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Leigh Bloomfield
University of Windsor

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by

Leigh Bloomfield

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Effects of Forward Lunge Training on Balance Control in Elderly Women

by

Leigh Bloomfield

APPROVED BY:

Michelle Freeman RN, MSN
Faculty of Nursing

Dr. Kenji Kenno
Department of Kinesiology

Dr. James Frank
Department of Kinesiology

July 29, 2009

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ABSTRACT

Falls among the elderly are a common event and can lead to serious injury. Many studies have linked medial-lateral instability with increased fall risk. The current study aims to answer the following questions: Does lunge training with elderly women improve balance control during the lunge? Does lunge training result in better performance during other balance tasks?

Nineteen elderly women were assigned to a 6 week lunge training group or a control group. Balance was assessed and lunges were recorded using a Vicon motion analysis system at 0, 3 and 6 weeks. Following training, individuals in the exercise group performed lunges with lower forward trunk velocities $F(2,34)=4.13$, $p<0.025$, lower forward pelvis velocities $F(2,34)=5.26$, $p<0.01$, lower medial-lateral trunk velocities $F(2,34)=6.6$, $p<0.004$ and shorter step lengths $F(2,34)=4.83$, $p<0.016$ compared to their controlled counterparts. The use of the forward lunge as the sole training tool with elderly women can improve medial-lateral trunk stability during a lunge by decreasing peak medial-lateral trunk velocity in only six weeks.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ABC	Activities-specific Balance Confidence
ACL	Anterior Cruciate Ligament
ANOVA	Analysis of Variance
A-P	Anterior-posterior
ASIS	Anterior Superior Iliac Spine
EC	Eyes Closed
EO	Eyes Open
CoM	Center of Mass
CoP	Center of Pressure
EMG	Electromyography
M-L	Medial-lateral
MSL	Maximal Step Length
OLS	One Legged Stance
PSIS	Posterior Superior Iliac Spine
TUG	Timed Up and Go

LIST OF APPENDICES

INTRODUCTION

As a large portion of the population continues to age into their senior years, clinicians and researchers have focused more attention on the health and quality of life of the elderly (Shumway-Cook et al., 1997; Pereira et al., 1998; Buchner et al., 1997; Hauer et al., 2001; Rogers et al., 2001; Carter et al., 2002; Cornillon et al., 2002; Day et al., 2002; Maejima et al., 2009; Santiworakul et al., 2009). Falls among the elderly are a common event that can result in serious injuries such as hip fracture. Many studies have been conducted that aim to describe the frequency of falls, prevalence of falls within the population, possible reasons for falls and possible fall prevention strategies. When destabilized, there are two ways to reorient the center of mass over the base of support: use of lower limb and trunk musculature to pull the center of mass back over the base of support, or stepping to increase the size of the base of support. Several experiments have concluded that medial-lateral instability seems to be a major contributor to falls and fall risk. Decreased performance on many balance tests that stress medial-lateral stability, such as the maximal step length test and many variations of the one legged stance test, have been linked to increased risk of falls and increased fall incidence. Furthermore, exercise training programs for the elderly have been implemented successfully in an effort to reduce fall risk and fall incidence. Most successful exercise programs for the elderly are multi-component programs that include cardiovascular, resistive and balance exercises. However, by training older adults using a single exercise that challenges medial-lateral stability, increased balance control during the exercise and increased performance in balance tasks may be attained which may contribute to decreases in fall risk. The current study tested the training effects of a six week long home forward lunge exercise protocol in elderly women, when comparing a control group with an exercise group. Balance control during the lunge, as well as, performance on several balance tests were recorded and analyzed before, during, and after the lunge training protocol.

BACKGROUND

FALL PREVALENCE AND FALL RISK

It has been estimated that one third of the population over the age of 65 will experience 1-2 falls per year (Campbell, Reinken, Allan, & Martinez, 1981). A more recent Canadian study reported similar fall rates of 41.4 falls per 1000 people per month within a community-dwelling elderly sample; 17.6% of individuals fell once, while 11.5% of individuals fell two or more times, which translates into an overall fall incidence of 29% (O'Loughlin, Robitaille, Boivin, & Suissa, 1993). As falls are so prevalent, and can cause serious injury or even death, it is important to examine why they take place, as well as, how interventions that prevent them from occurring can be created. There are many possible causes for the increased incidence in falls as age increases. These sources range from increased anxiety, muscle weakness, impaired sensory feedback, and decreased coordination, to decreased or improper reactions to perturbations. However, none of these sources have been proven as the sole basis for increased fall risk.

Some research has been aimed at investigating performance indicators that change over the course of the lifespan that predict postural instability and falls. The changes that occur as we age are many and varied. Several factors coalesce to create differences in balance between young and elderly individuals. Many balance tasks have been used to assess a person’s fall risk and overall balance ability. Studies have produced evidence that elderly individuals have greater amounts of postural sway during stance and gait tasks, such as standing on one leg on and off foam, tandem standing (standing heel to toe) and tandem walking (walking heel to toe), especially during eyes closed conditions (Gill, Allum, Carpenter, Held-Ziolkowska, Adkin, Honegger, & Pierchala, 2001). Increased postural sway with eyes closed is evidence that elderly individuals become more reliant on vision for balance control as they age. The increased variability in postural sway seen in elderly individuals may signal instability during walking and may also play a role in falls associated with perturbations and/or tripping. Individuals that have higher amounts of postural sway during normal walking may lack the control to maintain their center of mass (CoM) over their base of support during a trip or perturbation resulting in a fall. Elderly persons have also been shown to have poorer performances during balance tests, such as the timed up and go test and the one legged stance test (Vereeck, Wuyts, Truijen, & Heyning, 2008; Samson, Meeuwsen, Crowe, Dessens, & Duursma, 2000). Furthermore, Samson et al., (2000) showed an acceleration in muscle weakness declines occurring in individuals over the age of 55; this effect only occurring in women. Furthermore, a poor performance on the timed up and go test has been associated with an individual being a recurrent faller (Cho, Scarpace, & Alexander, 2004). These tests, therefore, would seem to be good indicators of fall risk. Age also appears to have a detrimental effect on the performance of standing balance tests such as tandem standing (standing heel to toe) and standing on one leg with eyes closed (Vereeck et al., 2008). Further experimentation has revealed that better performance on the tandem stance task and the rapid rise from a chair task are associated with a decrease in risk of falls and decreased risk of functional decline (Shubert, Schrodt, Mercer, Busby-Whitehead, & Giuliani, 2006). This finding highlights the importance of having both static and dynamic tests when assessing fall risk and mobility. Elderly individuals also have been revealed to have lower limits of stability when asked to complete maximal voluntary leans in anterior-posterior and medial-lateral directions (Blaszczyk, Lowe, & Hansen, 1994). Evidence has been provided that show elderly individuals have all around poorer performance on balance tests and a higher incidence of falls.

Furthermore, fear of falling has been noted as an important area of study when examining fall risk and fall incidence. A review completed by Scheffer, Schuurmans, van Dijk, van der Hooft, & de Rooij (2008) revealed that risk factors for developing fear of falling are increasing age, being female, and having had a previous fall. The anxiety associated with fear of falling has been shown to increase with age as well as history of a previous fall (Scheffer et al., 2008). A study with 3474 respondents has given insights into fear of falling which have linked it to activity avoidance (Bertera & Bertera, 2008). Activity avoidance can then initiate many health related problems and could, in turn, increase the risk of falling. Bertera & Bertera (2008) also concluded that the number of falls experienced increases the impact that fear of falling has on activity avoidance. Fear of falling directly and indirectly contributes to an individual's risk of falling; however, it is not the only factor involved. Fall risk is a complicated, multi-factorial issue and is not easily calculated.

MEDIAL-LATERAL STABILITY TESTING

Studies have been completed to further dissect the components of balance control and to analyze what parts of balance control are breaking down in elderly individuals that lead to increased instability, increased fall risk and increased fall incidence. The research groups of Stel, Smit, Pluijm, & Lips (2003) and Maki, Holliday, & Topper, (1994) have revealed that increased medial-lateral sway is associated with recurrent fallers. These findings explain why the tandem stance task and the one legged stance tasks are a good measure of fall risk as these tests require a great deal of medial-lateral stability. Cho, Scarpace & Alexander (2004) have shown that the maximum forward step length test is a good predictor of mobility, performance, frequency of falls, self reported function and balance confidence. As stepping as far as is possible challenges medial-lateral stability, the findings by Cho et al. (2004) provide further evidence that medial-lateral instability is an important factor in the source of falls among the elderly. Obstacle crossing while walking also reveals increased medial-lateral instability with aging. Healthy elderly individuals were distinguishable from elderly individuals with balance disorders when comparing CoM peak displacements and CoM peak velocities in the medial-lateral direction during obstacle crossing, such that elderly individuals with balance disorders exhibited greater peak displacements and greater peak velocities (Chou, Kaufman, Hahn, & Brey, 2003; Hahn & Chou, 2003). Interestingly, young healthy individuals exhibit greater CoM displacements in the anterior-posterior direction and greater CoM velocities in the vertical direction during obstacle crossing (Chou, Kaufman, Brey, & Draganich, 2001). Chou et al. (2001) also concluded that CoM motion in the medial-lateral direction is less likely to be affected by obstacle crossing in young healthy individuals. The difference in CoM motion from greater anterior-posterior displacement to greater medial-lateral displacement as individuals age, reconfirms the notion that a deterioration in medial-lateral stability occurs over the lifespan.

A number of investigations have reported differences in CoM control between healthy young and elderly people when walking at different speeds and over uneven ground. Van Emmerik, McDermott, Haddad, & Van Wegen (2004) reported that elderly individuals consistently have reduced amounts of trunk flexion and extension while having greater amounts of trunk axial rotation during walking at higher speeds. Increased age also seemed to have a negative effect on compensatory movement between the pelvis and trunk (Van Emmerik et al., 2004). When challenged with walking on irregular surfaces elderly individuals tend to take shorter steps at reduced velocities with increased step time variability compared to their younger counterparts (Menz, Lord, & Fitzpatrick, 2003b). Elderly individuals minimize head and trunk accelerations by taking on a more conservative gait pattern, possibly to compensate for age related reductions in physiological function (Menz, Lord, & Fitzpatrick, 2003a). Healthy young individuals will tend to increase stride length rather than step frequency when forced to walk at higher speeds or walk on irregular surfaces (Hirasaki, Moore, Raphan, & Cohen, 1999; Menz, Lord, & Fitzpatrick, 2003b). In other experiments, young healthy individuals demonstrate stabilization patterns that maximize vertical and anterior-posterior stability at the expense of medial-lateral stability, during walking at higher speeds (Latt, Menz, Fung, & Lord, 2008). However, young individuals exhibit medial-lateral stability that is still at a level sufficient to maintain balance. If an elderly individual is forced to increase walking speed they could be using a similar strategy as younger individuals. However, due to the deficits in balance control that occur as a function of age, the destabilization that occurs in the medial-lateral direction is too great to maintain balance resulting in a fall. It is clear that one key component of balance that deteriorates over the lifespan is medial-lateral stability. The reason for this deterioration is still unknown, however, it is most likely not due to one specific variable but is rather a combination of muscle weakness, deteriorating muscle coordination patterns and deteriorating or changing sensory systems.

BALANCE STRATEGIES AND EXERCISE EFFECTS

An experiment by Wolfson, Judge, Whipple, and King (1995) produced evidence that lower extremity muscle weakness is correlated with falls in the elderly. Muscle weakness may play a role in the completion of certain exercises, such as the forward lunge. Evidence will be provided later in this document that points to using forward lunge training as an instrument for improvements in lower limb muscle strength, which then may result in a decrease in fall risk. Other areas of research have focused on the decline in sensation that occurs over the lifespan. Evidence exists showing that elderly individuals have decreases in the function of visual, vestibular and somatosensory systems (Sekuler & Hutman, 1980; Rosenhall, 1973; Skinner, Barrack, & Cook, 1984; Whanger & Wang, 1974). This may hinder the ability to perform a balance task, especially tasks that include the loss of a sensory system, such as any task requiring that the eyes be closed. There are three sensory systems the body uses to maintain balance; visual, vestibular and proprioceptive (somatosensory). Evidence has shown that with young individuals, during walking on irregular surfaces, the stability of the head is maintained by increasing accelerations about the pelvis (Menz, Lord, & Fitzpatrick, 2003a). This would ensure that the visual and vestibular systems are stabilized to allow for better indications of loss of balance should it occur. In elderly individuals, head accelerations were generally smaller but the smoothness of the signals was no different than from young individuals (Menz, Lord, & Fitzpatrick, 2003b). The decrease in acceleration of the head in elderly individuals suggests that they employ a more conservative approach to walking on the irregular surface to allow a more stable platform for the visual and vestibular systems; possibly to compensate for age-related physiological deficits. Head stability was found to be unaffected by age during a walking study completed by Kavanagh, Barrett, & Morrison (2005). However, the manner in which head stability was achieved was different between young and elderly individuals. Elderly individuals employed a head stabilizing strategy that involved an increase in trunk acceleration variability. This finding illustrates that elderly individuals are keeping their head stable by utilizing trunk joint movements, while younger individuals are maintaining head stability through the lower limb and pelvis. Kavanagh, Barrett, & Morrison (2005) also noted a decrease in head and trunk signal smoothness in the medial-lateral direction in the elderly group, consistent with previous research. This is evidence that elderly individuals may use a balance control strategy that manipulates CoM by reorientation of the trunk, while younger individuals may utilize foot placement to remain stable.

In a review completed by Zijlstra, van Haastregt, van Rossum, van Eijk, Yardley & Kempen (2007), it was uncovered that many different exercise interventions, such as home based exercise programs, multifactorial fall related programs, and tai chi interventions, decreased fear of falling and fall risk in older individuals. Other reviews of the literature have uncovered a plethora of experiments that have investigated the efficacy of exercise in its ability to reduce falls, fall risk and improve balance in elderly individuals. The following examples of exercise intervention experiments are a selected few based on the presence of a control group and randomized group selection. In 1997, Shumway-Cook, Gruber, Baldwin & Liao demonstrated that an exercise program for community-dwelling elderly individuals can reduce fall risk. Shumway-Cook utilized a protocol that targeted specific weaknesses for each participant and matched resistive or balance exercises to each weakness. Therefore, each person received a different exercise program that was designed to improve their specific weaknesses. The reduction in fall risk was also shown to be proportional to the adherence to the program; the greater the adherence to the exercise program, the greater the reduction in fall risk. This finding highlights the importance of continued exercise as individuals' age, as well as, the importance of maintaining an exercise program once it is initiated. However, there is some conjecture over the efficacy of exercise programs directed towards the elderly with the goal of reducing fall risk. Nowalk, Prendergast, Bayeles, D'Amico, & Colvin (2001) completed an experiment that aimed to compare the efficacy of a resistance and endurance training program, and a tai chi program with a control group of elderly individuals that were living in a long term care facility. The findings from Nowalk et al. (2001) were that no difference between any of the groups existed for time to first fall, number of days hospitalized, and incidence of falls. Adding to this conclusion was Latham, Anderson, Lee, Bennett, Moseley, & Cameron (2003) who conducted an experiment involving 243 frail elderly split up into an exercise and a control group. The persons in the exercise group were given daily vitamin D pills and participated in a home based high-intensity quadriceps training program. The researchers concluded that neither the quadriceps training nor the vitamin D supplementation had an effect on rehabilitation outcomes in frail elderly (Latham et al., 2003). Furthermore, an exercise program consisting of a seated balance exercise program was found to not have an effect on fall prevalence or fall risk (McMurdo, Millar, & Daly, 2000). In support of Nowalk et al. (2001) and Latham et al. (2003), Faber, Bosscher, Chin A Pow, & van Wieringen (2006) reported that fall incidence was highest among groups that actually received the exercise treatment. When the groups were subdivided into frail elderly and pre-frail elderly it was revealed that this effect was largest among the frail elderly. The authors concluded that exercise interventions have a detrimental effect on the frail elderly but can produce positive effects on physical performance and fall risk with the pre-frail elderly (Faber et al., 2006). Since the researchers found no difference in physical performance measures after the intervention, the increased fall incidence among frail elderly could be due to the exercise making the frail elderly more confident and more apt to put themselves in higher risk situations. These conclusions lie in contrast with the conclusions drawn by Hauer, Rost, Rutschle, Opitz, Specht, Bartsch, Oster & Schlierf (2001) who suggest that progressive resistance training and progressive functional training reduce fall related behavioral restrictions, increase strength and increase physical performance in high risk elderly individuals with a history of falls. Furthermore, a study by Buchner, Cress, Lateur, Esselman, Margherita, Price, & Wagner in 1997 revealed that although no effects on gait, balance and health status occurred after an extensive exercise program, a control group suffered a higher risk of falls and had more outpatient hospital visits during months

7-18 of the study. The exercise group in this study completed strength and endurance training using weight machines as well as stationary bicycles in supervised exercise bouts three times per week. This is evidence that a multidimensional exercise program in elderly individuals may lead to lower fall rates and lower medical costs. These differences in results between exercise studies may be due to the use of different exercise prescriptions.

