

# **Improving Lateral Stability in Older Adults at Risk of Falls**

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## **ABSTRACT**

**SHUO-HSIU J. CHANG: Improving Lateral Stability in Older Adults at Risk of Falls**

**(Under the direction of Vicki S. Mercer, PT, PhD)**

Age-related changes in the ability to control lateral body motion have been associated with falls. Maintenance of lateral stability requires activation of appropriate muscle groups, primarily the hip abductors and adductors. Lateral trainer exercise has potential for increasing hip abductor muscle strength and rate of force development (RFD) and improving lateral stability by providing high velocity resistance training for the hip abductor muscles. The purpose of this dissertation was to examine lateral trainer exercise as a novel intervention for improving lateral stability in older adults.

In the first project, forty-two older adults at high and low risk of falls were recruited to participate in kinematic and electromyographic data collection during lateral trainer, lateral step-up and side leg raise exercises performed at self-selected and maximal speeds. Results showed that the lateral trainer exercise can be performed safely by older adults and can provide an adequate level of hip abductor muscle activation for stimulating muscle strength adaptation. The side leg raise exercise produced the highest level of neuromuscular activation, however, indicating that this exercise may be the most beneficial for healthy older adults of the 3 hip abductor strengthening exercises investigated.

In the second project, 21 older adults at risk of falls participated in a small randomized controlled trial of the effects of a 10-week lateral trainer exercise program on balance confidence, hip abductor maximal muscle strength and rate of force development,

and lateral stability. Results showed that older adults in the exercise group performed better than those in the control group on one dynamic balance test, a timed 360° turn, but not on the other measured outcomes. The limited intervention effects may be related to the small sample size, the relatively high level of balance confidence and physical function of the older adults in the sample, and possible inadequacies in the duration of the exercise intervention and/or in the level of resistance used.

Lateral trainer exercise provides an addition to the variety of hip abductor exercises from which older adults can choose. Additional research is needed to identify optimal intervention strategies for improving lateral stability in older adults. A multifactorial approach, one that takes the principle of specificity of training into account by incorporating specific balance training as well as strength training, may produce the best outcomes.

**To Grandma**

**I did it!**

## **ACKNOWLEDGEMENTS**

“Don’t read the sentences on your article when you present!” “Look at us when you talk!” It was my first time to do a presentation in English in my life. It was back in 2000 but I felt it just happened yesterday. I cannot accomplish this far without supports and expertise from my mentors. I would like to express my sincere gratitude to my dissertation committee members: Drs. Mercer, Giuliani, Morey, Sloane and Williams. I would like to extend special thanks to my advisor, Dr. Vicki Mercer. Vicki served as the committee chair in my master thesis and dissertation. She provided exceptional guidance in not only research concepts but also scientific writing. Her patience as a parent and ability as a researcher is a role model for my future life and career.

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## **LIST OF ABBREVIATIONS**

ABC	Activities-specific Balance Scale
ACSM	American College of Sports Medicine
BOS	Base of Support
CHMS	Center for Human Movement Science
COM	Center of Mass
EMG	Electromyography
FSST	Four Square Step Test
GM	Gluteus Medius
HR	High Risk of Falls
HRR	Heart Rate Reserve
ICC	Intraclass Correlation Coefficient
LR	Low Risk of Falls
MVICs	Maximal Voluntary Isometric Contractions
PAR-Q	Physical Activities Readiness Questionnaire
RFD	Rate of Force Development
RMS	Root Mean Square
SLS	Single Limb Stance
VAS	Visual Analog Scale

# **CHAPTER I**

## **INTRODUCTION**

Lateral instability, defined as the inability to control center of mass (COM) position in the frontal plane, is a complex problem. Results of recent research suggest that impaired lateral stability affects static and dynamic balance performance in older adults.<sup>1, 2</sup> Lateral instability has also been found to be associated with falls and fall-related injuries in older adults.<sup>3, 4</sup> Falls most often involve lateral body motion, and hip fractures are most commonly associated with lateral falls.<sup>5-9</sup>

Interventions to improve balance and prevent falls can be categorized as single-risk-factor or multifactorial approaches. Single-risk-factor interventions are effective in improving balance or preventing falls when targeted to groups most at risk, such as those with decreased muscle strength or impaired vision or proprioception.<sup>10, 11</sup> Multifactorial approaches use a combination of interventions to address an individual's impairments and circumstances, and generally appear to be more effective than single-risk-factor interventions.<sup>12-14</sup> Recent multifactorial intervention studies incorporating task-specific training<sup>15</sup> or Tai Chi<sup>16, 17</sup> have shown positive effects in terms of improved balance or decreased incidence of falls in older adults. These studies, however, have included interventions to address balance problems in general rather than specific problems with lateral stability. A review of the literature reveals no previous studies targeting the effects of exercise intervention on lateral stability.

Maintenance of lateral stability requires activation of appropriate muscle groups, primarily the hip abductors and adductors.<sup>18</sup> The hip abductors and adductors play a key role in stabilizing the body over one or both feet during turning, walking, and other daily activities.<sup>19, 20</sup> These muscle groups must generate force rapidly and with precise coordination for stability during performance of volitional and reactive movements.

Compared to flexor and extensor muscle groups, however, hip abductors and adductors may be less likely to receive adequate daily exercise and more susceptible to age-related declines in force-generating capabilities.<sup>21</sup>

Despite their critical role in maintenance of lateral stability, hip abductor and adductor muscle groups have been largely overlooked in previous investigations of physical function, balance, and falls in older adults. Researchers have tended to emphasize movement in the sagittal plane and strengthening of muscles that produce sagittal plane movements (such as hip and knee flexors and extensors).<sup>22-24</sup> Recent evidence, however, supports the need for interventions targeting muscle groups that control movement in the frontal plane.<sup>18, 25</sup>

Age-related changes in the time needed to produce a required level of muscle force are important for postural control.<sup>26, 27</sup> The rate of muscle force development (RFD), is lower in older adults than in young adults.<sup>28</sup> Decreased ability to develop muscle force rapidly may be related to impaired neuromuscular responses for controlling postural sway.<sup>29</sup> In a previous study of community dwelling older adults,<sup>30</sup> we demonstrated that hip abductor RFD was significantly related to performance on two clinical tests that challenge lateral stability- single limb stance and tandem gait. An older adult who is unable to generate sufficient muscle force in the hip abductors and adductors in the time frame necessary to control the position of the COM relative to the base of support (BOS) will be at increased risk for falls. Therefore, hip abductor rate of muscle force development should be considered in assessment and treatment of older adults with balance deficits.

Evidence supports the efficacy of interventions designed to improve muscle RFD in older adults.<sup>31-34</sup> Different types of strength training, including resistance training<sup>35</sup> and

high-velocity training,<sup>31-34, 36</sup> can improve RFD in older adults. Training that focuses on speed of movement (e.g., high-velocity resistance training) increases the incidence of discharge doublets in individual motor units and produces increases in RFD.<sup>37, 38</sup> Several studies suggest that neural adaptation mechanisms, especially increased incidence of discharge doublets and motor unit synchronization, are important for training-induced RFD increases.<sup>37-39</sup> High-velocity resistance training also has been shown to improve balance and physical performance in older adults with and without physical limitations.<sup>40-42</sup>

Several hip abductor exercises are recommended for older adults, but generally without evidence for the benefits of the exercise and without information about how to perform the exercise efficiently. One exercise recommended for older adults by the National Institute on Aging is the side leg raise performed in standing.<sup>43</sup> The side leg raise requires a concentric contraction of the hip abductors to lift the leg against gravity, with the foot coming off the floor as the hip moves into abduction. Hip abductor muscle activation may be lower for this type of non-weight-bearing exercise than for weight-bearing hip abductor exercise.<sup>44</sup> Another exercise that is thought to activate the hip abductor muscles is the lateral step-up exercise, in which the individual, while facing forward, steps on and off a step placed on one side of the body. Older adults with balance problems or with lower extremity joint problems such as osteoarthritis may have difficulty with this exercise.

We propose a novel intervention for improving lateral stability and, ultimately, decreasing falls in older adults. The intervention targets the hip abductor and adductor muscles through exercise on a lateral trainer,<sup>\*</sup> a device that is currently used in athletic training and sport rehabilitation. The lateral trainer provides a mode of exercise that, based on the principle of high-velocity resistance training, should improve both the magnitude and

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<sup>\*</sup> Dynamic Edge® RPM™, The Skier's Edge Company, P.O. Box 2700, Park City, Utah 84060

the rate of force production of the hip abductors/adductors. The lateral trainer includes a dynamic slide plate with independent-action footpads allowing rhythmic lateral motions at self-controlled speeds and with various levels of resistance. Exercise on the lateral trainer is continuous and requires phasic activation of lower extremity muscle groups in a weight bearing position. As a means of providing high velocity resistance training for muscles that control movement in the frontal plane, lateral trainer exercise has potential for increasing hip abductor muscle strength and RFD and improving lateral stability. Pilot work with subjects who are post-stroke provides evidence for the feasibility of this exercise intervention for the older adult population.

The purpose of this dissertation was to examine lateral trainer exercise as a novel intervention for improving lateral stability in older adults. A conceptual model of the effects of hip abductor exercise on lateral stability in older adults is presented in Figure 1.1. In this model, lateral stability is influenced by age-related changes in sensory and motor systems and by cognitive factors such as balance confidence. This dissertation focused on the effects of lateral trainer exercise on motor system variables and cognitive/psychological factors and on lateral stability in older adults. The dissertation was completed as two separate projects, which are presented here in three manuscripts. Specific aims and hypotheses for each project are listed below:

### Project 1

#### *Specific Aims*

1) To describe bilateral lower extremity kinematics and hip abductor muscle activity during exercise on the lateral trainer by older adults who are and are not at increased risk of falls (Manuscript 1).



2) To compare amplitude of hip abductor muscle activation during lateral trainer, lateral step-up, and side leg raise exercises (Manuscript 2).

*Hypotheses:* We hypothesized that the amplitude of hip abductor muscle activity would be greater during performance of lateral trainer as compared to side leg raise and lateral step-up exercises. We also hypothesized that hip abductor muscle activity would be greater for performance at maximal as compared to self-selected speeds.

### Project 2

*Specific Aim:* To obtain preliminary data on the effects of a 10-week program of lateral trainer exercise on a) balance confidence, b) hip abductor muscle strength and RFD, and c) lateral stability in older adults who are at increased risk of falls (Manuscript 3).

*Hypothesis:* We hypothesized that older adults who participated in the exercise program would show greater balance confidence, greater hip abductor muscle strength and RFD, and better lateral stability than control group subjects.

## References

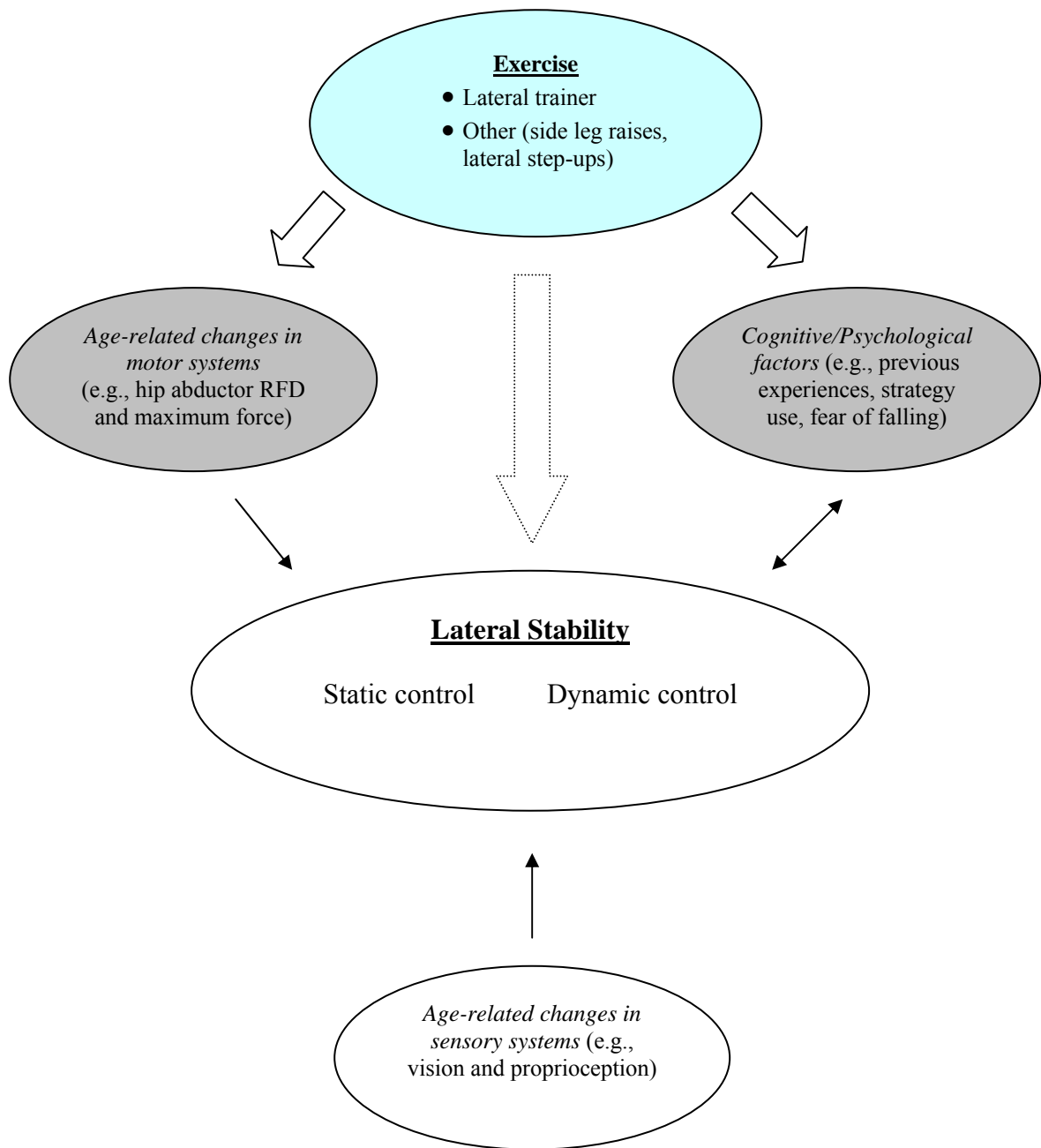
1. Hayes WC, Myers ER, Robinovitch SN, Van Den Kroonenberg A, Courtney AC, McMahon TA. Etiology and prevention of age-related hip fractures. *Bone* 1996; 18:77S-86S.
2. Nevitt MC, Cummings SR. Type of fall and risk of hip and wrist fractures: the study of osteoporotic fractures. The Study of Osteoporotic Fractures Research Group. *J Am Geriatr Soc* 1993; 41:1226-34.
3. Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. *J Am Geriatr Soc* 1999; 47:1077-81.
4. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J Gerontol* 1994; 49:M72-84.
5. Cumming RG, Klineberg RJ. Fall frequency and characteristics and the risk of hip fractures. *J Am Geriatr Soc* 1994; 42:774-8.
6. Greenspan SL, Myers ER, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *Jama* 1994; 271:128-33.
7. Hayes WC, Myers ER, Morris JN, Gerhart TN, Yett HS, Lipsitz LA. Impact near the hip dominates fracture risk in elderly nursing home residents who fall. *Calcif Tissue Int* 1993; 52:192-8.
8. Robinovitch SN, Hayes WC, McMahon TA. Prediction of femoral impact forces in falls on the hip. *J Biomech Eng* 1991; 113:366-74.
9. Smeesters C, Hayes WC, McMahon TA. Disturbance type and gait speed affect fall direction and impact location. *J Biomech* 2001; 34:309-17.
10. Hess JA, Woollacott M. Effect of high-intensity strength-training on functional measures of balance ability in balance-impaired older adults. *J Manipulative Physiol Ther* 2005; 28:582-90.
11. Sihvonen S, Sipila S, Taskinen S, Era P. Fall incidence in frail older women after individualized visual feedback-based balance training. *Gerontology* 2004; 50:411-6.
12. Delbaere K, Bourgois J, Van Den Noortgate N, Vanderstraeten G, Willems T, Cambier D. A home-based multidimensional exercise program reduced physical impairment and fear of falling. *Acta Clin Belg* 2006; 61:340-50.
13. Nnodim JO, Strasburg D, Nabozny M, et al. Dynamic balance and stepping versus tai chi training to improve balance and stepping in at-risk older adults. *J Am Geriatr Soc* 2006; 54:1825-31.

14. DiBrezza R, Shadden BB, Raybon BH, Powers M. Exercise intervention designed to improve strength and dynamic balance among community-dwelling older adults. *J Aging Phys Act* 2005; 13:198-209.
15. Nitz JC, Choy NL. The efficacy of a specific balance-strategy training programme for preventing falls among older people: a pilot randomised controlled trial. *Age Ageing* 2004; 33:52-8.
16. Gatts SK, Woollacott MH. Neural mechanisms underlying balance improvement with short term Tai Chi training. *Aging Clin Exp Res* 2006; 18:7-19.
17. Lin MR, Hwang HF, Wang YW, Chang SH, Wolf SL. Community-based tai chi and its effect on injurious falls, balance, gait, and fear of falling in older people. *Phys Ther* 2006; 86:1189-201.
18. Rogers MW, Hedman LD, Johnson ME, Cain TD, Hanke TA. Lateral stability during forward-induced stepping for dynamic balance recovery in young and older adults. *J Gerontol A Biol Sci Med Sci* 2001; 56:M589-94.
19. Kirker SG, Simpson DS, Jenner JR, Wing AM. Stepping before standing: hip muscle function in stepping and standing balance after stroke. *J Neurol Neurosurg Psychiatry* 2000; 68:458-64.
20. Pai YC, Chang HJ, Chang RW, Sinacore JM, Lewis JL. Alteration in multijoint dynamics in patients with bilateral knee osteoarthritis. *Arthritis Rheum* 1994; 37:1297-304.
21. Johnson ME, Mille ML, Martinez KM, Crombie G, Rogers MW. Age-related changes in hip abductor and adductor joint torques. *Arch Phys Med Rehabil* 2004; 85:593-7.
22. Rantanen T, Guralnik JM, Izmirlian G, et al. Association of muscle strength with maximum walking speed in disabled older women. *Am J Phys Med Rehabil* 1998; 77:299-305.
23. Brown M, Holloszy JO. Effects of walking, jogging and cycling on strength, flexibility, speed and balance in 60- to 72-year olds. *Aging (Milano)* 1993; 5:427-34.
24. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther* 1993; 73:254-62; discussion 263-5.
25. Miller K, Johnson M, Roger M. Stance hip abduction torque characteristics during volitional and induced stepping in young and older adults. *Neurology report* 2002; 26.
26. Hakkinen K, Hakkinen A. Muscle cross-sectional area, force production and relaxation characteristics in women at different ages. *Eur J Appl Physiol Occup Physiol* 1991; 62:410-4.

27. Hakkinen K, Kraemer WJ, Newton RU. Muscle activation and force production during bilateral and unilateral concentric and isometric contractions of the knee extensors in men and women at different ages. *Electromyogr Clin Neurophysiol* 1997; 37:131-42.
28. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol A Biol Sci Med Sci* 2000; 55:M192-9.
29. Izquierdo M, Ibanez J, Gorostiaga E, et al. Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiol Scand* 1999; 167:57-68.
30. Chang SH, Mercer VS, Giuliani CA, Sloane PD. Relationship between hip abductor rate of force development and mediolateral stability in older adults. *Arch Phys Med Rehabil* 2005; 86:1843-50.
31. Hakkinen K, Kallinen M, Izquierdo M, et al. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J Appl Physiol* 1998; 84:1341-9.
32. Hakkinen K, Pakarinen A, Kraemer WJ, Hakkinen A, Valkeinen H, Alen M. Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol* 2001; 91:569-80.
33. Suetta C, Aagaard P, Rosted A, et al. Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. *J Appl Physiol* 2004; 97:1954-61.
34. Barry BK, Warman GE, Carson RG. Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. *Exp Brain Res* 2005; 162:122-32.
35. Maganaris CN, Narici MV, Reeves ND. In vivo human tendon mechanical properties: effect of resistance training in old age. *J Musculoskelet Neuronal Interact* 2004; 4:204-8.
36. Hakkinen K, Newton RU, Gordon SE, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol A Biol Sci Med Sci* 1998; 53:B415-23.
37. Van Cutsem M, Duchateau J, Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol* 1998; 513 ( Pt 1):295-305.
38. Aagaard P. Training-induced changes in neural function. *Exerc Sport Sci Rev* 2003; 31:61-7.

39. Semmler JG. Motor unit synchronization and neuromuscular performance. *Exerc Sport Sci Rev* 2002; 30:8-14.
40. Miszko TA, Cress ME, Slade JM, Covey CJ, Agrawal SK, Doerr CE. Effect of strength and power training on physical function in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci* 2003; 58:171-5.
41. Sayers SP, Bean J, Cuoco A, LeBrasseur NK, Jette A, Fielding RA. Changes in function and disability after resistance training: does velocity matter?: a pilot study. *Am J Phys Med Rehabil* 2003; 82:605-13.
42. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology* 2005; 51:108-15.
43. Exercise: A guide from the National Institute on Aging: National Institute on Aging, 2004:44.
44. Bolgla LA, Uhl TL. Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. *J Orthop Sports Phys Ther* 2005; 35:487-94.

