki, 2010). Researchers administered perturbations to older adult participants between the ages of 64 and 80 years old. These perturbations were meant to challenge the relationship between the COM and the BOS by means of unpredictable translations of a platform on which participants stood. Training and measurement objectives included reducing the frequency of multi-step reactions, as well as the number of foot collisions experienced during recovery stepping. Participants were randomly assigned to either the perturbation-based balance training or a muscle relaxation control. For those that participated in perturbation-based training, differences between pre-trial evaluations to post-trial demonstrated that there was a significant reduction in the number of trials in which the swing and stance leg collided during a recovery step, as well as a significant reduction in the frequency of multi-step reactions in response to the perturbation (Mansfield et al., 2010). This evidence suggests that if trained, older adults will be better equipped to respond to balance perturbations and in turn reduce their risk of falling since programs such as this have the potential to reverse the age related losses in balance recovery. There is further research needed to establish the effectiveness of compensatory stepping training in response to unexpected somatosensory perturbations.
1.4 Measuring Balance Control

Previous literature has demonstrated significant improvements in balance following exercise programs using a variety of subjective measures (Berg Balance Scale, the Activities-specific Balance Confidence scale, etc.), frequency of falls, and timed outcome measures (Timed-Up-And-Go, reaction times, static balance time) (Logghe et al., 2010; Muir, Berg, Chesworth, & Speechley, 2008; Nnodim et al., 2006; William W.N. Tsang & Hui-Chan, 2004; Tse & Bailey, 1992; Wolf, Coogler, et al., 1997). However, few investigations have used objective measures such as COP and COM as indicators of balance improvement to evaluate the effectiveness of a TC exercise program for the elderly.

The Activities-Specific Balance Confidence Scale (ABC) is a questionnaire presenting respondents with 16 items on which they are asked to score their confidence (from 0-100%, 0 indicating no confidence and 100 indicating complete confidence) in completing the listed tasks “without losing balance or becoming unsteady”. Task examples include “walking through a crowded mall”, “reaching at eye level” and “reaching on tip toes”. Powell and Myers (1995) documented that the ABC has good test-retest reliability as well as good criterion and convergent validity. The ABC provides great insight into an older adult’s perceived balance control ability and may be an indication of the types of activities older adults are willing to engage in based on their balance confidence (Powell & Myers, 1995; Schepens, Goldberg, & Wallace, 2010).

Among the many tests used to assess balance control in an elderly population, the Timed-Up-and-Go is one of the most common. Introduced in 1991, the TUG is a measure of the time that it takes an individual to stand from a seated position, walk for a distance of 3m, turn around, and walk back returning to their original seated position (Podsiadlo & Richardson, 1991). Validated using correlation scores with the Berg Balance Scale, functional indexes and ability to
distinguish between individuals of residential status, falls and mortality (Bohannon, 2006; Podsiadlo & Richardson, 1991), the TUG is an excellent measure of functional mobility among older adults because the task itself requires precise control over the ability to change from seated to standing position as well as control walking amidst changing demands. Progress is limitless because the time to complete the task can always be improved upon. A faster completion time is an indicator of greater functional ability (Steffen et al., 2002). A discriminate analysis conducted by Shumway-Cook and colleagues (2000) suggests that older adults who take longer than 14 seconds to complete the TUG is accurate for predicting individuals at risk for falling.

The Berg Balance Scale is a subjective scale used to assess functional balance in the elderly through a series of 14 tasks common in everyday life (Berg, Wood-Dauphinee, Williams, & Gayton, 1989). Identified as the gold standard for measuring functional balance in older adults, its interrater and intrarater reliabilities were found to be 0.98 and 0.99 according to intraclass correlation coefficients (Berg et al., 1989; Lajoie & Gallagher, 2004; Muir et al., 2008). The scale has also been validated by examining how scores compare to clinical judgements and self-perceptions of balance control. Tasks included in the scale vary in difficulty in their balance movements, and throughout performance scores from 1 to 4 are given to represent balance ability. This scale has demonstrated itself as a useful agent in predicting fallers from non-fallers based on their lower and higher scores respectively (Kuptniratsaikul et al., 2011). In this experiment, the BBS was used to supplement the objective measures of COP and COM during quiet standing, and two self-perturbation tasks.

Centre of pressure (COP) is defined as “the position of global ground reaction force vector that accommodates the sway of the body” (Ruhe, Fejer, & Walker, 2010, p. 4). In other words, it is the place in which the entire pressure of the body would be concentrated if it were to
be all in one location. COP is an indirect measure of relative trunk movement and is calculated from a horizontal moment and vertical force data. Using a centre axis and evaluating the movement of COP in the anterior-posterior (AP) and medial-lateral (ML) directions provides an understanding of a person’s stability. Individuals with greater control over their postural stability will have smaller deviations about this centre axis (Winter, 1995).

The relationship between COP and the COM is a helpful tool in assessing balance. COP plays a crucial role in controlling the trajectory of the COM and works to maintain the COM within the BOS during static balance and maintain tight regulation even in dynamic balance when the COM is primarily outside of the BOS. As soon as motion is initiated, this relationship is disturbed and there is potential for a loss of balance. Since COP and COM are distinct, yet related signals, the assessment of the measures together can provide great insight into a person’s balance ability. Even the slightest difference between the COP and the COM is a measure of instability, therefore a greater difference between these values, is an indication of a less stable individual (Corriveau, Hébert, Prince, & Raîche, 2000). The COP-COM relationship has been extensively evaluated during gait initiation, but few studies have examined the relationship in gait termination.

Throughout dynamic motion, there is a constant threat to balance since the COM is outside of the BOS for 80% of walking movement. Gait termination also poses a threat to balance because the COP must move ahead of the COM in order to decelerate and bring it to a stop within a stable BOS (Jian, Winter, Ishac, & Gilchrist, 1993). This requires accurate foot placement and effective control of COM by means of COP. Perry et al. (2001) explored the effect of reduced cutaneous sensation upon gait termination and found that longer steps were necessary to safely cease motion when sensations were reduced (Perry et al., 2001). This is
comparable to the elderly population who also have a reduced sensation and ability to control COM upon gait termination.

In recent years, pressure insoles that can be inserted directly into shoes have been used to record COP under the foot without restricting measurement to the specific confines of a force plate. Forner Cordero and colleagues (2004) compared pressure sensor and force plate recordings of COP, demonstrating that pressure insoles reliably measured excursion of the centre of pressure as accurately as a force plate in exploring ground reaction forces (Forner Cordero, Koopman, & van der Helm, 2004). Researchers found the use of pressure sensors as opposed to force plates useful for measuring several consecutive steps without limiting foot placement (Forner Cordero et al., 2004). This technology makes it possible to evaluate COP excursion throughout a variety of movements. Therefore it is useful to examine patterns of COP movement since it has been deemed a reliable measure for assessing balance control and is useful for detecting postural deficiencies such as those found in the aging population (LeClair & Riach, 1996).

Based on this insight, Hass et al. in 2004 explored the effect of Tai Chi on the COP trajectory during gait initiation where results demonstrated that Tai Chi was effective in improving postural stability and executing improved coordination during gait initiation. Outcome measures examined COP control throughout 3 different phases of gait initiation. Gait initiation was broken down into three sections (S#). S1 began with the start command and ceased with the COP in its most posterior and lateral location toward initial swing limb. S2 began with translation of COP toward stance limb and ended when it began forward movement under the stance foot. Lastly, S3 extended from the forward movement under stance limb to the toe-off of the initial stance limb. Results indicated that for those who practiced Tai Chi, there was a
significantly greater posterior displacement upon initiation (indication of propelling COM forward) and there was 26% more smoothness in the forward stepping phase. Researchers attributed these improvements to Tai Chi’s incorporation of elements focused on improving environmental awareness, strength, slow deliberate challenges to balance, and endurance (Hass et al., 2004). It was this study’s intention that by executing an exercise program that challenged participants to shift weight from a large to small BOS by means of Tai Chi (Hass et al., 2004) and compensatory stepping training, that they would become better equipped to respond successfully when signalled to terminate gait and in turn reduce the difference between COP-COM from their baseline to post-intervention, signalling greater balance control.

By examining the COP-COM patterns throughout quiet standing and self-perturbations, it provides insight into the stability of older adults who participate in Tai Chi and compensatory stepping training, and those who do not. Since falls are a major concern among the elderly population, this area of exercise research is relevant to the development of future exercise interventions. It is evident among previous literature that exercise, specifically Tai Chi and compensatory stepping have been effective interventions for improving balance control.

Previously, balance specific interventions have concentrated their efforts on solely exercise intervention or compensatory stepping training independently and yielded beneficial results. This study aims to combine Tai Chi and compensatory stepping training in hopes of maximizing beneficial balance control improvements. It was thought that by successfully incorporating elements of both intervention types that this approach has the potential to better prepare elderly individuals to react successfully when balance is compromised. The main purpose of this study was to explore the benefits of a 10-week training program on balance control in older adults by examining static and dynamic balance responses to perturbations.
1.6 Hypotheses

It was predicted that the participants in the Tai Chi and compensatory stepping intervention would significantly improve in measures of balance control from baseline to 10-week testing. These improvements would be reflected in the scoring values of the Berg Balance Scale, percentages in the ABC and the time to complete the TUG.

Higher scores on the Berg Balance scale indicate greater functional balance where scores range from 0-56 (Berg et al., 1989). Therefore it was predicted that due to Tai Chi’s requirement for precise foot movements and specific training to maintain COM tightly within BOS during compensatory stepping patterns, that participants would be able to complete the 14 tasks in the Berg Balance Scale with higher functional balance scores than before the intervention. Secondly, time to complete the TUG was expected to decrease as participants gained greater strength and control over their balance throughout movements by participating in the Tai Chi and compensatory stepping intervention. This is related to ABC scores since it has been found that with greater confidence in performing certain tasks, participants are more likely to engage in movements previously considered threatening. It was hypothesized that completing this intervention program would have reduced the time needed to complete the TUG and that ABC scores will improve (Manchester et al., 1989; Powell & Myers, 1995).

As previously stated, greater displacement of the COP (range values) during quiet stance and dynamic gait, a large COP variability (measured by the root mean square (RMS)) as well as a large difference between COP and COM is an indication of poorer balance control (Jian et al., 1993; Lugade, Lin, & Chou, 2011). It is predicted that after participating in the Tai Chi intervention program that all of these values will decrease, indicating a tighter regulation of balance control. These predictions were based upon previous literature demonstrating that
interventions that strengthen the lower extremities, as well as train the efficiency of the
neuromuscular system have shown significant improvements on tests of functional balance (Li et
al., 2004; Logghe et al., 2010; William W.N. Tsang & Hui-Chan, 2004; Tse & Bailey, 1992;
Wolf, Coogler, et al., 1997).
2. Methodology

2.1. Participant Recruitment, Screening and Attrition

Participants were community dwelling older adults aged 65+ (mean = 75.4) who were recruited through poster, church bulletins and newspaper advertisements displayed throughout local businesses, churches and senior activity centres in the cities of Waterloo and Guelph, Ontario. Waterloo residents participated in the Tai Chi Qigong Intervention group (n=11) and Guelph residents in a control group (n = 8). Participants were screened prior to the intervention using a questionnaire to collect data regarding age, gender, medication, history of falls within the last 6 months, physical activity participation and assisted devices (See Appendix A). None of the participants in the intervention group reported experiencing a fall in the 6 months prior to taking part in the TC intervention. One control group participant reported a fall in the 6 months prior to balance testing because of a slip on ice. This questionnaire provided information about medications taken by the participants, ailments and diseases. Participants were excluded from the study if they were living with Parkinson’s disease, multiple sclerosis, cerebral palsy, or were unable to stand upright on their own for more than one hour. Medications taken by individuals were voluntarily listed and were taken into consideration according to the Compendium of Pharmaceuticals and Specialties (CPS) (Canadian Pharmaceutical Association, 2014). Participants were asked if they experienced any side effects from their medication that significantly influenced their balance. No participants reported any problems, therefore none were excluded based on medicinal side effects. Only participants who had not participated in any Tai Chi exercise within the previous 12 months were included in this study. All participants were required to review and sign an informed consent form. Participation in this study was entirely voluntary. This project was reviewed and approved by the Wilfrid Laurier University Research
Ethics Board (project #4002) and the University of Guelph Research Ethics Board (project #14AU002).