Further evidence for the efficacy of exercise training was found by Rogers, Fernandez, & Bohlken (2001) who reported that postural sway decreased and functional reach performance increased, in an elderly sample following an exercise program that included activities completed on an inflatable exercise ball. Long term benefits of participation in a clinical walking trial in a large sample of post-menopausal women was found by Pereira, Kriska, Day, Cauley, LaPorte, & Kuller in 1998. A ten year follow-up was conducted after participation in a clinical walking trial exercise program. Pereira et al. (1998) found that the women in the clinical walking trial walked more often, had fewer falls, fewer hospital visits and fewer surgeries than the women in the control group. They also reported a higher incidence of physician diagnosed heart disease in the control group. This follow-up study was based on self reports by the participants; however, it does reveal a trend that participation in a randomized controlled clinical trial encourages individuals to exercise more often, even many years after the trial, which translates into lower incidence of falls and an overall healthier life. Benefits of exercise programs have also been shown for diseased populations, such as individuals with osteoporosis (Carter, Khan, McKay, Petit, Waterman, Heinonen, Janssen, Donoldson, Mallinson, Riddell, Kruse, Prior, & Flicker, 2002). Carter et al. (2002) evaluated the efficacy of a physician prescribed exercise program with 80 elderly women with osteoporosis. The researchers reported significant improvements in dynamic balance and strength, as well as, larger but non-significant improvements in static balance in the exercise group when compared to the control group after 20 weeks of exercise (Carter et al., 2002). Further evidence for the efficacy of exercise programs has been provided by Cornillon, Blanchon, Ramboatsisetraina, Braize, Beauchet, Dubost, Blanc, & Gonthier (2002). Cornillon et al., (2002) recruited over 300 participants to take part in a randomized controlled trial study.

One hundred fifty elderly people took part in a ten session long exercise program that focused on balance, muscular activity and coordination. Participants in the exercise group performed better on exercise tests and had lower rates of falls post-exercise training when compared to the participants in the control group (Cornillon et al., 2002). The most important finding from this study was the fact that the participants recruited for the experiment were already active, independent living individuals. Therefore, exercise programs can further benefit balance and reduce falls even in those that have active lifestyles. In the same year a different group of researchers, Day, Fildes, Gordom, Fitzharris, Flamer, Lord (2002), also came to similar conclusions as Cornillion et al. (2002). In the study by Day et al. (2002), several interventions, such as exercise training, home hazard management, and vision correction were tested with a total sample of 1090 home dwelling elderly participants, aged 70 and over, that also rated their health as excellent. Day et al. (2002) found that a group-based exercise intervention improved balance measures and resulted in a decreased fall rate, over the course of eighteen months, when compared to a control group. However, the positive effects of exercise do not always persist after the exercise program is discontinued. Improvements found with an exercise program were not seen during an eight week follow up in an experiment completed by Westlake, Wu & Culham (2007).

Strength changes are not the only changes that have been shown to occur with exercise training in older adults. Maejima, Sunahori, Kanetada, Murase, Tobimatsu, Otani, & Yoshimura (2009) recruited twenty six healthy elderly individuals to take part in a three month exercise program that included extended walking periods, stretching, strengthening and balance exercises. Postural responses to a fore and aft horizontal translation by a force plate platform were recorded before and after the exercise training. Neurological adaptations, such as an increase in lower limb musculature EMG amplitude and a decrease in muscle activation onset following a perturbation to standing balance was reported after the three months of multi-component exercise training that included balance exercises (Maejima et al., 2009). Home based exercise programs have also been shown to be effective. In a study from 2009, a group of 61-74 year old chronic obstructive pulmonary disease patients were given a series of exercises that included the forward step up, lateral step up, heel raise, and lunges to be complete at home for eight weeks (Santiworakul, Jarungjitaree, Jalayondeja, Chantarothorn, & Supaibulpipat, 2009). Interestingly, no change in muscle strength was seen post exercise when compared to a control group; however, individuals in the exercise group showed a significant increase in the distance covered in the six minute walk test post exercise when compared to the control group (Santiworakul et al., 2009). This study is of importance since it has given evidence that simple short duration exercises can have an impact on an individuals walking capacity. The type of exercise used as the intervention seems to have an effect on the efficacy of the intervention. Thus, the above research suggests that exercise programs that contain a strong upright balance component appear to have the greatest effect on risk of falling.

THE FORWARD LUNGE STEP

Exercise programs that are complicated and difficult to follow without assistance can result in a large drop-out rate. Therefore, when creating exercise programs, the ability and ease with which an individual can complete an exercise program unsupervised should be considered. The simplest exercise program is one that contains only one component. The forward lunge makes an excellent exercise for the senior population because it combines balance control, specifically in the medial-lateral direction, with lower extremity muscle strength. It also provides a proprioceptive challenge to the lower limb. Although the forward lunge destabilizes the trunk in the anterior-posterior direction, the planting of the lead foot arrests this destabilization. The destabilization that occurs in the medial-lateral direction can only be compensated for by altering foot placement of the lead limb to create a wider base of support, or by utilizing pelvis and trunk musculature to keep the CoM within the base of support.

Previous research has shed some light on the kinetics and kinematics involved in the forward lunge. The hip of the lead limb has been shown to generate 53% of the total extensor impulse while the knee and ankle contribute 26% and 21% respectively during the forward lunge (Flanagan, Wang, Greendale, Azen, & Salem, 2004). The forward lunge requires activation of core stabilizers as well as stabilizers of the knee, ankle and hip. Co-activation of the quadriceps and hamstrings has been shown to be present during all phases of the forward lunge indicating the strong association this exercise has with knee stability (Pincivero, Aldworth, Dickerson, Petry, & Shultz, 2000). One report on EMG activity in the vastus medialis during the lunge approximated it to be 45% of maximum voluntary contraction, suggesting that strengthening of that muscle may occur (Ekstrom, Donatelli, & Carp, 2007). The lunge has been included in many different exercise programs and has been recommended, as early as 1977, as an excellent exercise for the elderly (Frankel & Richard, 1977). The lunge, when completed with proper form, has also been recommended as a good exercise for back injury rehabilitation because it challenges strength, endurance, balance and mobility in the lower limbs (McGill, 2002). Importantly, the ACL strain during the forward lunge was found to be equal or similar to other rehabilitative exercises (Heijne, Fleming, Renstrom, Peura Beynnon, & Werner, 2004). However, results from a study by Escamilla, Zheng, Macleod, Edwards, Hreljac, Fleisig, Wilk, Moorman, Imamura, and Andrews (2008) suggest that the distance an individual steps during the lunge exercise would seem to alter the patellofemoral joint force that is experienced. Escamilla et al., (2008) tested eighteen subjects as they completed a 12 repetition lunge exercise with maximum weight and found that shorter steps during the lunge caused greater amounts of petellofemoral joint force. In 2008, Wilson, Gibson & Masterson used an inverse dynamic model to test shear forces produced during two styles of forward lunges in ten healthy volunteers. Wilson et al. (2008) concluded that the shear forces produced clinically safe inertial shear forces in both styles of lunge. Other researchers have looked at trunk position during the forward lunge and found that it influences hip and ankle musculature EMG (Farrokhi, Pollard, Souza, Chen, Reischl, & Powers, 2008). Farrokhi et al. (2008) had five young male and five young female participants perform forward lunges with their trunks at varying degrees of flexion and extension. Farrokhi et al. (2008) found that hip extensor and ankle plantar flexor impulses, as well as, gluteus maximus and biceps femoris EMG were all increased during lunges with the trunk forward when compared to lunges with an erect trunk. Therefore, if the goal is to minimize injury, as is the case when dealing with an elderly population, it is important to instruct individuals to keep their trunk in an upright position during a forward lunge. This evidence suggests that the lunge is a simple and effective way to challenge the elderly as long as proper form is used.

There are two main variables involved in an individual’s ability to maintain balance during any sort of stepping activity, foot placement and trunk stabilization. In the current study, differences in balance strategy between exercise and control groups during a forward lunge in elderly women will be dissected by examining foot placement and trunk stabilization. This study’s primary aim is to record differences between an exercise and a control group in balance task performance after a six week lunge training exercise protocol. A secondary purpose is to assess differences in the balance strategy of exercise and control groups while performing a forward lunge exercise. This exercise was chosen because it challenges medial-lateral stability in the elderly.

METHODS

PARTICIPANTS

Nineteen community dwelling elderly individuals were recruited from line dancing classes from two locations of the Centers For Seniors located within the city of Windsor. Participants from one location were assigned as an exercise group, while participants from the other location were assigned as the control group. The two locations of the senior's center have identical recreation and dance programs. Furthermore, the same instructor taught the classes at both locations. Eleven volunteers participated in the exercise group and eight individuals were assigned to the control group. All participants were free of musculoskeletal and neuromuscular disorders that may have prevented them from completing a forward lunge.

EQUIPMENT

Full body motion capture was recorded using a passive marker system with Vicon. A Basler digital video camera was also used to record data throughout the trials. All equipment was synchronized and a sample rate of 50Hz was used. Data was collected and processed using the VICON software Nexus. The full body (UPA and FRM) plug-in gait model was used to process the motion capture data. The model outputs include an X,Y,Z coordinate for each marker placed on the participant 50 times per second. The model also calculates X,Y,Z coordinates for the center of mass (CoM). Plug-in gait also calculates forces, moments and powers at each major joint in the body. Data was further analysed using custom MatLab scripts. The coordinate system used set X in the medial-lateral direction, Y in the anterior-posterior direction and Z in the vertical direction.

PROTOCOL

Ethics approval was garnered for the following methods by the University of Windsor Research Ethics Board. Individuals in the control group were instructed to come into the lab, one at a time, for an initial balance assessment, as well as, a balance assessment after three weeks and again after six weeks. Participants in the control group were asked to maintain their normal daily activities and to not practice anything that they experienced in the lab during their initial, or follow-up assessments. Participants in the exercise group were also asked to come into the lab, one at a time, for an initial balance assessment as well as a three week, and six week follow-up balance assessment. The balance assessment had the same components every visit and was consistent across groups. A detailed description of the balance assessment is provided later in this document. Individuals in both the exercise and control group were given proper instructions about how to complete a forward lunge exercise. Participants in the exercise group, however, were instructed to practice the forward lunge every day for the six weeks of the experiment. These individuals were given daily journals and were asked to answer the same four questions per day. They had to record how many sets of lunges they completed, how many lunges they completed per set, what time of the day they completed the lunges, as well as, indicate whether they used assistance while completing the lunges. Assistance was classified as a participant holding onto something, such as a chair, table, countertop or railing, for support while completing the lunges. Every participant in the exercise group was instructed to use assistance for the first three weeks of daily lunging to assist the learning of proper posture. During the three week follow-up lunge posture was corrected once more for participants in both groups to ensure that individuals were completing the lunges to the best of their abilities. All participants in the exercise group started with a prescription of between 10-20 lunges per day. The number of lunges completed each day was increased periodically throughout the initial three weeks of lunging and was increased on a per person basis, adjusted to meet the individuals' ability level, to ensure that everyone was similarly challenged. When participants were asked to start completing the daily lunges without assistance, after the conclusion of the three week follow-up, the lunge prescription was temporarily decreased to avoid participants being overly challenged. Participants received a phone call from the experimenter once a week between lab visits to check up on the progression of the activity, and to allow time for any questions, comments or concerns. An increase or decrease to the lunge prescription was done at this time based on the feedback gained from the participant.

Initial Lab Visit

All individuals began the experiment after the protocol was explained to them in detail. They were then asked to read the Information Letter and were given an opportunity to ask questions. Once the individual was ready to continue with the experiment she was asked to sign the Letter of Informed Consent (Appendix IV). The participants were also reminded verbally that they may withdraw from the experiment, for any reason, at any time without consequence. Participants started by filling out the Godin Leisure Time Questionnaire (Godin & Shephard, 1985), the Activities-specific Balance Confidence (ABC) questionnaire (Powell & Myers, 1995) and the SF-36 Health Survey (Ware, Snow, Koninski, & Gandek, 1993). The Godin Leisure-Time Exercise Questionnaire (Appendix I) revealed how physically active the participants were. The ABC questionnaire (Appendix II) provided information on how confident people are that they will not lose their balance or fall during many different activities. The SF-36 Healthy Survey (Appendix III) provided insight into the self-reported mental and physical wellbeing of each individual. Following the questionnaires, the individuals were fitted with 39 passive Vicon markers. Four markers were placed on the head: front left, front right, back left, and back right. Each arm had 7 markers placed on it: superior acromioclavicular joint, lateral upper arm, lateral epicondyle, lateral lower arm, medial wrist, lateral wrist and posterior head of the third metacarpal. The torso and pelvis had 9 markers placed on it: suprasternal notch, xiphoid process, spinous process of vertebrae C7 and T10, inferior angle of the right scapula, left and right ASIS, as well as, left and right PSIS. Each leg had 6 markers placed on it: upper lateral thigh, lateral lower leg, lateral knee joint, lateral malleolus, posterior heel, and superior surface of the head of the second metatarsal. A visual representation of the marker placement is illustrated in Fig. 1. The participant was instructed to walk around for a few minutes wearing the markers to get comfortable with them being attached to her body.

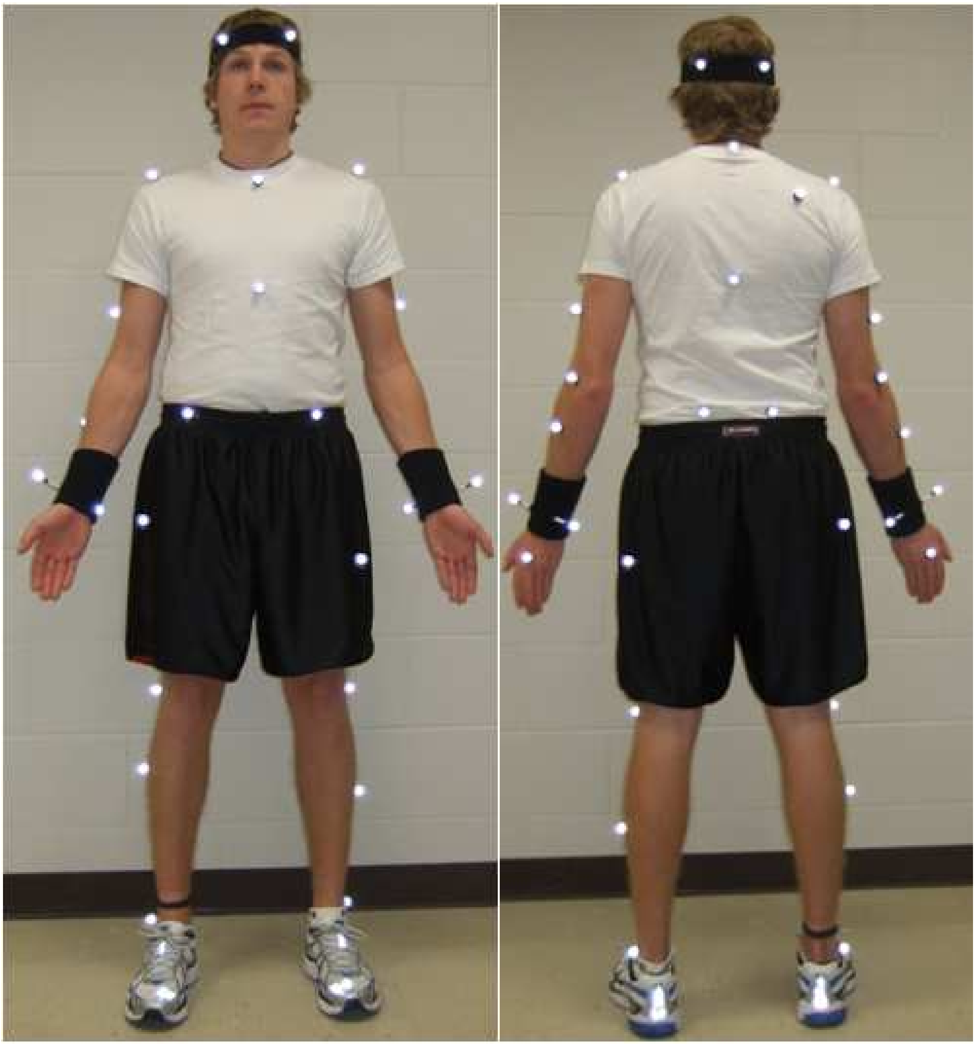

Figure 1- Full body motion capture marker placement of 39 passive reflective markers used for Vicon data collection. Anterior view (left) Posterior view (right).