**Figure 1.1.** Conceptual Model of Effects of Lateral Trainer Exercise on Lateral Stability in Older Adults



## **CHAPTER II**

### **FIRST MANUSCRIPT**

#### **Electromyographic and Kinematic Analysis of Lateral Trainer Exercise in Older Adults**

## ABSTRACT

**Background and purpose.** Appropriate activation of hip abductor muscles is necessary for maintenance of lateral stability. Lateral trainer exercise is a type of exercise that involves controlled movement in the frontal plane and may provide an appropriate level of neuromuscular activation of the hip abductors for promoting lateral stability. With an emphasis on speed of movement, lateral trainer exercise has potential for improving both the magnitude and the rate of force development of the hip abductor muscles. The purpose of this study was to describe hip abductor muscle activity and bilateral lower extremity kinematics during exercise on the lateral trainer by older adults at high risk (HR) and low risk (LR) of falls. **Methods.** Forty-two older adults between 65 and 89 years of age (HR: n= 20, LR: n=22) participated in a single data collection session. Categorization of fall risk was based on clinical balance test performance. Kinematic variables (bilateral hip and knee angular displacements) and electromyographic (EMG) variables (peak amplitude, root mean square, and integrated EMG from bilateral hip abductors) were determined for exercise on the lateral trainer at self-selected and maximal speeds. Linear mixed model analyses were applied to estimate means of kinematic and EMG variables by risk group and exercise speed. **Results.** Older adults at high risk of falls showed less hip abduction/adduction angular displacement but similar EMG activity compared to older adults at low risk of falls. Subjects in both groups demonstrated higher normalized peak and root mean square EMG and greater integrated EMG during maximal speed compared to self-selected speed trials. Exercise at maximal speed was also characterized by slightly greater hip abduction/adduction angular displacement and hip and knee flexion/extension angular displacement than exercise at self-selected speed. **Conclusion.** Lateral trainer exercise, particularly when performed at



maximal speed, may provide adequate exercise intensity to stimulate muscle strength adaptation of the hip abductors.

## INTRODUCTION

The hip abductors and adductors play a key role in stabilizing the body over one or both feet during turning, walking, and other daily activities.<sup>1,2</sup> Appropriate activation of hip abductors and adductors is required for maintenance of lateral stability, defined as the ability to control center of mass (COM) position in the frontal plane.<sup>3</sup> These muscle groups must generate force rapidly and with precise coordination for stability during performance of volitional and reactive movements. Despite their critical role in maintenance of lateral stability, hip abductor and adductor muscle groups have been largely overlooked in previous investigations of physical function, balance, and falls in older adults. Researchers have tended to emphasize movement in the sagittal plane and strengthening of muscles that produce sagittal plane movements (such as hip and knee flexors and extensors).<sup>4-6</sup> Recent evidence, however, supports the need for interventions targeting muscle groups that control movement in the frontal plane.<sup>3,7</sup>

High velocity resistance training, a type of exercise that emphasizes speed of movement, has been shown to improve lower extremity muscle rate of force development (RFD)<sup>8,9</sup> and gait speed<sup>10</sup> in older adults. To stimulate muscle strength adaptation, an exercise should provide at least 40% to 60% of maximal neuromuscular activation.<sup>11</sup> The lateral trainer<sup>\*</sup> is a device that is currently used in athletic training and sport rehabilitation. This device provides a mode of exercise that, based on principles of high-velocity resistance training, should provide an adequate level of neuromuscular activation to improve both the magnitude and the rate of force production of the hip abductors. The lateral trainer includes a dynamic slide plate with independent-action footpads allowing lateral motions in the

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<sup>\*</sup>Dynamic Edge® RPM™, The Skier's Edge Company, P.O. Box 2700, Park City, Utah 84060

frontal plane at self-controlled speeds and with various levels of resistance.

Interventions for improving lateral stability are often directed toward the population of older adults who are at high risk of falls. Unfortunately, little is known about exercise performance in this population. To achieve maximal effects, exercise should be prescribed with an understanding of older adults' movement characteristics and capabilities (e.g., range of motion, movement speed) relative to the requirements of the exercise. Information about these movement characteristics in older adults at high and low risk of falls can help guide the decision-making process needed for appropriate exercise prescription.

The purposes of this study were to describe hip abductor muscle activity and bilateral lower extremity kinematics during exercise on the lateral trainer by older adults with high and low risk of falls. These data are important to inform the design of exercise programs targeting older adults with hip muscle weakness and impaired balance.

## **METHODS**

### **Subjects**

Subjects were recruited by emails, flyers, and presentations at senior centers, the YMCA, and continuing care retirement communities (see Appendix B). Inclusion criteria were as follows: 65 years of age or older; able to read and speak English; able to ambulate at least 50 feet without physical assistance; no more than 1 error on the Six-Items Test (a cognitive screening tool);<sup>12</sup> normal or corrected-to-normal vision and hearing (by self-report); and able to follow instructions and perform all experimental procedures. Volunteers were excluded if they had any of the following: body weight of 200 lb or above (the upper weight limit of the lateral trainer); diagnosed neurological disease or disorder; lower extremity joint replacement (because of the possibility of impaired joint proprioception affecting movement

control); acute back or extremity musculoskeletal problems, such as strains, sprains, or fractures; unstable cardiovascular disease; or uncontrolled diabetes mellitus.

Screening and demographic information of potential subjects including age, dominant lower extremity, contact information, physical activity level and self-reported fall history were obtained by telephone or in-person interview. Dominant lower extremity was defined as the leg used to kick a ball (by self-report). Informed consent was obtained at the start of the screening session following the initial interview (see Appendix C). This screening session included administration of a medical history questionnaire, the Six-Item test<sup>12</sup> (a cognitive screening test), and fall risk assessment (see Appendix D). The fall risk assessment included the Four Square Step Test (FSST) and Single Limb Stance (SLS) to determine risk of falls. These tests were administered according to standardized procedures described by Dite et al<sup>13</sup> and Tinetti<sup>14</sup>, respectively. Both the FSST and SLS have evidence of reliability<sup>13,15</sup> and can be used to identify individuals at risk of falls<sup>13</sup> or injurious falls<sup>16</sup>. Subjects were considered as being at high risk (HR) of falls if they 1) required  $\geq 15$  seconds to complete the FSST or were unable to face forward or needed to turn before stepping into the next square<sup>13</sup> or 2) were unable to maintain SLS for at least 5 seconds<sup>16</sup>. Subjects who completed the FSST in less than 15 seconds and were able to maintain SLS for at least 5 seconds comprised a low risk (LR) group.

Each subject completed a Modified Physical Activity Readiness Questionnaire (PAR-Q) that was sent to his/her primary care physician with a request for medical approval to participate in the study. The Modified PAR-Q is a screening tool to identify risk factors or symptoms that are contraindications for exercise (see Appendix E). We obtained medical approval (in writing) from each subject's physician prior to the laboratory testing session (see

Appendix F).

One hundred and five volunteers who showed interest in this study received telephone or face-to-face interviews. Forty-eight were excluded during the screening process. Another 13 volunteers withdrew after they were enrolled in the study but prior to the laboratory testing session (6 were lost to follow-up or declined further participation; 6 developed health problems; 1 had heart surgery). The remaining 44 volunteers, 20 in the HR group and 24 in the LR group, participated in one test session at our laboratory for collection of EMG and kinematic data. Subjects were paid \$20 at the completion of testing.

## **Procedures**

### *Data Collection*

Measurements of subjects' height, weight, and thigh length were recorded. Subjects performed warm-ups including lower extremity muscle stretching exercises prior to performance of lateral trainer exercise.<sup>17</sup>

A 16-channel telemetry EMG system (Konigsberg Instruments, Inc., Pasadena, CA) was used to record muscle activity from the gluteus medius (GM) bilaterally. After standard skin preparation,<sup>18</sup> active surface electrodes (Neuroline, pre-gelled, AG/AgCl, bipolar disposable electrodes) were placed over the belly of the muscle.<sup>17</sup> Electrode placements were verified using manual muscle testing techniques to minimize crosstalk. The electrode surface was 15 mm in diameter, and inter-electrode distance was 20 mm center to center. A common reference electrode was placed on the skin overlying the anterior border of the mid-shaft of the tibia. EMG signals were converted from analog to digital (A/D converter, Peak Performance Technologies, Englewood, CO) at 1200 Hz and recorded using Peak Motus software (Peak Performance Technologies, Englewood, CO).

Subjects performed three maximal voluntary isometric contractions (MVICs) of the GM of the dominant leg for EMG signal normalization. The MVICs were performed with subjects in the supine position to provide stabilization of the trunk and opposite lower extremity and to maximize safety. Procedures were based on those described by Andrews et al.<sup>19</sup> Subjects were positioned supine with the hips in neutral rotation. A Quantrol AFG digital force gauge (Dillon/Quality Plus, Inc., Camarillo, CA) was mounted on a wooden frame and stabilized against a wall during testing. The force gauge was placed perpendicular to the thigh of the dominant leg, with the padded attachment on the distal lateral femoral condyle for hip abduction. The examiner explained the desired muscle action of hip abduction with the knee extended, and allowed the subject to perform 1-2 practice trials as needed. Subjects were encouraged to push against the gauge as hard as possible. Force and EMG signals were recorded for 5 seconds to allow the subject to build up to a maximal contraction. The digital readouts on the force gauge were used to examine consistency across trials. Three test trials for each movement were performed with a rest period of at least 30 seconds between trials.

After completion of the MVICs, reflective markers were placed on the following bony landmarks bilaterally: acromion process, anterior superior iliac spine, lateral thigh (midpoint at the central line), lateral femoral condyle, tibia (midpoint), and lateral malleolus. Three-dimensional videographic data were collected in one standing trial prior to exercise. Eight infrared video cameras sampling at 120 Hz were used in conjunction with the Peak Motus real time motion analysis system to record the trajectories of reflective markers placed on each subject's trunk and lower extremities. Trajectories of these markers during exercises were used to create virtual trunk and lower extremity segments for joint angle

calculation. Joint angle was calculated using customized software (Motion Soft 3D v. 6.5, Bing Yu, University of North Carolina at Chapel Hill, Chapel Hill, NC).

One standing trial was used to create a virtual model of the trunk and lower extremities in the static situation. In the standing trial, additional passive reflective markers were placed at the medial malleolus and medial and lateral femoral condyles bilaterally. These additional markers were needed for estimation of joint centers, but were removed prior to exercise to avoid interference with the subject's movement and collision of the markers during exercise.

The resistance provided by the lateral trainer was adjusted to the lowest level. Subjects held onto the balance bar during exercise (Figure 2.1). The distance between footplates was adjusted according to the subject's preference. The researchers instructed subjects to move the footplates as far as possible from side to side, and to practice until they felt comfortable performing the exercise. The researchers provided verbal and tactile cues to encourage subjects to maintain an upright position with the trunk in midline (stationary in the center of the machine) during the practice trials.

Subjects then performed lateral trainer exercise, first at self-selected speed and then at maximal speed. They were asked to move as fast as possible for the maximal speed trials. The speed of exercise was determined from the time required to finish 10 repetitions of each exercise and then transformed to the number of repetitions performed in one minute. One repetition was defined as movement of the footplates from the farthest point on the subject's left side to the farthest point on the subject's right side and back. Subjects were asked to perform 2 sets of 10 repetitions at each speed with at least 2 minutes rest between sets and exercises. EMG and kinematics signals were recorded while subjects exercised at each

speed.

### **Data Reduction**

Mean values for the kinematic and EMG variables of the middle 4 repetitions during each exercise set were calculated for each subject and used for subsequent data analyses. The first three and last three repetitions of each set of exercises were excluded to minimize warm-up and fatigue effects.

For kinematics, the reflective markers were first identified within the Peak Motus program (Performance Technologies Inc, Centennial, CO 80112) and the data were then exported to customized software (Motion Soft 3D v. 6.5, Bing Yu, University of North Carolina at Chapel Hill, Chapel Hill, NC) for processing. Joint angular displacements were calculated for hip abduction-adduction and flexion-extension and knee flexion-extension. A customized Matlab program (Matlab v. 6.5, Mathworks, Natick, MA 01760-2098) was used to identify movement repetitions based on trajectories of the markers on the lateral malleoli.

EMG data were exported from Peak Motus to a customized Matlab program on a personal computer for data processing and calculation. Raw EMG data were bandpass filtered using a fourth order Butterworth Filter at 10 – 300 Hz and rectified. A moving average with a fixed window of 30 ms was used to smooth the data. For each movement repetition, determined from the kinematic data, peak amplitude was identified, and root-mean-square (RMS) and integrated EMG amplitude were determined for the right and left GM. Integrated EMG was calculated to determine the total amount of muscle activity occurring during one repetition of lateral trainer exercise. For normalization, the peak and RMS amplitudes were expressed as a percentage of the maximal RMS amplitude recorded over a 500-ms window across the 3 MVICs.<sup>20</sup> An example of processed EMG data from



lateral trainer exercises at self-selected and maximal speeds is shown in Figure 2.2.

### **Statistical Analysis**

Descriptive statistics were generated for subject characteristics. Distributions of all data were examined and screened for outliers. T-tests were conducted to detect any differences between HR and LR groups in subject characteristics including age, body height, and weight. Linear mixed models were used to estimate means and standard errors of kinematic (angular displacements in hip abduction-adduction, hip flexion-extension and knee flexion-extension) and EMG (normalized peak, RMS and integrated EMG) variables, overall and by risk group and exercise speed.

The models included a random effect for participant and fixed effects for risk group and exercise speed for all kinematic and EMG variables. Model-based adjusted means for kinematic and EMG variables were then estimated from linear mixed models including the participant random effect and the following fixed covariates: age, gender; maximal hip abductor torque (kg-m), exercise speed (repetition per minute), body weight (kg) and height (m). Gender was eliminated from the model because there were no significant gender differences (all  $p > .05$ ). Model-based adjusted means for exercise speed were estimated from linear mixed models including the participant random effect and the following fixed covariates: age, maximal hip abductor torque (kg-m), body weight (kg) and height (m). We also tested for interaction between risk group and exercise speed for all dependent variables. A significance level of  $p < .05$  was used for all statistical tests. All analyses were conducted using SAS 8.02 (SAS Institute Inc., Cary, NC 27513).

## RESULTS

Forty-four older adults participated in the study. Only 42 of these subjects were included in data analyses because of technical problems during data collection for 2 subjects. Characteristics of these 42 subjects (24 women, 18 men; mean age =  $77.4 \pm 7.5$  years; range 65 – 89 years) are presented in Table 2.1. Twenty older adults were identified as being at high risk of falls (HR) and twenty-two at low risk of falls (LR). As shown in Table 2.1, the HR group had more subjects at the upper end of the age range compared to the LR group. As expected from the criteria for group classification, LR subjects had significantly higher scores for SLS and lower scores for FSST than HR subjects. Subjects reported regular physical activity (for example: walking, gardening, dancing) and exercise (for example: exercise class, water aerobics, yoga, swimming), except for 1 subject in the LR group.

Exercise Speed. A significant group by exercise speed interaction was found ( $p=.017$ ). Subjects in both groups performed more repetitions (moved faster) during maximal speed trials (HR:  $52 \pm 2$ , LR:  $58 \pm 2$  repetitions per minute) than self-selected speed trials (HR:  $48 \pm 2$ , LR:  $48 \pm 1$  repetitions per minute; all  $p<.05$ ; Table 2.2). LR subjects did not perform more repetitions compared to HR subjects in maximal speed trials (HR:  $52 \pm 2$ , LR:  $58 \pm 2$ ;  $p=.069$ ) and in self-selected speed trials (HR:  $48 \pm 2$ , LR:  $48 \pm 1$ ;  $p=.887$ ).

Kinematics. No group by exercise speed interaction was found for any of the kinematic variables (all  $p>.05$ ). HR subjects showed slightly less right hip abduction-adduction angular displacement compared to LR subjects (for self-selected speed, HR:  $16.9 \pm 1.5^\circ$ , LR:  $20.1 \pm 1.3^\circ$ ; for maximal speed, HR:  $19.3 \pm 1.6^\circ$ , LR:  $24.2 \pm 1.5^\circ$ ;  $p=.049$ ; Table 2.2). Both HR and LR groups displayed slightly greater hip abduction/adduction angular displacement bilaterally in maximal speed compared to

self-selected speed trials (Table 2.2, all  $p < .05$ ). Adjusted means for right hip abduction/adduction angular displacement for the HR group were  $19.3 \pm 1.6^\circ$  at maximal speed and  $16.9 \pm 1.5^\circ$  at self-selected speed and for the LR group were  $24.2 \pm 1.5^\circ$  at maximal speed and  $20.1 \pm 1.3^\circ$  at self-selected speed. Values for hip abduction/adduction angular displacement of the left leg were very similar to those for the right leg (Table 2.2). Both groups of subjects also displayed slightly greater left hip and knee flexion/extension angular displacements in maximal compared to self-selected speed trials (Table 2.2). For left hip flexion/extension, adjusted means for maximal and self-selected speeds were  $21.6 \pm 1.3^\circ$  and  $18.5 \pm 1.3^\circ$ , respectively, in the HR group and  $23.4 \pm 1.3^\circ$  and  $20.8 \pm 1.2^\circ$ , respectively, in the LR group ( $p = .006$ ). For left knee flexion/extension, adjusted means for maximal and self-selected speeds were  $38.9 \pm 1.8^\circ$  and  $34.3 \pm 1.7^\circ$ , respectively, in the HR group and  $40.4 \pm 1.8^\circ$  and  $37.3 \pm 1.6^\circ$ , respectively, in the LR group ( $p = .021$ ).

EMG. No group by exercise speed interaction was found for any of the EMG variables (all  $p > .05$ ). Level of muscle activation (normalized peak and RMS EMG) and integrated EMG values were similar in HR and LR groups during performance of lateral trainer exercise (all  $p > .05$ , Table 2.3). Subjects in both groups demonstrated higher normalized peak, RMS, and integrated EMG values bilaterally during maximal speed trials compared to self-selected speed trials (all  $p < .05$ , Table 2.3). Adjusted means for peak EMG ranged from 77.7% to 80.3% MVIC at self-selected speed and from 100.7% to 107.3% MVIC at maximal speed. For RMS EMG, these values ranged from 38.2% to 43.3% MVIC at self-selected speed and from 48.2% to 56.1% MVIC at maximal speed.

## DISCUSSION

Older adults at high and low risk of falls performed the lateral trainer exercise safely and without difficulty. For subjects in both groups, level of neuromuscular activation during exercise was greater than 40% of MVIC. Compared to LR subjects, subjects in the HR group demonstrated lower exercise speed and less hip abduction/adduction during lateral trainer exercise, but had similar levels of muscle activation. Greater hip abductor muscle activity was observed for performance at maximal compared to self-selected speed.

Results of this study suggest that lateral trainer exercise can provide an adequate stimulus for muscle strengthening in older adults. Assuming a positive linear relationship between isometric muscle force and surface EMG, an exercise that provides at least 40% to 60% of neuromuscular activation is expected to stimulate muscle strength adaptation.<sup>11</sup> Intensity of lateral trainer exercise performed at self-selected speed may be adequate for muscle strengthening in older adults, but exercise at maximal speed may provide optimal results. High speed movements can produce a higher level of muscle activation,<sup>21, 22</sup> promote muscle strength gains, and increase the rate of force development.<sup>23</sup> Results from previous studies applying high velocity strength training support the efficacy of interventions designed to improve muscle RFD and strength in older adults.<sup>8, 9, 24, 25</sup>

During lateral trainer exercise, older adults at high risk of falls tended to move slowly and to limit their hip abduction/adduction movement. However, no difference was found in percentage of maximal muscle activation between older adults at high and low risk of falls. These results might reflect greater lower extremity muscle co-contraction among older adults at high risk of falls. Such a co-contraction strategy has been reported previously for older adults in situations in which their balance was challenged.<sup>26-28</sup> Amount of co-contraction of

antagonist muscles was not directly measured in the present study, but might provide insights into motor control strategies and potential exercise effects in future studies.

The between-group differences in movement speed and hip abduction/adduction angular displacement observed in the present study may be related to low balance confidence. Older adults at high risk of falls may have low balance confidence that may affect their performance.<sup>29</sup> Decreased balance confidence has been associated with slower walking speeds<sup>30</sup> and with shorter step lengths during a maximal step length test and longer stepping times during a rapid step test<sup>31</sup>. Assessment of balance confidence should be included in future studies.

The present study has several limitations. Although the age distribution of our subjects was good (Table 2.1), their maximal hip abductor strength was lower than the normative values in the same age groups as presented by Andrews et al<sup>19</sup> (2 – 8 kg lower in males, 6 – 8 kg lower in females). The results presented here may not be representative of the aging population as a whole. Furthermore, our results may have been influenced by inability to obtain true maximal contraction on some MVIC trials. Submaximal effort may have occurred during MVIC testing if stabilization was not adequate or subjects were not able to produce maximal effort consistently. If so, the values of normalized EMG variables may be overestimated. In future studies, a normalization method using muscle activity during dynamic tasks, such as walking, may be preferable.<sup>32, 33</sup>

## **CONCLUSION**

This study investigated lower extremity kinematics and hip abductor muscle activity during lateral trainer exercise in older adults at high and low risk of falls. Older adults at high risk of falls showed less hip abduction/adduction movement but similar EMG activity

compared to older adults at low risk of falls. Higher values of normalized peak, RMS, and integrated EMG were found during maximal as compared to self-selected speed movements. Lateral trainer exercise may provide adequate exercise intensity to stimulate hip abductor muscle strength adaptation. Future studies should focus on identifying the most effective hip abductor exercise for older adults.