Participants in the intervention group were recruited during the months of May and June and the classes began in June and ran continuously into the month of August. Nineteen participants were screened for participation in the Tai Chi Qigong Intervention. Two dropped out before the intervention began, one after the first 2 classes. Two participants realized the time commitment and felt unable to comply; another did not want to take part in the research any longer and withdrew. Twenty classes were held as a part of the intervention and attendance marked for each class. Three participants, who were absent 3 classes or more, were excluded. Classes missed were often because of vacation or family commitments, while others conflicted with medical appointments. Thirteen participants completed the full Tai Chi Qi Gong intervention, missing fewer than 3 classes and 11 of these individuals participated in the 12-week follow-up period. One participant was out of the country during the follow-up time, another was unable to be contacted.

Control group participants were recruited during the months of November and December. Twelve participants were screened for participation in the control group, 2 dropped out before baseline testing, and 2 more dropped out after initial baseline testing. One participant who dropped out before baseline was unable to find transportation to the testing facility while the other decided that the commitment was too large during a busy part of the year. After the first testing one participant withdrew due to health reasons, the other was unavailable due to vacation. Eight participants completed baseline, 5 week and 10 week testing.
2.2. *Tai Chi Qigong and Compensatory Stepping Intervention*

The intervention group participated in 20 Tai Chi Qigong classes spread out over 10 weeks. One hour classes took place twice weekly at Wilfrid Laurier University in an open concept classroom at the Athletics Complex. Each lesson was taught by a certified Tai Chi Qigong instructor accredited by the National Qigong Association and the National American Studio Alliance (NAMASTA). Participants took part in 55 minutes of Tai Chi Qigong instruction and were rotated out individually to take part in five minutes of compensatory stepping training. The intervention group received instruction according to the 18 form Tai Chi Qigong Shibashi Level 1. Detailed instruction on these 18 forms and the precise movements involved can be found in the manual created by the instructor (Nunes, 2012). Order of participant’s compensatory stepping training was changed upon each lesson to ensure equal participation in the classes. At this time, participants were asked if they had experienced a fall since the last class as a means of recording the occurrence of falls throughout the intervention. A fall was defined as “inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest on furniture, wall or other objects” (World Health Organization, 2007, p. 1). If any participants answered “yes”, they were asked to stay after class to fill out a Falls Follow-up Questionnaire, which detailed the nature of the fall (See Appendix B).

Manual perturbations in the medial/lateral and anterior/posterior directions were administered by the researcher in a controlled manor according to the ability of participant while a second volunteer spotted from the opposite side. Perturbations were delivered approximately 10cm below the shoulders on each participant’s back, front (AP) and arms (ML). Participants were instructed to remain in a relaxed posture and not to intentionally resist the perturbation. Manual perturbations caused participants to respond by taking a recovery step since the perturbation forced their posture to move beyond that which could be recovered using an ankle
or hip strategy. The amount of push required to cause a compensatory step for each perturbation was recorded using a force transducer (Baseline Evaluation Instruments, New York). As improvements were made, intensity of the manual perturbations was increased accordingly. The need for an increased perturbation was identifiable when the magnitude applied was no longer sufficient to cause a compensatory step. Force was therefore increased to produce the compensatory stepping reaction.

2.3. Outcome Measures

The intervention group took part in four rounds of identical balance testing. Baseline testing occurred the same week as the Tai Chi Qigong classes began (week 0 / baseline), midpoint testing after five weeks of training (week 5), upon completion of the intervention (week 10), and 12 weeks post-intervention. During the intervention and for the 12 weeks following cessation of the intervention, participants were not instructed on which types of physical activities to participate in. During the 12 weeks after the intervention and prior to follow-up testing, participants were free to continue practicing Tai Chi Qigong or any other type of physical activity if desired at whichever intensity desired.

The control group did not participate in any form of Tai Chi Qigong training and were also free to participate in any type of physical activity they desired. Participants were invited to come in to a laboratory at the University of Guelph for three identical rounds of balance testing at week 0, week 5, and week 10. At this time participants were also asked to report on the number of falls they had experienced since the last time they came in (every 5 weeks).

Balance testing was comprised of several components. A typical balance testing session began with the completion of the Activities-Specific Balance Confidence Scale (Powell & Myers, 1995) administered by the researcher (Appendix C). Participants were also asked to
report on their current physical activity levels according to activity, duration and intensity
(Appendix D). The same researcher administered the Berg Balance Scale (Berg, Wood-
Dauphinee, Williams, & Maki, 1992) at each session for consistency (See Appendix E). Three
trials of the Timed-Up-And-Go (Podsiadlo & Richardson, 1991) were completed and the time to
complete the task was recorded in seconds.

Pressure data was collected using Medilogic pressure sensor system (T&T medilogic
Medizintechnik GmbH, Shônefeld) so as to calculate the COP with insoles inserted directly into
size specific, standardized Rockport shoes (The Rockport Company, Massachusetts). Each insole
records the pressure under the foot in Newtons. Eleven (11) Optotrak markers were placed on
each individual for recording COM, BOS and velocity of limbs during select balance tests (see
Figure 1). A three-marker COM set-up was used where a marker was placed on the xiphoid
process and on the front of each shoulder at the centre of the clavicle. Two markers were placed
on each foot. Markers were placed along the centre line of the foot from anterior to posterior at
the ankle (located approximately where the tongue of the shoe sits) and the metatarsals (over top
of the 3\textsuperscript{rd} metatarso-phalangeal joint). An eighth marker was placed at approximately 60\% of the
participant’s height, on their anterior superior iliac spine (ASIS), as a single marker reference for
COM measurements when the side of the participant was facing the Optotrak camera. Marker
nine was placed on the head of the humerus and the last two markers placed 10cm apart spanning
across the elbow joint. The last three markers were purely for reference to the velocity of the arm
during arm raise trials. This set-up can be observed in Figure 1.
The first task was a measure of static balance. Each participant stood on a paper tracing with their feet a small distance apart, specific to their body height (this distance was calculated as 11% of height) and angled outwardly at a standardized 14 degrees from the forward facing direction (McIlroy & Maki, 1997). Upon a verbal cue, participants were asked to raise their right leg slightly off of the ground, in order to synchronize the Optotrak system with the pressure sensor data for processing purposes. They were then asked to remain standing in a relaxed position and Optotrak (kinematic) and Medilogic (pressure) data was collected for 15 seconds, where the first 5 seconds allowed for the foot lift and the last 10 seconds were analyzed. Three trials were conducted with eyes open, and three trials were conducted with eyes closed.

The next task was a measure of participant’s response to a static self-perturbation. This used the participant’s own body weight as a perturbation, causing a change in the body’s COM, requiring a reactive balance response. Participants again raised their right leg for alignment of
Medilogic and Optotrak systems and after regaining balance, were then given an auditory cue to raise their arms, as fast as possible, from a resting position to a horizontal position at shoulder height. Data was collected for 3 trials of 10 seconds.

Lastly, unexpected gait termination was used as a measure of response to a dynamic self-perturbation. Participants were instructed to walk counter-clockwise around a set of 4 chairs at a “slightly faster than normal” pace, and to terminate gait upon hearing a doorbell. The doorbell signalled individuals to immediately cease walking and terminate gait by placing their feet side-by-side. Rapid gait termination has been found to challenge balance for older adults since aging impairs their muscular and neurological ability to respond rapidly without compromising upright balance and putting oneself at risk for falling (Menant, Steele, Menz, Munro, & Lord, 2009).

Analyzing kinematic and pressure data together, makes it possible to calculate the maximum spatial difference between the COP and COM at any time during the trial. Analysis software was created to aid the process of aligning pressure sensor and kinematic data as well as calculating the minimum/maximum excursion values, the range and RMS of the COP and COM and the minimum and maximum difference between each value in both the anterior-posterior (AP) and medial-lateral (ML) directions. The RMS was identified using an unbiased signal. The mean was calculated for both the COP and COM of each trial. All of the COP or COM values from a trial were squared, and the mean of this set of number was calculated. To identify the RMS, the square root of this was taken. This formula can be found in Figure 2.

\[
RMS = \sqrt{\frac{x_1^2 + x_2^2 + x_3^2 + \ldots + x_n^2}{n}}
\]

Figure 2: Equation utilized to calculate the RMS.

Participant’s foot raise at the beginning of each trial was used to align pressure and kinematic data. For quiet standing trials the midpoint of each foot raise movement was identified
(when the foot was completely off the ground). The analyzed data was a window of 10 seconds that followed the foot raise, which took place during an initial 5 seconds dedicated specifically to the foot raise and recovery. Synchronization of the coordinate systems used anthropometric measurements of kinematic marker placements on the foot in relation to the location of the shoes and pressure sensors worn by the individual. The foot angle was calculated from the kinematic markers placed on the foot, which was then used to create a rotational matrix of the foot’s local coordinate system, orienting it within the global coordinate system as defined by the kinematic system. This matrix was created to rotate the individual COP measurements from underneath each foot in order to combine them as a net COP and compare them within the same reference system as that of the COM.

COP specifically, was gauged using a weighted average calculation. Each pressure sensor has a specific configuration of pressure sensing cells aligned in a grid (in an ML direction and AP direction). The COP under each foot was calculated separately by identifying the average pressure across each column (ML) and row (AP), divided by the total pressure across the foot and multiplied by the spatial location of the cell based on the grid formation and size of individual sensors aligned throughout the insole. This specifies a percentage of the pressure distributed across each row and column whereby the coordinates of the COP movement under the foot are identified. In order to find the Net COP, or the integrated COP, the following formula was utilized (Figure 3).

\[
\text{COP}_{\text{net}} = \left( \text{COP}_{\text{foot1}} \times \frac{\text{total pressure}_{\text{foot1}}}{\text{total pressure}_{\text{foot1}} + \text{total pressure}_{\text{foot2}}}) + \left( \text{COP}_{\text{foot2}} \times \frac{\text{total pressure}_{\text{foot2}}}{\text{total pressure}_{\text{foot1}} + \text{total pressure}_{\text{foot2}}} \right) \right)
\]

Figure 3: Equation utilized to calculate the net COP from pressure sensors.
The spatial location of the COP was then compared to the transverse plane projection of the COM and the difference between the values was quantified. A three marker COM calculation was used to quantify the movement of the body’s overall COM. An average of the location of the shoulder and xiphoid markers were taken and moved posteriorly, proportionate to the depth of the participant’s chest.

Arm raise trials were analyzed from 2s after the synchronization at foot lift and for 10s following. Arm raise analysis also included the velocity of the arm raise in the vertical and AP direction. Gait termination pressure and kinematic data were synchronized at heel contact of the second last step. The window of analysis of gait termination began at the single stance of the last step and continued for the following 5s. The RMS, range, minimum and maximum excursion values of the COP and COM were calculated as well as the difference between the COP and COM and lastly the spatial difference between the COM and the lateral BOS as an indication of the stability margin.