Participants completed all tasks while wearing walking or running shoes. Once the balance tests were completed, the participant observed a video depicting a person completing a lunge. The participants were also given verbal instructions about the proper technique of a forward lunge. Once the participants understood how to complete a forward lunge they were asked to perform 5 lunges with each leg as the lead leg, (10 lunges in total). Participants also received the following verbal instructions: forward lunges are performed by first, taking a step as far forward as is comfortable while keeping the back upright in a neutral position. Then, lower your trunk by flexing the lead knee and hip while keeping an upright posture. The lead limb knee must never pass beyond the toes of the same leg.

After completing ten lunges, participants were given verbal feedback about their performance. The experimenter corrected any improper technique while the participant performed 2-6 more lunges without any data being recorded. Once the participant could complete a lunge with proper technique the testing session was ended. Rest periods were provided as needed by the participant throughout the experiment.

Balance Assessment

One legged stance test (OLS)

Procedures for the OLS test followed those by Cho, Scarpace, & Alexander (2004). The participant was instructed to stand on her preferred leg. For this experiment, the preferred leg was classified as the leg with which the participant thought she could perform the best with. To help the participant decide which leg was their preferred leg they were asked to try standing on one leg for a few seconds with each leg. It was usually very obvious that there was a difference between the performance of each leg and participants, for the most part, chose the preferred leg very easily. The length of time participants could stand on one leg was recorded with a stopwatch by the experimenter. The test was stopped when the participant’s non-stance foot touched the ground, a fall was prevented by an experimenter or 30secs of one legged stance elapsed. This was repeated over 3 trials. This test was then repeated with eyes closed (EC), eyes open (EO) while standing on a compliant surface (10cm thick foam), and eyes closed while standing on the foam. Participants were then asked to complete the EO and EC on non-compliant ground with their non-preferred leg. During eyes closed trials timing was suspended if the individual opened their eyes, their non-stance foot touched the ground, a fall was prevented by an experimenter or 30secs of one legged stance elapsed. Participants were instructed to take a short walk around the room between standing trials to help decrease the likelihood of fatigue in the leg used for support. Participants were also given short rest periods if they felt as though their legs were getting tired.

Maximal step length test (MSL)

Procedures for the MSL test followed those by Cho, Scarpace & Alexander (2004). The participants were instructed to step forward with one leg as far as they could, then return to a standing position. They completed this task three times with whichever leg they thought they could step furthest with. The distance from toe of the lead leg to the toe of the trailing leg for all of the trials was recorded using Vicon.

Timed up and go test (TUG)

Procedures for the TUG followed those by Podsiadlo, & Richardson (1991). The participants started in a seated position on an armless chair. On a go signal given by the experimenter, participants were instructed to stand up, walk three meters, turn 180 degrees, and walk back to the chair to sit down. Participants were instructed to complete the task as quickly as possible without running, jogging, and without putting themselves in danger of losing balance. Timing was recorded with a stopwatch. Timing began as soon as the participant made forward motion to get out of the chair and ended when the participant made contact with the chair when sitting back down.

For all eight balance test measures, the median of the three trials was used in the statistical analysis. This was done to prevent one trial from having a greater affect if the participant had one abnormally bad or one abnormally good trial.

Variables of Interest during the Forward Lunge

During each lab session participants were asked to complete ten lunges, five with each limb as the lead limb. Several variables were used from the analyses of the full body motion capture data. All of the lunge trials were clipped to include only the step forward and the downward motion as the participants lowered themselves towards the floor. The cut-off point was the moment that the downward motion of the trunk changed direction upward. The return to standing position from the lunge position was therefore not included in the anaylses.

Measures included: step length and width, maximum displacement of the CoM in all directions, maximum knee flexion angle, maximum trunk angle in all directions and maximum velocity of the head, trunk and pelvis in all directions. The last point in the data for each trial was used to calculate step width and step length using the distances between the toe marker for each foot in the X (medial-lateral) and Y (anterior-posterior) directions respectively. The maximum distance that the center of mass (CoM) traveled away from the starting position in the Z (up and down) direction, as well as the X (medial-lateral) direction was calculated. The angle of each lead knee was calculated when the participant was at the lowest part of the lunge. The maximum angle of the trunk in the X, Y, Z direction was calculated. The maximum velocity, in all three planes (X, Y, Z), of the head, trunk and pelvis was also calculated by averaging the maximum velocities of the two markers placed on the left and right front head, clavicle and C7, and left and right front pelvis respectively. The displacement of the trunk relative to the pelvis was calculated at the end point of the lunge in the medial-lateral and forward directions.

Data Gaps

Several kinds of gaps in the data were found and each kind of gap was treated in a different way. Firstly, due to data corruption one participant in the exercise group was missing lunge data during the baseline testing session. The group average for each variable was used to fill in this participant's missing data. Secondly, two participants from the control group were missing data from the second testing session. One individual was sick and therefore missed the testing session while the other participant's lunge data was unobtainable due to marker dropout that was too severe to be reconstructed. Both of the data sets for these individuals were treated in the same manner. The first and third testing session were averaged to produce data for the second session. The data set that was created for these participants matched the group trends. Finally, marker dropout occurred frequently throughout the testing of all participants. Marker dropout occurs when a marker is unable to be located by the Vicon camera system. The Vicon software, Nexus, has two ways of dealing with marker drop out. The first is to use a mathematical algorithm called spline fills to bridge the gap in the marker trajectory. The second is to use the location of a known marker to calculate the position of the missing marker, this is known as position fill. For gaps in the data that were six frames (<0.12seconds) or smaller, the spline fill option was used to bridge the gap. For gaps that were larger than six frames (>0.12seconds) the position fill was used.

Statistical Design

For each testing session participants completed eight balance tests and ten lunges. The data recorded from the eight balance tests consisted of three trials for each test. The median value for each test was used in the statistical analyses. Each variable of interest for the lunges was averaged across the ten lunge trials for each participant on each testing session. Participant data was separated into exercise group and control group data. Firstly, a one way ANOVA was completed for all balance measures, as well as the data garnered from the questionnaires, using baseline data only to ensure that the participant groups did not differ at baseline with regard to their balance ability, age, number of medications taken, self-reported physical and mental wellbeing and activity level. Secondly, a two way mixed ANOVA with repeated measures was conducted for all eight balance tests as well as all variables of interest during the lunge; data was compared between groups and across three testing sessions. Thirdly, a Pearson Product Correlation was performed using the baseline balance measures and lunge data with all participants pooled together. Significance for all statistical analyses was defined as a $p<0.05$.

RESULTS

PARTICIPANT DEMOGRAPHICS

A one-way analysis of variance (ANOVA) revealed that the exercise group and the control group did not differ significantly with respect to age, height, weight, number of medications taken, self-reported physical and mental wellbeing, balance confidence and activity level (Table 1). Both the ABC questionnaire and the SF-36 Health Survey are based on a 100 point scale with larger numbers representing greater amounts of balance confidence and greater self reported physical and mental health respectively. The SF-36 questionnaire can be divided into several components which are shown in Table 2. Participant groups did not differ with respect to self reported physical function, as well as, general health. All participants were moderately active according to the American College of Sports Medicine and the American Heart Association (Haskell, Lee, Pate, Powell, Blair, Franklin, Macera, Heath, Thompson, & Bauman, 2007) with an average self-reported weekly participation in moderate to vigorous activity of 3 times per week. However, the amount of activity is below the recommended amount for adults of five 20 minute bouts of moderate activity per week, as stated by the American College of Sports Medicine and the American Heart Association (Haskell et al., 2007). Furthermore, several one-way ANOVAs confirmed that the exercise and control groups did not differ significantly on any of the eight balance tests at baseline.

Table 1

Average demographic data scores for exercise and control groups

	Age (yrs)	Height (cm)	Weight (kg)	Number of medications taken	Activity level (moderate + vigorous) per week	Balance confidence (ABC) score	SF-36 Health Survey Score
Exercise	72 ±3	158 ±6	65 ±10	2 ±1	3 ±3	89 ±6	90 ±6
Control	69 ±3	161 ±8	73 ±17	3 ±3	3 ±2	80 ±12	90 ±7

Table 2

Average of Sub-categories of the SF-36 Healthy Survey for exercise and control groups

	Physical Function	Physical Limitations	Emotional Limitations	Energy	Emotional Wellbeing	Social Function	Pain	General Health
Exercise	83 ±18	100 ±0	100 ±0	75 ±11	88 ±9	98 ±8	84 ±10	82 ±12
Control	82 ±15	91 ±18	79 ±39	63 ±18	76 ±15	94 ±11	76 ±15	79 ±10

Results from the daily journals maintained by the exercise group revealed that there was a very good compliance with the assigned lunge prescription. Participants missed an average of 4 ±4 days out of the six week period. This translates into participants not completing the assigned lunges less than one day per week, on average, during the experiment. None of the participants dropped out of the experiment. Furthermore, all individuals were able to perform non-supported lunges.

BALANCE TESTING

For all of the repeated measures ANOVAs completed, Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated. Of the eight balance tests performed, only one revealed a significant time by group interaction. A two-way mixed ANOVA with repeated measures showed a significant testing session by group interaction of the Maximal Step Length test $F(2,34)=3.758$, $p<0.034$. The exercise and control groups did not differ significantly at baseline; however, the control group was stepping significantly further during the MSL test at the 6 week (session 3) testing period (Fig. 2).

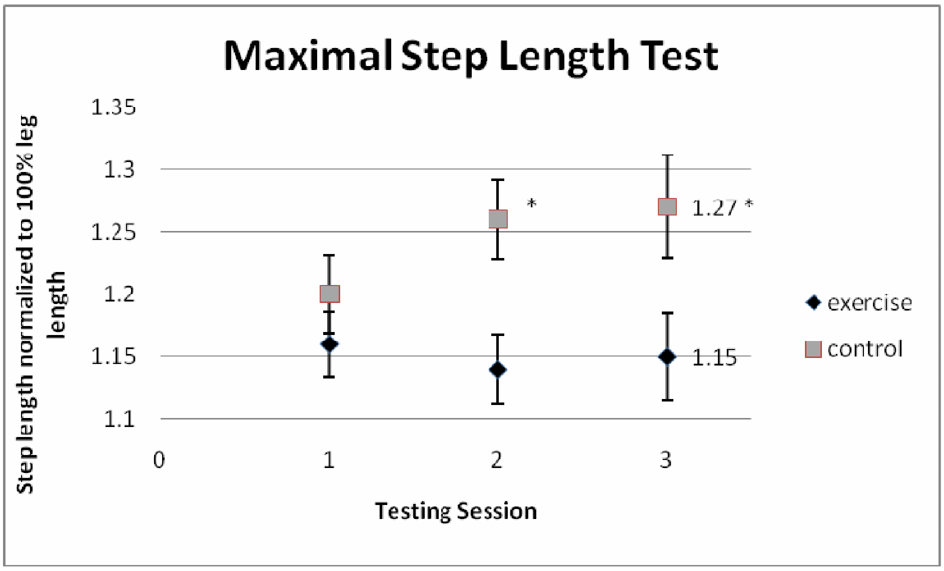

Fig. 2 – Maximal step length test with step length normalized to 100% of leg length. Data represents average values for each participant group at each testing session, based on the median of three trials per participant at each session. There is a significant testing session by group interaction. (error bars represent Standard Error) n=19

* indicates significant difference at testing session 2 and 3 ($p<0.05$)

Two-way mixed ANOVAs with repeated measures indicated a strong time main effect with three of the balance tests. Firstly, one legged standing with eyes open on the preferred leg performance significantly improved for all participants across testing sessions $F(2,34)=6.93$, $p<0.003$ (Fig. 3). Secondly, one legged standing performance with eyes closed on a foam surface increased as a function of testing session for all participants $F(2,34)=3.52$, $p<0.041$ (Fig. 4). Thirdly, performance on the Timed-up-and-go test increased over time for all participants $F(2,34)=19.6$, $p<0.001$ (Fig. 5).

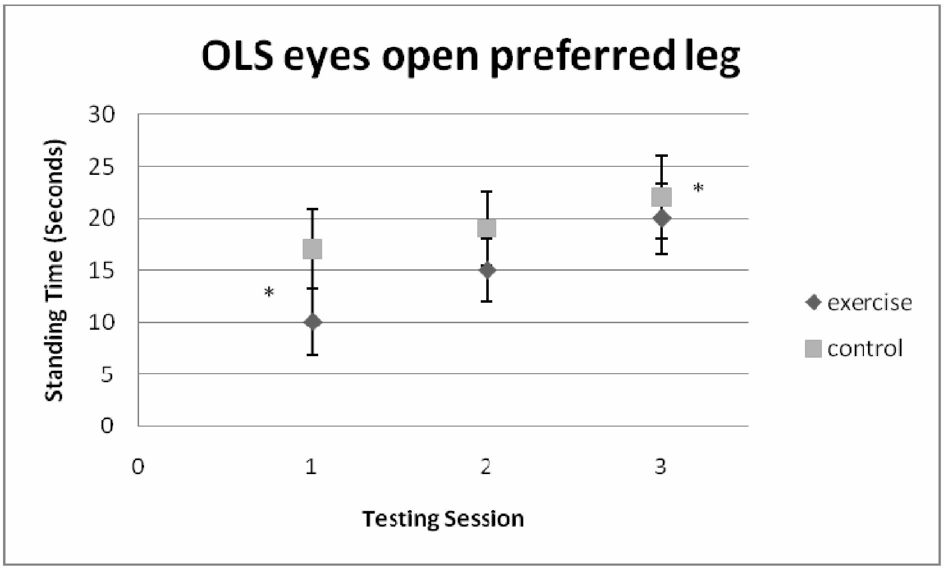

Fig. 3 – Main effect of one legged stance eyes open on the preferred leg. Data represents average values for each participant group at each testing session, based on the median of three trials per participant at each session. There is no difference between groups, however, there is a significant time effect. (error bars represent Standard Error) n=19

* indicates significant difference between testing session 1 and 3 ($p<0.05$)

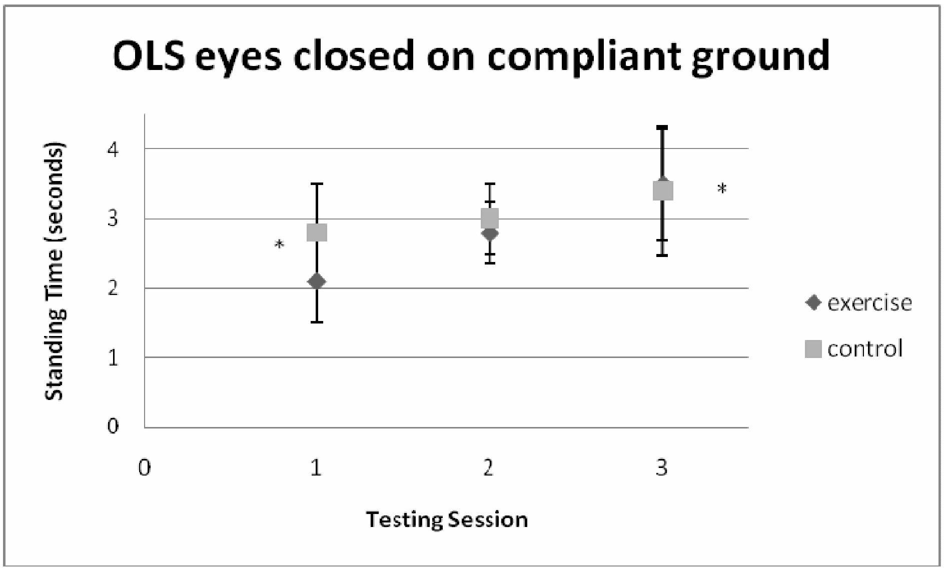

Fig. 4 – Main effect of one legged stance with eyes closed on compliant ground. Data represents average values for each participant group at each testing session, based on the median of three trials per participant at each session. There is no difference between groups, however, there is a significant time effect. (error bars represent Standard Error) n=19

* indicates significant difference between testing session 1 and 3 ($p<0.05$)

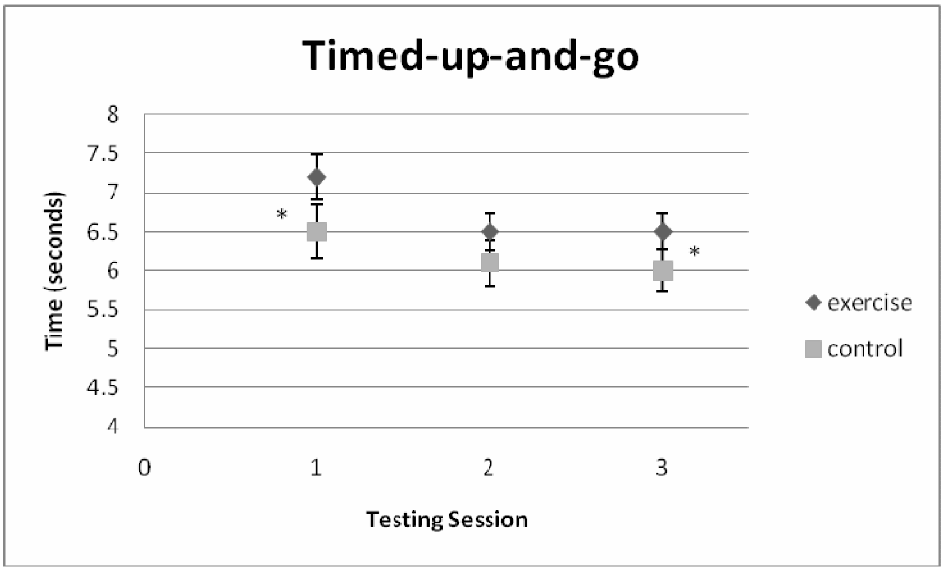

Fig. 5 – Main effect of the Timed-up-and-go test. Data represents average values for each participant group at each testing session, based on the median of three trials per participant at each session. There is no difference between groups, however, there is a significant time effect. (error bars represent Standard Error) n=19

* indicates significant difference between testing session 1 and 2 ($p<0.05$)

LUNGE PERFORMANCE

Measures of lunge performance included: step length and width, maximum displacement of the CoM in all directions, maximum knee flexion angle, maximum trunk angle in all directions and maximum velocity of the head, trunk and pelvis in all directions.