## References

1. Kirker SG, Simpson DS, Jenner JR, Wing AM. Stepping before standing: hip muscle function in stepping and standing balance after stroke. *J Neurol Neurosurg Psychiatry* 2000; 68:458-64.
2. Pai YC, Chang HJ, Chang RW, Sinacore JM, Lewis JL. Alteration in multijoint dynamics in patients with bilateral knee osteoarthritis. *Arthritis Rheum* 1994; 37:1297-304.
3. Rogers MW, Hedman LD, Johnson ME, Cain TD, Hanke TA. Lateral stability during forward-induced stepping for dynamic balance recovery in young and older adults. *J Gerontol A Biol Sci Med Sci* 2001; 56:M589-94.
4. Rantanen T, Guralnik JM, Izmirlian G, et al. Association of muscle strength with maximum walking speed in disabled older women. *Am J Phys Med Rehabil* 1998; 77:299-305.
5. Brown M, Holloszy JO. Effects of walking, jogging and cycling on strength, flexibility, speed and balance in 60- to 72-year olds. *Aging (Milano)* 1993; 5:427-34.
6. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther* 1993; 73:254-62; discussion 263-5.
7. Miller K, Johnson M, Roger M. Stance hip abduction torque characteristics during volitional and induced stepping in young and older adults. *Neurology report* 2002; 26.
8. Hakkinen K, Kallinen M, Izquierdo M, et al. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J Appl Physiol* 1998; 84:1341-9.
9. Hakkinen K, Pakarinen A, Kraemer WJ, Hakkinen A, Valkeinen H, Alen M. Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol* 2001; 91:569-80.
10. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology* 2005; 51:108-15.
11. Andersen LL, Magnusson SP, Nielsen M, Haleem J, Poulsen K, Aagaard P. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: implications for rehabilitation. *Phys Ther* 2006; 86:683-97.
12. Callahan CM, Unverzagt FW, Hui SL, Perkins AJ, Hendrie HC. Six-item screener to identify cognitive impairment among potential subjects for clinical research. *Med Care* 2002; 40:771-81.
13. Dite W, Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. *Arch Phys Med Rehabil* 2002; 83:1566-71.

14. Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 1986; 34:119-26.
15. Potvin AR, Syndulko K, Tourtellotte WW, Lemmon JA, Potvin JH. Human neurologic function and the aging process. *J Am Geriatr Soc* 1980; 28:1-9.
16. Vellas BJ, Wayne SJ, Romero L, Baumgartner RN, Rubenstein LZ, Garry PJ. One-leg balance is an important predictor of injurious falls in older persons. *J Am Geriatr Soc* 1997; 45:735-8.
17. Bolgla LA, Uhl TL. Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. *J Orthop Sports Phys Ther* 2005; 35:487-94.
18. Basmajian JV, De Luca CJ. *Muscle Alive: Their Function Revealed by Electromyography*. Baltimore, MD: Williams & Wilkins, 1985.
19. Andrews AW, Thomas MW, Bohannon RW. Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Phys Ther* 1996; 76:248-59.
20. Bolgla LA, Uhl TL. Reliability of electromyographic normalization methods for evaluating the hip musculature. *J Electromyogr Kinesiol* 2006.
21. Anders C, Wagner H, Puta C, Grassme R, Petrovitch A, Scholle HC. Trunk muscle activation patterns during walking at different speeds. *J Electromyogr Kinesiol* 2006.
22. Chiu MC, Wang MJ. The effect of gait speed and gender on perceived exertion, muscle activity, joint motion of lower extremity, ground reaction force and heart rate during normal walking. *Gait Posture* 2006; 25:385-92.
23. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol* 2002; 93:1318-26.
24. Suetta C, Aagaard P, Rosted A, et al. Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. *J Appl Physiol* 2004; 97:1954-61.
25. Barry BK, Warman GE, Carson RG. Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. *Exp Brain Res* 2005; 162:122-32.
26. Tang PF, Woollacott MH. Inefficient postural responses to unexpected slips during walking in older adults. *J Gerontol A Biol Sci Med Sci* 1998; 53:M471-80.
27. Melzer I, Benjuya N, Kaplanski J. Age-related changes of postural control: effect of cognitive tasks. *Gerontology* 2001; 47:189-94.



28. Laughton CA, Slavin M, Katdare K, et al. Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait Posture* 2003; 18:101-8.
29. Cumming RG, Salkeld G, Thomas M, Szonyi G. Prospective study of the impact of fear of falling on activities of daily living, SF-36 scores, and nursing home admission. *J Gerontol A Biol Sci Med Sci* 2000; 55:M299-305.
30. Whitehead C, Miller M, Crotty M. Falls in community-dwelling older persons following hip fracture: impact on self-efficacy, balance and handicap. *Clin Rehabil* 2003; 17:899-906.
31. Cho BL, Scarpace D, Alexander NB. Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. *J Am Geriatr Soc* 2004; 52:1168-73.
32. Winter DA, Yack HJ. EMG profiles during normal human walking: stride-to-stride and inter-subject variability. *Electroencephalogr Clin Neurophysiol* 1987; 67:402-11.
33. Benoit DL, Lamontagne M, Cerulli G, Liti A. The clinical significance of electromyography normalisation techniques in subjects with anterior cruciate ligament injury during treadmill walking. *Gait Posture* 2003; 18:56-63.

**Table 2.1.** Subject Characteristics According to Falls Risk (N=42)

	<b>High Risk (n=20)</b>	<b>Low Risk (n=22)</b>	<i>p value</i>
	N (% or Mean $\pm$ SD)		
<b>Female Gender</b>	10 (50)	14 (64)	
<b>Age (years)</b>	81.9 $\pm$ 6.0	73.4 $\pm$ 6.4	<i>&lt;.001</i>
<b>65-70</b>	1 (5)	n=8 (36)	
<b>71-75</b>	2 (10)	n=7 (32)	
<b>76-80</b>	5 (25)	n=4 (18.)	
<b>81-85</b>	4 (20)	n=2 (9)	
<b>86-90</b>	8 (40)	n=1 (5)	
<b>Height (m)</b>	1.7 $\pm$ 0.1	1.7 $\pm$ 0.1	.963
<b>Weight (kg)</b>	70.8 $\pm$ 12.2	69.6 $\pm$ 11.7	.765
<b>Four Square Step Test (s)</b>	9.4 $\pm$ 2.6	7.1 $\pm$ 1.3	.002
<b>Single Limb Stance (s)</b>	2.2 $\pm$ 1.0	23.8 $\pm$ 8.3	<i>&lt;.001</i>
<b>Maximal Hip Abductor Torque (kg-m)</b>	6.0 $\pm$ 2.4	6.5 $\pm$ 2.9	.560

HR: if subjects 1) required  $\geq 15$  seconds to complete the FSST or were unable to face forward or needed to turn before stepping into the next square<sup>13</sup> or 2) were unable to maintain SLS for at least 5 seconds. LR: if subjects completed the FSST in less than 15 seconds and were able to maintain SLS for at least 5 seconds.

**Table 2.2.** Adjusted Means (Standard Errors) of Exercise Speed and Angular Displacement and Results of Linear Mixed Model Analysis of Hip and Knee Joint Kinematics during Lateral Trainer Exercise (N=42)

Exercise Group					Linear Mixed Model Comparisons			
HR		LR		Between Groups	Between Speeds	Interaction		
SS		Max	SS	Max	p value			
Exercise Speed (reps / min)								
48		52	48	58	.261	<.001	.017	
(2)		(2)	(1)	(2)			HR: max vs ss	.025
							LR: max vs ss	<.001
							SS: HR vs LR	.887
							Max: HR vs LR	.069
Hip Abduction-Adduction (degree)								
Right	16.9	19.3	20.1	24.2	.049	.009		.397
	(1.5)	(1.6)	(1.3)	(1.5)				
Left	17.0	19.4	18.9	23.8	.106	.005		.258
	(1.5)	(1.5)	(1.4)	(1.5)				
Hip Flexion-Extension (degree)								
Right	20.8	21.6	21.6	23.0	.593	.299		.694
	(1.5)	(1.6)	(1.4)	(1.6)				
Left	18.5	21.6	20.8	23.4	.235	.006		.790
	(1.3)	(1.3)	(1.2)	(1.3)				
Knee Flexion-Extension (degree)								
Right	37.9	38.4	39.0	39.0	.777	.792		.738
	(2.1)	(2.1)	(1.9)	(1.9)				
Left	34.3	38.9	37.3	40.4	.308	.021		.602
	(1.7)	(1.8)	(1.6)	(1.8)				

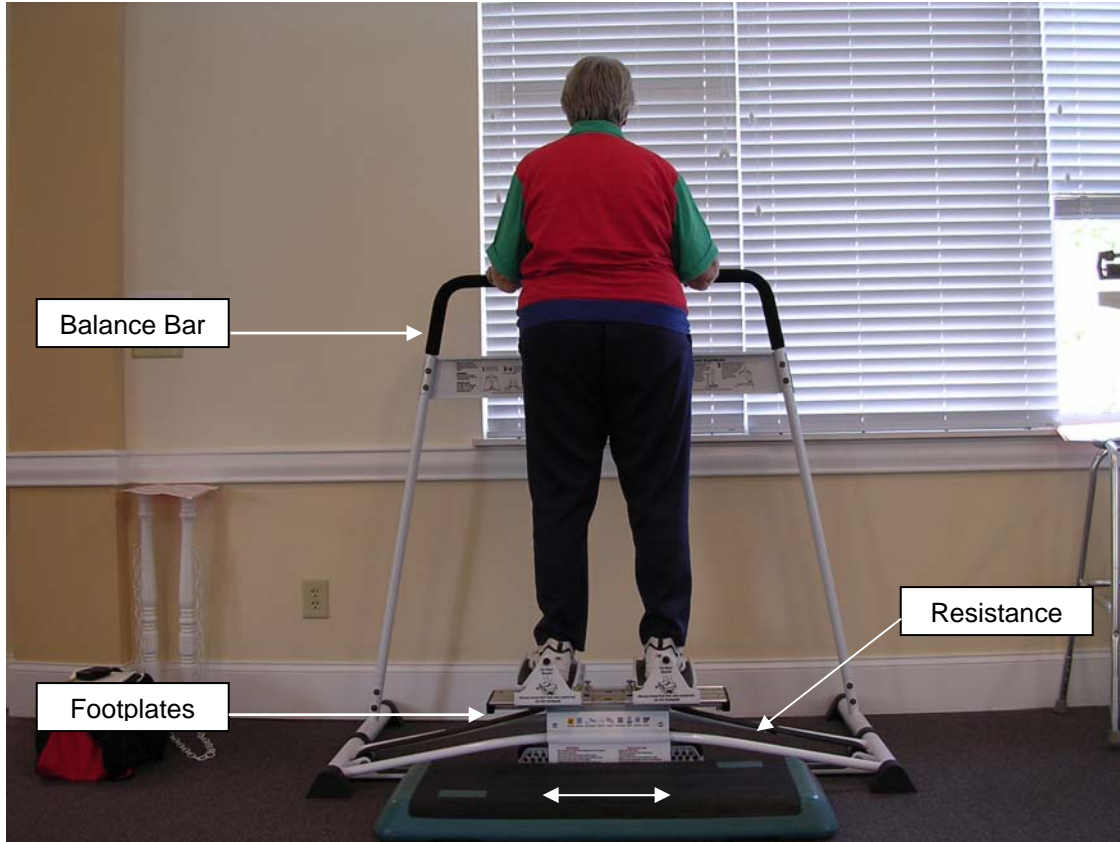
HR=high risk group, LR=low risk group, SS= self-selected speed, Max=maximal speed. The linear mixed models included a random effect for participant and fixed effects for risk group and exercise speed. Model-based adjusted means for kinematic variables were estimated from linear mixed models including the participant random effect and the following fixed covariates: age, maximal hip abductor torque (kg-m), exercise speed (repetition per minute), body weight (kg) and height (m).

**Table 2.3.** Adjusted Means (Standard Errors) and Results of Linear Mixed Model Analysis of Normalized Peak, RMS, and Integrated EMG for Lateral Trainer Exercise

	Exercise Group				Comparison Between Speeds
	High Risk		Low Risk		
	SS	Max	SS	Max	<i>p value</i>
<b>Peak (% MVIC )</b>					
<b>Right</b>	78.9 (10.0)	100.8 (12.0)	80.3 (9.4)	100.7 (11.9)	<i>.003</i>
<b>Left</b>	77.7 (11.3)	107.3 (13.6)	79.9 (10.7))	103.8 (13.5)	<i>.001</i>
<b>RMS (% MVIC )</b>					
<b>Right</b>	38.8 (5.2)	51.2 (5.5)	38.2 (4.9)	48.2 (5.4)	<i>&lt;.001</i>
<b>Left</b>	38.7 (6.3)	53.4 (7.3)	43.3 (6.0)	56.1 (7.2)	<i>&lt;.001</i>
<b>Integrated</b>					
<b>Righ</b>	115.7 (25.2)	150.9 (27.2)	115.3 (23.8)	145.8 (26.3)	<i>.002</i>
<b>Left</b>	110.3 (18.9)	154.5 (26.5)	117.8 (17.6)	164.8 (26.0)	<i>&lt;.001</i>

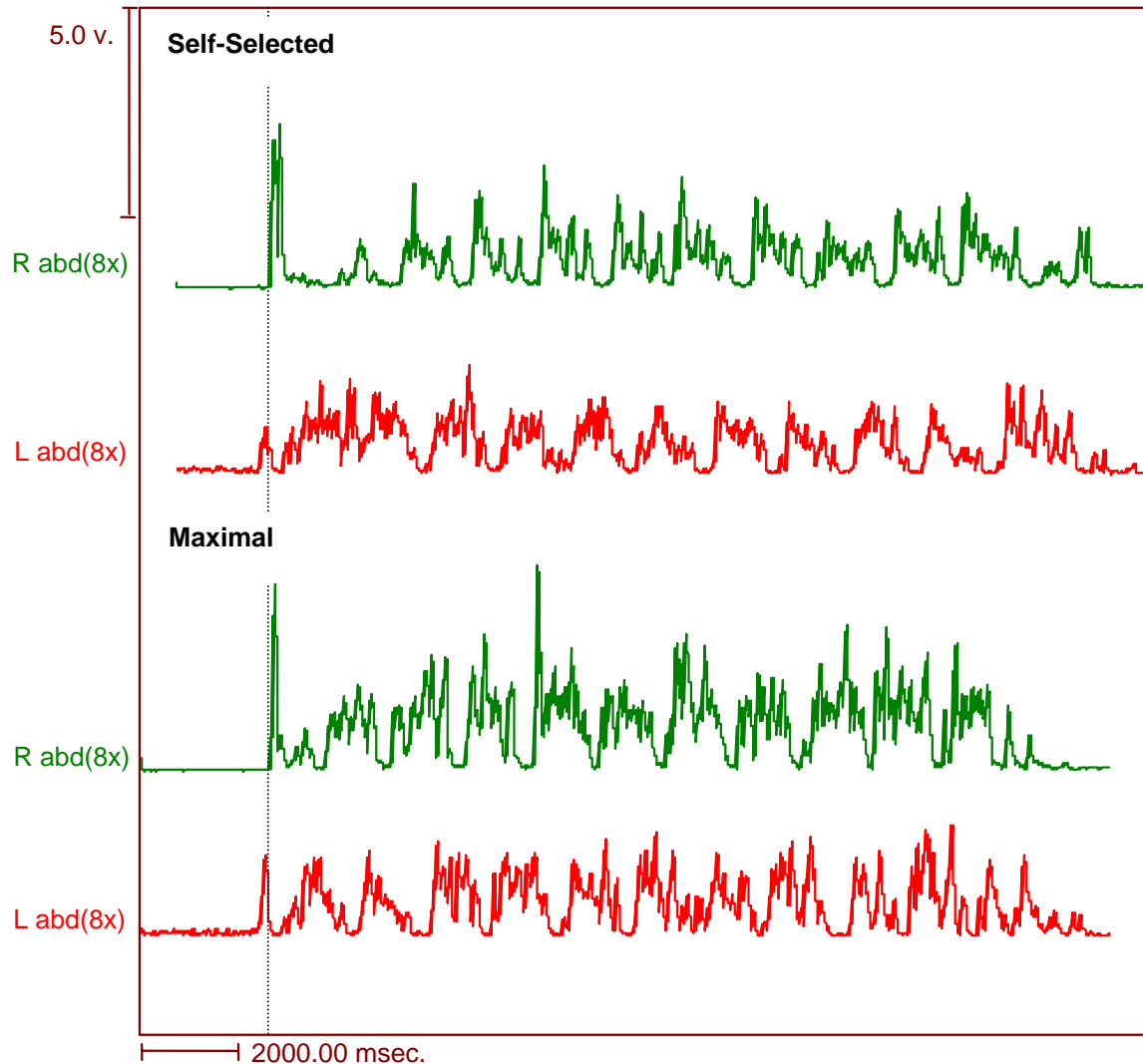
HR=high risk group, LR=low risk group, SS= self-selected speed, Max=maximal speed. Comparisons between groups in all EMG variables are not significant ( $p>.05$ ). Linear mixed models included a random effect for participant and fixed effects for risk group and exercise speed for all EMG variables. Model-based adjusted means for EMG variables were then estimated from linear mixed models including the participant random effect and the following fixed covariates: age, maximal hip abductor torque (kg-m), exercise speed (repetition per minute), body weight (kg) and height (m).

**Figure 2.1.** Starting Position for Lateral Trainer Exercise



Subjects stood in the center of the lateral trainer. Subjects held onto the balance bar during exercise. The distance between footplates was adjusted according to the subject's preference. A step was placed in front of the later trainer to assist subjects getting on and off the device.

**Figure 2.2.** Example of Processed EMG Data for Lateral Trainer Exercise



The figure shows the processed EMG curves from one subject. The Raw EMG data were bandpass filtered using a fourth order Butterworth Filter at 10 – 300 Hz and rectified. A moving average with a fixed window of 30 ms was used to smooth the data. Top two curves are the bilateral hip abductor EMG in self-selected trials and the bottom two are in maximal speed trials. The dotted line represented the time when the subject started moving the footplates.

## **CHAPTER III**

### **SECOND MANUSCRIPT**

#### **Electromyographic and Kinematic Analysis of Three Hip Abductor Exercises in Older Adults**

## ABSTRACT

**Background and purpose.** Strengthening exercises for the hip abductor muscles are often recommended for older adults. Side leg raises and lateral step-ups are two common examples of such exercises. Lateral trainer exercise is a newer hip abductor exercise option that can be performed safely by older adults. The purpose of this study was to compare hip abductor muscle activation during side leg raise, lateral step-up, and lateral trainer exercises performed by older adults. **Methods.** Forty-two older adults between 65 and 89 years of age participated in this study. Kinematic and electromyographic (EMG) variables were determined during side leg raise, lateral step-up, and lateral trainer exercises at self-selected and maximal speeds. Linear mixed model analyses were applied to compare means of kinematic and EMG variables between exercises and exercise speeds. **Results.** Amplitude of muscle activity (normalized RMS EMG) was highest for side leg raises and lowest for lateral trainer exercise across speeds. For all three exercises, performance at maximal speed produced higher normalized peak and RMS EMG values compared with self-selected speed. **Conclusion.** Considering the high levels of muscle activity for side leg raises, this exercise may be the most efficient for strengthening hip abductor muscles. Lateral step-up and lateral trainer exercises provide additional options to add variety to exercise programs for hip abductor strengthening.



## INTRODUCTION

Hip abductors and adductors play a key role in stabilizing the body over one or both feet during turning, walking, and other daily activities.<sup>1, 2</sup> Appropriate activation of hip abductors and adductors is required for maintenance of lateral stability.<sup>3</sup> Researchers have tended to emphasize movement in the sagittal plane and strengthening of muscles that produce sagittal plane movements (such as hip and knee flexors and extensors).<sup>4-6</sup> Recent evidence, however, supports the need for interventions targeting muscle groups that control movement in the frontal plane.<sup>3, 7</sup>

Several hip abductor exercises are recommended for older adults, but generally without evidence for the benefits of the exercise and without information about how to perform the exercise efficiently. One exercise recommended for older adults by the National Institute on Aging is the side leg raise performed in standing.<sup>8</sup> The side leg raise requires a concentric contraction of the hip abductors to lift the leg against gravity, with the foot coming off the floor as the hip moves into abduction. Hip abductor muscle activation may be lower for this type of non-weight-bearing exercise than for weight-bearing hip abductor exercise.<sup>9</sup> Another exercise that is thought to activate the hip abductor muscles is the lateral step-up exercise, in which the individual, while facing forward, steps on and off a step placed on one side of the body. Older adults with balance problems or with lower extremity joint problems such as osteoarthritis may have difficulty with this exercise. Our clinical experience suggests that, because of the need for correct foot placement with each step, this exercise may result in an ankle sprain or a fall.