2.4. Data Analysis

Statistical analyses for this study involved a mixed model approach to differentiate between the intervention group and the control group across time. Testing time points occurred at baseline (week 0), midpoint (week 5), post-intervention (week 10) and 12 weeks post-intervention (intervention group only). Dependent variables included: scores on the Berg Balance Scale, time to complete the Timed-Up-and-Go, scores on the Activities-Specific Balance Confidence Scale, measures of AP and ML COP and COM (minimum, maximum, range and RMS), and COP/COM relationship (minimum and maximum differences). Values from each dependent variable were compared across testing times and between groups using a mixed model
statistical analysis and the main effect of time was assessed. Every trial was inspected for errors and any data sets with high variability (indicated by standard deviation) were further inspected.
3. Results

Two participant groups (Tai Chi Qigong intervention and control) were measured at multiple time points. The TC intervention group had 4 rounds of testing (baseline (week 0), midpoint (week 5), post-intervention testing (week 10) and 12 week post-intervention testing). The control group was measured at weeks 0, 5 and 10. The main effect of changes across time was analyzed. Participant demographics and baseline ABC, Berg and TUG scores can be found in Table 1. The following sections highlight the analyzed results from the ABC Scale, Berg Balance Scale, TUG times and a breakdown of the centre of pressure (COP) and centre of mass (COM) in both the anterior-posterior and medial-lateral directions from quiet standing, arm raise and gait termination measurements.
Table 1: Participant demographics and baseline scores for the ABC, Berg and TUG tests.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Sex</th>
<th>Age</th>
<th>Baseline Berg Score</th>
<th>Baseline ABC Score</th>
<th>Baseline TUG Time</th>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>M</td>
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<td>54</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td>74.3</td>
<td>51.5</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>±5.6</td>
<td>±2.3</td>
<td>±8.7</td>
<td>±1.9s</td>
<td></td>
</tr>
</tbody>
</table>

3.1 ABC, Berg, Timed-Up-And-Go

ABC test scores were recorded at each of the testing times for both the intervention and control group. The mean scores for each visit are recorded in Table 2. A mixed model analysis was performed for the total ABC score results from each visit. Scores were recorded as a percentage of the total possible score (100%). There was a main effect of Time for the ABC
(F(3,49.1)=5.9, p=.003). Results from the analysis showed that the intervention group’s ABC (confidence) scores increased significantly from baseline (x=78.1) to midpoint (x=82.8, p=.02), and from baseline to post-intervention (x=85.6, p=<.001), as well as from baseline to 12 weeks post-intervention (x=82.4, p=.03). However the ABC (confidence) scores of the control group did not change significantly between testing days. There were no significant group differences between confidence scores of the intervention and control group. All effect sizes are reported as small (d=>.2), medium (d=>.5) and large (d=>.8) (Cohen, 1988).

Table 2: ABC Scale average scores across each test point for the intervention and control group recorded as a percentage (mean (± SD)).

<table>
<thead>
<tr>
<th>Group</th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Weeks Post-testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERVENTION</td>
<td>78.1 (±17.8)</td>
<td>82.8*~ (±12.0)</td>
<td>85.6*^ (±10.2)</td>
<td>82.4 (±12.8)</td>
</tr>
<tr>
<td>CONTROL</td>
<td>86.1 (±8.7)</td>
<td>90.2 (±10.2)</td>
<td>89.2 (±10.6)</td>
<td></td>
</tr>
</tbody>
</table>

*values are significantly different from baseline measures at a p=<.05 level. Significantly different values that were of medium effect size values (d=>0.5) are followed by the symbol “^”. Values followed by the symbol “~” had a small effect size (d=>.3)

For the Berg Balance Scale, there was a significant main effect of Group x Time (F(2, 49.6)=5.4, p=.008) and a main effect of Time (F=(3,49.6)=10.5, p=<.001). There were no significant group differences between the intervention and control group at any of the time points. The intervention group analysis yielded significant improvements in BBS scores from baseline (x= 51.5) to post-intervention (x= 54.2, p=.001), as well as between midpoint (x=52.1) and post-intervention (p=.01). A significant decrease in score was depicted between initial post-intervention testing and 12 week post-intervention testing (x= 52.6, p=.04). The control group also showed improvements in BBS scores between baseline (x=49.4) and midpoint (x=54.0, p=<.0010), and between baseline and week 10 (x=53.3, p=<.001). Findings are depicted in Figure 4.
Figure 4: Scores on the Berg Balance Scale at each testing time point for the Tai Chi intervention group and the control group.

TUG analysis showed a significant main effect of Group x Time (F(2,185.01)=9.8, p=<.001) and a main effect of Time (F=3,185)=13.7, p=<.001). Results from the analysis showed that there was a significant decrease in time to complete the Timed Up and Go for the intervention group from baseline (x= 8.8s) to midpoint (x= 7.6s, p=<.001), as well as from baseline to post-intervention (x= 7.3, p=<.001), and from baseline to 12 weeks post-intervention (x= 8.3s, p=.02). There was also a significant decrease in performance between midpoint and 12 week post-intervention testing (p=<.001) and also between initial post-intervention testing and
12 week post testing (p<.001). There were no significant differences in TUG time for the control group across time. At baseline, the TUG times were significantly lower for control group (x=7.1s) participants than for the intervention group (x=8.8, p=.05). A representation of TUG times upon each visit can be found in Figure 5.

Figure 5: Time to complete the Timed-Up-and-Go test for the Tai Chi intervention group (top line) and the control group (bottom line) at each test point.
3.2 Quiet Standing, Eyes Open

Quiet standing stability was measured using kinematic tracking to determine COM movement and pressure sensors to record COP movement. Several variables were measured and analyzed that included the minimum and maximum displacement between the AP and ML COM and COP, the minimum and maximum displacement and the range of the COM-BOS, and the minimum, maximum, range and variability of the AP and ML COM and COP separately. Measures of quiet standing were recorded with eyes open and eyes closed and collected at baseline, midpoint (week 5), initial post-intervention testing (week 10) and 12 weeks post-intervention for the TC intervention group.

3.2.1 Anterior-Posterior Stability

Overall, results showed statistically significant improvements in anterior-posterior stability for those who participated in the TC intervention. There were significant main effects of Group x Time for AP net COP RMS (F(2,183.9)=31.2, p=<.001) and AP COM RMS (F(2,183.9)=32.8, p=<.001). Further, improvements in the data were supported by near-significant main effects of Group x Time for the AP net COP range (F(2,185.4)=2.1, p=.13). Trends showed decreases from baseline (x=0.029m) to the end of the intervention (x=0.021m) program for AP net COP range. Significant differences from baseline to week 10 for AP Net COP RMS (Week 0 x=0.504m, Week 10 x=0.289m, p=<.001) and AP COM RMS (Week 0 x=0.532, Week 10 x=0.316m, p=<.001) were maintained until at least 12 week post-intervention testing. AP Net COP range values returned to a level similar to that measured at baseline. A representation of the change across time for AP Net COP range is depicted in Figure 6.
Figure 6: This graph displays the near-significant decrease in AP net COP range for the intervention group from baseline to week 10 and the return to baseline-like results after 12-weeks post-intervention. There were no notable changes over time for the control group.

No significant changes were found over time for the control group in the following variables: AP net COP range and AP COP/COM max Difference. Control group measures however, decreased similarly to the intervention group across time with significant differences between baseline and week 10 for AP net COP RMS (Week 0 x=0.483m, Week 10 x=0.057m, p=<.001), and AP COM RMS (Week 0 x=0.496m, Week 10 x=0.088m, p=<.001).

There was a main effect of Group for AP net COP RMS (F(1,19.6)=29.5, p=<.001) and AP COM RMS (F(1,19.7)=31.0, p=<.001) measures. The intervention group showed significantly higher results than the control group at week 5 and 10 for AP net COP RMS (Intervention Week 5 x=0.528m, Control x=0.289m, p=<.001) and AP COM RMS measures
(Intervention Week 10 x=0.560m, Control x=0.316, p=<.001). A summary of these results is depicted in Table 3.

Table 3: Comparison of AP parameters between testing time points for TC intervention participants for quiet standing with eyes open (mean (± SD)).

<table>
<thead>
<tr>
<th></th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Week Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTERVENTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP Net COP Range (m)</td>
<td>0.029 (± 0.021)</td>
<td>0.028 (± 0.018)</td>
<td>0.021 (± 0.016)</td>
<td>0.030 (± 0.020)</td>
</tr>
<tr>
<td>AP Net COP RMS (m)</td>
<td>0.504 (± 0.081)</td>
<td>0.528 (± 0.203)</td>
<td>0.289* (± 0.032)</td>
<td>0.308* (± 0.082)</td>
</tr>
<tr>
<td>AP COM RMS (m)</td>
<td>0.532 (± 0.095)</td>
<td>0.560 (± 0.202)</td>
<td>0.316* (± 0.037)</td>
<td>0.342* (± 0.090)</td>
</tr>
<tr>
<td><strong>CONTROL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP Net COP RMS (m)</td>
<td>0.483 (± 0.450)</td>
<td>0.030* (± 0.017)</td>
<td>0.057* (± 0.051)</td>
<td></td>
</tr>
<tr>
<td>AP COM Range (m)</td>
<td>0.051 (± 0.064)</td>
<td>0.037 (± 0.015)</td>
<td>0.033 (± 0.019)</td>
<td></td>
</tr>
<tr>
<td>AP COM RMS (m)</td>
<td>0.496 (± 0.444)</td>
<td>0.041* (± 0.025)</td>
<td>0.088* (± 0.058)</td>
<td></td>
</tr>
</tbody>
</table>

*values are significantly different from baseline measures at a p=<.05 level. Effect sizes of significant values were all greater than d=0.8 (large effect size).

3.2.2 Medial-Lateral Stability

Medial-lateral stability showed an improvement across time for the TC intervention participants depicted by significant main effects of Group x Time and decreases in measures of ML Net COP RMS (F(2,183.9)=32.2, p=<.001). There was also a main effect of Time for ML COM Range (F(3,184.6)=7.8, p=<.001). Improvements were observed for the control group for ML net COP RMS across time, whereas all other variables showed no significant change over time. Neither the intervention nor the control group displayed any significant differences across time in the range of net ML COP movement. There was a significant main effect of group for ML net COP RMS (F(1,19.5)=19.1, p=<.001) where the intervention group showed significantly higher measures than the control group at week 5 (Intervention Week 5 x=0.114m, Control
x=0.032, p=.001) and week 10 (Intervention Week 10 x=0.208m, Control x=0.029, p=<.001). A summary of these results is found in Table 4.

Table 4: Comparison of ML parameters between testing time points for TC intervention and control group participants for quiet standing with eyes open (mean (± SD)).

<table>
<thead>
<tr>
<th></th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Week Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTERVENTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML Net COP RMS (m)</td>
<td>0.135 (± 0.046)</td>
<td>0.114 (± 0.093)</td>
<td>0.208* (± 0.033)</td>
<td>0.269* (± 0.039)</td>
</tr>
<tr>
<td>ML COM Range (m)</td>
<td>0.049 (± 0.042)</td>
<td>0.025*^ (± 0.018)</td>
<td>0.028*^ (± 0.021)</td>
<td>0.025*^ (± 0.018)</td>
</tr>
<tr>
<td><strong>CONTROL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML Net COP RMS (m)</td>
<td>0.146 (± 0.158)</td>
<td>0.032* (± 0.022)</td>
<td>0.029* (± 0.022)</td>
<td></td>
</tr>
</tbody>
</table>

*values are significantly different from baseline measures at a p=<.05 level. Effect sizes of significant values were greater than d=0.8 (large effect size), medium effect size values (d=>0.5) are followed by the symbol “^”.

3.3 Quiet Standing, Eyes Closed

3.3.1 Anterior-Posterior Stability

There was a significant main effect of Group x Time for AP net COP RMS (F(2,183.9)=32.1, p=<.001) and AP COM RMS (F(2,184.1)=33.6, p=<.001). Both the intervention and control groups showed decreases from baseline to week 10 testing in AP net COP RMS (Intervention Week 0 x=0.500m, Week 10 x=0.297m, p=<.001, Control Week 0 x=0.476m, Week 10 x=0.046m, p=<.001) and AP COM RMS (Intervention Week 0 x=0.533m, Week 10 x=0.324m, p=<.001, Control Week 0 x=0.489m, Week 10 x=0.076m, p=<.001). The control group did not show any significant changes across time for any other variables.