A two way mixed ANOVA with repeated measures revealed several variables that were shown to have a significant testing session by group interaction. Firstly, step length while lunging at the baseline testing period (session 1) did not differ between groups. However, by the end of six weeks the control group was stepping further than their baseline values while the exercise group maintained their original step length F(2,34)=4.83, p<0.016 (Fig. 6). Step length data for all participants in each of the control and exercise groups are presented in Fig. 7 and Fig. 8.

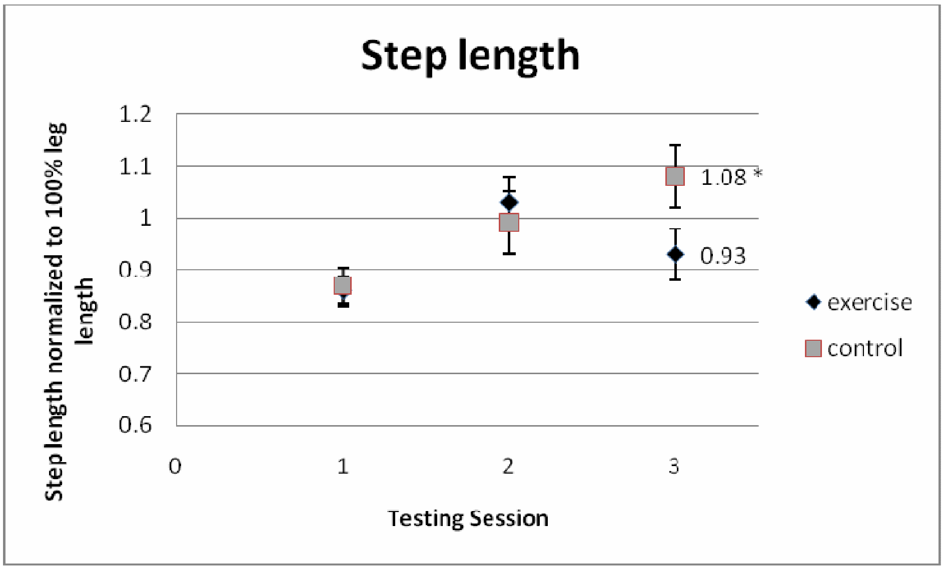

Fig. 6 – Step length normalized to 100% leg length during the lunge. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is a significant testing session by group interaction. (error bars represent Standard Error) n=19

* indicates significant difference between groups at testing session 3 (p<0.05)

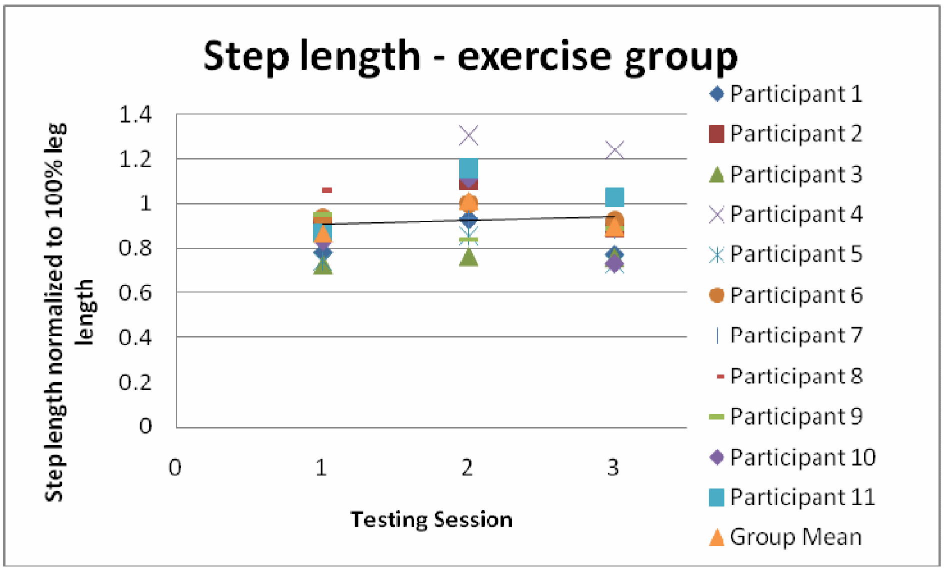

Fig. 7 – Step length during the lunge normalized to 100% leg length for all participants in the exercise group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Eight of eleven participants followed the same linear trend as the group mean. (n=11)

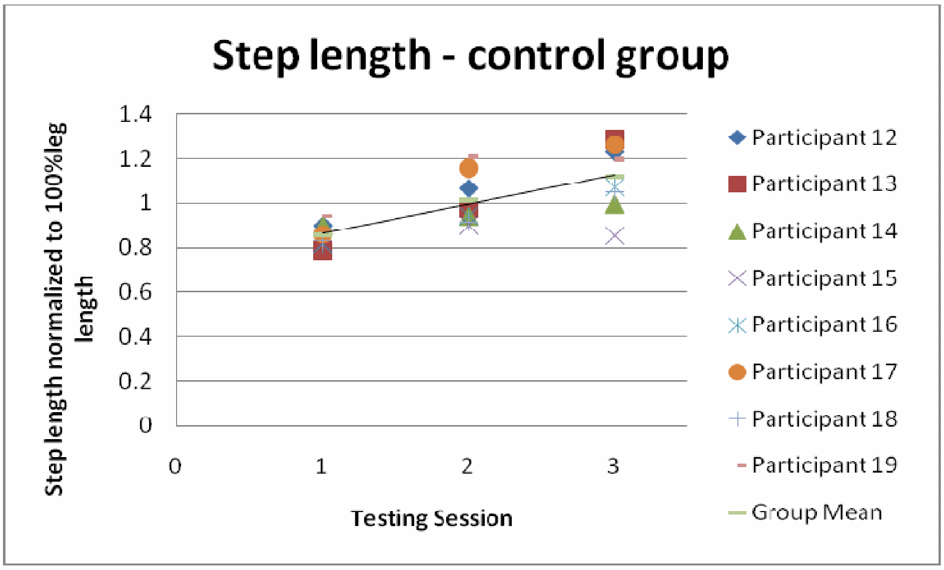

Fig. 8 - Step length during the lunge normalized to 100% leg length for all participants in the control group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Seven of eight participants followed the same linear trend as the group mean. (n=8)

Peak forward pelvis velocity and peak forward trunk velocity also revealed significant group x testing session interactions, such that the control group was completing the lunge with higher peak velocities after 6 weeks while the exercise group maintained their original velocities. Significance for the peak pelvis velocity in the forward direction was F(2,34)=5.26, p<0.01 (Fig. 9). For this variable, each group is plotted separately in Fig. 10 and Fig. 11 to more easily see the effect that each participant had on the overall trends throughout the data.

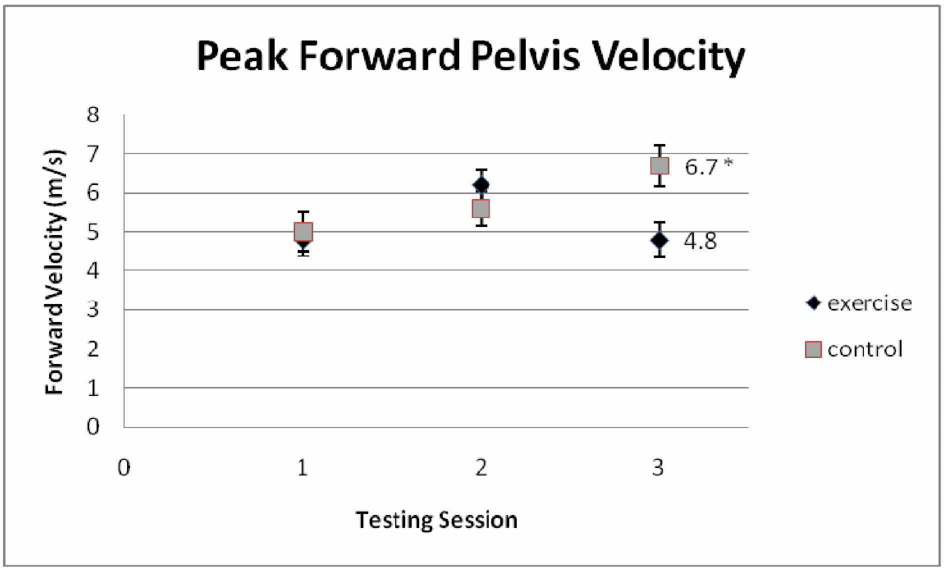

Fig. 9 – Peak pelvis velocity in the anterior-posterior direction expressed in meters per second. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is a significant testing session by group interaction. (error bars represent Standard Error) n=19

* indicates significant difference between groups at testing session 3 (p<0.05)

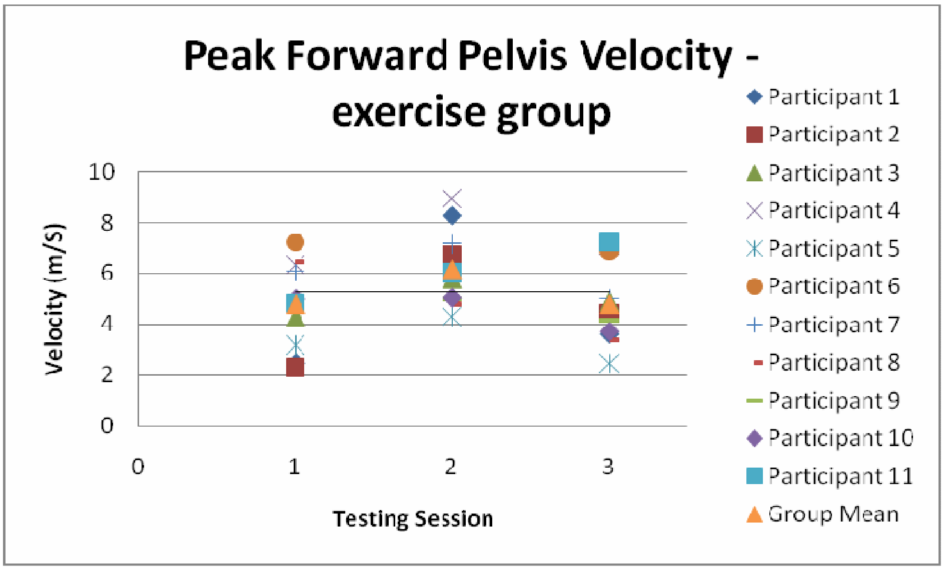

Fig. 10 – Peak forward pelvis velocity with all participants from the exercise group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Eight of eleven participants followed the same linear trend as the group mean. (n=11)

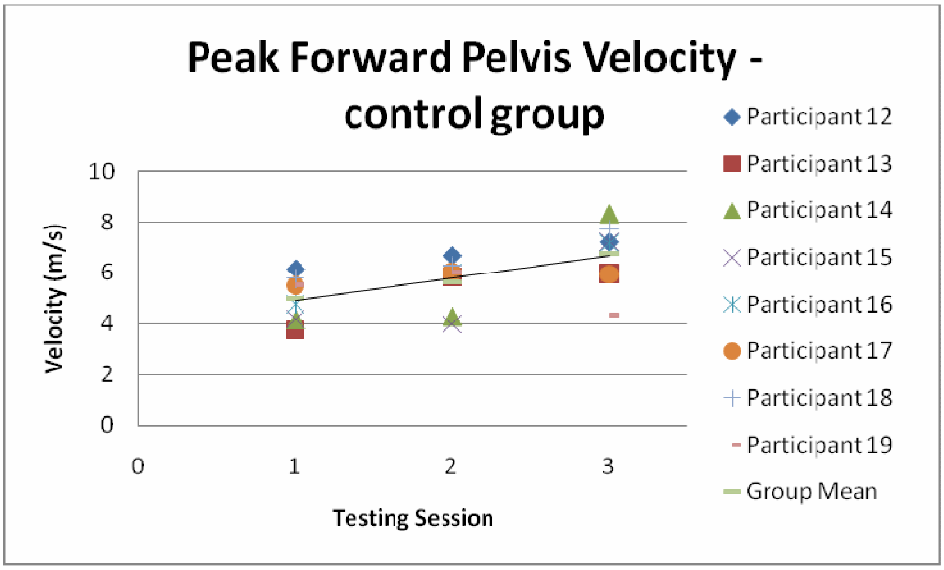

Fig. 11 – Peak forward pelvis velocity with all participants from the control group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Seven of eight participants followed the same linear trend as the group mean. (n=8)

The significance for the group by testing session interaction for the peak trunk velocity in the forward direction was F(2,34)=4.13, p<0.025 (Fig.12). Groups were plotted separately in Fig. 13 and Fig 14. to see the overall trend of each participant.