The lateral trainer,<sup>\*</sup> a device that is currently used in athletic training and sport rehabilitation, may offer another option for hip abductor muscle strengthening. The lateral

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<sup>\*</sup> Dynamic Edge® RPM™, The Skier's Edge Company, P.O. Box 2700, Park City, Utah 84060

trainer provides a mode of exercise that, based on the principle of high-velocity resistance training, should improve both the magnitude and the rate of force production of the hip abductors. The trainer includes a dynamic slide plate with independent-action footpads allowing rhythmic lateral motions at self-controlled speeds and with various levels of resistance. Exercise on the trainer is continuous and requires phasic activation of lower extremity muscle groups in a weight bearing position.

Electromyography (EMG) is a measure of muscle activation and is often used as an indicator of intensity of exercise<sup>10</sup> and level of muscle activation during exercise.<sup>9, 11-13</sup> Two EMG measures that are commonly used in strengthening intervention studies are peak and root-mean-square (RMS). Peak and RMS EMG values represent the level of muscle activity present during muscle contraction.<sup>14</sup> Exercises that produce higher levels of muscle activation are thought to benefit exercisers by generating greater strengthening effects.<sup>13, 15</sup> Information about muscle activation during exercise can help guide exercise program design and prescription.

The purpose of this study was to compare lower extremity muscle activation characteristics during side leg raise, lateral step-up, and lateral trainer exercises performed by older adults. We hypothesized that hip abductor muscle activity (peak and RMS EMG values) would be greater for lateral trainer exercises than for the other two exercises. We also hypothesized that hip abductor muscle activity would be greater for performance at maximal as compared to self-selected speeds.

## **METHODS**

### **Subjects**

Subjects were recruited by emails, flyers, and presentations at senior centers, the

YMCA, and continuing care retirement communities (see Appendix B). Inclusion criteria were as follows: 65 years of age or older; able to read and speak English; able to ambulate at least 50 feet without physical assistance; no more than 1 error on the Six-Items Test (a cognitive screening tool)<sup>16</sup>; normal or corrected-to-normal vision and hearing (by self-report); and able to follow instructions and perform all experimental procedures. Volunteers were excluded if they had any of the following: body weight of 200 lb or above (the upper weight limit of the lateral trainer); diagnosed neurological disease or disorder; lower extremity joint replacement (because of the possibility of impaired joint proprioception affecting movement control); acute back or extremity musculoskeletal problems, such as strains, sprains, or fractures; unstable cardiovascular disease; or uncontrolled diabetes mellitus.

Screening and demographic information of potential subjects including age, dominant lower extremity, physical activity level and self-reported fall history were obtained by telephone or in-person interview. Dominant lower extremity was defined as the leg used to kick a ball (by self-report). Informed consent was obtained at the start of the screening session following the initial interview (see Appendix C). Additional screening included administration of a medical history questionnaire, the Six-Item test<sup>16</sup> (a cognitive screening test) and fall risk assessment (see Appendix D). In order to recruit older adults with a wide range of ability in balance control, fall risk assessment were conducted to identify subjects at high and low risk of falls. The fall risk assessment included the Four Square Step Test (FSST) and Single Leg Stance (SLS). These tests were administered according to standardized procedures described by Dite et al<sup>17</sup> and Tinetti<sup>18</sup>, respectively. Both the FSST and SLS have evidence of reliability<sup>17, 19</sup> and can be used to identify individuals at risk of falls<sup>17</sup> or injurious falls<sup>20</sup>. Subjects were considered as being at high risk (HR) of falls if they

1) required  $\geq 15$  seconds to complete the FSST or were unable to face forward or needed to turn before stepping into the next square<sup>17</sup> or 2) were unable to maintain SLS for at least 5 seconds<sup>20</sup>. Subjects who completed the FSST in less than 15 seconds and were able to maintain SLS for at least 5 seconds comprised a low risk (LR) group.

Each subject completed a Modified Physical Activity Readiness Questionnaire (PAR-Q) that was sent to his/her primary care physician with a request for medical approval to participate in the study (see Appendix E). The Modified PAR-Q is a screening tool to identify risk factors or symptoms that are contraindications for exercise. We obtained medical approval (in writing) from each subject's physician prior to the laboratory testing session (see Appendix F).

One hundred and five volunteers who showed interest in this study received telephone or face-to-face interviews. Forty-eight volunteers were excluded after screening. Another 13 volunteers withdrew after they were enrolled in the study but prior to the laboratory testing session (6 were lost to follow-up or declined further participation; 6 developed health problems; 1 had heart surgery). The remaining 44 volunteers were scheduled to participate in one test session at our laboratory for collection of EMG and kinematic data. Subjects were paid \$20 after testing was completed.

## **Procedures**

### *Data Collection*

Measurements of subjects' height, weight, and thigh length were recorded. Subjects performed warm-ups including lower extremity muscle stretching exercises prior to performance of side leg raise, lateral step-up, and lateral trainer exercises.<sup>9</sup> Order of performance of the three exercises was randomized by having each subject draw from 3 slips

of paper, each with the name of one of the exercises.

A 16-channel telemetry EMG system (Konigsberg Instruments, Inc., Pasadena, CA) was used to record activity from bilateral gluteus medius (GM) muscles during all exercises. After standard skin preparation,<sup>21</sup> active surface electrodes (Neuroline, pre-gelled, AG/AgCl, bipolar disposable electrodes) were placed parallel to the muscle fibers over the belly of the GM (at the mid-point between the iliac crest and the greater trochanter)<sup>9</sup> bilaterally. Electrode placements were verified using manual muscle testing techniques to minimize crosstalk. The electrode surface was 15 mm in diameter, and inter-electrode distance was 20 mm center to center. A common reference electrode was placed on the skin overlying the anterior border of the mid-shaft of the tibia. Raw EMG signals were converted from analog to digital (A/D converter, Peak Performance Technologies, Englewood, CO) at 1200 Hz and recorded using Peak Motus software (Peak Performance Technologies, Englewood, CO).

Subjects performed three maximal voluntary isometric contractions (MVICs) of the GM muscle of the dominant leg for EMG signal normalization. The MVICs were performed with subjects in the supine position to provide stabilization of the trunk and opposite lower extremity and to maximize safety. Procedures were based on those described by Andrews et al<sup>22</sup>. Subjects were positioned supine with the hips in neutral rotation. A Quantrol AFG digital force gauge (Dillon/Quality Plus, Inc., Camarillo, CA) was mounted on a wooden frame and stabilized against a wall during testing. The force gauge was placed perpendicular to the thigh of the dominant leg, with the padded attachment on the distal lateral femoral condyle for hip abduction. The examiner explained the desired muscle action of hip abduction with the knee extended, and allowed the subject to perform

1-2 practice trials as needed. Subjects were encouraged to push against the gauge as hard as possible. Force and EMG signals were recorded for 5 seconds to allow the subject to build up to a maximal contraction. The digital readouts on the force gauge were used to examine consistency across trials. Three test trials for each movement were performed with a rest period of at least 30 seconds between trials.

After performing the MVICs, reflective markers were placed on the following bony landmarks bilaterally: acromion process, anterior superior iliac spine, lateral thigh (midpoint at the central line), lateral femoral condyle, tibia (midpoint), and lateral malleolus. Three-dimensional videographic data were collected in one standing trial prior to exercise. Eight infrared video cameras sampling at 120 Hz were used in conjunction with the Peak Motus real time motion analysis system to record the trajectories of reflective markers placed on each subject's trunk and lower extremities. Trajectories of these markers during exercises were used to create virtual trunk and lower extremity segments for joint angle calculation. Joint angle was calculated using customized software (Motion Soft 3D v. 6.5, Bing Yu, University of North Carolina at Chapel Hill, Chapel Hill, NC).

One standing trial was used to create a virtual model of the trunk and lower extremities in the static situation. In the standing trial, additional passive reflective markers were placed at the medial malleolus and medial and lateral femoral condyles bilaterally. These additional markers were needed for estimation of joint centers, but were removed prior to exercise to avoid interfering with the subject's movement and to avoid collision of the markers during exercise.

Subjects performed each exercise first at self-selected speed and then at maximal speed. Subjects initiated all three exercises with the right leg. They were asked to move

as fast as possible for the maximal speed trials. The speed of exercise was determined from the time required to finish 10 repetitions of each exercise and then expressed as the number of repetitions performed in one minute. One repetition was defined as follows for each exercise: for side leg raises, movement of the leg into a position of hip abduction and return to starting position; for lateral step-ups, movement of both feet onto the step and back down to the floor; and for lateral trainer exercise, movement of the footplates from the farthest point on the subject's left side to the farthest point on the subject's right side and back. Subjects were asked to perform 2 sets of 10 repetitions for each exercise at each speed with at least 2 minutes rest between sets. At least two practice trials for each exercise at each speed were also performed.

EMG and kinematic data were recorded while subjects exercised at both speeds. During data collection, a member of the research team stood behind the subject to provide instructions and guard against falls. Subjects completed a post-exercise evaluation questionnaire about their opinions of and responses to the exercises after the session (see Appendix G).

Side leg raises. For the side leg raise exercise, subjects were asked to stand facing the back of a standard chair and hold but not lean on to the backrest of the chair for balance if necessary. During the exercise, the subject lifted the dominant leg laterally and lowered it back to the floor while standing up straight with hip and knee joints extended and toes facing forward. Subjects were instructed to lift the leg as high as possible without leaning or bending the trunk.

Lateral step-ups. For the lateral step-up exercise, a standard step (73.03 cm x 36.20 cm x 15.24 cm) was placed on the subject's dominant side.<sup>23</sup> Subjects were instructed to

step on and off the step laterally while facing forward. The subject was asked to stand up straight to avoid trunk rotation during the exercise. Several practice trials were performed. A standard chair was placed in front of and slightly to the left side of the subject. Subjects were permitted to hold but not lean on to the backrest of the chair for balance if necessary during the exercise.

Lateral trainer exercise. The resistance provided by the lateral trainer was adjusted to the lowest level. Subjects held onto the balance bar during exercise for balance and were asked not to lean on the bar (Figure 2.1). The distance between footplates was adjusted according to the subject's preference. The researchers instructed subjects to move the footplates as far as possible from side-to-side, and to practice until they felt comfortable performing the exercise. The researchers provided verbal and tactile cues to encourage subjects to maintain an upright position with the trunk in midline (stationary in the center of the machine) during the practice trials.

### **Data Reduction**

Mean values for kinematic and EMG variables of the middle 4 repetitions during each exercise set were calculated for each subject and used for subsequent data analyses. The first three and last three repetitions of each set of exercises were excluded to minimize warm-up and fatigue effects.

For kinematics, the reflective markers were identified within the Peak Motus program (Performance Technologies Inc, Centennial, CO 80112) and the data were then exported to customized software (Motion Soft 3D v. 6.5, Bing Yu, University of North Carolina at Chapel Hill, Chapel Hill, NC) for processing. Joint angular displacements were calculated for hip abduction-adduction. Movement repetitions were identified based on trajectories of



the markers placed on the lateral malleoli bilaterally using a customized Matlab program (Matlab v. 6.5, Mathworks, Natick, MA 01760-2098).

EMG data were exported from Peak Motus to a customized Matlab program on a personal computer for data processing and reduction. Raw EMG data were bandpass filtered using a fourth order Butterworth filter at 10 – 300 Hz and then rectified. A moving average with a fixed window of 30 ms was used to smooth the data. The maximal amplitude recorded over a 500-ms window across the 3 MVICs was determined.<sup>15</sup> For each movement repetition, determined from the kinematic data, peak amplitude was identified and root-mean-square (RMS) EMG amplitude were determined for right and left GM. The peak and RMS amplitudes were normalized by expressing them as a percentage of the peak amplitude during the MVICs for each muscle. Examples of processed EMG signals for each exercise are presented in Figure 3.1.

### **Statistical Analysis**

Descriptive statistics were generated for subject characteristics. Distributions of all data were examined and screened for outliers. Linear mixed models were used to estimate means and standard errors of kinematic (angular displacements in hip abduction-adduction) and EMG (normalized peak and RMS EMG) variables, overall and by exercise and exercise speed, specifying a random effect for participant and fixed effects for type of exercise and exercise speed. Model-based adjusted means for kinematic and EMG variables were then estimated from linear mixed models including the participant random effect and the following fixed covariates: gender, risk group, use of upper extremity support, maximal hip abductor torque (kg-m), body weight (kg) and height (m), and exercise speed. Gender and chair use were eliminated from the model because there were no significant gender

differences and no effects of chair use (all  $p > .05$ ). Model-based adjusted mean for exercise speed was estimated from linear mixed models including the participant random effect and the following fixed covariates: risk group, maximal hip abductor torque (kg-m), body weight (kg) and height (m). We also tested for interactions between exercise and exercise speed for all dependent variables. A significance level of  $p < .05$  was used for all statistical tests. All analyses were conducted using SAS 8.02 (SAS Institute Inc., Cary, NC 27513).

## RESULTS

Forty-four older adults participated in the study. Data from 42 subjects (24 women, 18 men; mean age  $77.4 \pm 7.5$  years, range 65 – 89 years) were included in analyses because technical problems occurred during data collection for 2 subjects. Subject characteristics for each risk group are presented in Table 3.1. All but one subject in the LR group reported regular physical activity (for example: walking, gardening, dancing) and exercise (for example: exercise class, water aerobics, yoga, swimming). All subjects completed at least one set of each exercise at each speed. Seventeen subjects reported fatigue and asked to stop after the first set of an exercise.

A significant exercise by exercise speed interaction was found for exercise speed ( $p < .001$ ). The number of repetitions per minute was highest for side leg raises (self-selected:  $67 \pm 2$ , maximal:  $84 \pm 2$  repetition per minute; all  $p < .05$ ; Table 3.2) and lowest for lateral step-ups at both exercise speeds (self-selected:  $29 \pm 1$ , maximal:  $36 \pm 1$  repetition per minute; all  $p < .05$ ; Table 3.2). Subjects performed faster for all exercises during maximal speed trials compared to self-selected speed trials (all  $p < .05$ ; Table 3.2).

A significant exercise by exercise speed interaction was found for hip abduction-adduction angular displacement bilaterally (right:  $p < .001$ , left:  $p = .002$ ; Table 3.2).

For right hip abduction/adduction angular displacement, subjects displayed the largest values for side leg raises and the smallest for lateral step-ups at both exercise speeds (all  $p < .05$ ; Table 3.2). Adjusted means for right hip abduction/adduction angular displacement for side leg raises, lateral step-ups and lateral trainer were  $33.9 \pm 1.1^\circ$ ,  $9.4 \pm 1.1^\circ$  and  $18 \pm 0.9^\circ$ , respectively, at self-selected speed; and were  $36.0 \pm 1.5^\circ$ ,  $9.2 \pm 0.8^\circ$  and  $22.1 \pm 1.0^\circ$ , respectively, at maximal speeds. For the left leg, which was the stance leg for side leg raises, hip abduction-adduction displacement was smallest during side leg raise exercises for both exercise speeds (self-selected:  $8.7 \pm 0.6^\circ$ , maximal:  $9.0 \pm 0.8^\circ$ ; all  $p < .05$ ; Table 3.2). Mean values for left hip abduction-adduction angular displacement were largest for lateral trainer exercises at both speeds (self-selected:  $17.4 \pm 0.9^\circ$ , maximal:  $21.9 \pm 1.1^\circ$ ; all  $p < .05$ ; Table 3.2). When the two exercise speeds were compared, slight differences were found for hip abduction-adduction angular displacement bilaterally. Angular displacement was higher for maximal speed compared to self-selected speed during side leg raise (maximal:  $36.0 \pm 1.5^\circ$ , self-selected:  $33.9 \pm 1.1^\circ$ ;  $p = .031$ ; Table 3.2) and lateral trainer (maximal:  $22.1 \pm 1.0^\circ$ , self-selected:  $18.0 \pm 0.9^\circ$ ;  $p < .001$ ; Table 3.2) exercises for the right leg, but only during lateral trainer exercise for the left leg (maximal:  $21.9 \pm 1.1^\circ$ , self-selected:  $17.4 \pm 0.9^\circ$ ;  $p < .001$ ; Table 3.2).

With regard to our first hypothesis, mean values for normalized peak and RMS EMG activity were highest for side leg raises and lowest for lateral trainer exercises for both legs (Table 3.3). Differences between side leg raises and lateral step-ups reached statistical significance only for RMS EMG values for both legs across speeds (all  $p < .05$ ; Table 3.3). Adjust mean values for right RMS EMG for side leg raises, lateral step-ups and lateral trainer exercise were  $85.1 \pm 7.4\%$ ,  $53.6 \pm 5.2\%$  and  $37.5 \pm 3.2\%$  MVIC, respectively, at self-selected

speed, and  $95.8 \pm 9.5\%$ ,  $74.0 \pm 9.5\%$  and  $50.3 \pm 3.7\%$  MVIC, respectively, at maximal speed. Values of RMS EMG for left leg were very similar to those for the right leg (Table 3.3).

With regard to our second hypothesis concerning the effects of exercise speed on muscle activation, normalized peak and RMS EMG values were higher in maximal compared to self-selected speed trials across exercises (all  $p < .05$ ; Table 3.3).

Subjects' responses on the post-exercise questionnaire are presented in Figure 3.2. Subjects generally viewed all three exercises favorably (mean ratings greater than 3.0). The highest mean ratings were those indicating level of interest in the lateral trainer exercise.

## **DISCUSSION**

The purpose of this project was to compare hip abductor muscle activation during side leg raise, lateral step-up, and lateral trainer exercises performed by older adults. The main findings were: 1) GM muscle activation was highest during side leg raises and lowest during lateral trainer exercise, 2) For all exercises, greater muscle activity was observed during exercises performed at maximal as compared to self-selected speeds.

Our first hypothesis, which was not supported, was that hip abductor muscle activity would be greater for lateral trainer exercises than for the other two exercises. Our finding that muscle activation was highest for side leg raises may reflect hip and knee movement characteristics of this task. The side leg raise is an isolated hip abduction movement that requires GM muscle activation in both the moving and the stance leg. Little or no sagittal plane movement is involved. Performance of lateral trainer and lateral step-up exercises, on the other hand, requires activation of a number of muscle groups other than the hip abductors, including the hip and knee extensors (unpublished data). Greater hip knee flexion/extension

angles were observed for lateral step-ups compared to side leg raises in the present study.

The amount of external force applied to the hip abductors also differed among the three exercises. In previous research, greater muscle activation was observed during weight-bearing compared to non-weight-bearing hip abductor exercises. Bolgia et al<sup>9</sup> used surface EMG to measure activation of the right hip GM. Weight-bearing exercises (left-sided pelvic drop and left hip abduction in standing) produced greater right GM muscle activation compared to non-weight-bearing exercise (right hip abduction in standing). One possible explanation for the discrepancy between these results and those in the present study relates to the direction and magnitude of the external torque applied to the hip abductor musculature. The external force applied to the hip abductor of the lifted (non-weight-bearing) leg and stance (weight-bearing) leg during side leg raises can be determined by multiplying the length of the external moment arm by approximately 19% and 84 % body weight, respectively.<sup>9</sup> The length of the external moment arm for the leg is the perpendicular distance of the force from the hip joint center of rotation. During lateral trainer exercise, the external force provided by the resistance band (at the bottom of the track, to which the footplates were attached) was acting on the ankle joints. The external moment arm was approximately the distance from the greater trochanter to the ankle joint. However, the resistance to motion provided by the machine's resistance band may have varied throughout the range of movement. Furthermore, the resistance was adjusted to the lowest level. We expect that a higher percentage of maximal muscle activation would be produced during lateral trainer exercise if the resistance level were increased.

Two additional factors that may have affected our results are upper extremity support during exercises and subjects' familiarity with the exercises. All subjects were told that

they could use upper extremity support if they felt they needed such support when exercising. The number of subjects who used upper extremity support was 39 (92.9%) for side leg raises, 17 (40.5%) for lateral step-ups, and 42 (100%) for lateral trainer exercise. Upper extremity support may reduce the amount of muscle activity in the lower extremities.<sup>24</sup> In our follow-up analyses, the pattern of results did not change when trials with no upper extremity support were excluded for side leg raise and lateral step-up exercises. However, because the forces applied on the upper extremity supports were not measured, we cannot rule out the possibility that subjects used more upper extremity support for some exercises than for others. The use of upper extremity support for balance in the present study reflects the reality that many older adults will use upper extremity support during exercise. Second, particularly in older adults, degree of familiarity with an exercise or activity can affect the amount of muscle activation observed.<sup>25</sup> Subjects were least familiar with the lateral trainer exercise; none had performed this type of exercise prior to data collection. For complex exercises, task learning and improved intermuscular coordination play a major role during initial training.<sup>26</sup>

Our second hypothesis, which was supported, was that hip abductor muscle activity would be greater for performance at maximal as compared to self-selected speeds. Greater muscle activity was observed during high-velocity movement/exercise compared to movement/exercise at self-selected speeds. As mentioned above, a higher percentage of maximal muscle activity is needed to perform high speed movement. The results suggest that exercise at fast speeds may be best for muscle strengthening.