There was a near-significant main effect of Time for the AP net COP range (F(1,26.3)=2.2, p=.15) for the intervention group. These trends displayed decreases across time in AP Net COP range from baseline (x=0.053m) to week 10 (x=0.028m).
There was a significant main effect of group for AP net COP RMS \( (F(1,19.7)=32.2, p=<.001) \) and AP COM RMS \( (F(1,19.7)=34.4, p=<.001) \). The intervention group showed significantly higher results than the control group at week 5 and 10 for AP net COP RMS (Intervention Week 5 \( x=0.534m \), Control \( x=0.028m \), \( p=<.001 \), Intervention Week 10 \( x=0.297m \), Control \( x=0.046m \), \( p=<.001 \)) and AP COM RMS measures (Intervention Week 5 \( x=0.568m \), Control \( x=0.032m \), \( p=<.001 \), Intervention Week 10 \( x=0.324 \), Control \( x=0.076 \), \( p=<.001 \)). Results are summarized in Table 5.

Table 5: Comparison of AP parameters between testing time points for TC intervention and control participants for quiet standing with eyes closed (mean \( \pm \) SD).

<table>
<thead>
<tr>
<th></th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Week Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTERVENTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP Net COP Range (m)</td>
<td>0.053 ( \pm 0.098 )</td>
<td>0.037 ( \pm 0.054 )</td>
<td>0.028 ( \pm 0.023 )</td>
<td>0.029 ( \pm 0.017 )</td>
</tr>
<tr>
<td>AP Net COP RMS (m)</td>
<td>0.500 ( \pm 0.089 )</td>
<td>0.534 ( \pm 0.205 )</td>
<td>0.297* ( \pm 0.036 )</td>
<td>0.312* ( \pm 0.085 )</td>
</tr>
<tr>
<td>AP COM RMS (m)</td>
<td>0.533 ( \pm 0.091 )</td>
<td>0.568 ( \pm 0.209 )</td>
<td>0.324* ( \pm 0.036 )</td>
<td>0.344* ( \pm 0.088 )</td>
</tr>
<tr>
<td><strong>CONTROL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP Net COP RMS (m)</td>
<td>0.476 ( \pm 0.443 )</td>
<td>0.028* ( \pm 0.013 )</td>
<td>0.046* ( \pm 0.046 )</td>
<td></td>
</tr>
<tr>
<td>AP COM RMS (m)</td>
<td>0.489 ( \pm 0.444 )</td>
<td>0.032* ( \pm 0.017 )</td>
<td>0.076* ( \pm 0.056 )</td>
<td></td>
</tr>
</tbody>
</table>

* values are significantly different from baseline measures at a \( p=<.05 \) level. Effect sizes of significant values were all greater than \( d=0.8 \) (large effect size).

3.3.2 Medial-Lateral Stability

During quiet standing with eyes closed, select ML variables showed significant decreases across time for the intervention group. There was a significant main effect of Time for ML net COP range \( (F(3,186.4)=3.8, p=.01) \) and ML COM range \( (F(3,186.4)=6.2, p=.01) \). Measures that changed significantly decreased over time include the ML net COP range and the ML COM range. Details of the significant decreases demonstrated by the TC intervention group are summarized in Table 6. There was also a significant main effect for group for ML COM range.
(F(1,25.3)=13.4, p=.001). The control group displayed a significantly lower ML COM range score (x=0.023m) than the intervention group (x=0.055m, p=<.001) at week 0. The control group did not exhibit any significant changes in ML stability over time.

Table 6: Comparison of ML parameters between testing time points for TC intervention participants for quiet standing with eyes closed (mean (± SD)).

<table>
<thead>
<tr>
<th></th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Week Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTERVENTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML Net COP Range (m)</td>
<td>0.045 (± 0.058)</td>
<td>0.025*~ (± 0.043)</td>
<td>0.035 (± 0.046)</td>
<td>0.020*^ (± 0.021)</td>
</tr>
<tr>
<td>ML COM Range (m)</td>
<td>0.055 (± 0.049)</td>
<td>0.043 (± 0.047)</td>
<td>0.028*^ (± 0.024)</td>
<td>0.023* (± 0.020)</td>
</tr>
</tbody>
</table>

*values are significantly different from baseline measures at a p=<=.05 level.
Unlabelled effect sizes of significant values were greater than d=0.8 (large effect size), medium effect size values (d=>0.5) are followed by the symbol “^”. Values followed by the symbol “~” had a small effect size (d=>.3).

Note: Control group did not demonstrate any significant changes over time.

3.4 Arm Raise

Arm raise trials were collected in the sagittal plane, therefore all COP values were measured only in the AP direction by one foot since only one foot was visible. It was assumed that the perturbation would exhort similar offsets in each foot since it was a full body and primarily AP perturbation. Vertical velocity of the arm raise was recorded during the self-perturbation. The intervention group’s velocities did not change significantly over time, indicating that the magnitude of the perturbation was similar across each testing interval. The control group however significantly increased their vertical velocity from baseline (x=.259m/s) to midpoint (x=.213m/s, p=<.001), from baseline to week 10 (x=.173m/s, p=<.001) and from midpoint to week 10 (p=.002).
Table 7: Comparison of arm raise AP parameters between testing time points for TC intervention participants (mean (± SD)).

<table>
<thead>
<tr>
<th>INTERVENTION</th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Week Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP Net COP Range (m)</td>
<td>0.035</td>
<td>0.024*^</td>
<td>0.028</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>(± 0.019)</td>
<td>(± 0.010)</td>
<td>(± 0.020)</td>
<td>(± 0.015)</td>
</tr>
<tr>
<td>AP Net COP RMS (m)</td>
<td>0.128</td>
<td>0.085*^</td>
<td>0.128</td>
<td>0.181°</td>
</tr>
<tr>
<td></td>
<td>(± 0.081)</td>
<td>(± 0.054)</td>
<td>(± 0.054)</td>
<td>(± 0.054)</td>
</tr>
<tr>
<td>AP COM Range (m)</td>
<td>0.040</td>
<td>0.034*~</td>
<td>0.033*^</td>
<td>0.029*</td>
</tr>
<tr>
<td></td>
<td>(± 0.014)</td>
<td>(± 0.014)</td>
<td>(± 0.011)</td>
<td>(± 0.011)</td>
</tr>
<tr>
<td>AP COM RMS (m)</td>
<td>0.115</td>
<td>0.076*^</td>
<td>0.107</td>
<td>0.168°</td>
</tr>
<tr>
<td></td>
<td>(± 0.062)</td>
<td>(± 0.043)</td>
<td>(± 0.038)</td>
<td>(± 0.065)</td>
</tr>
<tr>
<td>AP COP/COM Max Difference (m)</td>
<td>0.320</td>
<td>0.255</td>
<td>0.117*</td>
<td>0.335*°</td>
</tr>
<tr>
<td></td>
<td>(± 0.115)</td>
<td>(± 0.189)</td>
<td>(± 0.066)</td>
<td>(± 0.070)</td>
</tr>
</tbody>
</table>

* values are significantly different from baseline measures at a p=<.05 level.  
° values are significantly different from week 10 at a p=<.05 level.  
Unlabelled effect sizes of significant values were greater than d=0.8 (large effect size), medium effect size values (d=>0.5) are followed by the symbol “^”, Values followed by the symbol “~” had a small effect size (d=>.3) 
Note: Control group did not demonstrate any significant changes over time.

It was observed that across testing times the intervention group had several variables decrease over time, even as the participants inflicted a self-perturbation, the magnitude remained constant. There was a significant main effect of Group x Time for (F(2,185)=4.2, p=.02) and Time (F(3,185)=2.8, p=.04) for AP net COP range. A noteworthy finding was that for AP net COP range, significant decreases were observed between baseline and midpoint, however, further testing days (week 10 and 12 week post-testing) showed a similar decrease in range, trending towards significance.

A main effect of Group x Time (F(2,185)=3.1, p=.05) and Time (F(3,185)=17.5, p=<.001) was found for AP net COP RMS. Significant main effects were also found for AP COM range for Group x Time (F(2,187.2)=5.6, p=.004) and Time (F(3,187.2)=4, p=.009) and AP COM RMS for Group x Time (F(2,184.6)=3.6, p=.03) and Time (F(3,184.6)=17.3, p=<.001).  
Lastly there was also a significant main effects found for AP COP/COM Max difference in
Group x Time (F(2,184.2)=16.9, p=<.001) and Time (F(3,184.2)=43.5, p=<.001). There were no significant group differences at any of the time points in the AP direction. Details of significant changes over time in the AP direction are detailed in Table 7.

There was a significant main effect of Time found for the ML COM range (F(3,186.1)=5, p=.002) and ML COM RMS for Group x Time (F(2,183.9)=15.1, p=<.001) and Time (F(3,183.9)=50.2, p=<.001) as well as a significant group effect (F(1,19.2)=23.3, p=<.001). ML COM RMS values were significantly higher for the intervention group than the control group at week 5 (Intervention x=0.463m, Control x=0.132m, p=<.001) and week 10 (Intervention x=0.345m, Control x=0.095m, p=<.001). Details of ML changes across time can be found in Table 8.

Table 8: Comparison of arm raise ML parameters between testing time points for TC intervention and control participants (mean (± SD)).

<table>
<thead>
<tr>
<th></th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Week Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTERVENTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML Net COM Range (m)</td>
<td>0.045 (± 0.033)</td>
<td>0.028*^ (± 0.016)</td>
<td>0.038 (± 0.025)</td>
<td>0.026*^ (± 0.019)</td>
</tr>
<tr>
<td>ML COM RMS (m)</td>
<td>0.534 (± 0.071)</td>
<td>0.463*^ (± 0.138)</td>
<td>0.345* (± 0.032)</td>
<td>0.335* (± 0.064)</td>
</tr>
<tr>
<td><strong>CONTROL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML COM RMS (m)</td>
<td>0.477 (± 0.405)</td>
<td>0.132* (± 0.085)</td>
<td>0.095* (± 0.071)</td>
<td></td>
</tr>
</tbody>
</table>

*values are significantly different from baseline measures at a p=<.05 level. 
° values are significantly different from week 10 at a p=<.05 level. 
Unlabelled effect sizes of significant values were greater than d=0.8 (large effect size), medium effect size values (d=>0.5) are followed by the symbol “^”.

3.5 Gait Termination

Gait termination variables were analyzed from the last foot’s heel contact and for 5 subsequent seconds. The following measures showed significance after the summary of the statistical analysis. Statistically different changes across time for the intervention group occurred in the ML direction in COP and COM RMS. There was a main effect of Group x Time
(F(2,185)=3.5, p=.03) and Time (F(3,185)=54.4, p=<.001) for ML COP RMS as well as for ML COM RMS for Group x Time (F(2.185.1)=3.04, p=.05) and Time (F(3.185.1)=59, p=<.001). A noteworthy finding was the trend towards a significant main effect of Time in the AP net COP range (F(3,186)=1.62, p=.19) which decreased from baseline to week 10 testing. There were no significant group effects found for any of the variables measured. A graphical representation of the change in ML net COM RMS is displayed in Figure 7 and all noteworthy findings are summarized in Table 9.

Figure 7. Both the intervention and control group showed significant decreases in ML net COM RMS values from baseline to week 10. Intervention group values rose significantly from week 10 when re-tested 12 weeks post-intervention.
Table 9: Comparison of AP and ML gait termination parameters between testing time points for TC intervention and control participants (mean (± SD)).