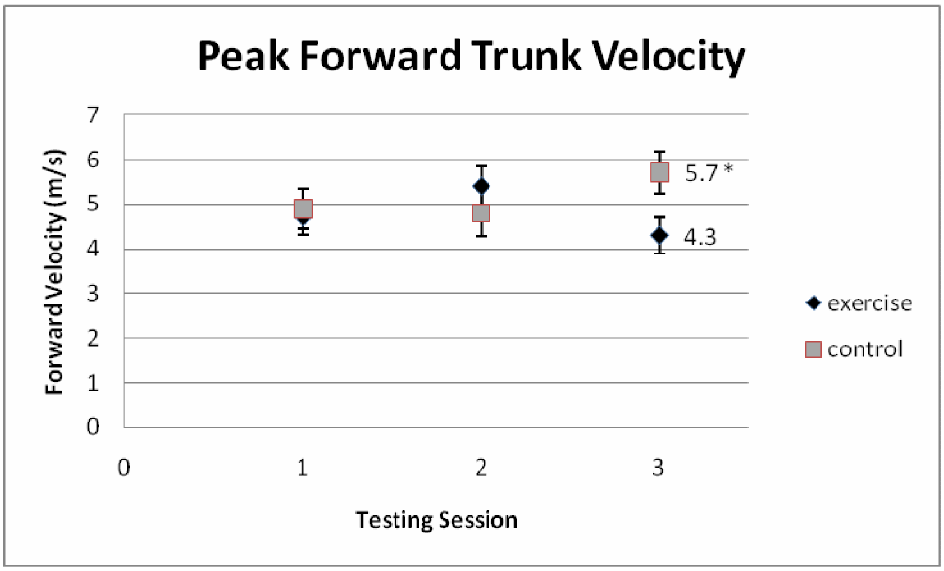

Fig. 12 – Peak trunk velocity in the anterior-posterior direction expressed in meters per second. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is a significant testing session by group interaction. (error bars represent Standard Error) n=19

* indicates significant difference between groups at testing session 3 (p<0.05)

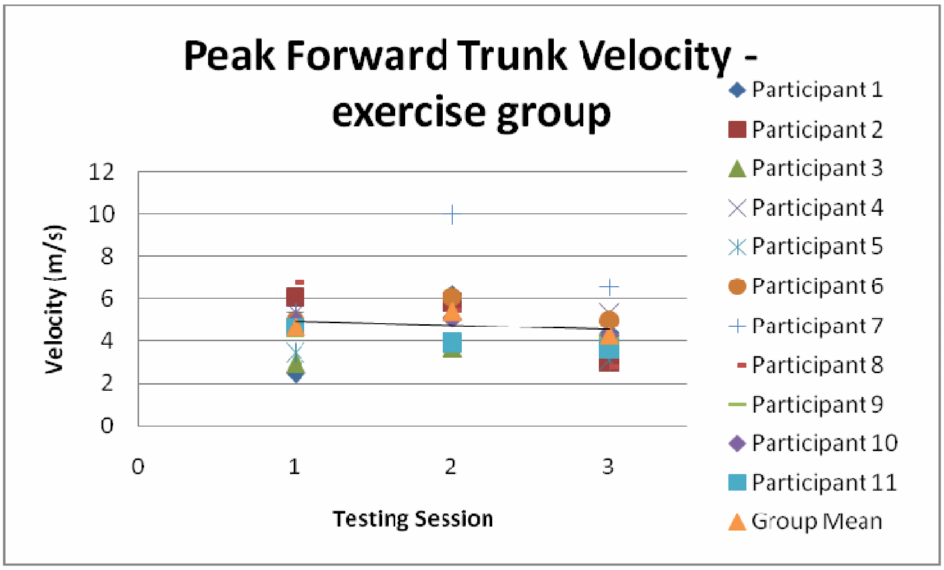

Fig. 13 – Peak forward trunk velocity for all participants in the exercise group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Ten of eleven participants followed the same linear trend as the group mean. (n=11)

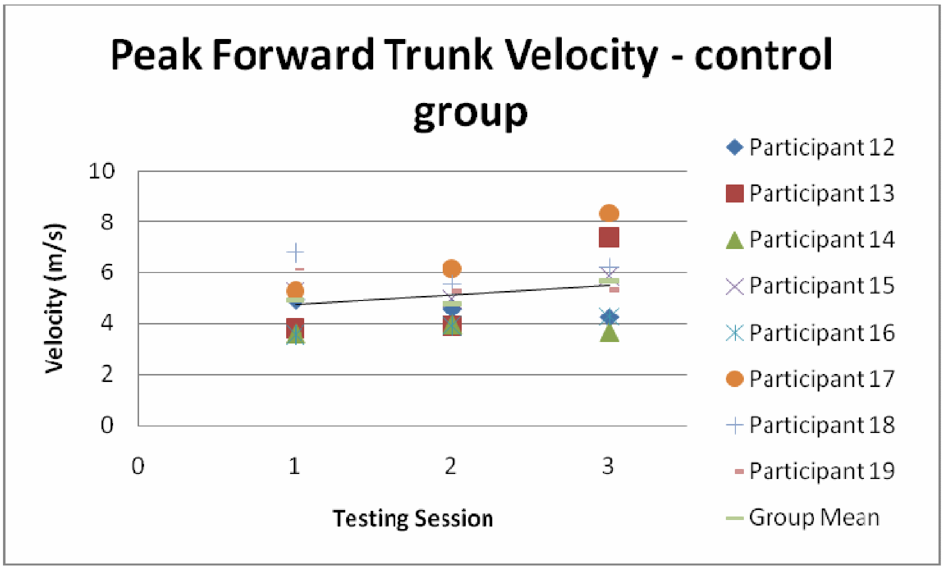

Fig. 14 – Peak forward trunk velocity for all participants in the control group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Six of eight participants followed the same linear trend as the group mean. (n=8)

Another two-way mixed ANOVA with repeated measures found that peak trunk velocity in the medial-lateral direction was significantly different between groups and across testing sessions. The participants in the control group exhibited increased amounts of peak M-L trunk velocity over the six weeks while the participants in the exercise group decreased their peak M-L trunk velocity while lunging F(2,34)=6.6, p<0.004 (Fig. 15). For this variable, each group is plotted separately in Fig. 16 and Fig. 17 to more easily see the effect that each participant had on the overall trends of the data.

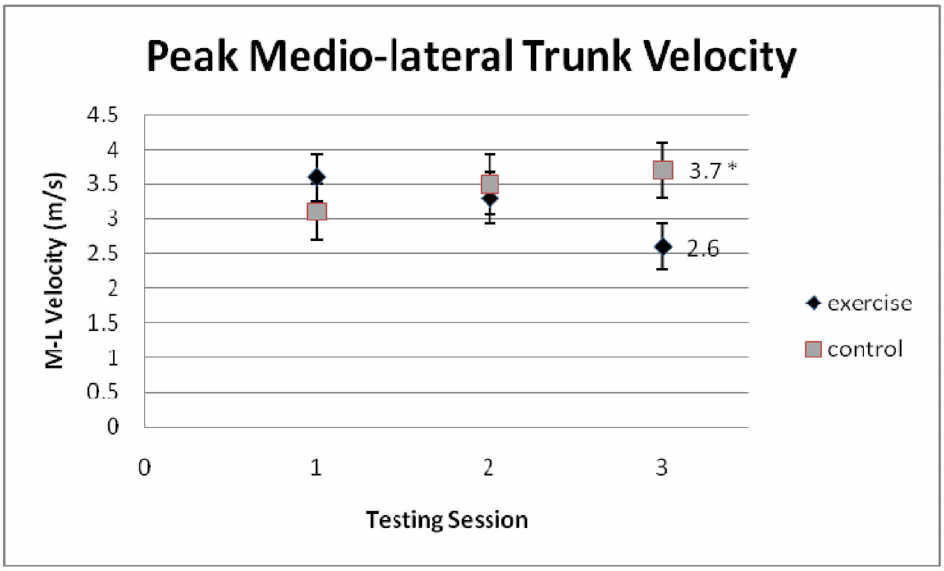

Fig. 15 – Peak medial-lateral trunk velocity expressed in meters per second. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is a significant testing session by group interaction. (error bars represent Standard Error) n=19

* indicates significant difference between groups at testing session 3 (p<0.05)

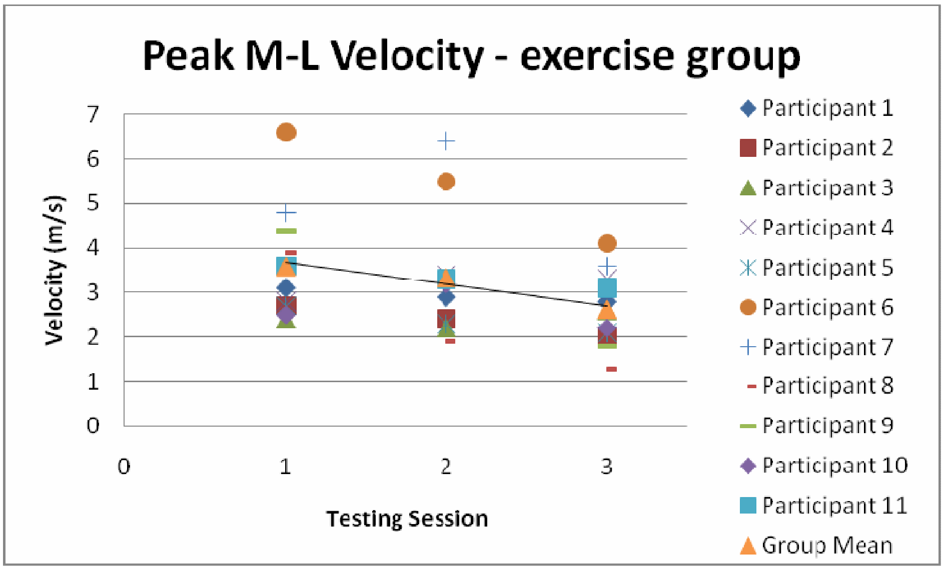

Fig. 16 – Peak M-L trunk velocity for all participant in the exercise group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Ten of eleven participants followed the same linear trend as the group mean. (n=11)

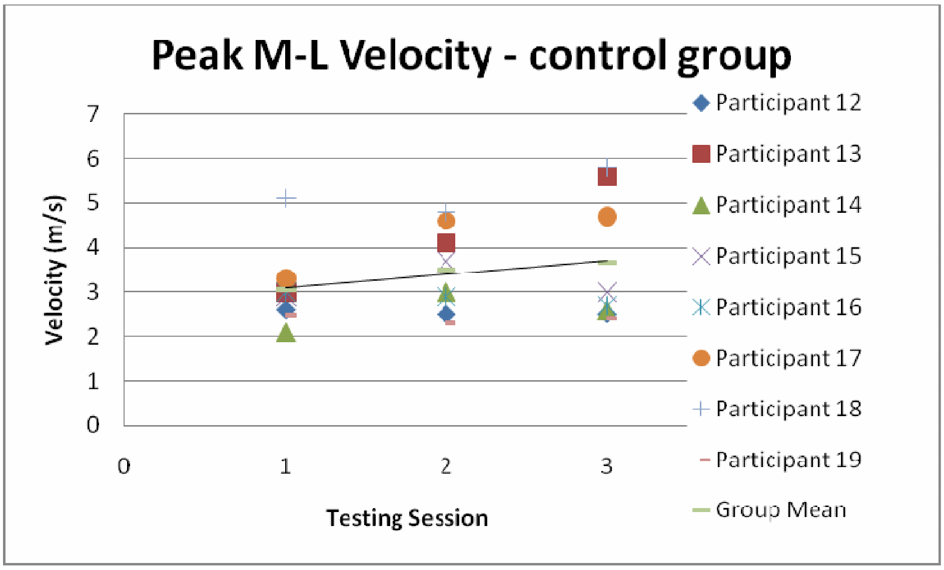

Fig. 17 – Peak M-L trunk velocity for all participants in the control group. Data represents mean values for 10 lunges at each testing session for each participant. A linear trendline was added for the group mean. Six of eight participants followed the same linear trend as the group mean. (n=8)

Furthermore, the medial-lateral displacement of the trunk relative to the pelvis at the lowest point in the lunge was indicated to have a difference between groups and across testing sessions, such that participants in the exercise group were able to significantly lower trunk displacements relative to the pelvis over time F(2,34)=3.41, p<0.045 (Fig.18).

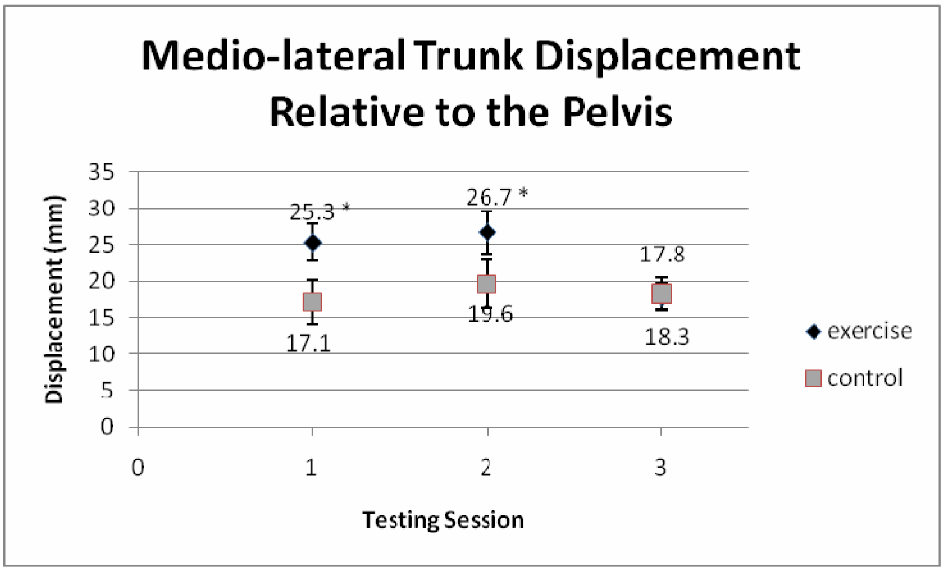

Fig. 18 – Medial-lateral trunk displacement relative to the pelvis at the lowest point in a lunge expressed in milimeters. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is a significant testing session by group interaction. (error bars represent Standard Error) n=19

* indicates significant difference between groups at testing session 1 and 2 (p<0.05)

Many other variables were not shown to have a significant time by group interaction. Step width did not differ between the groups across the testing sessions; the exercise group started with an average step width of 13.5cm while having a step width of 10.7cm by the third testing session, whereas the control group had a step width of 15.4cm on the first testing session and 12.5cm by the third testing session (Fig. 19).

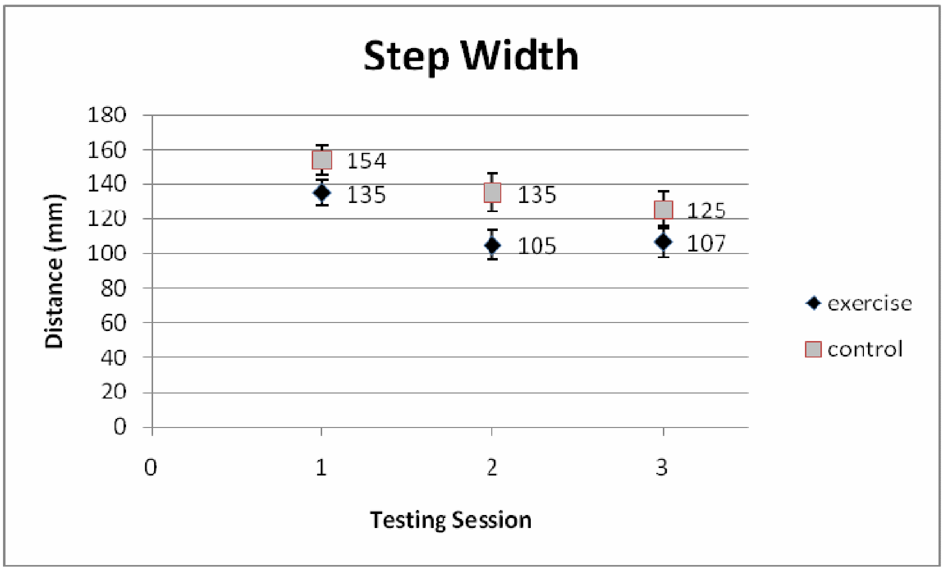

Fig. 19 - Step width during the lunges. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is no significant difference between groups and across time. (error bars represent Standard Error) n=19

The peak displacement of the CoM downward also didn't differ between the groups, such that the exercise group had an average CoM displacement of 23.2cm on the first testing session and having a displacement of 22.4cm by the third session, while the control group exhibited an average downward CoM displacement of 22.7cm on the first session and 20.5cm by the third session (Fig. 20).

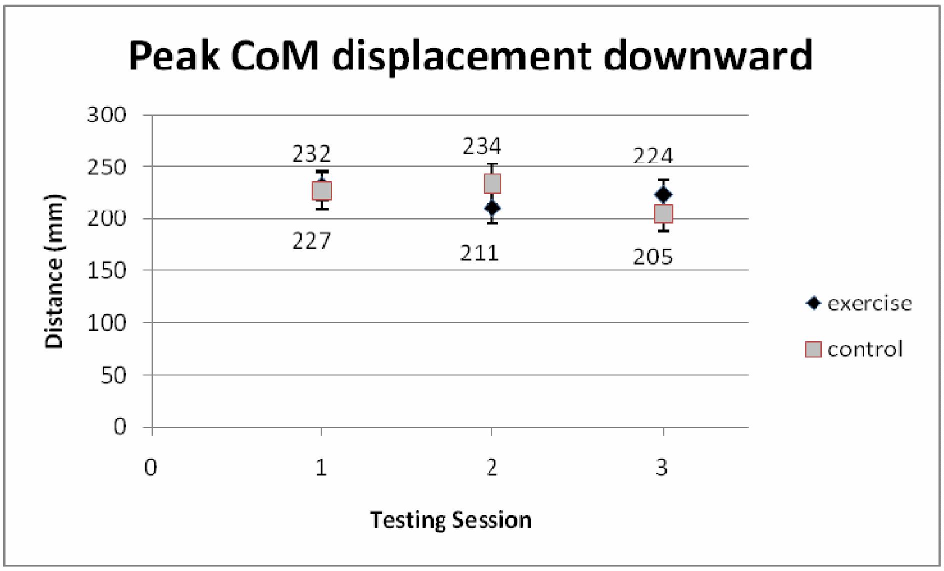

Fig. 20 - Peak CoM displacement downward. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is no significant difference between groups and across time. (error bars represent Standard Error) n=19

The peak medial-lateral displacement of the CoM didn't differ between the groups. The exercise group and control group exhibited almost identical medial-lateral CoM displacements of 4.8cm on the first testing session and 5cm and 4.9cm for the exercise group and control group respectively by the third testing session (Fig. 21).