All three exercises provided a sufficient level of neuromuscular activation to stimulate muscle strength adaption (greater than 60% of MVIC). According to the

post-exercise questionnaire responses, subjects rated lateral trainer exercise as most interesting and as most likely to improve balance and/or hip muscle strength. The responses indicate that older adults are interested in new types of exercise that may be of benefit to them. The design of the lateral trainer, in addition, may minimize demands for lower extremity control because the feet remain in contact with the footplates throughout the exercise and the exerciser can use the balance bar for support as needed. Having various options from which to choose may help increase exercise adherence in older adults.

This project had several limitations. Our results may have been influenced by inability to obtain true maximal contraction on some MVIC trials. Submaximal effort may have occurred during MVIC testing if stabilization was not adequate or subjects were not able to produce maximal effort consistently. If so, the values of normalized EMG variables may be overestimated. In future studies, a normalization method using muscle activity during dynamic tasks, such as walking, may be preferable.<sup>27, 28</sup> As discussed earlier, the inconsistency of upper extremity support used during data collection may have influenced the results. Measurement and restriction of upper extremity support may provide further insights in future studies.

## **CONCLUSION**

This study compared hip abductor muscle activity during three exercises performed by older adults. Side leg raise exercises produced greater muscle activity, as did exercise at maximal speed. Although all three exercises produced levels of neuromuscular activation considered adequate for stimulating hip abductor muscle strength adaptation, side leg raise exercise may be the most efficient. Future research should focus on the effects of various exercise protocols on improving hip abductor muscle strength in older adults.

## References

1. Kirker SG, Simpson DS, Jenner JR, Wing AM. Stepping before standing: hip muscle function in stepping and standing balance after stroke. *J Neurol Neurosurg Psychiatry* 2000; 68:458-64.
2. Pai YC, Chang HJ, Chang RW, Sinacore JM, Lewis JL. Alteration in multijoint dynamics in patients with bilateral knee osteoarthritis. *Arthritis Rheum* 1994; 37:1297-304.
3. Rogers MW, Hedman LD, Johnson ME, Cain TD, Hanke TA. Lateral stability during forward-induced stepping for dynamic balance recovery in young and older adults. *J Gerontol A Biol Sci Med Sci* 2001; 56:M589-94.
4. Rantanen T, Guralnik JM, Izmirlian G, et al. Association of muscle strength with maximum walking speed in disabled older women. *Am J Phys Med Rehabil* 1998; 77:299-305.
5. Brown M, Holloszy JO. Effects of walking, jogging and cycling on strength, flexibility, speed and balance in 60- to 72-year olds. *Aging (Milano)* 1993; 5:427-34.
6. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther* 1993; 73:254-62; discussion 263-5.
7. Miller K, Johnson M, Roger M. Stance hip abduction torque characteristics during volitional and induced stepping in young and older adults. *Neurology report* 2002; 26.
8. Exercise: A guide from the National Institute on Aging: National Institute on Aging, 2004:44.
9. Bolgla LA, Uhl TL. Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. *J Orthop Sports Phys Ther* 2005; 35:487-94.
10. Andersen LL, Magnusson SP, Nielsen M, Haleem J, Poulsen K, Aagaard P. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: implications for rehabilitation. *Phys Ther* 2006; 86:683-97.
11. Sims KJ, Richardson CA, Brauer SG. Investigation of hip abductor activation in subjects with clinical unilateral hip osteoarthritis. *Ann Rheum Dis* 2002; 61:687-92.
12. Hertel J, Sloss BR, Earl JE. Effect of foot orthotics on quadriceps and gluteus medius electromyographic activity during selected exercises. *Arch Phys Med Rehabil* 2005; 86:26-30.
13. Ayotte NW, Stetts DM, Keenan G, Greenway EH. Electromyographical analysis of selected lower extremity muscles during 5 unilateral weight-bearing exercises. *J Orthop Sports Phys Ther* 2007; 37:48-55.



14. Soderberg GL, Knutson LM. A guide for use and interpretation of kinesiologic electromyographic data. *Phys Ther* 2000; 80:485-98.
15. Bolgla LA, Uhl TL. Reliability of electromyographic normalization methods for evaluating the hip musculature. *J Electromyogr Kinesiol* 2006.
16. Callahan CM, Unverzagt FW, Hui SL, Perkins AJ, Hendrie HC. Six-item screener to identify cognitive impairment among potential subjects for clinical research. *Med Care* 2002; 40:771-81.
17. Dite W, Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. *Arch Phys Med Rehabil* 2002; 83:1566-71.
18. Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 1986; 34:119-26.
19. Potvin AR, Syndulko K, Tourtellotte WW, Lemmon JA, Potvin JH. Human neurologic function and the aging process. *J Am Geriatr Soc* 1980; 28:1-9.
20. Vellas BJ, Wayne SJ, Romero L, Baumgartner RN, Rubenstein LZ, Garry PJ. One-leg balance is an important predictor of injurious falls in older persons. *J Am Geriatr Soc* 1997; 45:735-8.
21. Basmajian JV, De Luca CJ. *Muscle Alive: Their Function Revealed by Electromyography*. Baltimore, MD: Williams & Wilkins, 1985.
22. Andrews AW, Thomas MW, Bohannon RW. Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Phys Ther* 1996; 76:248-59.
23. Ross CM. Test-retest reliability of the lateral step-up test in young adult healthy subjects. *J Orthop Sports Phys Ther* 1997; 25:128-132.
24. Albayrak A, van Veelen MA, Prins JF, Snijders CJ, de Ridder H, Kazemier G. A newly designed ergonomic body support for surgeons. *Surg Endosc* 2007.
25. Shumway-Cook A, Woollacott M. *Constraints on motor control. Motor control: Theory and practical applications*. Baltimore, Maryland: Lippincott Williams & Wilkins, 2001:p.142.
26. Rutherford OM, Jones DA. The role of learning and coordination in strength training. *Eur J Appl Physiol Occup Physiol* 1986; 55:100-5.
27. Winter DA, Yack HJ. EMG profiles during normal human walking: stride-to-stride and inter-subject variability. *Electroencephalogr Clin Neurophysiol* 1987; 67:402-11.

28. Benoit DL, Lamontagne M, Cerulli G, Liti A. The clinical significance of electromyography normalisation techniques in subjects with anterior cruciate ligament injury during treadmill walking. *Gait Posture* 2003; 18:56-63.

**Table 3.1.** Subject Characteristics (N=42)

	<b>High Risk (n=20)</b>	<b>Low Risk (n=22)</b>
	N (%) or Mean $\pm$ SD	
<b>Female Gender</b>	10 (50)	14 (64)
<b>Age (years)</b>	81.9 $\pm$ 6.0	73.4 $\pm$ 6.4
<b>65-70</b>	1 (5)	n=8 (36)
<b>71-75</b>	2 (10)	n=7 (32)
<b>76-80</b>	5 (25)	n=4 (18)
<b>81-85</b>	4 (20)	n=2 (9)
<b>86-90</b>	8 (40)	n=1 (5)
<b>Height (m)</b>	1.7 $\pm$ 0.1	1.7 $\pm$ 0.1
<b>Weight (kg)</b>	70.8 $\pm$ 12.2	69.6 $\pm$ 11.7
<b>Four Square Step Test (s)</b>	9.4 $\pm$ 2.6	7.1 $\pm$ 1.3
<b>Single Limb Stance (s)</b>	2.2 $\pm$ 1.0	23.8 $\pm$ 8.3
<b>Maximal Hip Abductor Torque (kg-m)</b>	6.0 $\pm$ 2.4	6.5 $\pm$ 2.9

**Table 3.2.** Adjusted Means (Standard Errors) and Results of Linear Mixed Model Analysis for Exercise Speed and Angular Displacement

Mean (Standard Error)	Exercise			Mixed Model Comparison			
	SLR	LSU	LT	Exercise by Speed Interaction			
				exercise	<i>p</i>	speed	<i>p</i>
<b>Speed (Rep/Min)</b>				.000			
<b>SS</b>	67 (2)	29 (1)	48 (1)	SLR Max : SS LSU Max : SS	<.001 <.001 <.001 <.001	SS SLR : LSU SLR : LT LSU : LT	<.001 <.001 <.001 <.001
<b>Max</b>	84 (2)	36 (1)	55 (2)	LT Max : SS	<.001 <.001	Max SLR : LSU SLR : LT LSU : LT	<.001 <.001 <.001 <.001
<b>Hip Abduction-Adduction Angular Displacement (degree)</b>							
<b>Right</b>				<.001			
<b>SS</b>	33.9 (1.1)	9.4 (1.1)	18.0 (0.9)	SLR Max : SS LSU Max : SS	.031 .770	SS SLR : LSU SLR : LT LSU : LT	<.001 <.001 <.001 <.001
<b>Max</b>	36.0 (1.5)	9.2 (0.8)	22.1 (1.0)	LT Max : SS	<.001	Max SLR : LSU SLR : LT LSU : LT	<.001 <.001 <.001 <.001
<b>Left</b>				.002			
<b>SS</b>	8.7 (0.6)	15.5 (0.6)	17.4 (0.9)	SLR Max : SS LSU Max : SS	.499 .282	SS SLR : LSU SLR : LT LSU : LT	<.001 <.001 <.001 .034
<b>Max</b>	9.0 (0.8)	15.9 (0.6)	21.9 (1.1)	LT Max : SS	<.001	Max SLR : LSU SLR : LT LSU : LT	<.001 <.001 <.001 <.001

SLR = side leg raise, LSU=lateral step-up, LT=lateral trainer, SS=self-selected speed; Max = maximum speed. Model-based adjusted means for kinematic were estimated from linear mixed models including the participant random effect and the following fixed covariates: risk

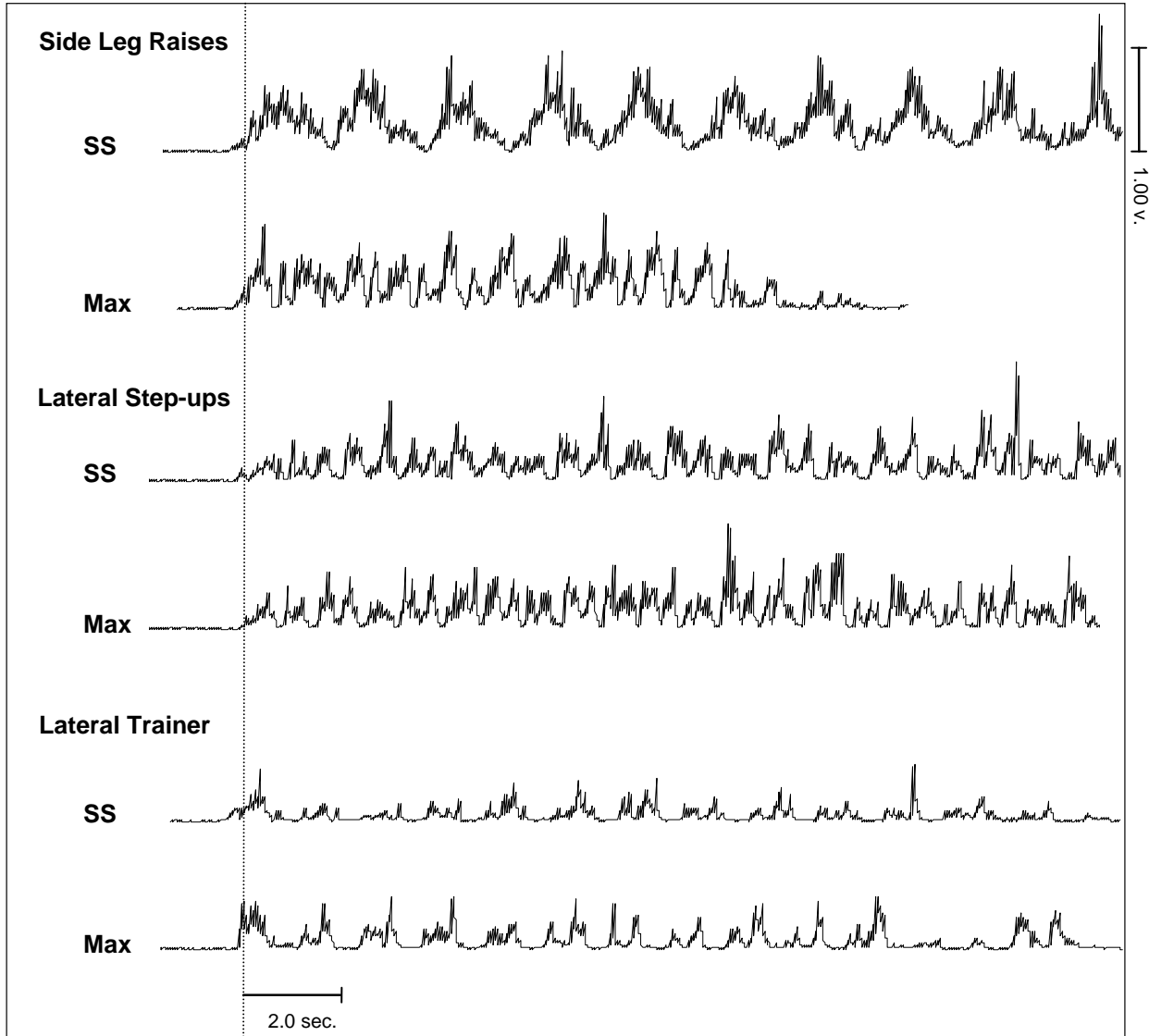
group, maximal hip abductor torque (kg-m), body weight (kg) and height (m), and exercise speed.

**Table 3.3.** Adjusted Means (Standard Errors) and Results of Linear Mixed Model Analysis of Normalized Peak and RMS EMG

		Exercise			Mixed Model Comparison		
	SLR	LSU Mean (Standard Error)	LT	Exercise	<i>p value</i>	Speed	
<b>Peak (% MVIC)</b>							
<i>Right</i>					<.001	.004	
SS	174.5 (15.6)	142.2 (15.7)	77.3 (6.1)	SLR : LSU	.704		
				SLR : LT	<.001		
Max	203.1 (25.8)	214.5 (40.3)	102.7 (7.9)	LSU : LT	.001		
<i>Left</i>					<.001	.002	
SS	167.4 (17.1)	134.1 (17.5)	76.6 (7.1)	SLR : LSU	.269		
				SLR : LT	<.001		
Max	197.3 (24.5)	184.8 (31.5)	105.6 (8.6)	LSU : LT	.002		
<b>RMS (% MVIC)</b>							
<i>Right</i>					<.001	<.001	
SS	85.1 (7.4)	53.6 (5.2)	37.5 (3.2)	SLR : LSU	.002		
				SLR : LT	<.001		
Max	95.8 (9.5)	74.0 (9.5)	50.3 (3.7)	LSU : LT	.001		
<i>Left</i>					<.001	<.001	
SS	92.5 (9.3)	57.6 (6.7)	40.2 (3.8)	SLR : LSU	<.001		
				SLR : LT	<.001		
Max	104.1 (10.9)	74.4 (9.3)	54.9 (4.6)	LSU : LT	.003		

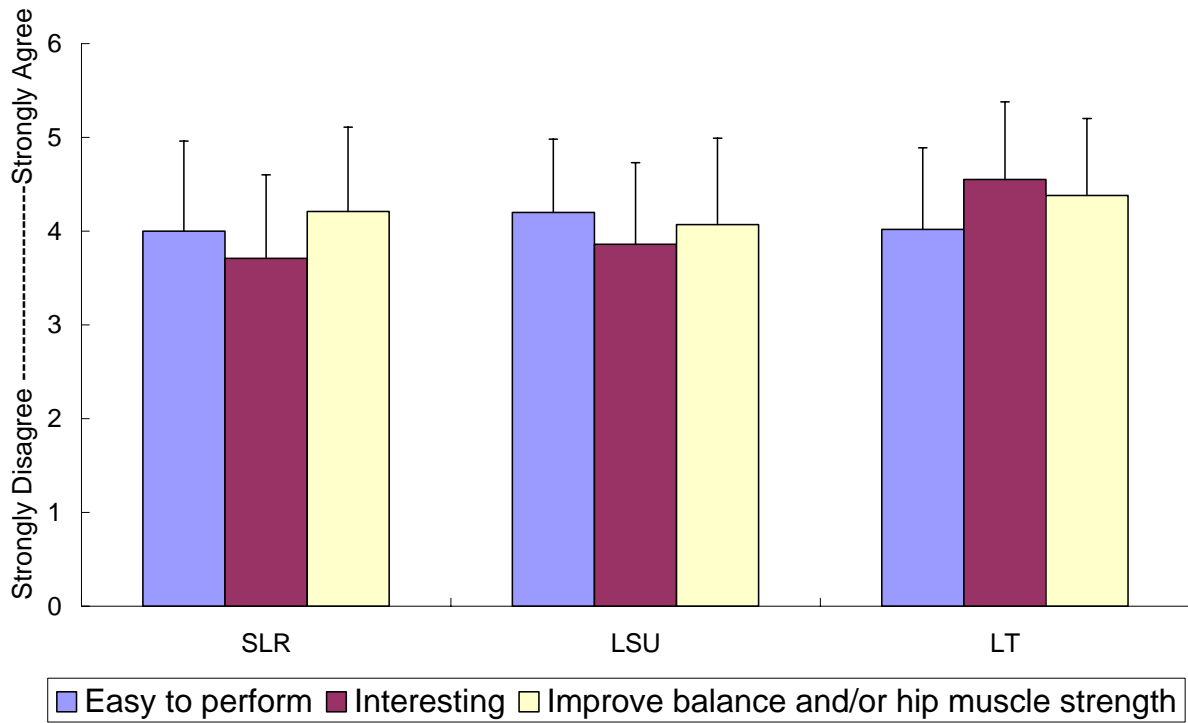
SLR = side leg raise, LSU=lateral step-up, LT=lateral trainer, SS=self-selected speed; Max = maximum speed. All exercise by speed interaction are not significant ( $p>.05$ ). Model-based adjusted means for EMG were estimated from linear mixed models including the participant random effect and the following fixed covariates: risk group, maximal hip abductor torque (kg-m), body weight (kg) and height (m), and exercise speed.

**Figure 3.1.** Example of Processed EMG Data for Each Exercise



SS: self-selected speed; Max: maximal speed. The figure shows the processed EMG curves for right hip abductor from one subject. The raw EMG data were bandpass filtered using a fourth order Butterworth Filter at 10-300 Hz and rectified. A moving average with a fixed window of 30 ms was used to smooth the data. The dotted line represented the time when the subject started moving.

**Figure 3.2.** Mean Ratings and Standard Deviations on Post-Exercise Questionnaire for Side Leg Raise, Lateral Step-up, and Lateral Trainer Exercises



SLR = side leg raise, LSU=lateral step-up, LT=lateral trainer.



## **CHAPTER IV**

### **THIRD MANUSCRIPT**

#### **Hip Abductor Exercise and Lateral Stability in Older Adults at Risk of Falls**

## ABSTRACT

**Background and purpose.** Maintenance of lateral stability requires the hip abductor muscles to generate force rapidly and with precise coordination. High-velocity resistance training can improve performance of functional tasks that require rapid movement. The purpose of this study was to obtain preliminary data on the effects of a 10-week program of high-velocity resistance training using a lateral trainer in older adults at increased risk for falls. **Methods.** Twenty-one older adults whose clinical balance test scores indicated increased risk for falls were randomized to exercise ( $n=10$ , mean age  $84.5 \pm 5.6$  years) and control ( $n=11$ , mean age  $83.5 \pm 3.2$  years) groups. Exercise group subjects received lateral trainer exercise 3 times per week for 10 weeks. Control group subjects were asked to maintain their regular physical activity and exercise levels. Balance confidence, hip abductor maximal muscle strength and rate of force development, clinical balance test performance (Four Square Step Test, Single Limb Stance, 360° Turn), and walking speed (self-selected and maximal speed) were evaluated at pre-, mid- (5-week) and post-intervention sessions. Linear mixed model analyses were applied to estimate means of outcome variables by group and time. **Results.** Compared to control group subjects, exercise group subjects demonstrated faster performance on the 360° Turn after intervention ( $p=.013$ ). There were no other significant between-group differences after intervention. **Conclusion.** Lateral trainer exercise can be performed safely by older adults. Although older adults had better performance on one dynamic balance test after the lateral trainer exercise program, no between-group differences were observed for the other measures examined. Lateral trainer exercise may be useful as one component of a multifaceted intervention program.

## INTRODUCTION

Results of recent research suggest that impaired lateral stability affects static and dynamic balance performance in older adults.<sup>1,2</sup> Age-related changes in the ability to control lateral body motion have been associated with falls.<sup>3,4</sup> Nearly one-third of adults who are 75 years of age or older fall at least once a year.<sup>5</sup> Falls lead to ongoing health problems and to motor and psychological restrictions that can further increase falls risk.<sup>6</sup>

Maintenance of lateral stability requires activation of appropriate muscle groups, primarily the hip abductors and adductors.<sup>7</sup> The hip abductors and adductors play a key role in stabilizing the body over one or both feet during turning, walking, and other daily activities.<sup>8,9</sup> These muscle groups must generate force rapidly and with precise coordination for stability during performance of volitional and reactive movements. Compared to flexor and extensor muscle groups, however, hip abductors and adductors may be less likely to receive adequate daily exercise and more susceptible to age-related declines in force-generating capabilities.<sup>10</sup> An older adult who is unable to generate sufficient muscle force in the hip abductors and adductors in the time frame necessary to control the position of the center of mass (COM) relative to the base of support (BOS) will be at increased risk for falls.