<table>
<thead>
<tr>
<th></th>
<th>Week 0</th>
<th>Week 5</th>
<th>Week 10</th>
<th>12 Week Post-Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTERVENTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP Net COP Range</td>
<td>0.090 (± 0.117)</td>
<td>0.065 (± 0.030)</td>
<td>0.061 (± 0.034)</td>
<td>0.074 (± 0.037)</td>
</tr>
<tr>
<td>ML Net COP RMS</td>
<td>0.215 (± 0.122)</td>
<td>0.146*^ (± 0.089)</td>
<td>0.128*^ (± 0.096)</td>
<td>0.350° (± 0.139)</td>
</tr>
<tr>
<td>ML COM RMS</td>
<td>0.216 (± 0.121)</td>
<td>0.140*^ (± 0.090)</td>
<td>0.132*^ (± 0.097)</td>
<td>0.351*° (± 0.148)</td>
</tr>
<tr>
<td><strong>CONTROL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML Net COP RMS</td>
<td>0.292 (± 0.147)</td>
<td>0.137* (± 0.088)</td>
<td>0.180* (± 0.096)</td>
<td></td>
</tr>
<tr>
<td>ML COM RMS</td>
<td>0.288 (± 0.148)</td>
<td>0.131* (± 0.089)</td>
<td>0.170* (± 0.102)</td>
<td></td>
</tr>
</tbody>
</table>

*values are significantly different from baseline measures at a p=<.05 level.
° values are significantly different from week 10 at a p=<.05 level.
Unlabelled effect sizes of significant values were greater than d=0.8 (large effect size), medium effect size values (d>=0.5) are followed by the symbol “^”.

3.6 Compensatory Stepping Training

There was a significant change across time for the amount of force needed to push the participants off balance. This trend is documented in Figure 8. The first trial, a great amount of force was required to push participants off balance, whereas from the second class onward steady and gradual increases were observed. Significant increases were observed from the second class (x=25.2N) to the last class (x=34.2N, p=<.0001).
Figure 8: Representation of the force required to push participants off balance enough to evoke a compensatory step during training. There were 20 classes, this graph represents the change over the 10 week training period.

3.7 Falls

Intervention participants were asked upon each visit if they had experienced a fall since the last time they attended. Control groups participants were asked to report on falls since the time of their last testing session. Answers were recorded as “Yes” or “No”. If participants answered “Yes”, they were required to fill out a Falls Follow-Up Questionnaire. Two participants in the intervention group reported a fall during the time of the intervention training. One participant fell between the ending of the intervention and the 12-week post-intervention follow-up testing. One control group participant reported a fall between week 5 and week 10 at their last testing session. Since the numbers were so small no further analysis seemed warranted.
4.0 Discussion

4.1 Purpose and Hypotheses

The purpose of this study was to explore the benefits of a 10-week combined Tai Chi Qigong and compensatory stepping training program on balance control in older adults. It was predicted that over time, participants who took part in the intervention would significantly improve in measures of balance confidence and balance control from baseline to 10-week testing and that these improvements would be reflected in improved scores on the ABC scale and the Berg Balance Scale and decreased timed to complete the Timed-Up-and-Go. It was also predicted that after having completed the intervention that participants would demonstrate tighter control over their COP and COM (decreases in range and RMS) as well as a decreased maximum difference between the two values.

4.2 ABC, Berg Balance Scale and Timed-Up-and-Go

4.2.1 ABC

Previous literature indicates that the ABC gives excellent insight into the confidence that an older adult has engaging in various activities. It can also be used to predict the types of activities that an older adult would be willing to participate in, in the future (Powell & Myers, 1995; Schepens et al., 2010). Balance confidence for the intervention group increased significantly across time from the beginning to the end of the intervention, and after being tested 12 weeks post-intervention decreased to scores similar to midpoint testing, but lower than at week 10. It is interesting to note the vast difference in baseline scores for the intervention and control group. Control group scores (x=86.1) at the beginning of the program were already notably greater than those participating in the intervention group (x=78.1). According to Myers and colleagues, the intervention group, at baseline was at a moderate level of physical function,
whereas the control group’s performance was indicative of high functional ability (Myers, Fletcher, Myers, & Sherk, 1998). It is clear that members of the control group had greater confidence in their balance abilities than did the intervention participants when beginning testing. This may have been related to how each participant group was recruited. Intervention posters targeted individuals seeking to improve balance control through an exercise program, whereas control participants were recruited to take part in “balance testing”, so as to evaluate their current ability. Typically, it is those who have inferior balance coordination that would have lesser confidence in their abilities (Powell & Myers, 1995), and as such, might seek out a method such as this intervention to improve balance.

It is important to note that there was an improvement in balance confidence over time for the intervention group which was attributable to the Tai Chi and compensatory stepping training. Throughout the program, individuals were required to perform precise stepping and weight shifting movements, causing them to move outside of a typical stance and challenging their balance (Frye et al., 2007; Jahnke, Larkey, Rogers, Etnier, & Lin, 2010; Nunes, 2012). Secondly, compensatory stepping training required participants to respond to an unexpected perturbation force, upon which successful recovery may have improved self-efficacy. These challenges, and their ability to successfully perform TC movements and perturbation recovery over time is the most likely relation to their confidence improvements.

4.2.2 Berg Balance Scale

It has been observed that the Berg Balance Scale is typically only sensitive to frail older adults, or a severely balance impaired population, (Lajoie & Gallagher, 2004; Shumway-Cook, Baldwin, Polissar, & Gruber, 1997). The Berg Balance Scale was included in this study, because it is an excellent tool for comparison between the current investigation and previously conducted
interventions. As the gold standard for testing balance control among older adults, much of the previous literature includes this measure as an indication of functional balance control and prediction of future falls (Frye et al., 2007; Kuptniratsaikul et al., 2011; Li et al., 2004; Podsiadlo & Richardson, 1991; Steffen et al., 2002; Yang et al., 2007). It is clear that both the intervention and the control group were high functioning older adults, which is to be expected from a group still living independently throughout the community. Research suggests that those who score between 41 and 56, as all intervention and control participants did, are independent and at low risk for falling (Berg et al., 1992; Shumway-Cook et al., 1997).

The intervention group demonstrated significant and steady improvements over time as represented by scores on the Berg Balance Scale. These improvements are consistent with previous literature where Tai Chi exercise has been used as an intervention for balance control (Li et al., 2004). The average increase in the Li and colleagues’ study was a 4-point improvement in scoring on the Berg Balance Scale. The intervention group in the current study demonstrated a similar 3-point improvement. The training received by the intervention group is the most probable explanation for the improvement. Since much of the intervention involved similar muscle groups and coordination movements to those tested in the Berg Balance Scale (e.g. Quadriceps are used in a squatting position during Tai Chi practice and to get out of a chair as required by the Berg), it is likely that training these gross motion muscles is linked to increased strength and coordination (Frye et al., 2007; Wallsten, Bintrim, Denman, Parrish, & Hughes, 2006; Xu et al., 2008). Many participants at baseline were unable to stand on one leg for more than 1-2 seconds whereas by the end of the program, most were able to balance on one leg for up to 10 seconds or more. The Tai Chi movements are excellent for training individuals to become more comfortable shifting between double and single stance postures, as well as shifting between
loading and unloading each of the lower limbs in conjunction with moving upper extremities (Li et al., 2004).

The control group however, also showed significant improvements from baseline to midpoint testing, but no significant changes from midpoint to week 10. Initial low scores may have been related to external weather conditions. The seasons had just begun to change and the first few snowfalls had just taken place as the control group came in for their first round of testing (November / December). As indicated on the ABC, participants who are less confident “walking on ice” are less likely participate in ‘riskier’ balance activities such as those presented in the Berg Balance Scale (Lajoie & Gallagher, 2004; Powell & Myers, 1995). Control group improvements may have also been related to familiarity with the test, or a determination to improve their previous score. Most participants seemed quite self-competitive, often times asking how they were performing compared to the last time.

4.2.3 Timed-Up-and-Go

The Timed-Up-and-Go test yielded some very promising results for the TC intervention group. Both the intervention and control group performed their tests well below the 14s (Shumway-Cook, Brauer, & Woollacott, 2000) or 15s cut-off (Nordin, Lindelöf, Rosendahl, Jensen, & Lundin-Olsson, 2008) which predicts a high risk of fall. Therefore it can be concluded that both groups are high functioning and at a low risk for falling. At baseline, the control group performed their TUG test at a significantly faster time than the intervention group, and maintained a consistently fast time throughout testing. Those who participated in the TC intervention however significantly improved their time from baseline to midpoint and week 10. Improvements may be attributed to the Tai Chi program’s coordination training, which included weight transfers that often required movement of multiple limbs while twisting at the
waist. Increases in core strength to maintain stability throughout these upper limb movements is another likely explanation for these improvements (Okada, Huxel, & Nesser, 2011). The TUG incorporates a number of balance challenging components including standing from a chair, turning to change direction and returning to a seated position which require the same agility and coordination practiced during the intervention (Podsiadlo & Richardson, 1991).

Second, compensatory stepping training was intended to improve agility. Previous literature suggests that if trained to respond correctly to balance perturbations, older adults will be better equipped to successfully regain balance (Mansfield et al., 2010). Since quick stepping responses were necessary to regain balance after the applied manual perturbation, and participants were trained consistently for 10 weeks to correctly execute successful stepping, it is likely that this is transferrable to dynamic movement. Completion of the TUG test puts individuals at risk for losing their balance during the rising from or return to their seat as well as during the turning sequence in the middle. Therefore this improvement in TUG time may have been directly related to the training that required successful stepping in situations where a perturbation or a balance-challenging task is required.

Faster times may have also been related to an increased balance confidence. Since the TUG includes some “risky” movement, the training received may have given individuals the confidence to increase their speed during the test (Powell & Myers, 1995; Schepens et al., 2010).

However once the intervention ended and participants were tested at 12 weeks post intervention, times increased significantly from week 10. This provides further evidence that although training is received, unless it is kept up, gains can diminish over time (Salzman, 2011).
4.3 Quiet Standing

It was predicted that the range and RMS of the COP and COM trajectory as well as the maximum difference between the COP/COM would decrease over time for those who participated in the Tai Chi and compensatory stepping intervention. Previous literature has found that COP excursion is an excellent measure of balance control about the ankle joint and is relatable to how well an older adult is able to maintain stability during quiet stance (Ruhe et al., 2010; Verhagen et al., 2005; Winter, Patla, & Frank, 1990; Winter, 1995). In this study, trajectories of both the COP and COM were measured. These variables are highly related since the COP moves directly ahead of the COM in order to ensure it is contained within stability parameters (Corriveau et al., 2000; Winter, 1995). In this study, participant’s quiet stance was evaluated with their eyes open as well as with their eyes closed.

Over time, improvements were seen in the AP direction with significant decreases in COP RMS and COM RMS from baseline to week 10 testing when eyes were open and closed as well as trending decreases in COP range. Improvements were regarded as a decreased range and RMS values, since previous literature has shown that greater sway (RMS) and greater COP movement are indications of poorer stability (Laughton et al., 2003; Melzer, Benjuya, & Kaplanski, 2004). Decreases in the AP COP range and RMS signify that over time, COP movement was limited and less variable than it had been previously. Variability (RMS) for the COM also decreased significantly over time, indicating that it needed less ‘controlling’, therefore less movement was required to keep the COM contained within acceptable postural limits (Winter et al., 1990). Results also yielded improvements in the ML direction (decreased lateral COP RMS and COM range [eyes open] and decreased lateral COP and COM range [eyes closed]). This indicates that there was less variability in COP movement, and the COM trajectory decreased over time for eyes open trials and less COP and COM movement during eyes closed.
It is interesting that although the Tai Chi or compensatory stepping regime did not include any training specific to static movement, improvements were seen in both the COP and COM in both the AP and ML directions. It is possible that these improvements are related to an increase in ankle stability developed throughout the intervention. Previous literature has demonstrated that poor ankle stability is directly related to higher COP excursions (Hlavackova & Vuillerme, 2012). Postural deficits however, are notably due to more than just insufficient ankle strength, but are also linked to neurological and sensory impairments common in older adults (Aagaard, Sueta, Caserotti, Magnusson, & Kjaer, 2010; Salzman, 2011). Tai Chi has been found to improve lower limb strength and in turn ankle stability, as well as enhance sensory uptake (Fong et al., 2013; González López-Arza et al., 2013; Tsang et al., 2004; Tsang & Hui-Chan, 2008). Therefore it is logical that these excursion decreases are related to increase ankle strength and greater sensorimotor awareness developed by taking part in the TC intervention.