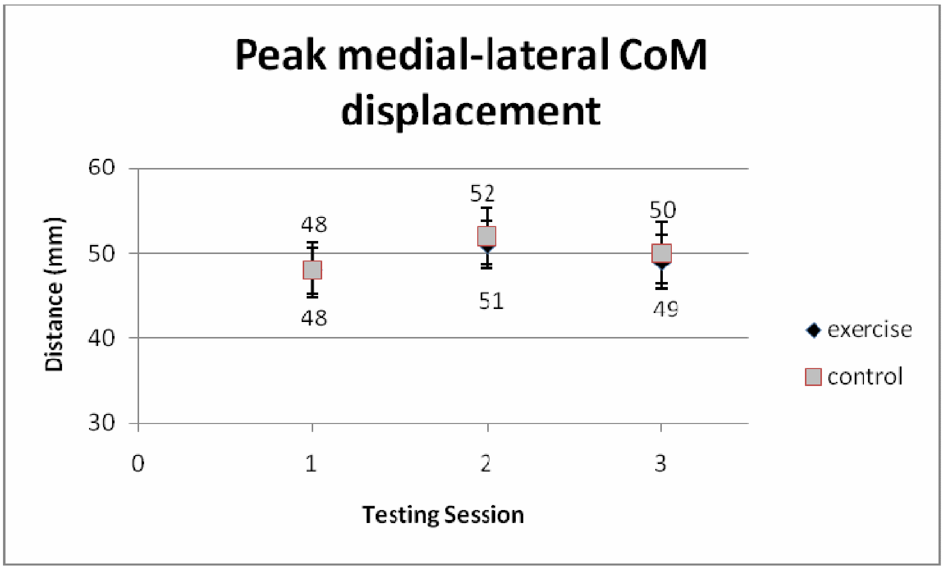

Fig. 21 - Peak medial-lateral CoM displacement. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is no significant difference between groups and across time. (error bars represent Standard Error) n=19

The peak forward head velocity recorded during the lunges did not differ between the groups. The exercise group displayed peak forward head velocities of 2.1m/s and 1.5m/s during the first and third testing session respectively while the control group demonstrated velocities of 1.4m/s and 1.7m/s for the first and third testing session respectively (Fig. 22).

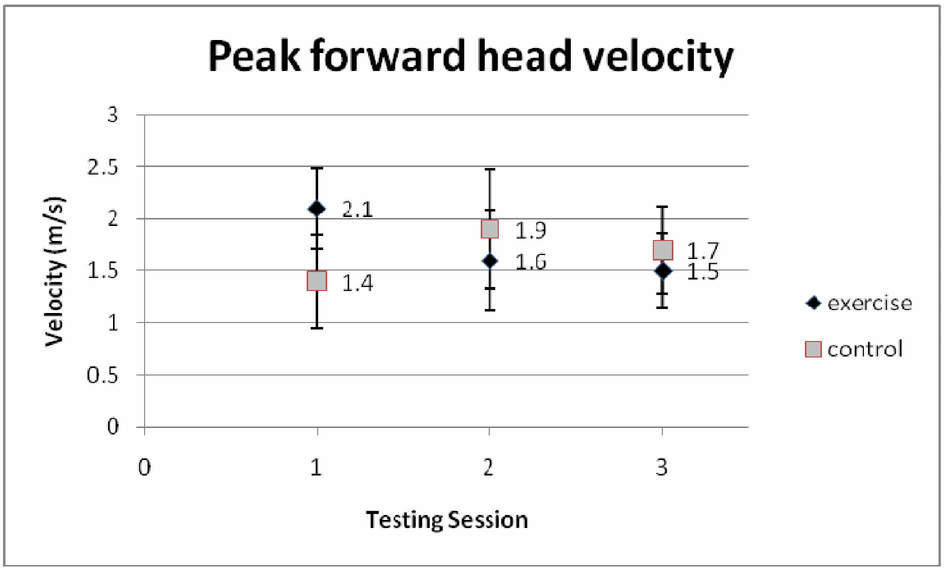

Fig. 22 - Peak forward head velocity. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is no significant difference between groups and across time. (error bars represent Standard Error) n=19

Furthermore, the peak lead limb knee angles did not significantly differ between the two groups. The participants in the exercise group were able to achieve knee angles of 79 degrees on both the first and third testing sessions whereas the control group achieved an average of 83 degrees during the first session and 76 degrees by the third session (Fig. 23).

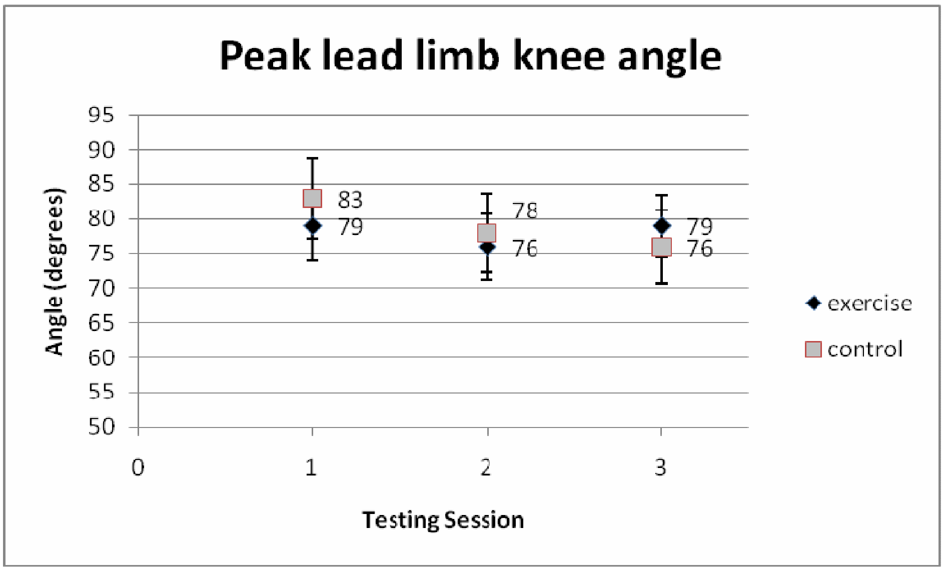

Fig. 23 - Lead limb knee angle at the lowest point in the lunge. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is no significant difference between groups and across time. (error bars represent Standard Error) n=19

Finally, the peak forward trunk angle measured at the lowest part of the lunge did not differ between the two groups. The exercise group had trunk angles of 9 degrees for the first testing session and 5 degrees for the third testing session while the control group had trunk angles of 7 degrees during the first session and 6 degrees during the third session (Fig. 24).

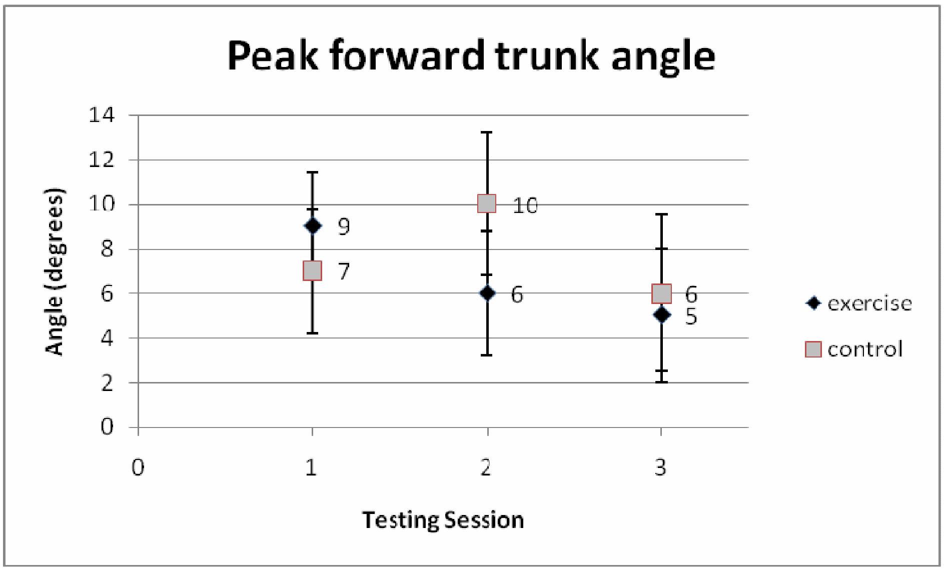

Fig. 24 - Peak forward trunk angle at the lowest point in the lunge. Data represents average values for each participant group at each testing session, based on the average of ten lunge trials per participant at each session. There is no significant difference between groups and across time. (error bars represent Standard Error) n=19

RELATIONSHIPS BETWEEN BALANCE TESTS AND LUNGE PERFORMANCE

Data for both groups was pooled at the baseline testing period and a Pearson Product Correlation revealed several variables that were correlated significantly. Data was pooled because at the baseline measure session all participants experienced the lunges as a novel task, therefore there were no between group differences as baseline. Most of the one legged stance conditions were positively correlated to one another, meaning that when participants did well on a certain one legged stance condition they most likely did well on the other one legged stance conditions (Table 3). In particular, when participants performed well on the OLS task with eyes open on their preferred leg they also performed well with eyes open on compliant ground $r(17)=0.788$, $p<0.001$, with eyes closed on compliant ground $r(17)=0.561$, $p<0.012$, with eyes open on their non-preferred leg $r(17)=0.753$, $p<0.001$, and with eyes closed on their non-preferred leg $r(17)=0.700$, $p<0.001$. Furthermore, the participants that exhibited better performance on the Maximal Step Length Test also performed better on the one legged stance tasks with the exception of one legged stance with eyes open on the preferred leg and one legged stance with eyes open on compliant ground. The participants that performed the Timed-up-and-go test faster were also shown to step further during the Maximal Step Length Test $r(17)= -0.55$, $p<0.015$.

Table 3

Correlation table of eight balance measures

		OLS eyes open preferred leg	OLS eyes closed preferred leg	OLS eyes open compliant ground	OLS eyes closed compliant ground	OLS eyes open non-preferred leg	OLS eyes closed non-preferred leg	Timed-up-and-go Test	Maximal Step Length Test
OLS eyes open preferred leg	Pearson Correlation	1	.332	.788**	.561*	.753**	.700**	-.301	.213
	Significance		.165	.000	.012	.000	.001	.210	.380
OLS eyes closed preferred leg	Pearson Correlation	.332	1	.421	.878**	.450	.718**	-.174	.557*
	Significance	.165		.073	.000	.053	.001	.477	.013
OLS eyes open compliant ground	Pearson Correlation	.788**	.421	1	.549*	.674**	.733**	-.287	.440
	Significance	.000	.073		.015	.002	.000	.233	.059
OLS eyes closed compliant ground	Pearson Correlation	.561*	.878**	.549*	1	.497*	.834**	-.420	.569*
	Significance	.012	.000	.015		.031	.000	.074	.011
OLS eyes open non-preferred leg	Pearson Correlation	.753**	.450	.674**	.497*	1	.642**	-.199	.467*
	Significance	.000	.053	.002	.031		.003	.413	.044
OLS eyes closed non-preferred leg	Pearson Correlation	.700**	.718**	.733**	.834**	.642**	1	-.407	.516*
	Significance	.001	.001	.000	.000	.003		.084	.024
Timed-up-and-go Test	Pearson Correlation	-.301	-.174	-.287	-.420	-.199	-.407	1	-.550*
	Significance	.210	.477	.233	.074	.413	.084		.015
Maximal Step Length Test	Pearson Correlation	.213	.557*	.440	.569*	.467*	.516*	-.550*	1
	Significance	.380	.013	.059	.011	.044	.024	.015	

Note: * Significant at the 0.05 level

** Significant at the 0.01 level

When dissecting the lunge variables several interesting correlations were found. To follow-up on the group by testing session interaction found with peak M-L trunk velocity, Table 4 provides the correlation of other variables with peak M-L trunk velocity. Participants that displayed increased amounts of M-L trunk velocity during the lunge also exhibited increased peak M-L CoM displacement $r(17)=0.527$, $p<0.02$, and increased peak M-L head velocity $r(17)=0.505$, $p<0.027$. Furthermore, participants that showed increased peak M-L trunk velocity also displayed decreased peak A-P head velocity $r(17)= -0.650$, $p<0.003$, decreased peak vertical head velocity $r(17)= -0.681$, $p<0.001$, decreased trunk flexion $r(17)= -0.548$, $p<0.015$, and decreased performance on the OLS task with eyes open on their non-preferred leg $r(17)= -0.594$, $p<0.007$.

Table 4

Correlation table of measures that significantly correlate with peak M-L trunk velocity while lunging

		M-L peak trunk velocity	M-L peak CoM disp.	M-L peak head velocity	A-P peak head velocity	Vertical peak head velocity	Trunk flexion angle	OLS eyes open non-preferred leg
M-L peak trunk velocity	Pearson Correlation	1	.527*	.505*	-.650**	-.681**	-.548*	-.594**
	Significance		.020	.027	.003	.001	.015	.007
M-L peak CoM displacement	Pearson Correlation	.527*	1	.497*	-.453	-.594**	-.172	-.215
	Significance	.020		.030	.052	.007	.482	.378
M-L peak head velocity	Pearson Correlation	.505*	.497*	1	-.866**	-.670**	-.370	-.475*
	Significance	.027	.030		.000	.002	.118	.040
A-P peak head velocity	Pearson Correlation	-.650**	-.453	-.866**	1	.728**	.462*	.498*
	Significance	.003	.052	.000		.000	.046	.030
Vertical peak head velocity	Pearson Correlation	-.681**	-.594**	-.670**	.728**	1	.472*	.375
	Significance	.001	.007	.002	.000		.041	.113
Trunk flexion angle	Pearson Correlation	-.548*	-.172	-.370	.462*	.472*	1	.444
	Significance	.015	.482	.118	.046	.041		.057
OLS eyes open non-preferred leg	Pearson Correlation	-.594**	-.215	-.475*	.498*	.375	.444	1
	Significance	.007	.378	.040	.030	.113	.057	

Note: * Significant at the 0.05 level

** Significant at the 0.01 level

Other notable lunge variables analyzed in the correlation are provided in Table 5. Step length was shown to not be correlated with step width, nor was it shown to be correlated with peak M-L trunk velocity. Step length was, however, correlated with peak A-P trunk velocity and the OLS task with eyes open on complaint ground. Participants that stepped longer tended to do so with decreased A-P trunk velocity r(17)= -0.627, p<0.004. Participants that stepped longer also performed better on the OLS task with eyes open on compliant ground r(17)=0.583, p<0.009. Peak medial-lateral trunk velocity was also shown to not be correlated with step width. Furthermore, peak trunk velocity in the forward direction was not shown to correlate with any of the OLS tasks. Also, performance on the Timed-up-and-go task was shown to not have correlations with any of the variables measured during the lunge.