Despite their critical role in maintenance of lateral stability, hip abductor and adductor muscle groups have been largely overlooked in previous investigations of physical function, balance, and falls in older adults. Researchers have tended to emphasize movement in the sagittal plane and strengthening of muscles that produce sagittal plane movements (such as hip and knee flexors and extensors).<sup>11-13</sup> Recent evidence, however, supports the need for interventions targeting muscle groups that control movement in the

frontal plane.<sup>7, 14</sup> In a previous study of community dwelling older adults,<sup>15</sup> we demonstrated that hip abductor rate of force development (RFD) was significantly related to performance on two clinical tests that challenge lateral stability, single limb stance and tandem gait.

Evidence also supports the efficacy of interventions, such as resistance training, designed to improve muscle RFD as well as strength in older adults.<sup>16-19</sup> Resistance training also can produce maintenance of or improvements in functional abilities in this population.<sup>20</sup> In previous studies, high velocity resistance training has been reported to increase muscle strength<sup>21</sup> and RFD<sup>16-19</sup> and physical function<sup>22-24</sup> in older adults. High-velocity training can improve performance of functional tasks that require rapid movement, and strength training can improve performance of functional tasks that require maximal muscle strength.

We propose a novel intervention for improving lateral stability and, ultimately, decreasing falls in older adults. The intervention targets the hip abductor and adductor muscles through exercise on a lateral trainer,<sup>\*</sup> a device that is currently used in athletic training and sport rehabilitation. The lateral trainer includes a dynamic slide plate with independent-action footpads allowing rhythmic lateral motions at self-controlled speeds and with various levels of resistance. As a means of providing high velocity resistance training for muscles that control movement in the frontal plane, lateral trainer exercise has potential for increasing hip abductor muscle strength and RFD and improving lateral stability.

The purpose of this small randomized controlled trial was to obtain preliminary data on the effects of a 10-week program of lateral trainer exercises on a) balance confidence, b) hip abductor muscle strength and RFD, and c) lateral stability in older adults at increased risk for falls. We hypothesized that subjects who participated in the exercise program would

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<sup>\*</sup> Dynamic Edge® RPM™, The Skier's Edge Company, P.O. Box 2700, Park City, Utah 84060

show greater balance confidence, greater hip abductor muscle strength and RFD, and better lateral stability than control group subjects.

## **METHODS**

### **Subject Recruitment and Screening**

Subjects were recruited by emails, flyers, and presentations at senior centers, the YMCA, and continuing care retirement communities (see Appendix B). Inclusion criteria were as follows: 65 years of age or older; able to read and speak English; able to ambulate at least 50 feet without physical assistance; no more than 1 error on the Six-Items Test (a cognitive screening tool)<sup>25</sup>; normal or corrected-to-normal vision and hearing (by self-report); and able to follow instructions and perform all experimental procedures. Volunteers were excluded if they had any of the following: body weight of 200 lb or above (the upper weight limit of the lateral trainer); diagnosed neurological disease or disorder; lower extremity joint replacement (because of the possibility of impaired joint proprioception affecting movement control); acute back or extremity musculoskeletal problems, such as strains, sprains, or fractures; unstable cardiovascular disease; or uncontrolled diabetes mellitus.

The flow of subjects through the study is diagrammed in Figure 4.1. One hundred and eight volunteers who showed interest in this study received telephone or face-to-face interviews. Screening and demographic information of potential volunteers including age, dominant lower extremity, contact information, activity level and self-reported fall history (6 months) were obtained by telephone or in-person interview. A fall was defined as “an event that results in a person coming to rest unintentionally on the ground or other lower level regardless of whether an injury was sustained, and not as a result of a major intrinsic event or overwhelming hazard”.<sup>4(p. 1708)</sup> An overwhelming hazard was defined as a hazard that

would result in a fall by most young and healthy persons.<sup>5</sup>

Informed consent was obtained at the start of the screening session following the initial interview (see Appendix C). This screening session included administration of a medical history questionnaire, the Six-Item test<sup>25</sup> (a cognitive screening test), and a fall risk assessment consisting of the Four Square Step Test (FSST)<sup>26</sup> and the Single Limb Stance test (SLS)<sup>27</sup> (see Appendix D). These fall risk assessment tests were administered according to standardized procedures described by Dite et al<sup>26</sup> and Tinetti<sup>27</sup>, respectively. Both the FSST and SLS have evidence of reliability<sup>26, 28</sup> and can be used to identify individuals at risk of falls<sup>26</sup> or injurious falls<sup>29</sup>. Subjects were considered as being at high risk of falls if they 1) required  $\geq 15$  seconds to complete the FSST or were unable to face forward or needed to turn before stepping into the next square<sup>26</sup> or 2) were unable to maintain SLS for at least 5 seconds<sup>29</sup>. Volunteers who met all other eligibility criteria and required 15 or more seconds to complete the FSST or maintained SLS for less than 5 seconds were enrolled in the study.

Fifty-five of the original 108 volunteers were excluded during the screening process because of impaired hearing or cognition (n=2), neuromuscular or musculoskeletal disorder (n=8), cardiopulmonary disorder (n=2), hip or knee joint replacement (n=12), body weight over 200 lb (n=4), lower extremity pain or surgery (n=2), or not at risk of falls (n=25). Twenty-four volunteers who were eligible following screening declined further participation. The remaining 29 subjects were enrolled in the study. Each subject completed a Modified Physical Activity Readiness Questionnaire (PAR-Q) that was sent to his/her primary care physician with a request for medical approval for exercise participation (see Appendix E). The Modified PAR-Q is a screening tool to identify risk factors or symptoms that are contraindications for exercise. We obtained medical approval (in writing) from each

subject's physician prior to laboratory testing (see Appendix F). Subjects were paid up to \$230 for their participation.

### **Randomization**

Among the 29 subjects enrolled in the study, four subjects withdrew before group assignment. Twenty-five subjects were randomly assigned to an exercise group or to a no-intervention control group. Prior to randomization, pairs of subjects in the same wave of recruitment were matched by gender and SLS score (within 1-second intervals). One member of each matched pair was then randomized to the exercise group and 1 to the control group. Five subjects who could not be paired were simply randomized to either the exercise or the control group. After randomization was completed, an additional 4 subjects declined further participation. A total of ten subjects were assigned to the exercise group and 11 subjects to the control group (Figure 4.1).

### **Exercise Intervention**

Subjects assigned to the exercise group performed an exercise program 3 times per week for 10 weeks, with each session lasting a maximum of 45 minutes. Exercise sessions took place at one of two intervention sites, the Center for Human Movement Science (CHMS) at the University of North Carolina at Chapel Hill or a local continuing care retirement facility, whichever was more convenient for the subjects. Subjects assigned to the control group were asked to continue their usual physical activity levels and to refrain from enrolling in any new exercise programs or training during the time of their participation in the study. Telephone interviews were conducted every week to identify any protocol violations (see Appendix H). Subjects in the control group were offered participation in the exercise program after the conclusion of the study.

The exercise program was designed to increase the strength and rate of force development (RFD) of muscle groups that control movement in the frontal plane. Each session lasted approximately 30 to 45 minutes and included several bouts of exercise on the lateral trainer. Subjects held onto the balance bar during exercise (Figure 2.1). A repetition was defined as movement of the footplates from the farthest point on the subject's left side to the farthest point on the subject's right side and back. A hand-held counter was used to record the number of repetitions performed on the lateral trainer during a bout of exercise. Subjects performed a progressive exercise program based on standard American College of Sports Medicine (ACSM) guidelines, beginning at a very low workload. During the first 3 sessions, subjects were asked to perform the exercise at any speed and resistance they preferred for 3 bouts of 1 to 2 minutes of exercise with 1- to 2-minute rest intervals between bouts. Beginning in the second week, speed requirements and/or amount of resistance and/or the number of bouts for each exercise were adjusted in accordance with the subject's abilities. The amount of the resistance was increased when subjects were able to maintain their maximal movement speed throughout an exercise bout. The maximal speed of movement was determined from the time required to finish 10 repetitions of each exercise and then expressed as the number of repetitions to be performed in one minute. A metronome was used to pace the movements and was set at the subject's maximal speed at all times after the 3<sup>rd</sup> session.

The Borg scale<sup>30</sup> was used to provide safety guidelines (see Appendix I). In accordance with American College of Sports Medicine (ACSM) guidelines, the training zone was 12 – 16 on the Borg scale. Each subject's heart rate was monitored regularly, including before and after exercise and at any time a subject indicated any discomfort. During each



session, the researcher(s) recorded in an exercise log specific information about the exercise performed (number of repetitions, amount of resistance, duration, etc. as appropriate) and any observations about the subject's responses.

At each session, subjects performed approximately 5 to 10 minutes of warm-up and cool-down exercises such as stretching exercises and treadmill walking or stationary bike riding (subject's preference). At least one of the researchers was present during all exercise sessions to help insure subject safety (by using a safety belt or providing manual contact guarding) and to modify the exercise program for each subject as needed. A visual analog scale (VAS)<sup>31</sup> also was used to assess any discomfort or pain subjects experienced during or after exercise.

### **Post Intervention Questionnaire**

At the end of the 10-week exercise program, subjects completed a post-intervention questionnaire. The questionnaire was designed to obtain subjects' feedback about their participation in the lateral trainer exercise program. Subjects used a 10-cm VAS to indicate their responses to questions (see Appendix J).

### **Tests and Measures**

Subjects were tested prior to the intervention (baseline), at 5 weeks (mid-intervention), and after the intervention (at 10 weeks, post-intervention). Test sessions were conducted at the CHMS at baseline and post-intervention and at the exercise site at mid-intervention. All of the tests and measures listed below were completed at baseline and post-intervention. The mid-intervention test session did not include measurement of hip abductor muscle strength and RFD because the space and equipment were not available at one of the exercise sites (the retirement facility). The clinical balance tests involved

maintaining medial-lateral balance in static and dynamic conditions.

### *Balance Confidence*

Balance confidence was measured using the Activities-specific Balance Confidence (ABC) scale<sup>32</sup> (see Appendix K). The ABC is a 16-item questionnaire that was administered by face-to-face interview. Subjects were asked to indicate, by choosing a percentage point on an 11-point scale from 0 to 100%, their level of confidence in performing each activity without unsteadiness or loss of balance. Zero percent represented “no confidence” and 100% represented “complete confidence.”<sup>32</sup>

### *Hip Abductor Muscle Strength and Rate of Force Development*

Procedures for measuring isometric muscle strength of the hip abductors were based on those described by Andrews et al<sup>33</sup>. The subject was positioned supine with the hips in neutral rotation. A Quantrol AFG digital force gauge (Dillon/Quality Plus, Inc., Camarillo, CA) was mounted on a wooden block and stabilized against a wall during testing. The force gauge was placed perpendicular to the thigh of the dominant leg, with the padded attachment on the distal lateral femoral condyle. The examiner explained the desired muscle action of hip abduction with the knee extended, and allowed the subject to perform 1-2 practice trials as needed. Subjects were encouraged to push against the gauge as hard and as fast as possible. The force was measured for 5 seconds to allow the subject to build up to a maximal contraction, and the peak force was recorded. Three test trials were performed, with a rest period of at least 30 seconds between trials. During all test trials, the subject was given continuous verbal encouragement to push as fast and hard as possible. The analog output from the load cell of the dynamometer was recorded during testing and stored off line for later calculation of RFD variables from the slope of the force curve.

#### *Four Square Step Test*<sup>26</sup>

The FSST is a dynamic balance test that requires subjects to rapidly change direction while stepping forward, backward, and sideways over canes which create 4 squares on the floor. Subjects were asked to stand in square 1 and face forward (to square 2) and to step as fast as possible into each square in the sequence of square 2 – 3 – 4 – 1 – 4 – 3 – 2 – 1. Two trials were performed and the best time was taken. The trial was repeated if the subject was unable to complete the sequence successfully, lost balance or made contact with a cane during stepping. A digital stopwatch was used to measure to the nearest hundredth of a second the time from when the subject's first foot contacted the floor in square 2 to the time when the last foot came back to touch the floor in square 1. The instructions were "Try to complete the sequence as fast as possible without touching the sticks. Both feet must make contact with the floor in each square. If possible, face forward during the entire sequence."

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#### *Single Limb Stance*<sup>27</sup>

SLS is a static balance test involving balance control in the medial-lateral direction. Subjects were asked to stand on one leg (subject preference) with eyes open and arms at their sides. The researcher demonstrated the test position before testing. Subjects were instructed to look straight ahead, lift the left/right leg off the floor when they were ready, and maintain the position as long as possible. The researcher started timing when the subject achieved unilateral stance and stopped timing when the lifted leg touched the supporting leg, the supporting leg moved on the floor, or the lifted foot touched down. Thirty seconds was the upper limit for this test.<sup>34</sup> Two trials were performed and the mean time was recorded. If a subject was unable to achieve unilateral stance, the time was recorded as 0.00 seconds.

### *Timed 360° Turn*

This test requires dynamic balance during turning. A digital stopwatch was used to measure to the nearest hundredth of a second the time required for subjects to turn 360° in their preferred direction while standing. Subjects were asked to turn as quickly as possible completely around in a full circle, pause, and then turn a full circle in the other direction. The researcher demonstrated test performance prior to testing. Two trials were performed and the mean time was recorded. This test was adapted from an item in Berg balance scale<sup>35</sup>. This test was not performed in standardized procedures when it is rated as an isolated scale: subjects were asked to turn in one direction as quickly as possible completely around in one full circle.<sup>36</sup>

### *Ten-Meter Walk*<sup>37</sup>

A digital stopwatch was used to measure to the nearest hundredth of a second the time required for subjects to walk a 10-m distance using any customary assistive device(s). An additional five meters was measured and marked at the beginning and end of the 10-m distance to allow subjects enough distance to accelerate and decelerate. Subjects were instructed to walk “at a comfortable pace” (self-selected speed) and “as quickly as possible without feeling unsafe” (maximal speed). Two trials were performed for each condition, and the mean speed was calculated and recorded.

At each test session, the balance confidence measure was completed prior to administration of the remaining clinical balance tests, which were performed in random order. Balance confidence was measured first in order to avoid any effects of clinical balance testing on ratings of balance confidence.

### *Inter-rater Reliability*

The primary investigator (PI) scored all tests of balance and walking speed at all test sessions. To minimize any scoring bias, two raters who were blinded to group assignment independently scored the subject's performance in 41 (of a total of 62) individual test sessions. Rater 1 was a research assistant with no previous experience with balance test administration and rater 2 was a physical therapist with 2 years experience administering clinical balance tests. Both raters attended at least 3 training sessions. Inter-rater reliability was evaluated for the sessions that each rater attended. Inter-rater reliability was estimated using intraclass correlation coefficients (ICC [2,1]) and 95% confidence intervals. ICC values for the reliability of the PI's scores with those of Rater 1 and Rater 2 were  $> 0.88$  and  $> 0.98$ , respectively, for all tests.

### **RFD Data Reduction**

Data from the best two of the three trials of maximal isometric contraction of the hip abductors (based on the muscle strength values) were used to determine RFD variables. Customized Matlab software was used to determine the voltage level corresponding to maximum force for each trial. The time (in milliseconds) required to reach 60% and 90% of maximum force from an onset level of 10% of maximum was calculated and used to define two RFD variables: Time 10%-60% and Time 10%-90%, respectively.<sup>38, 39</sup> Three additional RFD variables were calculated as the average slope (rate: millivolts/milliseconds) of the initial phase of the force-time curve at 50, 100, and 200 ms relative to the onset level of 10% of maximum: Rate 50, Rate 100, and Rate 200, respectively.<sup>40</sup> Figure 4.2 shows the hip abductor RFD curve for a representative trial.

### **Statistical Analysis**

Descriptive statistics were generated for subject characteristics overall and by group.

T-tests were conducted to detect any group differences in subject characteristics including age, body height and weight. Scores of baseline (pre-intervention) clinical balance tests, balance confidence and hip abductor maximal strength and RFD measures were also compared using t-tests to determine if any group differences existed.

Using linear mixed models with a random effect for participant, model-based means and standard errors of clinical balance measures, balance confidence and hip abductor strength and RFD measures were estimated overall and by treatment group and testing time for each measure. Model-based adjusted means and standard errors were then estimated from linear mixed models including the participant random effect and the following fixed covariates: score at baseline, maximal hip abductor strength (kg), body weight (kg) and height (m). Maximal hip abductor strength, body weight and height were eliminated from the final model because there were no significant differences (all  $p > .05$ ). All 2-way interactions among group, time, and baseline scores as well as the 3-way interaction for all dependent variables were tested. A significance level of  $p < .05$  was used for all statistical tests. All analyses were conducted using SAS 8.02 (SAS Institute Inc., Cary, NC 27513).

## **RESULTS**

Data for 21 older adults were included in the analyses. Subject characteristics are presented in Table 4.1. One subject in the exercise group withdrew after mid-intervention testing. No significant differences were found between groups in age, body height, or weight.

Means of all dependent variables at baseline are presented in Table 4.2. The two groups did not differ at baseline in ABC scores, hip abductor muscle force measures (maximal strength and RFD), SLS, or self-selected walking speed. However, on average,

subjects in the control group had faster times on the FSST ( $9.0 \pm 2.4$  sec;  $p=.020$ ) and  $360^\circ$  Turn ( $5.0 \pm 1.0$  sec;  $p=.006$ ) and had a higher maximal walking speed ( $1.7 \pm 0.2$  m/s;  $p=.031$ ) than those in the exercise group (Table 4.2).

Exercise group subjects who completed the intervention attended at least 85% of the exercise sessions (at least 25 sessions). No significant adverse events occurred in association with the intervention. One subject reported right hip adductor pain (VAS= 4/10) and another reported wrist pain (VAS=7/10) at the beginning of the exercise program; however, the pain resolved in both cases following reduction of the exercise intensity and correction of hand position, respectively.

Exercise group subjects typically tolerated approximately 5 to 6 bouts of lateral trainer exercise during each session (total exercise time up to 9 minutes) throughout the intervention. Progression of training is summarized in Table 4.3. Most subjects were able to perform more repetitions per minute and to exercise longer in each exercise bout as the program continued. None of the subjects in the control group violated protocol.

Hip abductor muscle strength and RFD values obtained for each subject at each test session are presented in Figure 4.3. Individual subject scores for balance confidence and clinical balance tests at each test session are presented in Figure 4.4. As shown in Table 4.4, a majority of the subjects in the exercise group demonstrated improvement from pre- to post-intervention on all outcome measures except self-selected walking speed. Subjects in the control group improved as well, with a majority having better scores by post-intervention on all measures except for ABC scores and one of the RFD variables (Time 10%-60%). The percentage of subjects demonstrating improvement in hip abductor muscle force and RFD values, ABC scores, and scores on the FSST and SLS tests at the post-intervention

session was somewhat higher for the exercise group than for the control group.

The following are the results of statistical analyses for each outcome measure:

Balance Confidence (ABC). ABC scores were similar for exercise group subjects (mid:  $83.9 \pm 3.3\%$ , post:  $83.6 \pm 2.5\%$ ) as compared to control group subjects (mid:  $78.9 \pm 3.1\%$ , post:  $83.8 \pm 2.4\%$ ) at mid- and post-intervention testing (Figure 4.5.a). No main or interaction effects were found (all  $p > .05$ ).

Hip Abductor Muscle Strength and RFD. The two groups did not differ on any measures of hip abductor maximal strength or RFD at the post-intervention session (all  $p > .05$ ). Adjusted means from the mixed linear model are presented in Table 4.5.

Clinical Balance Tests. Time needed to complete the FSST was lower at the post-intervention test session (exercise:  $10.0 \pm 0.6$  sec, control:  $9.9 \pm 0.6$  sec) compared to the mid-intervention session (exercise:  $10.8 \pm 0.7$  sec, control:  $10.5 \pm 0.7$  sec) for subjects in both groups ( $p = .034$ ; Figure 4.5.b). The group main effect and group by time interaction effects were not significant (all  $p > .05$ ). For SLS, no significant main or interaction effects were found (all  $p > .05$ ; Figure 4.5.c). For the 360° Turn, the group by time interaction was significant ( $p = .043$ ). Subjects in the exercise group, unlike those in the control group (mid:  $6.2 \pm 0.4$  sec, post:  $6.3 \pm 0.4$  sec;  $p = .761$ ), completed the 360° Turn more quickly at the post-intervention test session compared with the mid-intervention session (mid:  $6.2 \pm 0.4$  sec, post:  $5.6 \pm 0.4$  sec;  $p = .013$ ; Figure 4.5.d).

Walking Speed. Self-selected and maximal walking speeds were not different between groups or between mid- and post-intervention sessions. No group by time interaction was found (all  $p > .05$ ; Figure 4.5.e and 4.5.f).