Another likely explanation for an improvement in functional balance is an increase in core strength. Core strength and endurance is essential for proximal stability when distal limb movements occur, as is so common during Tai Chi practice (Kibler, Press, & Sciascia, 2006). Core stability has been defined as “the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segment in integrated athletic activities” (Kibler et al., 2006, p. 189). A study was conducted to look specifically at trunk stability (using kinematic / COM measuring technology) related to Tai Chi practice among individuals with vestibular impairment. Results showed that those who participated in 10 weeks of Tai Chi weekly for 70 minutes at a time (compared to vestibular rehabilitation) showed greater control over their trunk during a gait analysis task where speed was a factor. Researchers attributed these improvements to a combination of neuromuscular
reorganization of the lower extremities and improved core stability (McGibbon et al., 2005). Therefore it is likely that the Tai Chi movements, which require tight muscular control of the core as the body moves via stepping or during upper limb movements, help develop core strength and endurance, which contribute to improved postural control.

When eyes are closed, stability is based on a correct response to only proprioception and sensory information since a major source of balance information (sight) has been removed. Therefore improvements from eyes closed trials are attributable to an increase in sensorimotor uptake and an improved ability to respond when visual information is no longer available (Priplata, Niemi, Harry, Lipsitz, & Collins, 2003). Altogether, it is likely that although the training regime did not include specific static training, that improving strength and sensory uptake through dynamic movement and perturbation training is transferrable to static stability.

4.4 Perturbations

4.4.1 Arm Raise

Previous literature has made it clear that older adults are less likely than younger adults to recover successfully from an unexpected perturbation (Maki et al., 2008; Rogers et al., 2003). As such, it has been recommended that specific, perturbation based trainings be implemented in order to better prepare older adults to respond in the case of an unanticipated loss of balance (Mansfield et al., 2010). In this study compensatory stepping in response to unexpected manual perturbations in the AP and ML directions was a regular part of the intervention group training. The arm raise protocol was intended to be a self-perturbation in the AP direction in order to measure the effectiveness of this training.

Results showed promising outcomes where the intervention group demonstrated a significant improvement from baseline to midpoint in AP COP range and AP COM RMS where
values remained lower at week 10, but were only approaching significance. Significant improvements from baseline to week 10 were found in AP COM range and max AP COP/COM difference. Interestingly AP COM range remained low at 12 week post-testing.

Results were inconsistent as to whether improvements were shown from baseline to midpoint or baseline to week 10. AP COP range and RMS as well as AP and ML COM range and RMS and lastly AP COP/COM max difference all showed significant or near significant improvements over time. Only AP and ML COM range improvements were maintained until 12 week post testing.

However inconsistent, improvements were evident in the intervention group across time. These decreases are attributable to their compensatory stepping as well as TC training. From the beginning to the end of the intervention, there was also a significantly greater amount of force needed to perturb individuals to the point where a compensatory step was necessary. In order to maintain COM within the BOS, ankle strategies are often employed where limbs remain in place and ankle joint muscles are engaged to maintain stability (Maki & McIlroy, 1997). It is predicted that this added force was necessary because individuals had developed a stronger fixed support strategy about the ankles, a necessary component to maintaining balance during this arm raise perturbation. Individuals may have also perfected this ankle strategy during Tai Chi movement. Specific movements often require a steady and solid base while upper limbs are in motion, which challenges balance (Tsang et al., 2004; Wallsten et al., 2006; Yang et al., 2007). In order to maintain this solid base, lower limb and specifically ankle stabilizers must be engaged (Maki & McIlroy, 1997). Constant activation strengthens not only the muscles, but the neurological pathways associated with balance are also trained to respond favourably when challenged by self-perturbations (Horak, Shupert, & Mirka, 1989; Manchester et al., 1989; Winter, 1995).
Sensory adaptations parallel these neurological changes, and it is likely that the sensory system became more attune to perturbations over time. Previous literature has found that increasing foot sole sensory stimulation can improve individuals’ ability to detect a perturbation and in turn facilitate the correct postural adjustment to remain stable. Tai Chi foot movements and constant weight shifting from one leg to another ensures constant stimulation of the foot sole. This stimulation causes the system to be more attuned to any postural shifts that may put the individual at risk for falling, and allow them to make any necessary adjustments (Maki et al., 2008; Priplata et al., 2003). Sensory awareness and response facilitation may be transferrable to daily encounters with unexpected perturbations.

In addition to increased ankle strength and neurological adaptation, it is likely that increases in core strength and endurance contributed to improved stability. During Tai Chi movement, it is necessary to maintain a stable base of support and remain in control of the upper body motion. This is only possible with strong core musculature essential for establishing proximal stability during distal limb movement (Kibler et al., 2006). Therefore it is likely that throughout the intervention, core musculature was strengthened and conditioned for endurance during both Tai Chi and compensatory stepping training which, contributing to improved stability over time during arm raise perturbations. In sum, improvements in arm raise parameters suggest that compensatory stepping and Tai Chi training is effective at reducing COP and COM range and RMS as well as the AP COP/COM maximum difference, representing improved balance control.

4.4.2 Gait Termination

Previous literature has shown that throughout dynamic motion there is a constant threat to balance since the COM is travelling outside of the BOS for 80% of the walking cycle. Gait
termination poses yet another threat since it requires that the COP moves ahead of the COM in order to decelerate it, and bring it to a full stop within a stable BOS (Jian et al., 1993). Gait termination therefore is an excellent mechanism to measure older adult’s responses to a dynamic form of self-perturbation.

Decreases were demonstrated for the intervention group from baseline to week 10 in the AP COP range and the ML COP and COM RMS. Some improvements were however notable in the control group as well in the ML COP and COM RMS from baseline to week 10. Having conducted testing with both the intervention and the control group, there was one distinct difference between them. Control group members were intentional about improving their scores from the previous time, though feedback was not given. During gait termination trials, many participants worked especially hard to come to a complete stop in the most stable fashion possible, often marked by very fast and rigid forward movements. It is predicted that these rigid gait termination trials are related to improvements in ML COP and COM RMS for the control group since less movement was conducted in the ML direction as a whole at successive testing dates. It is likely that these decreases were a result of purposefully less movement as a whole.

The intervention group however performed their trials with relative consistency, adhering to walking at a ‘slightly faster than normal pace’ as per the instructions. It is likely that improvements exhibited by the intervention group were related directly to the training they received. Decreases in the AP COP range signify that the COP moved significantly less distance ahead of the COM in order to decelerate it over time (Jian et al., 1993). As well, greater control was demonstrated in the ML direction for the intervention group where the COP and COM variability of sway was significantly reduced.
The use of manual perturbations in this training program was intended to be a means for preparing older adults to respond correctly to unexpected balance disturbances with an effective change in support strategy. It is likely that this training also prepared the participants to more effectively recover from unexpected termination of gait by encouraging successful muscle engagement in order to maintain stability. Specifically, improvements are likely related to improved strength in core musculature and about the ankle joint, both of which contribute to overall stability (Maki & McIlroy, 1997; McGibbon et al., 2005). The trunk of the body carries a large proportion of the body’s weight and is responsible for spine and pelvis stability as well as transferring energy from large to small body parts during any form of activity (Kibler et al., 2006). The ability to perform an efficient gait termination relied heavily on an individual’s ability to control their trunk as the body terminated movement and therefore improvements in stability over time were likely related to increased trunk stability after completing the intervention. Tai Chi and compensatory stepping training provided an opportunity for participants to engage and strengthen their core while being perturbed both voluntarily over time to improve muscular endurance (during Tai Chi) and involuntarily (compensatory stepping) which caused more acute muscular responses. Together these training protocols likely contributed to improved core strength related to more successful bodily coordination and stability during gait termination.

Much of maintaining balance during gait termination also comes from being able to employ a successful ankle strategy after the feet have come to a complete stop. Participants were asked to stop with feet side by side, meaning that often their COM would continue to move forward, and ankle joint stability was necessary to ensure deceleration of the COM by means of the COP (Jian et al., 1993).
The combination of core and lower limb strength is necessary to stop and recover from the gait termination as a perturbation may also be a result of Tai Chi training where the limits of the COM within the BOS were frequently challenged (Tsang et al., 2004; Tsang & Hui-Chan, 2004; Yang et al., 2007). Successful gait termination requires that the COM comes to a stop safely within the limits of the BOS (Jian et al., 1993). It is likely that by challenging the COM-BOS relationship during training during both Tai Chi and manual perturbation training, that individuals gained the strength and coordination necessary to respond favourably when challenged by gait termination as a perturbation (Tsang et al., 2004; Yang et al., 2007).

4.5 Applicability

The current study examined the combination of Tai Chi and compensatory stepping training. Previous literature examining the effects of Tai Chi or compensatory stepping individually, yielded similar balance confidence and functional balance benefits (Li et al., 2004; Maki, Edmondstone, & McIlroy, 2000; Mansfield et al., 2015; Tsang & Hui-Chan, 2008). Since the problem of falling is so multidimensional, it is essential that individuals possess both an ability to proactively prepare for and reactively respond to perturbations. Combining both voluntary and involuntary balance training therefore presents itself as an effective intervention. It was difficult however to gage the level of effect that the Tai Chi or compensatory stepping training had individually. Altogether, this research presents promising results for preparing older adults to respond when balance is challenged in either an expected or unexpected manner.

As the baby boomer generation ages, and the population of older adults continues to grow, it is necessary that communities take action to ensure the healthy aging of its people (Sherrington et al., 2011; Statistics Canada, 2011). Exercise, and specifically Tai Chi exercise has proven itself worthy as an intervention for improving balance control among the literature
(Li et al., 2004; C. E. Rogers, Larkey, & Keller, 2008; D. Xu, Hong, & Li, 2004; D. Q. Xu et al.,
2008). This study supports these results for the balance benefits of Tai Chi Qigong and adds to it
the benefits of compensatory stepping training. Instructors should be made aware of the
advantages of developing programs that incorporate voluntary and involuntary challenges to
balance and work to encompass both types of training into their exercise classes.

Compensatory stepping training using manually administered perturbations is a simple,
cost and time effective means for preparing older adults to effectively respond to unexpected
disruptions in balance (Mansfield et al., 2010). These losses in balance could be detrimental if
seniors are ill equipped to react (O’Loughlin et al., 1993).

The findings of this study are highly applicable to the area of fall prevention. This
intervention was conducted with high functioning older adults and benefits were nevertheless
exhibited. If such balance improvements were elicited among a well functioning group, the
benefits for a more frail population are expected to be exponentially greater. This is to be
expected since baseline balance measures would be presumably much less stable therefore the
potential for progress would be much greater.

4.6 Limitations and Future Directions

4.6.1 Limitations

A small sample size for both the intervention and control groups was a definite limitation
to this study. Recruitment was difficult in the Waterloo area since there is a wide variety of
research being conducted on a regular basis. Many of the intervention participants were retired
researchers themselves and were pleased to participate, others had noticed the poster and were
excited for the opportunity to potentially improve their balance control. Recruitment for the
control group was difficult due to the time of year that the research was being conducted (mid-
winter). Many older adults, for fear of slipping on ice are not inclined to leave the house in the winter (Powell & Myers, 1995; Schepens et al., 2010). Related to this, the different seasons of year when the study was conducted may have contributed to differences in results. Physical activity levels tend to be higher for the older adult population in the summer months than during colder months (Hjorthol, 2012).

For the intervention group, another limitation was that after the intervention group finished the 10 weeks of training, their physical activity was not controlled for between week 10 and 12 week post-intervention testing. 3 participants continued the Tai Chi Qigong practice after purchasing an instructional DVD from the instructor, though how often they participated was inconsistent with the training. It was difficult to know whether any improvements or declines in performance at 12 week post-intervention testing was related to participant’s physical activity levels, or any other confounding variables.