Table 5

Correlations of several variables of interest

Comparison	Pearson Correlation	Significance
Step length with Step width	-.249	.303
Step length with A-P trunk velocity	-.627**	.004
Step length with OLS eyes open on compliant ground	.583**	.009
Step length with M-L trunk velocity	.299	.214
M-L trunk velocity with Step width	.191	.432

Note: * Significant at the 0.05 level

** Significant at the 0.01 level

DISCUSSION

Our findings highlight the fact that the lunge exercise, when used as the only exercise, can produce a training effect in healthy elderly women after only six weeks of training. Lunge exercise training was shown to increase medial-lateral trunk stability during the performance of the lunge as exhibited by lower peak medial-lateral velocities with the participants in the exercise group following training. Lunge training resulted in participants taking shorter steps and exhibiting lower peak forward pelvis and trunk velocities. These findings suggest that the individuals that practiced the forward lunge for six weeks were performing the lunge with a higher degree of control. Lower forward velocity resulted in a more controlled movement since those individuals in the exercise group also exhibited lower peak trunk velocities in the medial-lateral direction. Schrager, Kelly, Price, Ferrucci, & Sumway-Cook (2008) were able to illustrate that elderly individuals exhibited greater peak medial-lateral trunk and CoM velocities when walking with a narrow base. This finding highlights the relationship between increased medial-lateral trunk and CoM velocity with increased instability, since walking with a narrow base of support is a destabilizing task. Performing a lunge with slower movements requires a higher degree of muscle control because the body is in an unstable position for a longer amount of time. As a result of training, individuals in the exercise group were also able to decrease the amount of displacement their trunk moved relative to their pelvis in the medial-lateral direction. There are three ways to control medial-lateral trunk displacements and velocities. One is to alter foot placement in the medial-lateral direction, also called step width, another is to alter the way hip and trunk musculature is affecting the trunk, and finally ankle musculature can be used to alter medial-lateral trunk displacements and velocities (Winter, 1995). Winter (1995) illustrated that ankle musculature plays a very small role in controlling medial-lateral trunk velocities. Winter (1995) concluded that hip musculature and lateral foot placement are largely responsible for control over medial-lateral CoM velocities. The fact that step width was not different between the groups suggests that lunge training had an effect on the hip and trunk musculature such that those individuals practicing the lunge improved the way that they were able to stabilize themselves with their hip and trunk musculature. This is supported by previous research showing the forward lunge to activate hip musculature to a greater degree than knee or ankle musculature (Flanagan et al., 2004). Furthermore, previous research has shown that quadriceps activation during the lunge is at a level sufficient enough to strengthen the muscle (Ekstrom et al., 2007). Furthermore, step length during the lunge exercise did not correlate with peak medial-lateral trunk velocity with novice lungers, r(17)= 0.299, p=0.214. Therefore, the increased stability shown by the exercise group post intervention was not due to them taking shorter steps than the control group. Increased medial-lateral stability during the lunge post intervention is an important finding. Greater control over medial-lateral stability may reduce risk of falls and fall incidence since medial-lateral instability has been linked to fall risk and fall incidence by Stel et al. (2003) and Maki et al. (1994).

The improvement in balance control during the lunge as seen in the exercise group did not, however, translate into better performance on frequently used tests of balance such as the one legged stance tasks and the timed-up-and-go test. For several of the balance tasks the act of simply retesting people seemed to improve their performance. This was most significant with the one legged stance task with eyes open on the preferred leg, as well as, one legged standing on a complaint surface and the timed-up-and-go test. The cause of the lack of larger improvement during the balance tests in the exercise group may be due to the fact that the one legged standing task may not be difficult enough to pick up the hip and trunk musculature change that occurred in the exercise group. This could be due to the different posture the hip is placed in during each of these tasks. Better control of a flexed hip, as what is occurring during the lunge, may not translate into better control of the CoM with a straight hip, as what takes place during the one legged standing task. The control group did, however, improve performance on the maximal step length task, while the exercise group did not. This could be due to the fact that the exercise group was being trained to have a more controlled, smaller length of step by completing lunges every day. The control group, on the other hand, was striving to step as far as they could for the maximal step length test as well as the lunges completed in the laboratory resulting in longer, but more destabilizing, step lengths. The control group may have viewed increased step length as a measure of improved performance even though this was never mentioned to them, and in fact, instruction was given as to perform the task with smaller more controlled step lengths. This may explain why the exercise group did not alter their maximal step lengths while the control group continued to increase their step lengths over time.

Another important finding is that verbal and visual instruction was able to produce a good performance of the lunge even for novice lungers. The control group, although not practicing the lunge, were still able to perform the basic mechanics of the lunge just as well as the exercise group. This is highlighted in the fact that step width, peak lead limb knee angle, forward flexion of the trunk, as well as, peak center of mass displacement downward did not differ between the groups. Proper lunge technique requires that the lead limb angle be ~80-90 degrees at its lowest point as was reported by Flanagan et al. (2004). Flanagan et al. (2004) also stated that the trunk be in an upright posture during the forward lunge. Both the exercise and control groups were able to come close to these performance markers at baseline and post-intervention. Furthermore, the amount of distance the center of mass was displaced while keeping an upright posture did not differ between groups and was greater than 20cm which further suggests a good performance during the lunge for all novice lungers.

Furthermore, several aspects of the lunge where found to correlate with one another in a group of individuals that experienced the lunge as a novel task. It seems as though elderly women completing lunges for the first time attempt to stabilize the head by lowering peak head velocities forward and downward. This is in agreement with previous research showing that elderly participants attempt to stabilize the head when completing a difficult balance task (Kavanagh et al., 2005). Participants in this study that took a more cautious approach to the lunge as seen with lower forward velocities were more unstable as seen with greater medial-lateral trunk and head velocities. Interestingly, individuals that exhibited higher amounts of medial-lateral trunk velocity during the lunges also performed poorer on the one legged standing task with their non-preferred leg ($r(17)= -0.594$, $p<0.007$) indicating that decreased balance control may be the factor affecting peak M-L trunk velocity. Previous research has linked increased medial-lateral velocities and displacements with decreased balance ability (Chou et al., 2001; Haun et al., 2003), which lies in agreement with the current findings. Another interesting finding is that individuals that take longer steps during the novel lunges perform better on the one legged stance task when standing on a compliant surface (r(17)= 0.583, p<0.009). This suggests that standing on one foot on compliant ground may provide some of the same challenges to the proprioceptive system as lunging. Individuals that have better performance on the compliant ground could have better balance and therefore will attempt a longer, and potentially more destabilizing, step during the lunge.

It is also of importance to point out that the maximal step length test correlated with many of the one legged stance tasks in this experiment For example, participants that exhibited increased performance on the OLS eyes closed on compliant ground also showed improved performance on the MSL test, r(17)= 0.569, p<0.01. The one legged stance tasks are a measure of static stability. The maximal step length test is a measure of dynamic balance. The fact that they correlate with one another suggests that static and dynamic balance both share some of the same components of balance control. That being said it is still important to collect measures of both dynamic and static balance when attempting to assess an elderly person’s balance ability.

Our findings support the notion that the forward lunge is an excellent exercise to prescribe for elderly women (Frankel & Richard, 1977; McGill, 2002). None of the women in the current study were injured as a result of completing the daily lunges for six weeks further supporting the argument that the forward lunge is a safe exercise for elderly women (Heijne, et al. 2004). Our findings also support the idea that lunge training should be coupled with periodic lunge performance corrections to prevent elderly individuals from having improper posture during the lunge.

The participants in the current study were in good health compared to other elderly women. Participants were also active, although below the recommended weekly activity level for adults as stated by the American College of Sports Medicine and the American Heart Association (Haskell et al., 2007). As a result, the forward lunge may not have challenged them as much as it would have with a more sedentary population. All participants in the current study found it very easy to complete a lunge while using assistance. Therefore, using assistance might be an excellent starting point for less active elderly individuals. To minimize confounding variables, the current study only included elderly women. Future research should include both elderly men and women. Future research should also include individuals that are less physically active and should include those individuals that are completely sedentary. The participant in the current study that experienced the highest amount of medial-lateral trunk velocity at baseline also showed one of the greatest improvements in medial-lateral trunk velocity after training. This finding suggests that the forward lunge may be more beneficial to less stable individuals. Previous research has revealed that exercise has a positive effect on frail elderly. For example, Hauer et al., 2001 concluded that "Progressive resistance training and progressive functional training are safe and effective methods of increasing strength and functional performance and reducing fall-related behavioral and emotional restrictions during ambulant rehabilitation in frail, high-risk geriatric patients with a history of injurious falls." This is further evidence that lunges may be more beneficial in a sample of elderly individuals that are at high risk for falls and could also be advantageous for those individuals that have a history of fall incidence.

Exercise training protocols have been shown to positively affect balance control, performance on balance tests, fear of falling, fall incidence and fall risk in elderly individuals (Shumway-Cook et al., 1997; Pereira et al., 1990; Buchner et al., 1997; Hauer et al., 2001; Rogers et al., 2001; Carter et al., 2002; Cornillon et al., 2002; Day et al., 2002; Maejima et al., 2009; Santiworakul et al., 2009). There are two major differences between the current study and the above experiments that may explain why the current experiment did not show improvements in the performance of balance tasks. Firstly, the current experiment used only one type of exercise as the intervention. All of the aforementioned studies utilized exercise protocols that consisted of many types of exercises being used, including resistive, cardiovascular and balance exercises. For example, Shumway-Cook et al., 1997 recruited 84 individuals to participate in a eight to twelve week long exercise program that consisted of many different exercises.

Individuals that scored low on a type of skill at the baseline testing session were then given exercises that stressed that type of skill, such that "...patients who scored less than 5 on manual muscle testing were given progressive resistive strength training exercises, whereas those who showed a significant impairment in range of motion in the trunk or lower extremities were given flexibility exercises" Shumway-Cook et al., 1997. This is evidence that matching a weakness to an exercise on a per person basis is a good way to improve functional capacity and reduce fall risk. Furthermore, Day et al., 2002 reported that a weekly one hour exercise class for 15 weeks accompanied by home exercises that included flexibility, leg strength and balance exercises decreased fall incidence in a sample of 70 community dwelling elderly participants. This is evidence that a broad array of exercises prescribed to everyone in the intervention can produce positive effects on fall rate. The second thing that differs between the current study and the aforementioned studies is that the current experiment utilized a shortened exercise period of six weeks. For example, Shumway-Cool et al. (1997) utilized an 8 week training protocol, Buchner et al. (1997) a 24 week training session, Hauer et al. (2001) a 12 week program, Rogers et al. (2001) a 10 week program, Carter et al. (2002) a 20 week program, Day et al. (2002) a 15 week training period, Maejima et al. (2009) a 12 week training period and finally Santiworakul et al. (2009) an 8 week training protocol. Many of these studies, however, included cardiovascular endurance exercises such as brisk walking which may be why they had longer training session since they were trying to achieve cardiovascular improvements along with improved balance performance. The current study was able to show changes in medial-lateral stability during a lunge after only six weeks, however a longer training period may allow for the increased stability to carry over to other balance tasks. Furthermore, Day et al. (2002) recruited healthy elderly individuals for a multi-component program whereas Shumway-Cook et al. (1997) recruited individuals that were at high risk of falls for a program that consisted of only a few exercises. Therefore, it may be that healthy community-dwelling elderly individuals, as was recruited for the current study, may require exercise programs that are higher intensity and contain many exercises, whereas elderly individuals at high risk for falls may benefit from a single exercise such as the forward lunge. Based on this evidence and the outcome of the current study, future research designs may want to include an extra exercise component to accompany the forward lunge if individuals in the intervention are not at high risk for falls. Future research may also want to have an exercise training period that is at least eight weeks in length. The current study was able to show improvements in balance control is only six weeks of training, however, utilizing a slightly longer training protocol may allow for greater improvements in balance control. Furthermore, the current study did not measure fall incidence, therefore, a longitudinal study that documents fall rate between a lunge exercising group and a control group would be beneficial to more completely understand the efficacy of a lunge exercising program for elderly women. To get a full understanding of the efficacy of the forward lunge as the sole exercise in an intervention it is suggested that a follow-up study be completed in a long term care facility utilizing participants with a high risk for falls and a protocol that is eight weeks in duration, with fall incidence between an exercise and control group, as well as, performance on several balance tests be measured.

CONCLUSION

Falling is a serious issue in an elderly population as it can lead to serious injuries. Falls occur in ~30% of the elderly population (Campbell et al. 1981; O'Loughlin et al., 1993). Medial-lateral instability has been linked to increased fall risk (Stel, et al. 2003; Maki et al., 1994). The current study provides data that suggests the use of the forward lunge as a training tool with elderly women improves medial-lateral trunk stability by decreasing peak medial-lateral trunk velocity during a lunge. This increase in stability was attained by using an exercise period of only six weeks and utilizing the forward lunge as the sole exercise as the intervention. This decrease in peak medial-lateral trunk velocity is due to an improvement in the way hip and trunk musculature is controlling balance, since foot placement did not differ between the two groups. The data suggests that the forward lunge may be able to improve medial-lateral stability which may reduce fall risk and fall incidence.

REFERENCES

Bertera, E., & Bertera, R. (2008). Fear of Falling and Activity Avoidance in a National Sample of Older Adults in the United States. *Health & Social Work, 33*(1), 54-62.

Blaszczyk, J., Lowe, D., & Hansen, P. (1994). Ranges of Postural stability and their changes in the elderly. *Gait and Posture. 2,* 11-17.

Buchner, D., Cress, M.E., Lateur, B., Esselman, P., Margherita, A., Price, R., & Wagner, E. (1997). The Effect of Strength and Endurance Training on Gait, Balance, Fall Risk, and Health Services Use in Community-Living Older Adults. *J of Geron, 52A,* M218-M224.

Campbell, A.J., Reinken, J., Allan, B.C., & Martinez, G.S. (1981). Falls in old age: A study of frequency and related clinical factors. *Age and Aging. 10,* 264-270.

Carter, N., Khan, K., McKay, H., Petit, M., Waterman, C., Heinonen, A., Janssen, P., Donoldson, M., Mallinson, A., Riddell, L., Kruse, K., Prior, J., & Flicker, L. (2002). Community-based exercise program reduces risk factors for falls in 65- to 76-year-old women with osteoporosis: randomized controlled trial. *CMAJ, 167,* 997-1004.

Cho, B., Scarpace, D., & Alexander, N. (2004). Tests of Stepping as Indicators of Mobility, Balance, and Fall Risk in Balance-Impared Older Adults. *JAGS, 52,* 1168-1173.

Chou, L., Kaufman, K., Brey, R., & Draganich, L. (2001). Motion of the whole body's center of mass when stepping over obstacles of different heights. *Gait & Posture, 13,* 17-26.

Chou, L., Kaufman, K., Hahn, M., & Brey, R. (2003). Medio-lateral motion of the center of mass during obstacle crossing distinguishes elderly individuals with imbalance. *Gait & Posture, 18,* 125-133.

Cornillon, E., Blanchon, M., Ramboatsisetraina, P., Braize, C., Beauchet, O., Dubost, V., Blanc, P., & Gonthier, R. (2002). Effectiveness of falls prevention strategies for elderly subjects who live in the community with performance assessment of physical activities (before-after). *Ann de Readaption et de Med Phys, 45,* 493-504.

Day, L., Fildes, B., Gordom, I., Fitzharris, M., Flamer, H., & Lord, S. (2002). Randomized factorial trial of falls prevention among older people living in their own homes. *BMJ, 325,* 128-134.

Ekstrom, R., Donatelli, R., & Carp, K. (2007). Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther, 37,* 754-762.

Escamilla, R., Zheng, N., Macleod, T., Edwards, W., Hreljac, A., Fleisig, G., Wilk, K., Moorman, C., Imamura, R., & Andrews, J. (2008). Patellofemoral joint force and stress between a short- and long-step forward lunge. *J Orthop Sports Phys Ther, 38,* 681-690.

Faber, M., Bosscher, R., Chin A Pow, M., & van Wieringen, P. (2006). Effects of Exercise Programs on Falls and Mobility in Frail and Pre-Frail Older Adults: A Multicenter Randomized Controlled Trial. *Arch Phys Med Rehabil, 87,* 885-896.

Farrokhi, S., Pollard, C., Souza, R., Chen, Y., Reischl, S., & Powers, C. (2008). Trunk position influences the kinematics, kinetics, and muscle activity of the lead lower extremity during the forward lunge exercise. *J Orthop Sports Phys Ther, 38,* 403-409.

Flanagan, S., Wang, M., Greendale, G., Azen, S., & Salem, G. (2004). Biomechanical Attributes of Lunging Activities for Older Adults. *J of Strength and Conditioning Research, 18,* 599-605.

Frankel, L., & Richard, B. (1977). *Be Alive as Long as You Live: Mobility exercises for the Older Person.* University of Michigan: Preventicare Publications.

Gill, J., Allum, J., Carpenter, M., Held-Ziolkowska, M., Adkin, A., Honegger, F., & Pierchala, K. (2001). Trunk sway measures of postural stability during clinical balance tests: Effects of age. *The J of Geron, 56,* M438-M447.

Godin, G., & Shephard, R.J. (1985). A simple method to assess exercise behavior in the community. *Can J Appl Sport Sci, 10,* 141-146.

Hahn, M., & Chou, L. (2003). Can motion of individual body segments identify dynamic instability in the elderly? *Clin Biomech, 18,* 737-744.

Halliday, S., Winter, D., Frank, J., Patla, A., & Prince, F. (1998). The initiation of gait in young, elderly, and Parkinson’s disease subjects. *Gait and Posture, 8,* 8-14.