Post Intervention Questionnaire. Responses of exercise group subjects on the post



intervention questionnaire indicated that the subjects viewed lateral trainer exercise as enjoyable (mean VAS rating =  $9.1 \pm 1.0$ ) and of moderate difficulty (mean VAS rating =  $5.5 \pm 3.3$ ). Mean VAS rating with respect to perceived benefits for muscle strengthening (“How much did this exercise help your hip muscle strength?”) and for balance improvement (“How much did this exercise help your balance?”) were  $7.3 \pm 2.4$  and  $4.8 \pm 2.8$ , respectively. Subjects indicated they would be likely to continue the lateral trainer exercise if the equipment was available to them (mean VAS rating =  $7.8 \pm 2.5$ ).

## DISCUSSION

This pilot lateral trainer exercise intervention was designed as a high velocity progressive resistance exercise. We hypothesized that older adults at risk of falls would demonstrate improved balance confidence, hip abductor muscle strength and RFD, and lateral stability after participation in a 10-week lateral trainer exercise program. Based on the individual data, higher percentage of subjects who received lateral trainer exercise performed better on balance confidence, hip abductor muscle strength and RFD measures, FSST, SLS and maximal walking speed tests. However, results from mixed model analyses showed that subjects who received lateral trainer exercise performed better than the control group on the 360° Turn, but not on the other outcome measures examined in this study.

Our first hypothesis, which was not supported, was that exercise group subjects would show higher balance confidence after the intervention. The lack of an effect on balance confidence is inconsistent with results of previous exercise studies in older adults.<sup>41,</sup>

<sup>42</sup> Subjects in the present study had relatively high balance confidence prior to the intervention. Their mean score at baseline ( $81.8 \pm 12.4$  %) was considerably higher than the scores reported by Sattin et al<sup>41</sup> ( $53.5 \pm 9.2$  % in Tai Chi group,  $52.1 \pm 6.0$  % in Education

group) for a group of subjects recruited from independent living facilities. The potential for improvement in balance confidence may have been limited in our subjects.

Our second hypothesis, which was not supported, was that exercise group subjects would show greater hip abductor maximal muscle strength and RFD after the intervention. The lack of an effect on hip abductor maximal strength and RFD measures may have resulted from inadequate overload during exercise. Overload is an important principle in strength training. The duration of this pilot intervention may not have been long enough to induce significant strength or functional changes. In studies by Hakkinen et al<sup>16, 17</sup>, strength and RFD in older adults were improved after participation in a 21- or 24-week high-velocity strengthening exercise program. Functional changes such as walking speed and balance were improved after a 16-week high-velocity strengthening program.<sup>23, 24</sup> In future studies, the duration of the program may need to be extended. The resistance provided during exercise also may need to be increased. According to previous research,<sup>16, 17</sup> improvement in muscle strength and RFD was observed when the resistance was set at 50% of the individual's 1 repetition maximum (1RM) at the beginning and then increased gradually to 80% of 1RM. In the present study, the resistance was set at the lowest level in order to emphasize the speed of movement. Most participants could perform the exercise against a higher resistance level and at a faster speed by the end of the exercise program.

Our third hypothesis, which was partially supported, was that exercise group subjects would perform better than those in the control group on clinical balance and walking speed tests. Older adults who received lateral trainer exercise had better dynamic balance performance as measured by a timed 360° turn. Maintaining balance in turning is a critical component for daily living activities such as walking in the community and maneuvering in

the bathroom. Previous research showed that poor turning performance (e.g. slowness) is linked to risk of falls in older adults.<sup>43</sup> However, we did not see better performance on another dynamic balance test, FSST. One explanation is that these two dynamic balance tasks require different movement patterns and types of postural control. When performing the FSST, subjects had to step over obstacles and transfer weight between feet in four different directions as fast as possible without turning their bodies. As compared to the 360° turn, maintaining balance during FSST requires more precise control of lower extremity muscle forces. The FSST also is more cognitively demanding in that subjects must remember the stepping sequence.<sup>26</sup>

Another explanation is that subjects may have had limited potential for improvement in physical performance measures, although they were identified as being at high risk of falls based on the fall assessment tests. The subjects may have had a moderate to high level of functioning. Given that the mean age of the subjects in the present study was over 80 years, they reported very few falls in the past 6 months, and those falls were related to extrinsic factors such as uneven and slippery outdoor surfaces. FSST scores of subjects without fall history in the present study (mean= 9.71 sec, range= 7.7 – 21.6) were similar to those reported by Dite et al<sup>26</sup> for younger subjects (74 ± 6 years old, mean=8.7 sec, range= 7.4 – 10.0). Based on previous evidence of a curvilinear relationship between impairments (such as reduced strength) and function (such as balance), small increases in strength can lead to large increases in function for older adults at lower functional levels (with severe functional limitations such as nursing home residents).<sup>44</sup> With the same increase in strength, however, healthy older adults who are at or above the functional threshold may achieve only minimal improvement in function.<sup>44, 45</sup>

In view of the limited findings of improvement in the present study, several aspects of study design should be considered in future research. First, physical activity and exercise levels in both groups during the study period should be evaluated. Subjects in the control group were asked to maintain their regular activity level during the study period; however, these subjects may have increased the amount of participation in regular physical and exercise activities and may have practiced the clinical balance tests. Research suggests that exercise and other types of physical activity can improve balance, muscle strength and functional activities and decrease the risk of falls.<sup>46-49</sup> In the future, quantitative measures of physical activity and exercise levels should be obtained for both the intervention and the control groups.

Second, a multifactorial-approach and specificity of training principles should be applied in designing exercise interventions to improve lateral stability in older adults. Lateral trainer exercise could be considered a single-risk-factor exercise because this exercise focused on hip abductor weakness. Interventions focused on a single risk factor such as decreased muscle strength, environmental hazards, or poor vision are effective in improving balance or preventing falls only when targeted to groups most at risk. The multifactorial approach uses interventions that target multiple risk factors. This type of intervention is most effective when designed to address an older adult's specific impairments and circumstances.<sup>47, 49, 50</sup> In future studies, lateral trainer exercise may be combined with other types of training to achieve maximal strength and functional improvements.

Third, the falls assessments used in screening in both projects might not have been adequate to identify older adults at risk of falls. According to the results, most subjects were identified at risk of falls on the basis of SLS scores, with only 4 subjects scoring above

the criterion time of 15 seconds on the FSST. The FSST may not have been sensitive for identifying individuals with deficits in lateral stability. Furthermore, SLS may not have been a reliable indicator of increased risk of falls among the subjects included in our study. In future studies, standardized balance tests with multiple levels of task difficulty, such as the Berg Balance Scale should be included.

With regard to specificity of training principles, we expected that lateral trainer exercise could provide sufficient neuromuscular activation to stimulate muscle strength adaptation, particularly when performed at maximal speeds. In addition, lateral trainer exercise involves lateral body movement and lower extremity weight transfer, both of which may be important for maintaining lateral stability. However, lateral trainer exercise does not require lower extremity balance reactions, and use of the balance bar for support in the present study further limited the balance challenges provided during training.

Lateral trainer exercise may be beneficial for some individuals, and has advantages for inclusion in a combination exercise program. The lateral trainer exercise was safe, and adherence to the exercise program was excellent. According to the ratings on the post-intervention questionnaires, participants thought the lateral trainer exercise was enjoyable and challenging. Lateral trainer exercise can provide an addition to the variety of hip abductor exercises recommended for older adults.

## **CONCLUSION**

Older adults who participated in a 10-week lateral trainer exercise program performed better than control group subjects on a test of dynamic balance (timed 360° turn). Little evidence was found for effects of lateral trainer exercise on measures of balance confidence, hip abductor muscle strength or hip abductor RFD. Additional research is needed to

determine whether lateral trainer exercise can be combined with other types of exercise to achieve maximal strength and functional improvements. Future studies should also focus on the efficacy of lateral trainer exercise in persons with greater physical limitations.

## References

1. Hayes WC, Myers ER, Robinovitch SN, Van Den Kroonenberg A, Courtney AC, McMahon TA. Etiology and prevention of age-related hip fractures. *Bone* 1996; 18:77S-86S.
2. Nevitt MC, Cummings SR. Type of fall and risk of hip and wrist fractures: the study of osteoporotic fractures. The Study of Osteoporotic Fractures Research Group. *J Am Geriatr Soc* 1993; 41:1226-34.
3. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J Gerontol* 1994; 49:M72-84.
4. Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. *J Am Geriatr Soc* 1999; 47:1077-81.
5. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med* 1988; 319:1701-7.
6. Hauer K, Rost B, Rutschle K, et al. Exercise training for rehabilitation and secondary prevention of falls in geriatric patients with a history of injurious falls. *J Am Geriatr Soc* 2001; 49:10-20.
7. Rogers MW, Hedman LD, Johnson ME, Cain TD, Hanke TA. Lateral stability during forward-induced stepping for dynamic balance recovery in young and older adults. *J Gerontol A Biol Sci Med Sci* 2001; 56:M589-94.
8. Kirker SG, Simpson DS, Jenner JR, Wing AM. Stepping before standing: hip muscle function in stepping and standing balance after stroke. *J Neurol Neurosurg Psychiatry* 2000; 68:458-64.
9. Pai YC, Chang HJ, Chang RW, Sinacore JM, Lewis JL. Alteration in multijoint dynamics in patients with bilateral knee osteoarthritis. *Arthritis Rheum* 1994; 37:1297-304.
10. Johnson ME, Mille ML, Martinez KM, Crombie G, Rogers MW. Age-related changes in hip abductor and adductor joint torques. *Arch Phys Med Rehabil* 2004; 85:593-7.
11. Rantanen T, Guralnik JM, Izmirlian G, et al. Association of muscle strength with maximum walking speed in disabled older women. *Am J Phys Med Rehabil* 1998; 77:299-305.
12. Brown M, Holloszy JO. Effects of walking, jogging and cycling on strength, flexibility, speed and balance in 60- to 72-year olds. *Aging (Milano)* 1993; 5:427-34.
13. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther* 1993; 73:254-62; discussion 263-5.

14. Miller K, Johnson M, Roger M. Stance hip abduction torque characteristics during volitional and induced stepping in young and older adults. *Neurology report* 2002; 26.
15. Chang SH, Mercer VS, Giuliani CA, Sloane PD. Relationship between hip abductor rate of force development and mediolateral stability in older adults. *Arch Phys Med Rehabil* 2005; 86:1843-50.
16. Hakkinen K, Kallinen M, Izquierdo M, et al. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J Appl Physiol* 1998; 84:1341-9.
17. Hakkinen K, Pakarinen A, Kraemer WJ, Hakkinen A, Valkeinen H, Alen M. Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol* 2001; 91:569-80.
18. Suetta C, Aagaard P, Rosted A, et al. Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. *J Appl Physiol* 2004; 97:1954-61.
19. Barry BK, Warman GE, Carson RG. Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. *Exp Brain Res* 2005; 162:122-32.
20. Fiatarone MA, Evans WJ. The etiology and reversibility of muscle dysfunction in the aged. *J Gerontol* 1993; 48 Spec No:77-83.
21. Hakkinen K, Newton RU, Gordon SE, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol A Biol Sci Med Sci* 1998; 53:B415-23.
22. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology* 2005; 51:108-15.
23. Miszko TA, Cress ME, Slade JM, Covey CJ, Agrawal SK, Doerr CE. Effect of strength and power training on physical function in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci* 2003; 58:171-5.
24. Sayers SP, Bean J, Cuoco A, LeBrasseur NK, Jette A, Fielding RA. Changes in function and disability after resistance training: does velocity matter?: a pilot study. *Am J Phys Med Rehabil* 2003; 82:605-13.
25. Callahan CM, Unverzagt FW, Hui SL, Perkins AJ, Hendrie HC. Six-item screener to identify cognitive impairment among potential subjects for clinical research. *Med Care* 2002; 40:771-81.
26. Dite W, Temple VA. A clinical test of stepping and change of direction to identify



- multiple falling older adults. *Arch Phys Med Rehabil* 2002; 83:1566-71.
27. Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 1986; 34:119-26.
  28. Potvin AR, Syndulko K, Tourtellotte WW, Lemmon JA, Potvin JH. Human neurologic function and the aging process. *J Am Geriatr Soc* 1980; 28:1-9.
  29. Vellas BJ, Wayne SJ, Romero L, Baumgartner RN, Rubenstein LZ, Garry PJ. One-leg balance is an important predictor of injurious falls in older persons. *J Am Geriatr Soc* 1997; 45:735-8.
  30. Borg G. Subjective effort in relation to physical performance and working capacity. In: Pick H, et al, ed. *Psychology: From Research to Practice*. New York, NY: Plenum Publishing Corp, 1978:333-361.
  31. Petrella RJ, Bartha C. Home based exercise therapy for older patients with knee osteoarthritis: a randomized clinical trial. *J Rheumatol* 2000; 27:2215-21.
  32. Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol A Biol Sci Med Sci* 1995; 50A:M28-34.
  33. Andrews AW, Thomas MW, Bohannon RW. Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Phys Ther* 1996; 76:248-59.
  34. Lipsitz LA, Jonsson PV, Kelley MM, Koestner JS. Causes and correlates of recurrent falls in ambulatory frail elderly. *J Gerontol* 1991; 46:M114-22.
  35. Berg KO, Maki BE, Williams JJ, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. *Arch Phys Med Rehabil* 1992; 73:1073-80.
  36. Shubert TE, Schrodtt LA, Mercer VS, Busby-Whitehead J, Giuliani CA. Are scores on balance screening tests associated with mobility in older adults? *J Geriatr Phys Ther* 2006; 29:35-9.
  37. Green J, Forster A, Young J. Reliability of gait speed measured by a timed walking test in patients one year after stroke. *Clin Rehabil* 2002; 16:306-14.
  38. Bellew J. A correlation analysis between rate of force development of the quadriceps and postural sway in healthy older adults. *J Geriatr Phys Ther* 2002; 25:11-15.
  39. Hakkinen K, Kraemer WJ, Newton RU. Muscle activation and force production during bilateral and unilateral concentric and isometric contractions of the knee extensors in men and women at different ages. *Electromyogr Clin Neurophysiol* 1997; 37:131-42.

40. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol* 2002; 93:1318-26.
41. Sattin RW, Easley KA, Wolf SL, Chen Y, Kutner MH. Reduction in fear of falling through intense tai chi exercise training in older, transitionally frail adults. *J Am Geriatr Soc* 2005; 53:1168-78.
42. Hess JA, Woollacott M. Effect of high-intensity strength-training on functional measures of balance ability in balance-impaired older adults. *J Manipulative Physiol Ther* 2005; 28:582-90.
43. Dite W, Temple VA. Development of a clinical measure of turning for older adults. *Am J Phys Med Rehabil* 2002; 81:857-66; quiz 867-8.
44. Bean JF, Vora A, Frontera WR. Benefits of exercise for community-dwelling older adults. *Arch Phys Med Rehabil* 2004; 85:S31-42; quiz S43-4.
45. Buchner DM, de Lateur BJ. The importance of skeletal muscle strength to physical function in older adults. *Ann Behav Med* 1991; 13:91-8.
46. Carter ND, Kannus P, Khan KM. Exercise in the prevention of falls in older people: a systematic literature review examining the rationale and the evidence. *Sports Med* 2001; 31:427-38.
47. Gardner MM, Buchner DM, Robertson MC, Campbell AJ. Practical implementation of an exercise-based falls prevention programme. *Age Ageing* 2001; 30:77-83.
48. Lord SR, Caplan GA, Ward JA. Balance, reaction time, and muscle strength in exercising and nonexercising older women: a pilot study. *Arch Phys Med Rehabil* 1993; 74:837-9.
49. Shumway-Cook A, Gruber W, Baldwin M, Liao S. The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Phys Ther* 1997; 77:46-57.
50. Rubenstein LZ, Josephson KR. Falls and their prevention in elderly people: what does the evidence show? *Med Clin North Am* 2006; 90:807-24.

**Table 4.1.** Subject Characteristics

Mean $\pm$ Standard Deviation	Exercise Group	Control Group
<b>N</b>	10	11
<b>Sex</b>	4F : 6M	7F : 4M
<b>Age (years)</b>	84.5 $\pm$ 5.6	83.5 $\pm$ 3.2
<b>Height (m)</b>	1.7 $\pm$ 0.1	1.7 $\pm$ 0.1
<b>Weight (kg)</b>	69.0 $\pm$ 15.7	68.8 $\pm$ 14.2
<b>Fall History</b>		
single event	1	2
$\geq 2$ events	0	1

**Table 4.2.** Mean Baseline Scores for Balance Confidence, Hip Abductor Muscle Force Characteristics, Clinical Balance Tests and Walking Speed Tests

Mean $\pm$ Standard Deviation	Exercise Group	Control Group	<i>p</i> value
<b>ABC (%)</b>	77.8 $\pm$ 12.3	85.5 $\pm$ 11.9	.158
<b>Hip Abductor Force</b>			
<b>Maximal Strength (kg)</b>	10.9 $\pm$ 3.7	13.3 $\pm$ 5.1	.234
<b>Rate of Force Development</b>			
<b>Time 10%-60% (ms)</b>	226.9 $\pm$ 199.8	164.0 $\pm$ 104.5	.371
<b>Time 10%-90% (ms)</b>	1013.3 $\pm$ 821.6	779.3 $\pm$ 585.6	.458
<b>Rate 50</b>	3.9 $\pm$ 2.5	5.4 $\pm$ 5.0	.388
<b>Rate 100</b>	2.9 $\pm$ 1.6	3.8 $\pm$ 2.6	.350
<b>Rate 200</b>	1.7 $\pm$ 0.8	2.5 $\pm$ 1.4	.104
<b>Clinical Balance Tests</b>			
<b>Four Square Step Test (s)</b>	13.9 $\pm$ 5.3	9.0 $\pm$ 2.4	.020
<b>Single Limb Stance (s)</b>	1.6 $\pm$ 1.1	2.4 $\pm$ 1.1	.108
<b>360° Turn (s)</b>	8.2 $\pm$ 2.8	5.0 $\pm$ 1.0	.006
<b>Walking Speed Test</b>			
<b>Self-Selected (m/s)</b>	1.0 $\pm$ 0.2	1.2 $\pm$ 0.2	.083
<b>Maximal (m/s)</b>	1.4 $\pm$ 0.3	1.7 $\pm$ 0.2	.031

360° Turn was adapted from an item in Berg balance scale. This test was not performed in standardized procedures when it is rated as an isolated scale: subjects were asked to turn in one direction as quickly as possible completely around in one full circle.

**Table 4.3.** Summary of Exercise Program Progression

Number of Subjects	Resistance Level (1-13)		Repetitions/Min		Min/Bout		Number of Bout	
	start	end	start	end (% increase)	start	end	Start	end
3 (S34, S35, S37)	3	9	45-54	60-65 (20-33%)	1	1	5	5
2 (S33, S42)	3	9	65-80	89-98 (22.5-37%)	1.5	1.5	5	5
1 (S24)	5	10	76	99 (30%)	1.5	1.5	5	6
1 (S27)	3	5	74	98 (32%)	1	1	5	5
1 (S09)	1	7	25	60 (140%)	0.5	1	5	5
1 (S28)	1	8	50	75 (50%)	1	1.5	4	5
1 (S46)	1	1	71	108 (52%)	1	1.5	5	5

Start: the 2<sup>nd</sup> week of the intervention, End: end of the intervention.