Perturbation training using manual pushes may have been a limitation since consistency and standardization of the magnitude of the perturbation was not controllable. Participants were pushed at the discretion of the researcher and increases in magnitude were applied as improvements were made and force was recorded. In the future, perturbation training should remain individualized to the ability of the participant, but also include standard and recordable increases in magnitude as improvements are made. This training could take place with the use of a moveable platform (Mansfield et al., 2010) or with a harness using a hold and release technique, where individuals lean forward and upon release are required to take a compensatory step (Mansfield et al., 2015).

There was potential for bias since the primary investigator was responsible for administering the ABC and the Berg Balance Scale. It would have been beneficial to include an
outside, trained professional in administering the tests to ensure that the researcher was blind to the findings throughout testing.

Measurement limitations were present in arm raise trials, which were limited to COP measurements in the AP direction since only one foot was visible. In the future, measures should be taken in such a way that both AP and ML measures can be recorded where both feet are visible. This will ensure that a broader scope of improvements can be interpreted.

Short duration COP measurements may have limited consistent findings. Recommendations for accurately recording quiet standing state that trials should be recorded for at least 20 seconds long, however this study measured for only 10 seconds due to time constraints (LeClair & Riach, 1996). In the future, it is recommended that longer recordings of quiet standing be measured in order to maximize accuracy, reliability and validity.

4.6.2 Future Directions

Future research should include a larger sample size to increase the power of results. It is also recommended that future interventions be conducted with a population of individuals that have severe balance impairments or are considered frail. This study included individuals whose results were often near to ceiling, and were at a low risk for falls. Since findings were favourable for those who were already at low risk for falling, the benefits for individuals of high risk of falling would likely be much greater. It may also be beneficial to examine one time fallers versus multiple fallers.

The current study examined Tai Chi and compensatory stepping together, but it was difficult to differentiate whether improvements were a result of Tai Chi, compensatory stepping, or the combination. In the future, it is recommended to examine different groups at the same time specifically looking at the benefits of each aspect of the program. For example, it would be
beneficial to assess 4 groups as a study where one group takes part in Tai Chi, another compensatory stepping, a third that practices a combination and a control group. This would allow for careful examination of the balance benefits of each type of training independently as well as the combination.

It is well understood among the literature that the reasons individuals experience a fall is multidimensional and there is great diversity in why adults tend to fall (Zecevic, Salmoni, Speechley, & Vandervoort, 2006). There are a number on intrinsic factors that contribute to falls (eg. muscular strength, neural control, trunk stability) as well as extrinsic or environmental factors (eg. clutter in the home, slips on ice, other obstacles). This study aimed to train individuals physically in order to enhance intrinsic bodily responses to balance perturbations that if left untrained may lead to a fall. Future research or training intervention programs would benefit from also including educational components to address proactive measures to take to create environments that reduce the risk of a fall around the home and in the community.

Currently there is a lack of standardization among measures of balance control, however recommendations have been made as a first step (Sibley et al., 2015). According to recent literature, the mini-Balance Evaluation Systems (mini-BES test) is an excellent method for evaluating balance control in stroke patients since it better assesses the mechanisms behind balance control and is less susceptible to ceiling effects than the Berg Balance Scale (C. S. L. Tsang, Liao, Chung, & Pang, 2013). The mini-BES test is a 14-item observational scale that includes evaluation of reactive balance control and dynamic stability during walking (Franchignoni, Horak, Godi, Nardone, & Giordano, 2010). In the future, it would be beneficial to include the mini-BES test into standard balance testing to achieve a comprehensive
understanding of the mechanisms behind balance control from before to after an exercise intervention.

The current study utilized both observational scales and lab-based, objective measurements of balance control. Often clinics are biased towards using observational scales and research settings towards objective kinetic and kinematic measurements. This study provides promising results for the use of both types of measures together. Since both yielded similar improvements, in the future it would be beneficial to correlate the results to represent that there are similar and mutually positive outcomes in either method.

While the results from this study presents positive findings for a combined Tai Chi Qigong and compensatory stepping program, further research must be conducted to gain a more comprehensive understanding of how this training can be used as a means for improving balance control for older adults. Next steps would include examining the long-term effects of training voluntary and involuntary balance control and how it relates specifically to fall prevention, which is the ultimate goal.
4.7 Conclusion

The current study examined the benefits of a combined Tai Chi and compensatory stepping program on balance control in older adults. Balance confidence, functional balance control as measured by the Berg Balance Scale and the time to complete the Timed-Up-and-Go test all yielded significant improvements from baseline to week 10. Inconsistent, yet significant improvements were demonstrated across quiet standing trials with eyes open and eyes closed, arm raise perturbations and gait termination trials in the AP and ML COP and COM range and RMS scores. The majority of improvements were shown in the AP direction.

It is thought that much of these improvements are due to an increase in strength about the ankle joint as well as sensory uptake information from the bottom of the feet brought about by specific balance challenging motions in Tai Chi training. Compensatory stepping training is thought to have enhanced individual’s ability to respond more successfully when faced with an unexpected perturbation. Altogether this study has shown promising results for the use of combined Tai Chi and compensatory stepping program to improve functional balance control among older adults. Further research should focus on training voluntary and involuntary balance responses in a population of older adults at high risk for falling and the development of standardized procedures for measuring balance control.
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APPENDIX A
A1. Screening Questionnaire

VOLUNTEER EXCLUSION CRITERIA  Participant # ______________

Age: _____ yrs.  Height: ______ cm  Weight: ______ kg  Shoe Size: _______

Gender:  M __  F __

Do you use an assistive device for mobility purposes?  Yes  No
☐  ☐

How dependent are you upon your assistive device?
I always use it  I use it sometimes  I hardly use it
☐  ☐  ☐

Is the use of your assistive device seasonal?  Yes  No
☐  ☐

Have you ever practiced Tai Chi?  Yes  No
☐  ☐

If yes please describe when and to what degree? ____________________________________________
____________________________________________________________________________________

How many minutes / day are you physically active doing non-sitting activities (eg. Walking, gardening)?
__________ minutes / day

How many minutes / day are you physically active recreationally? (eg. Swimming, biking)
__________ minutes / day

Of these times, how many leave you breathless? (eg. Breathing hard enough that a conversation would be difficult). Please describe:
____________________________________________________________________________________
____________________________________________________________________________________

Do you have any conditions that limit the use of your arms or legs?  Yes / No

If yes, how much does the condition interfere with your activities?
little or none  moderate  a great deal
☐  ☐  ☐
Describe: ____________________________________________________

__________________________________________________

Do you have or have you ever had: Yes / No
a) paralysis Yes / No
b) epilepsy Yes / No
c) cerebral palsy Yes / No
d) multiple sclerosis Yes / No
e) Parkinson's disease Yes / No
f) stroke Yes / No
g) any other neurological disorder

Have you ever had any serious problems with your memory? Yes / No
Do you have or ever had recurrent ear infections? Yes / No

How much do the conditions that you indicated with a 'yes' below interfere with your activities? Yes / No

Do you have or have you ever had:

<p>| | | | |</p>
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</thead>
<tbody>
<tr>
<td>a) diabetes</td>
<td>Yes / No</td>
<td></td>
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<tr>
<td>b) vision problem other than corrective glasses</td>
<td>Yes / No</td>
<td></td>
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<tr>
<td>c) cataract surgery</td>
<td>Yes / No</td>
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<tr>
<td>d) a balance or coordination problem</td>
<td>Yes / No</td>
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<tr>
<td>e) an inner ear disorder</td>
<td>Yes / No</td>
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<td></td>
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<tr>
<td>f) hearing problems</td>
<td>Yes / No</td>
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<tr>
<td>g) constant ringing in your ears</td>
<td>Yes / No</td>
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<tr>
<td>h) ear surgery</td>
<td>Yes / No</td>
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<tr>
<td>i) problems with your heart or lungs</td>
<td>Yes / No</td>
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<tr>
<td>j) high blood pressure</td>
<td>Yes / No</td>
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<tr>
<td>k) blood circulation problems (generally)</td>
<td>Yes / No</td>
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<tr>
<td>l) cancer</td>
<td>Yes / No</td>
<td></td>
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</tbody>
</table>
m) arthritis
n) rheumatism
o) back problems
p) a joint disorder
q) a muscle disorder
r) a bone disorder
s) spina bifida

How much do the conditions that you indicated with a ‘yes’ below interfere with your activities?

Have you ever severely injured or had surgery on your
a) head
b) neck
c) back
d) pelvis
e) ankle, knee, or hip joints?

Have you ever broken any bones?

Which ones?: ________________________________

Have you experienced a fall* within the last 6 months?  

* A fall is defined as: “an event which results in a person coming to rest inadvertently on the ground or floor or other lower level”.

If yes, how many times? Please describe how you fell:
____________________________________________________________________________________
____________________________________________________________________________________

Have you had any recent (specify)

a) illnesses
b) injuries
c) operations

Do you have difficulties performing any daily activities?  

Yes / No  

Which activities?:  

_________________________________________________  

_________________________________________________

Are you currently taking any medications (prescription or over-the-counter), or other drugs?

<table>
<thead>
<tr>
<th>Medication</th>
<th>Ailment</th>
<th>Frequency of use</th>
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<tbody>
<tr>
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APPENDIX B
B1. Falls Follow-up Questionnaire

Subject ID#: ___________ Fall#: _____  Interviewer: ______________
Date of fall (mm/dd/yy): ___________  Date of followup (mm/dd/yy): ___________

1. Please describe what happened (tape record subject's account).

2. What were you doing when you fell?

   □ Cannot recall (____)
   □ Sleeping (____)
   □ Sitting / lying (awake but not moving) (____)
   □ Standing (Not moving) (____)
   □ Walking on level surface (____)
   □ Walking up stairs / steps / curb (____)
   □ Walking down stairs / steps / curb (____)
   □ Rising out of: bed__ chair__ wheelchair__ toilet__ bath__ (____)
   □ Getting into: bed__ chair__ wheelchair__ toilet__ bath__ (____)
   □ Turning around (____)
   □ Reaching for something (____)
   □ Bending over (____)
   ☑ OTHER (Please Specify):______________________________________ (____)

3. Were you holding onto a handrail or grab-bar when you started to fall?

   □ No  □ Yes  □ Cannot recall (____)
4. Were you using an assistive device when you fell?

☐ Cannot recall
☐ Cane(s) (____)
☐ Walker (____)
☐ Rolling walker (____)
☐ Wheelchair (____)
☐ OTHER (Please Specify): ________________________________ (____)

5. Where did the fall occur?

☐ Cannot recall (____)
In your home or yard:
☐ Bedroom (____)
☐ Bathroom (____)
☐ Living room or dining room (____)
☐ Kitchen (____)
☐ Stairway (indoors) (____)
☐ Stairway (outdoors) (____)
☐ Yard, sidewalk or driveway (outdoors) (____)
☐ Indoors, but not your home (Please Specify): __________________________ (____)
☐ Outdoors, but not your yard (Please Specify): __________________________ (____)
☐ OTHER (Please Specify): ______________________________________ (____)

6. When did the fall occur (Please specify time of day): ____________

☐ Cannot recall ☐ 11pm-7am ☐ 7am-12pm ☐ 12pm-6pm ☐ 6pm-11pm (____)
7. What do you think caused you to fall?