Haskell, W., Lee, I., Pate, R., Powell, K., Blair, S., Franklin, B., Macera, C., Heath, G., Thompson, P., & Bauman, A. (2007). Recommendation for Adults from the American College of Sports Medicine and the American Heart Association. *Medicine & Science in Sports & Exercise, 39*(8), 1423-1434.

Hauer, K., Rost, B., Rutschle, K., Opitz, H., Specht, N., Bartsch, P., Oster, P., & Schlierf , G. (2001). Exercise Training for Rehabilitation and Secondary Prevention of Falls in Geriatric Patients with a History of Injurious Falls. *JAGS, 49*, 10-20.

Heijne, A., Fleming, B., Renstrom, P., Peura, G., Beynnon, B., & Werner, S. (2004). Strain on the Anterior Cruciate Ligament during Closed Kinetic Chain Exercises. *J of Am Col of Sports Medicine, 36,* 935-941.

Hirasaki, E., Moore, S., Raphan, T., & Cohen, B. (1999). Effects of walking velocity on vertical head and body movements during locomotion. *Exp Brain Res, 127,* 117-130.

Kavanagh, J., Barrett, R., & Morrison, S. (2005). Age-related differences in head and trunk coordination during walking. *Human Movement Science*, *24*, 574-587.

Latham, N., Anderson, C., Lee, A., Bennett, D., Moseley, A., & Cameron, I. (2003). A Randomized, Controlled Trial of Qaudriceps Resistance Exercise and Vitamin D in Frail Older People: The Frailty Interventions Trial in Elderly Subjects (FITNESS). *JAGS, 51,* 291-299.

Latt, M., Menz, H., Fung, V., & Lord, S. (2008). Walking speed, cadence and step length are selected to optimize the stability of head and pelvis accelerations. *Exp Brain Res, 184,* 201-209.

Maejima, H., Sunahori, H., Kanetada, Y., Murase, A., Tobimatsu, Y., Otani, T., & Yoshimura, O. (2009). The neural adjustment of postural response through community-based daily exercises in elderly persons. *Clin Biomech*, *24,* 499-503.

Maki, B., Holliday, P., & Topper, A. (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J of Geron, 49,* 72-84.

McGill, S. (2002). *Low Back Disorders: Evidence-Based Prevention and Rehabilitation.* Waterloo, Ontario: Human Kinetics.

McMurdo, M., Millar, A., & Daly, F. (2000). A Randomized Controlled Trial of Fall Prevention Strategies in Old Peoples' Homes. *Geron, 46,* 83-87.

Menz, H., Lord, S., & Fitzpatrick, R. (2003a). Acceleration patterns of the head and pelvis when walking on level and irregular surfaces. *Gait & Posture, 18*, 35-46.

Menz, H., Lord, S., & Fitzpatrick, R. (2003b). Age-related differences in walking stability. *Age & Aging, 32*, 137-142.

Nowalk, M., Prendergast, J., Bayeles, C., D'Amico, F., & Colvin, G. (2001). A Randomized Trial of Exercise Programs Among Older Individuals Living in Two Long-Term Care Facilities: The FallsFREE Program. *JAGS, 49,* 859-865.

O'Loughlin, J., Robitaille, Y., Boivin, J. F., & Suissa, S. (1993). Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. *Am J of Epid*, *137,* 342-354.

Pereira, M., Kriska, A., Day, R., Cauley, J., LaPorte, R., & Kuller, L. (1998). A Randomized Walking Trial in Postmenopausal Women: Effects on Physical Activity and Health 10 Years Later. *Arch Intern Med*, *158,* 1695-1701.

Pincivero, D., Aldworth, C., Dickerson, T., Petry, C., & Shultz, T. (2000). Quadriceps-hamstring EMG activity during functional, closed kinetic chain exercise to fatigue. *Eur J Appl Physiol, 81,* 504-509.

Podsiadlo, D. & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc, 39,* 142-148.

Powell, L., & Myers, A. (1995). The Activities-Specific Balance Confidence (ABC) Scale. *J Gerontol Med Sci, 50,* M28-M34.

Rogers, M., Fernandez, J., & Bohlken, R. (2001). Training to reduce postural sway and increase functional reach in the elderly. *J Occup Rehab,11,* 291-298.

Rosenhall, U. (1973). Degenerative changes in the aging human vestibular geriatric neuroepithelia. *Acta Otolaryngol, 76,* 208-220.

Schrager, M., Kelly, V., Price, R., Ferrucci, L., & Sumway-Cook, A. (2008). The effects of age on medio-lateral stability during normal and narrow base walking. *Gait & Posture, 28,* 466-471.

Samson, M., Meeuwsen, I., Crowe, A., Dessens, J., & Duursma, S. (2000). Relationships between physical performance measures, age, height and body weight in healthy adults. *Aging, 13,* 235-242.

Santiworakul, A., Jarungjitaree, S., Jalayondeja, W., Chantarothorn, S., & Supaibulpipat, S. (2009). Effect of Lower Extremity Exercise on Muscle Strength and Physical Capacity in COPD Patients. *J Med Assoc Thai, 92,* 556-563.

Scheffer, A., Schuurmans, M., van Dijk, N., van der Hooft, T., & de Rooij, S. (2008). Fear of falling: measurement strategy, prevalence, risk factors and consequences among older persons. *Age and Aging, 37,* 19-24.

Shubert, T., Schrodt, L., Mercer, V., Busby-Whitehead, J., & Giuliani, C. (2006). Are Scores on Balance Screening Tests Associated with Mobility in Older Adults? *J of Geri Phys Thera, 29,* 33-39.

Shumway-Cook, A., Gruber, W., Baldwin, M., & Liao, S. (1997). The Effect of Multidimensional Exercise on Balance, Mobility, and Fall Risk in Community-Dwelling Older Adults. *Phys Thera, 77,* 46-57.

Sekuler, R., & Hutman, L. (1980). Spatial vision and aging, I: contrast sensitivity. *J of Geron, 35,* 692-699.

Skinner, H., Barrack, R., & Cook, S. (1984). Age-related declines in proprioception. *Clin Orthop, 184,* 208-211.

Stel, V., Smit, J., Pluijm, S., & Lips, P. (2003). Balance and mobility performance as treatable risk factors for recurrent falling in older persons. *J of Clin Epid, 56,* 659-668.

Van Emmerik, R., McDermott, W., Haddad, J., & Van Wegen, E. (2004). Age-related changes in upper body adaptation to walking speed in human locomotion. *Gait & Posture, 22*, 233-239.

Vereeck, L., Wuyts, F., Truijen, S., & Heyning, P. (2008). Clinical Assessment of balance: Normative data, and gender and age effects. *Inter J of Audiology, 47,* 67-75.

Ware, J., Snow, K., Koninski, M., & Gandek, B. (1993). SF-36 Health Survey: Manual and interpretation guide. *The Health Institute, New England Medical Center.*

Westlake, K., Wu, Y., & Culham, E. (2007). Sensory-Specific Balance Training in Older Adults: Effect on Position, Movement, and Velocity Sense at the Ankle. *Phys Thera, 87,* 560-568.

Whanger, A., & Wang, H. (1974). Clinical correlates of the vibratory sense in elderly psychiatric patients. *J of Geron, 29,* 39-45.

Wilson, D., Gibson, K., & Masterson, G. (2008). Kinematics and Kinetics of 2 Styles of Partial Forward Lunge. *J of Sport Rehab, 17,* 387-398.

Winter, D. (1995). *A.B.C. of Balance during Standing and Walking.* Waterloo, Ontario: Waterloo Biomechanics.

Wolfson, L., Judge, J., Whipple, R., & King, M. (1995). Strength is a major factor in balance, gait, and the occurrence of falls. *J of Geron Med Sci, 50,* M64-M67.

Zijlstra, G., van Haastregt, J., van Rossum, E., van Eijk, J., Yardley, L., & Kempen, G. (2007). Interventions to reduce fear of falling in community-living older people: a systematic review. *JAGS, 55,* 603-615.

APPENDIX I

GODIN LEISURE-TIME EXERCISE QUESTIONNAIRE

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

a) **STRENUOUS EXERCISE** **Times**
Per Week
(HEART BEATS RAPIDLY)

(e.g., running, jogging, hockey, football, soccer,

squash, basketball, cross country skiing, judo,

roller skating, vigorous swimming,

vigorous long distance bicycling). ______

b) **MODERATE EXERCISE**
(NOT EXHAUSTED)

(e.g., fast walking, baseball, tennis, easy bicycling,

volleyball, badminton, easy swimming, alpine skiing,

popular and folk dancing). ______

c) MILD EXERCISE
(MINIMAL EFFORT)

(e.g., yoga,, archery, fishing from river bank, bowling,

horseshoes, golf, snow-mobiling, easy walking). ______

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

OFTEN	SOMETIMES	NEVER/RARELY
1. ☐	2. ☐	3. ☐

APPENDIX II

THE ACTIVITIES-SPECIFIC BALANCE CONFIDENCE (ABC) SCALE

Instructions to Participants:
For each of the following, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale form 0% to 100%. If you do not currently do the activity in question, try to imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as it you were using these supports. If you have any questions about answering any of these items, please ask the administrator.

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

0% 10 20 30 40 50 60 70 80 90 100%
no confidence completely confident

"How confident are you that you 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 to reach for something above your head? ____%
6. …stand on a chair to 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 of an escalator while you are holding onto a railing? ____%
15. … step onto or off of an escalator while holding onto parcels such that you cannot hold onto the railing? ____%
16. …walk outside on icy sidewalks? ____%

APPENDIX III

SF-36(TM) HEALTH SURVEY

Instructions for completing the questionnaire: Please answer every question. Some questions may look like others, but each one is different. Please take the time to read and answer each question carefully by filling in the bubble that best represents your response.
Patient Name:
____

1. In general, would you say your health is:
☐ Excellent
☐ Very good
☐ Good
☐ Fair
☐ Poor

2. Compared to one year ago, how would you rate your health in general now?
☐ Much better now than a year ago
☐ Somewhat better now than a year ago
☐ About the same as one year ago
☐ Somewhat worse now than one year ago
☐ Much worse now than one year ago

3. The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

a. Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports.
☐ Yes, limited a lot.
☐ Yes, limited a little.
☐ No, not limited at all.

b. Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf?
☐ Yes, limited a lot.
☐ Yes, limited a little.
☐ No, not limited at all.

c. Lifting or carrying groceries.
☐ Yes, limited a lot.
☐ Yes, limited a little.
☐ No, not limited at all.

d. Climbing several flights of stairs.

- ☐ Yes, limited a lot.
- ☐ Yes, limited a little.
- ☐ No, not limited at all.

e. Climbing one flight of stairs.

- ☐ Yes, limited a lot.
- ☐ Yes, limited a little.
- ☐ No, not limited at all.

f. Bending, kneeling or stooping.

- ☐ Yes, limited a lot.
- ☐ Yes, limited a little.
- ☐ No, not limited at all.

g. Walking more than one mile.

- ☐ Yes, limited a lot.
- ☐ Yes, limited a little.
- ☐ No, not limited at all.

h. Walking several blocks.

- ☐ Yes, limited a lot.
- ☐ Yes, limited a little.
- ☐ No, not limited at all.

i. Walking one block.

- ☐ Yes, limited a lot.
- ☐ Yes, limited a little.
- ☐ No, not limited at all.

j. Bathing or dressing yourself.

- ☐ Yes, limited a lot.
- ☐ Yes, limited a little.
- ☐ No, not limited at all.

4. During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

a. Cut down the amount of time you spent on work or other activities?

☐ Yes ☐ No

b. Accomplished less than you would like?

☐ Yes ☐ No

c. Were limited in the kind of work or other activities

☐ Yes ☐ No

d. Had difficulty performing the work or other activities (for example, it took extra time)

☐ Yes ☐ No

5. During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

a. Cut down the amount of time you spent on work or other activities?

☐ Yes ☐ No

b. Accomplished less than you would like

☐ Yes ☐ No

c. Didn't do work or other activities as carefully as usual

☐ Yes ☐ No

6. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

7. How much bodily pain have you had during the past 4 weeks?

- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

8. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Quite a bit
- ☐ Extremely

9. These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the past 4 weeks.

a. did you feel full of pep?

- ☐ All of the time
- ☐ Most of the time
- ☐ A good bit of the time
- ☐ Some of the time
- ☐ A little of the time
- ☐ None of the time

b. have you been a very nervous person?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

c. have you felt so down in the dumps nothing could cheer you up?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

d. have you felt calm and peaceful?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

e. did you have a lot of energy?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

f. have you felt downhearted and blue?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

g. did you feel worn out?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

h. have you been a happy person?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

i. did you feel tired?

☐ All of the time
☐ Most of the time
☐ A good bit of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

10. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?

☐ All of the time
☐ Most of the time
☐ Some of the time
☐ A little of the time
☐ None of the time

11. How TRUE or FALSE is each of the following statements for you?

a. I seem to get sick a little easier than other people

☐ Definitely true
☐ Mostly true
☐ Don't know
☐ Mostly false
☐ Definitely false

b. I am as healthy as anybody I know

☐ Definitely true
☐ Mostly true
☐ Don't know
☐ Mostly false
☐ Definitely false

c. I expect my health to get worse

☐ Definitely true
☐ Mostly true
☐ Don't know
☐ Mostly false
☐ Definitely false

d. My health is excellent

☐ Definitely true
☐ Mostly true
☐ Don't know
☐ Mostly false
☐ Definitely false

APPENDIX IV

University of Windsor

LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Effects of Forward Lunge Training on Balance Control in Elderly Women**

You are asked to participate in a research study conducted by Leigh Bloomfield (Master's Student) and Dr. Jim Frank (Faculty Supervisor), from the department of Human Kinetics at the University of Windsor. The results of this experiment will be used as part of the final thesis required for the completion of a Master's degree in Human Kinetics. Funding for this experiment has been provided by NSERC.

If you have any questions or concerns about the research, please feel to contact:

Leigh Bloomfield e-mail: bloomfil@uwindsor.ca

Dr. Jim Frank Tel.: 519-253-3000 ext. 2109, e-mail: jsfrank@uwindsor.ca

PURPOSE OF THE STUDY

The purpose of this study is to assess the effects of daily lunge training on balance control in a sample of elderly women. A secondary purpose is to link balance performance on certain balance tests with lunge performance in a sample of elderly women.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things each time you come into the lab (three lab visits in total):

- Complete three questionnaires regarding your level of physical activity, physical and mental wellbeing and your balance confidence

- An experimenter will attach 39 small reflective balls to your body with tape that will be used by the computer to capture your movements

- Complete several balance tests including one legged standing, maximal step length test, and timed up and go test

- Complete a total of 5 forward lunges with each leg

- Total time in the lab should be approximately 1 hour 15 minutes

POTENTIAL RISKS AND DISCOMFORTS

You may feel uncomfortable with the placement of the markers used to collect body motion. You may place the markers on your own body if you would prefer. An experimenter will ask your permission before touching you.

You may lose your balance during the balance tests. An experimenter will be close to you at all times to avoid a fall should you lose your balance. There will be at least one experimenter in the lab trained in first aid and CPR should an injury occur.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will be given instruction as to the proper and safe way to complete the forward lunge. You may choose to incorporate this exercise into your daily activities which may improve your balance abilities. The information gained this study will provide valuable information about the effects of daily lunge training in a sample of elderly women.

PAYMENT FOR PARTICIPATION

All participants will receive a refund for the amount spent on parking for participation in this experiment.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The lab that this experiment is taking place in is a high security area. All of your data will be held in this secure area. Any publications will not include any information that could identify you. You may view any of the video data that is taken of you. No one except those directly involved in the study (Leigh Bloomfield & Jim Frank) will view the tapes. All data will be destroyed after 3 years.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. You may have your data removed from the study if you would like. This can be done by contacting one of the researchers involved.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

You may obtain the results and explanation of the results by contacting one of the researchers any time after August 30, 2009. The results of this experiment will also be available on the Research Ethics Board website at www.uwindsor.ca/reb

SUBSEQUENT USE OF DATA

This data may be used in subsequent studies.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

These are the terms under which I will conduct research.

______________________________	____________________
Signature of Experimenter	Date
______________________________	____________________
Signature of Participant	Date

VITA AUCTORIS

Leigh Bloomfield was born in 1983 in Barrie, Ontario. He graduated from Elmvale District High School in 2002. From there he went on to the University of Waterloo where he earned a B.Sc. in Kinesiology. He is currently a candidate for a Master's degree in Human Kinetics at the University of Windsor and hopes to graduate in Fall 2009.