☐ Cannot recall
☐ Tripped / caught foot or leg on something / hit something with foot or leg / or feet got tangled up (Please specify obstacle): ________________________ (___)
☐ Slipped
☐ Missed (overstepped) a stair / step / or curb (___)
☐ Missed the seat when sitting down (___)
☐ Bumped into something (___)
☐ Was pushed (by someone or something or wind) (___)
☐ Knees "gave way" (___)
☐ Just collapsed (felt faint / dizzy / weak) (___)
☐ Fainted (lost consciousness before falling) (___)
☐ Just "tipped over" (None of above responses apply) (___)
☐ OTHER (Please Specify): ________________________________ (___)

8. What part of your body hit the ground first?

☐ Cannot recall (___)
☐ Hip or side of body (Please indicate L or R) ________ (___)
☐ Knees (___)
☐ Hands or arms (___)
☐ Buttocks or back (___)
☐ OTHER (Please Specify): ________________________________ (___)

9. Did you put out your arms or hands to protect yourself?
10. What was the position of your body after you fell?

☐ Cannot recall   
☐ Lying on side (Please indicate L or R) ________   
☐ Lying on back   
☐ Lying on stomach   
☐ Kneeling   
☐ Sitting   
☐ On "all fours"   
☐ OTHER (Please Specify): ____________________________

11. In what direction did you fall?

☐ Cannot recall   
☐ Sideways   
☐ Forward   
☐ Backward   
☐ Straight down   
☐ OTHER (Please Specify): ____________________________

12. Did you need help to get up after you fell?

☐ No       ☐ Yes       ☐ Cannot recall
13. How long did you lie on the floor or ground before you were able to get up?
   - Cannot recall
   - A few minutes or less
   - Less than one hour
   - One hour or more (___)

14. Did you receive or seek medical treatment as a result of the fall?
   - Cannot recall (___)
   - No injuries requiring medical treatment (___)
   - Injured but did not seek treatment (___)
   - Saw family physician (___)
   - Saw other health-care professional (Please Specify:) __________________ (___)
   - Treated at hospital emergency room (___)
   - Admitted to hospital (___)
   - OTHER (Please specify): ____________________________ (___)

15. Describe your injuries or medical consequences (if any) or the fall. Check one or more boxes where appropriate.
   - Cannot recall (___)
   - No injuries requiring medical attention (___)
   - Cuts or bruises requiring medical attention (___)
   - Joint sprain or dislocation (or other joint injury) requiring medical attention (___)
   - Dehydration requiring medical attention (___)
   - Pneumonia (___)
   - Wrist fracture (___)
   - Hip fracture (___)
   - Other fracture (Please Specify): ____________________________ (___)
   - Head injury (Please Specify): ____________________________ (___)
☐ OTHER (Please Specify): ________________________________ (____)

16. Are you afraid of falling?

☐ Unable to say (____)
☐ Not at all (____)
☐ Somewhat (____)
☐ Fairly (____)
☐ Very (____)

☐ Only in certain circumstances (Please specify:) ________________________(____)

17. Are you more afraid of falling now than you were before you fell?

☐ Unable to say (____)
☐ Not at all (____)
☐ Somewhat (____)
☐ Fairly (____)
☐ Very (____)

18. Has fear of falling made you avoid any activities that you used to do?

☐ No ☐ Yes ☐ Not applicable (No Fear) (____)

If YES, please specify up to three activities that you have, or plan to, avoid:

1. ________________________ 2. ________________________ 3. ________________________
19. Please indicate whether any of the following have occurred since you visited the Biomechanics Lab at Wilfrid Laurier University on ___________ (specify date):

☐ Any illness or injury:  
If so, please specify what and when:  ________________________________
_______________________________________________________________

☐ Any change in the drugs or medications that you use:  
If so, please specify what and when:  ________________________________
_______________________________________________________________

☐ Any change in your vision or the corrective lenses that you wear:  
If so, please specify what and when:  ________________________________
_______________________________________________________________

☐ Any change in your use of devices like canes, walkers or wheelchairs:  
If so, please specify what and when:  ________________________________
_______________________________________________________________

☐ Any change in any assistance that you get with housekeeping, meals, etc:  
If so, please specify what and when:  ________________________________
_______________________________________________________________

☐ Cannot recall  

20. Do you need someone to help you walk outdoors?

☐ No  ☐ Yes  ☐ Unable to say  

21. Do you use a cane to help you move about?

☐ Unable to say

☐ No

☐ Only when indoors
☐ Only when outdoors

☐ Indoors and outdoors (____)

22. Do you use a walker or rolling walking (rollator) to help you move about?
☐ Unable to say
☐ No
☐ Only when indoors
☐ Only when outdoors
☐ Indoors and outdoors (____)

23. Do you use a wheelchair?
☐ Unable to say
☐ No
☐ Only when indoors
☐ Only when outdoors
☐ Indoors and outdoors (____)

24. In good weather, do you walk outdoors once per week or more?
☐ No ☐ Yes ☐ Unable to say (____)

25. INTERVIEWER - Please comment on reliability of the information or any other concerns (on the back of this sheet).
APPENDIX C
C1. The Activities-Specific Balance Confidence Scale

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

<table>
<thead>
<tr>
<th>0%</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100%</th>
</tr>
</thead>
</table>

**no confidence** | **completely confident**

"How confident are you that you will not lose your balance or become unsteady 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? __%
APPENDIX D
D1. The Physical Activity Questionnaire

Participant: ___________________________ Date: ________________

**Physical Activity Questionnaire**

Please list the current physical activities you participate in outside of the Tai Chi study:

<table>
<thead>
<tr>
<th>Activity</th>
<th>How many times per week?</th>
<th>Duration</th>
<th>How long have you participated (#mths/#years)?</th>
</tr>
</thead>
<tbody>
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Of these activities, which leave you slightly out of breath?

_____________________________________________________________________________________

_____________________________________________________________________________________

_____________________________________________________________________________________

Of these activities, which leave you breathless? (breathing hard enough that a conversation would be difficult)

_____________________________________________________________________________________

_____________________________________________________________________________________

_____________________________________________________________________________________
APPENDIX E
E1. The Berg Balance Scale

**Berg Balance Scale**
The Berg Balance Scale (BBS) was developed to measure balance among older people with impairment in balance function by assessing the performance of functional tasks. It is a valid instrument used for evaluation of the effectiveness of interventions and for quantitative descriptions of function in clinical practice and research. The BBS has been evaluated in several reliability studies. A recent study of the BBS, which was completed in Finland, indicates that a change of eight (8) BBS points is required to reveal a genuine change in function between two assessments among older people who are dependent in ADL and living in residential care facilities.

**Description:**
14-item scale designed to measure balance of the older adult in a clinical setting.

**Equipment needed:** Ruler, two standard chairs (one with arm rests, one without), footstool or step, stopwatch or wristwatch, 15 ft walkway

**Completion:**
- **Time:** 15-20 minutes
- **Scoring:** A five-point scale, ranging from 0-4. “0” indicates the lowest level of function and “4” the highest level of function. Total Score = 56

**Interpretation:**
- 41-56 = low fall risk
- 21-40 = medium fall risk
- 0 -20 = high fall risk

A change of 8 points is required to reveal a genuine change in function between 2 assessments.
# Berg Balance Scale

Name: ___________________________ Date: _______________

Location: _________________________ Rater: _______________

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>SCORE (0-4)</th>
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<tbody>
<tr>
<td>Sitting to standing</td>
<td>__________</td>
</tr>
<tr>
<td>Standing unsupported</td>
<td>__________</td>
</tr>
<tr>
<td>Sitting unsupported</td>
<td>__________</td>
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<tr>
<td>Standing to sitting</td>
<td>__________</td>
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<tr>
<td>Transfers</td>
<td>__________</td>
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<tr>
<td>Standing with eyes closed</td>
<td>__________</td>
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<tr>
<td>Standing with feet together</td>
<td>__________</td>
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<tr>
<td>Reaching forward with outstretched arm</td>
<td>__________</td>
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<tr>
<td>Retrieving object from floor</td>
<td>__________</td>
</tr>
<tr>
<td>Turning to look behind</td>
<td>__________</td>
</tr>
<tr>
<td>Turning 360 degrees</td>
<td>__________</td>
</tr>
<tr>
<td>Placing alternate foot on stool</td>
<td>__________</td>
</tr>
<tr>
<td>Standing with one foot in front</td>
<td>__________</td>
</tr>
<tr>
<td>Standing on one foot</td>
<td>__________</td>
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</table>

Total __________

**GENERAL INSTRUCTIONS**

Please document each task and/or give instructions as written. When scoring, please record the lowest response category that applies for each item.

In most items, the subject is asked to maintain a given position for a specific time. Progressively more points are deducted if:

- the time or distance requirements are not met
- the subject’s performance warrants supervision
- the subject touches an external support or receives assistance from the examiner

Subject should understand that they must maintain their balance while attempting the tasks. The choices of which leg to stand on or how far to reach are left to the subject. Poor judgment will adversely influence the performance and the scoring.

Equipment required for testing is a stopwatch or watch with a second hand, and a ruler or other indicator of 2, 5, and 10 inches. Chairs used during testing should be a reasonable height. Either a step or a stool of average step height may be used for item # 12.
Berg Balance Scale

SITTING TO STANDING
INSTRUCTIONS: Please stand up. Try not to use your hand for support.
( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or stabilize
( ) 0 needs moderate or maximal assist to stand

STANDING UNSUPPORTED
INSTRUCTIONS: Please stand for two minutes without holding on.
( ) 4 able to stand safely for 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unsupported

If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL
INSTRUCTIONS: Please sit with arms folded for 2 minutes.
( ) 4 able to sit safely and securely for 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to sit 10 seconds
( ) 1 unable to sit 10 seconds unsupported
( ) 0 unable to sit without support 10 seconds

STANDING TO SITTING
INSTRUCTIONS: Please sit down.
( ) 4 sits safely with minimal use of hands
( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assist to sit

TRANSFERS
INSTRUCTIONS: Arrange chair(s) for pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.
( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cuing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

STANDING UNSUPPORTED WITH EYES CLOSED
INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.
( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays safely
( ) 0 needs help to keep from falling

STANDING UNSUPPORTED WITH FEET TOGETHER
INSTRUCTIONS: Place your feet together and stand without holding on.
( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand 1 minute with supervision
( ) 2 able to place feet together independently but unable to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds
Berg Balance Scale  continued...

REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING
INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

( ) 4 can reach forward confidently 25 cm (10 inches)
( ) 3 can reach forward 12 cm (5 inches)
( ) 2 can reach forward 5 cm (2 inches)
( ) 1 reaches forward but needs supervision
( ) 0 loses balance while trying/needs external support

PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION
INSTRUCTIONS: Pick up the shoe/slipper, which is in front of your feet.

( ) 4 able to pick up slipper safely and easily
( ) 3 able to pick up slipper but needs supervision
( ) 2 unable to pick up but reaches 2-5 cm (1-2 inches) from slipper and keeps balance independently
( ) 1 unable to pick up and needs supervision while trying
( ) 0 unable to try/needs assist to keep from losing balance or falling

TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING
INSTRUCTIONS: Turn to look directly behind you over toward the left shoulder. Repeat to the right. (Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.)

( ) 4 looks behind from both sides and weight shifts well
( ) 3 looks behind one side only other side shows less weight shift
( ) 2 turns sideways only but maintains balance
( ) 1 needs supervision when turning
( ) 0 needs assist to keep from losing balance or falling

TURN 360 DEGREES
INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

( ) 4 able to turn 360 degrees safely in 4 seconds or less
( ) 3 able to turn 360 degrees safely one side only 4 seconds or less
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision or verbal cuing
( ) 0 needs assistance while turning

PLACE ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED
INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.

( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps in > 20 seconds
( ) 2 able to complete 4 steps without aid with supervision
( ) 1 able to complete > 2 steps needs minimal assist
( ) 0 needs assistance to keep from falling/unable to try

STANDING UNSUPPORTED ONE FOOT IN FRONT
INSTRUCTIONS: (DEMONSTRATE TO SUBJECT) Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width.)

( ) 4 able to place foot tandem independently and hold 30 seconds
( ) 3 able to place foot ahead independently and hold 30 seconds
( ) 2 able to take small step independently and hold 30 seconds
( ) 1 needs help to step but can hold 15 seconds
( ) 0 loses balance while stepping or standing

STANDING ON ONE LEG
INSTRUCTIONS: Stand on one leg as long as you can without holding on.

( ) 4 able to lift leg independently and hold > 10 seconds
( ) 3 able to lift leg independently and hold 5-10 seconds
( ) 2 able to lift leg independently and hold L 3 seconds
( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently.
( ) 0 unable to try of needs assist to prevent fall

( ) TOTAL SCORE (Maximum = 56)