**Table 4.4.** Number of Subjects Demonstrating Improvement in Outcome Measures at Mid- and Post-Intervention Assessments

Number of Subjects (% of the group)	Direction of Change in Score Indicative of Improvement	Exercise Group		Control Group	
		Mid (n=10)	Post (n=9)	Mid (n=11)	Post (n=11)
<b>ABC (%)</b>	↑	4 (40.0)	5 (55.6)	5 (45.5)	5 (45.5)
<b>Hip Abductor Force</b>					
<b>Maximal Strength (kg)</b>	↑		8 (88.9)		8 (72.7)
<b>Rate of Force Development</b>					
<b>Time 10%-60% (ms)</b>	↓		5 (55.6)		4 (36.4)
<b>Time 10%-90% (ms)</b>	↓		5 (55.6)		6 (54.5)
<b>Rate 50</b>	↑		6 (66.7)		6 (54.5)
<b>Rate 100</b>	↑		8 (88.9)		7 (63.6)
<b>Rate 200</b>	↑		8 (88.9)		7 (63.6)
<b>Clinical Balance Tests</b>					
<b>Four Square Step Test (s)</b>	↓	8 (80.0)	8 (88.9)	7 (63.6)	9 (81.8)
<b>Single Limb Stance (s)</b>	↓	8 (80.0)	8 (88.9)	7 (63.6)	7 (63.6)
<b>360° Turn (s)</b>	↓	7 (70.0)	6 (66.7)	7 (63.6)	8 (72.7)
<b>Walking Speed Test</b>					
<b>Self-Selected (m/s)</b>	↑	4 (40.0)	3 (33.3)	5 (45.5)	7 (63.6)
<b>Maximal (m/s)</b>	↑	5 (50.0)	7 (77.8)	6 (54.5)	6 (54.5)

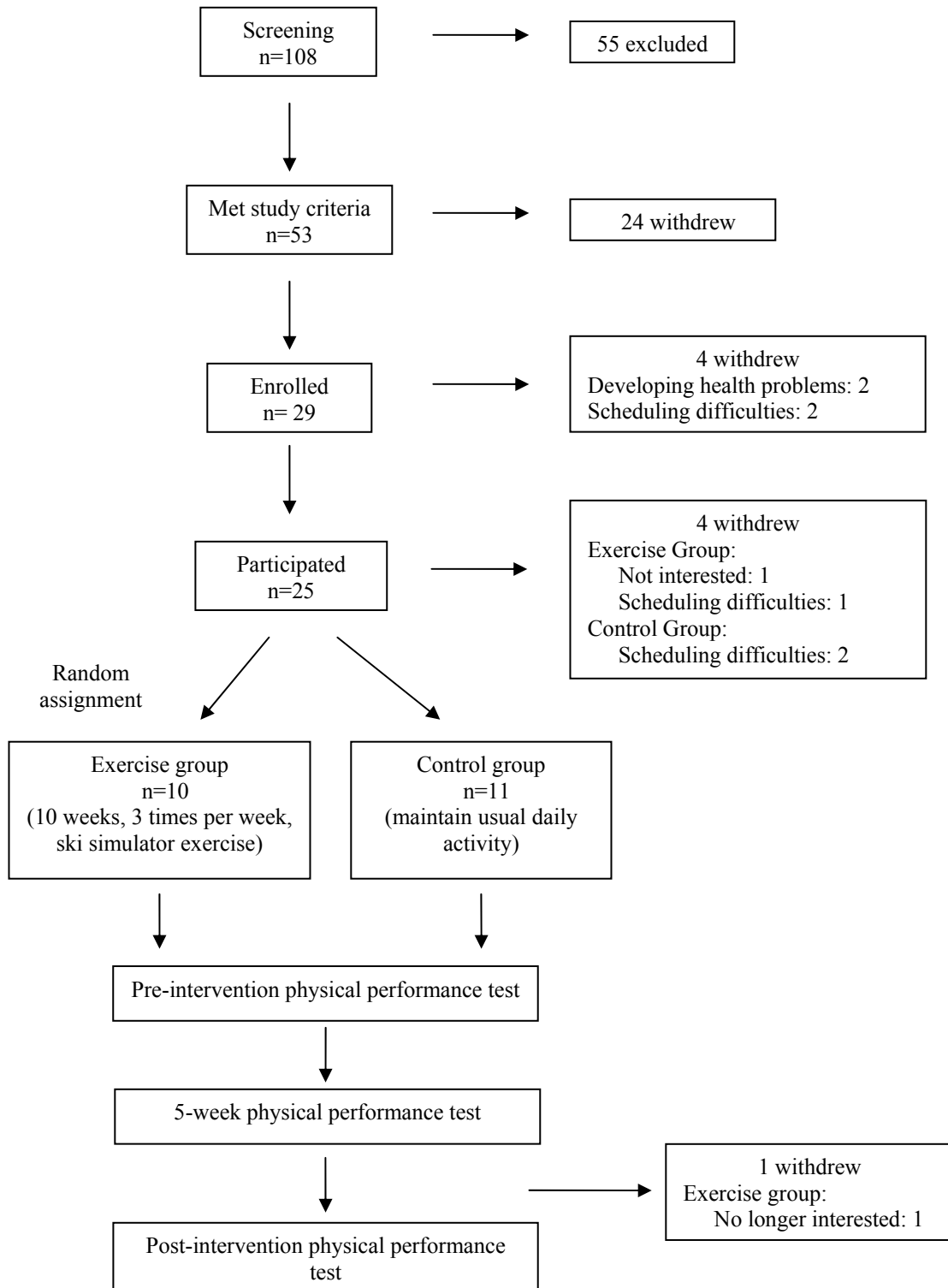
Mid: mid-intervention session, Post: post-intervention session. 360° Turn was adapted from an item in Berg balance scale. This test was not performed in standardized procedures when it is rated as an isolated scale: subjects were asked to turn in one direction as quickly as possible completely around in one full circle.

**Table 4.5.** Adjusted Means of Hip Abductor Muscle Strength and RFD Measures at Post-Intervention Assessments

Means (Standard Error)	Exercise Group	Control Group	<i>p value</i>
<b>Maximal Strength (kg)</b>	16.4 (1.7)	14.8 (1.5)	.533
<b>RFD</b>			
<b>Time 10%-60% (ms)</b>	186.3 (37.6)	187.5 (33.7)	.982
<b>Time 10%-90% (ms)</b>	786.1 (188.2)	851.9 (168.5)	.807
<b>Rate 50</b>	5.3 (0.9)	4.2 (0.8)	.426
<b>Rate 100</b>	4.9 (0.6)	3.7 (0.5)	.165
<b>Rate 200</b>	3.0 (0.3)	2.6 (0.3)	.291

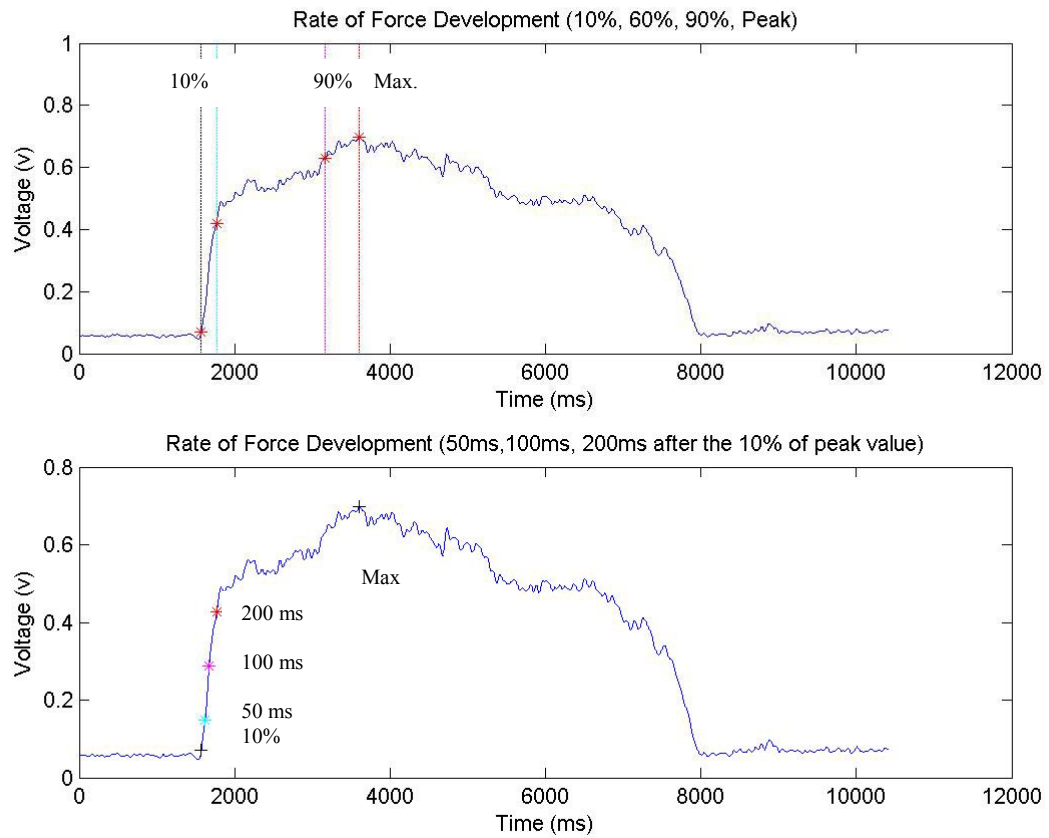
Model-based adjusted means and standard errors were estimated from linear mixed models including the participant random effect and the fixed covariate: score at baseline.

**Figure 4.1.** Flow of Subjects through the Study





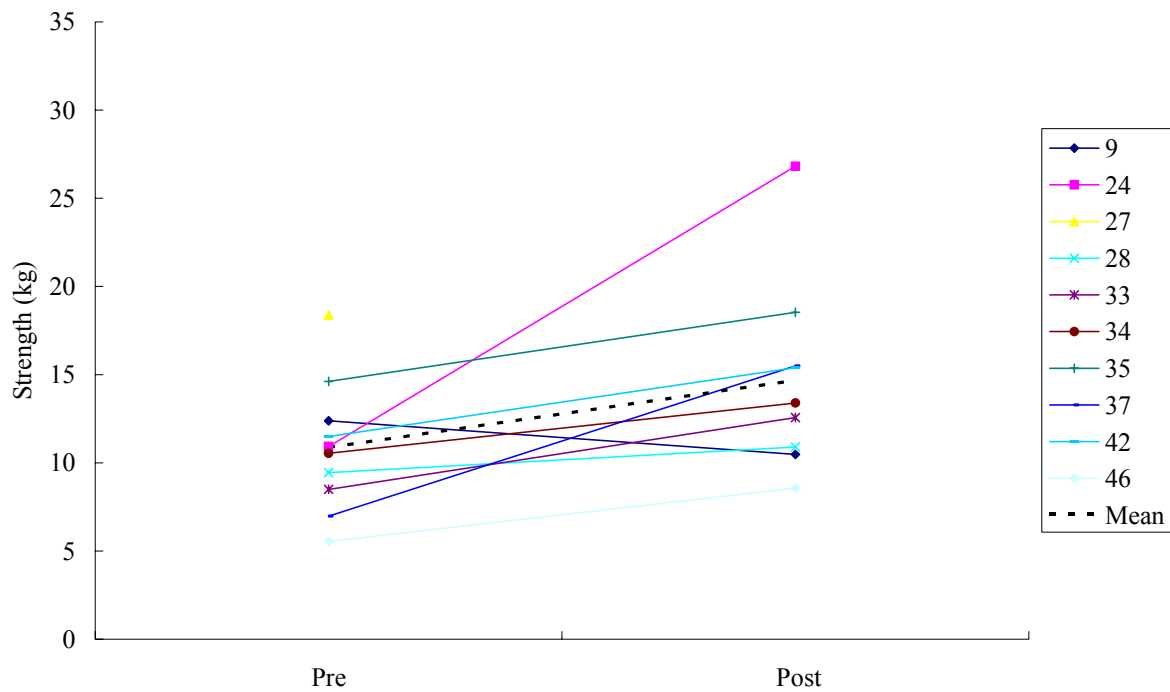
**Figure 4.2.** Example of Hip Abductor Rate of Force Development Calculation of One Trial



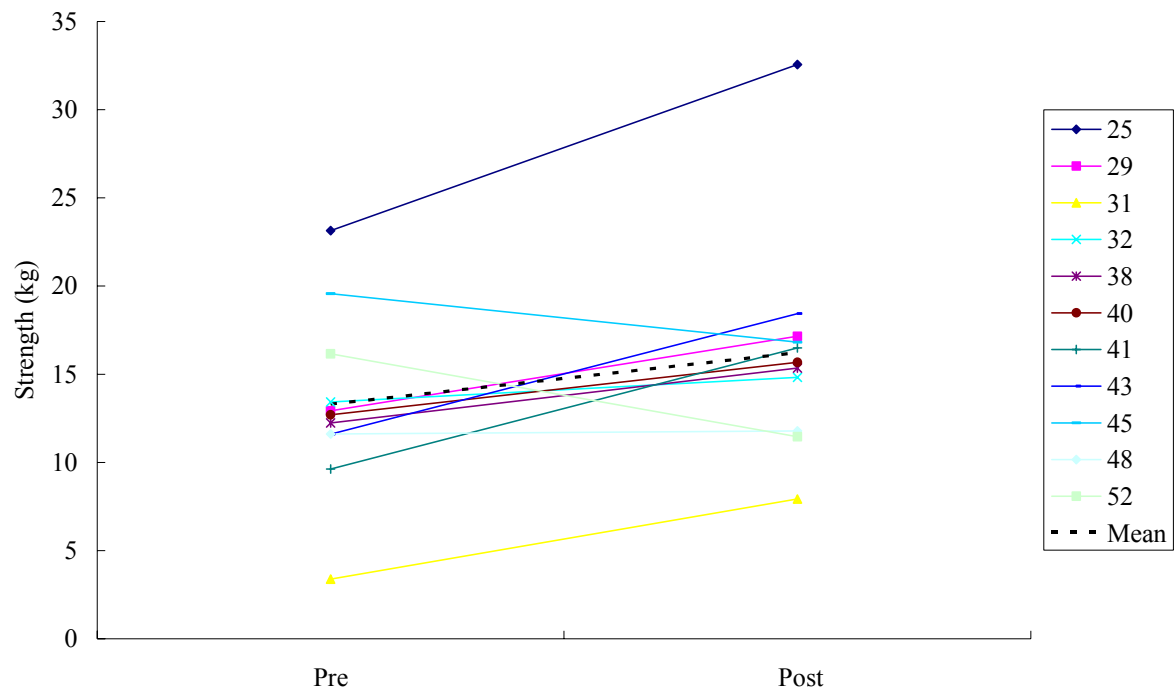
The top figure shows the points of 10% (onset), 60%, 90% of maximal voltage and maximal voltage corresponding to the maximal hip abductor muscle force of one trial during RFD testing. The bottom figure shows the points of 50 ms, 100 ms, 200 ms after onset.

**Figure 4.3.** Hip Abductor Muscle Strength and RFD Measures for Individual Subjects at Pre- and Post-Intervention Test Sessions. X axis is the Time of Testing

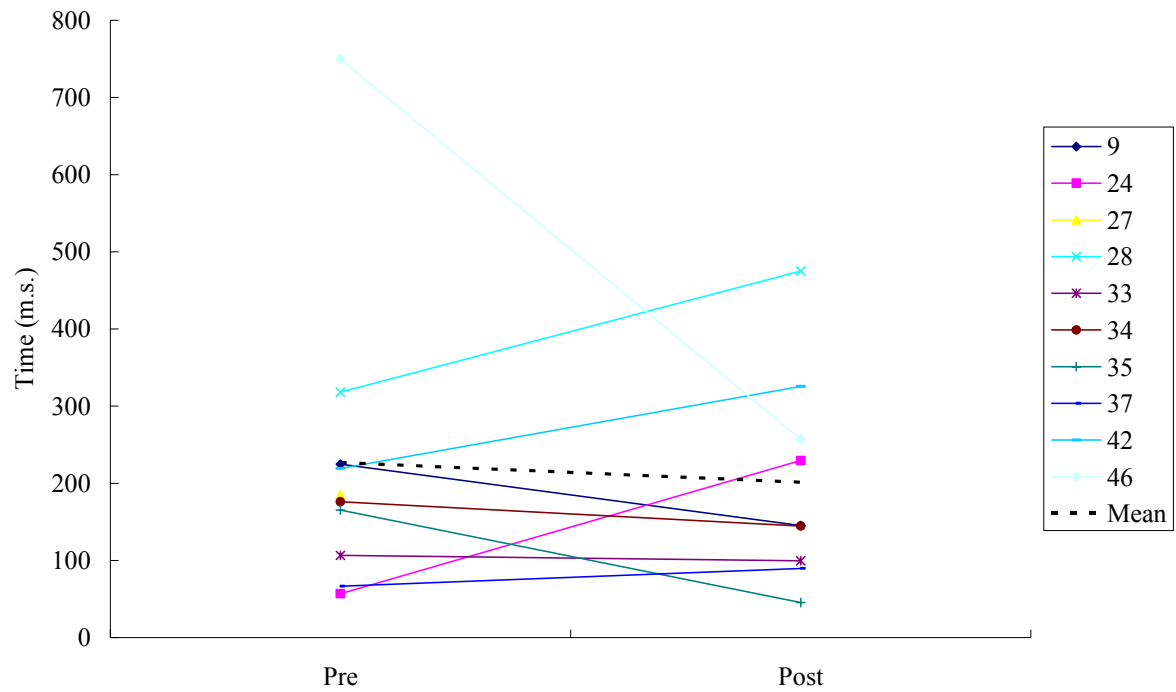
**4.3.a.** Exercise Group- Maximal Hip Abductor Muscle Strength



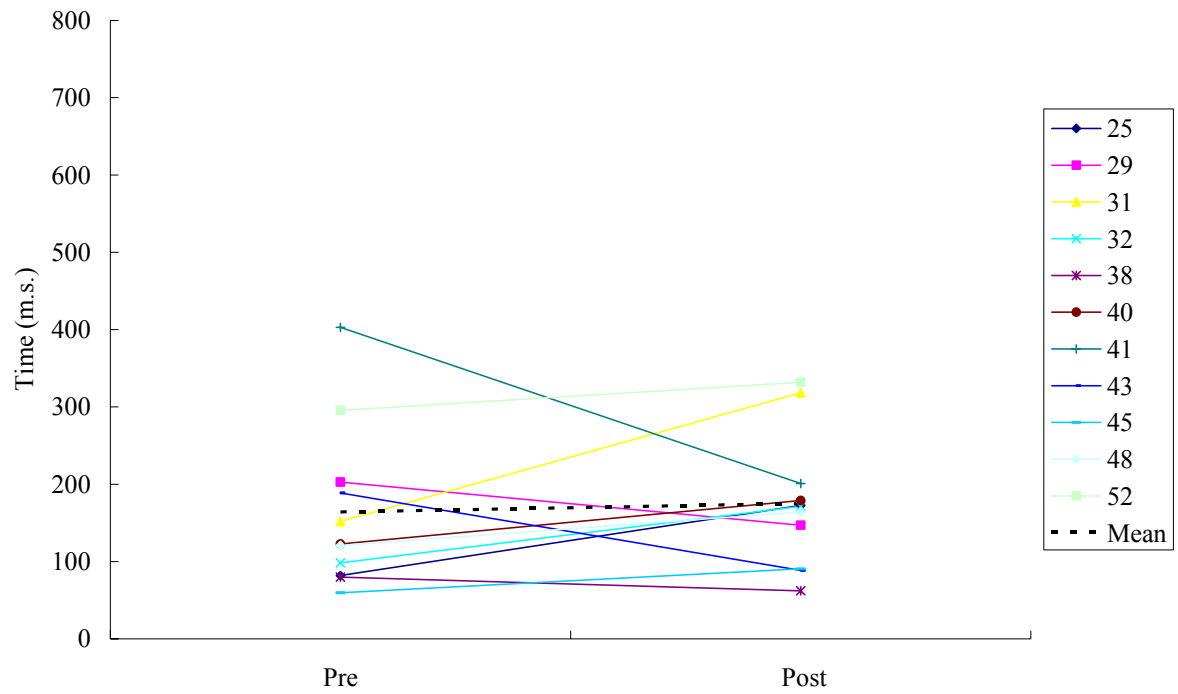
#### 4.3.b. Control Group- Maximal Hip Abductor Muscle Strength



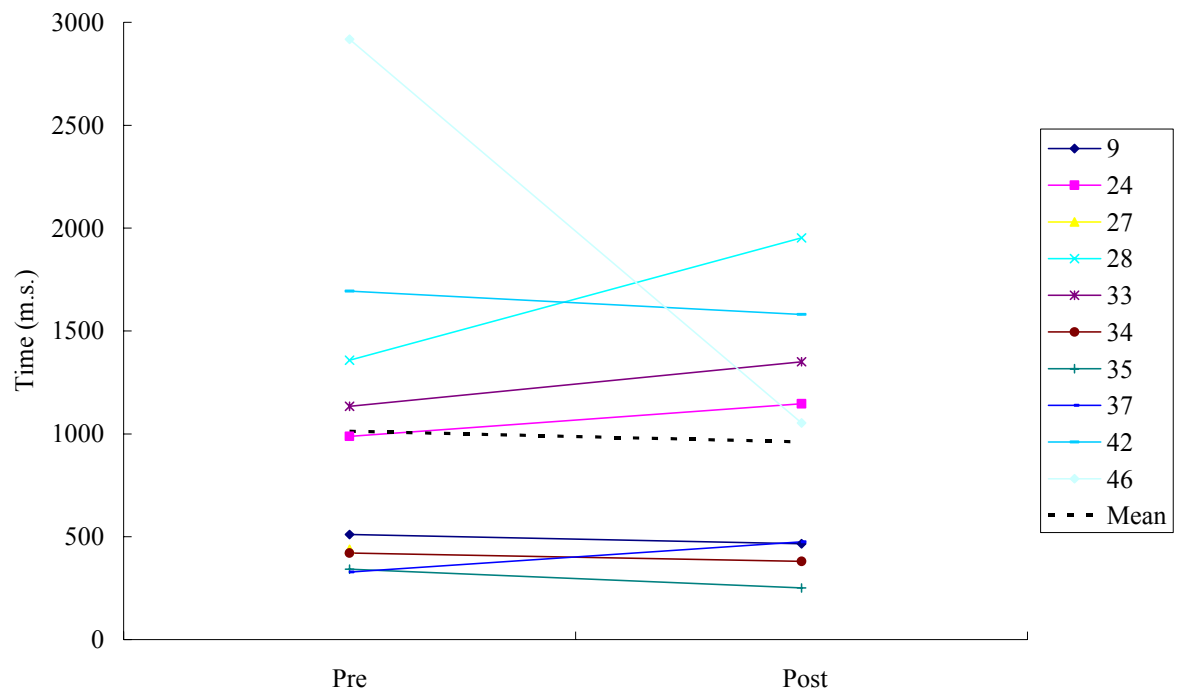
**4.3.c. Exercise Group- Time Required to Reach 60% of Maximum Force from an Onset Level of 10% of Maximum**



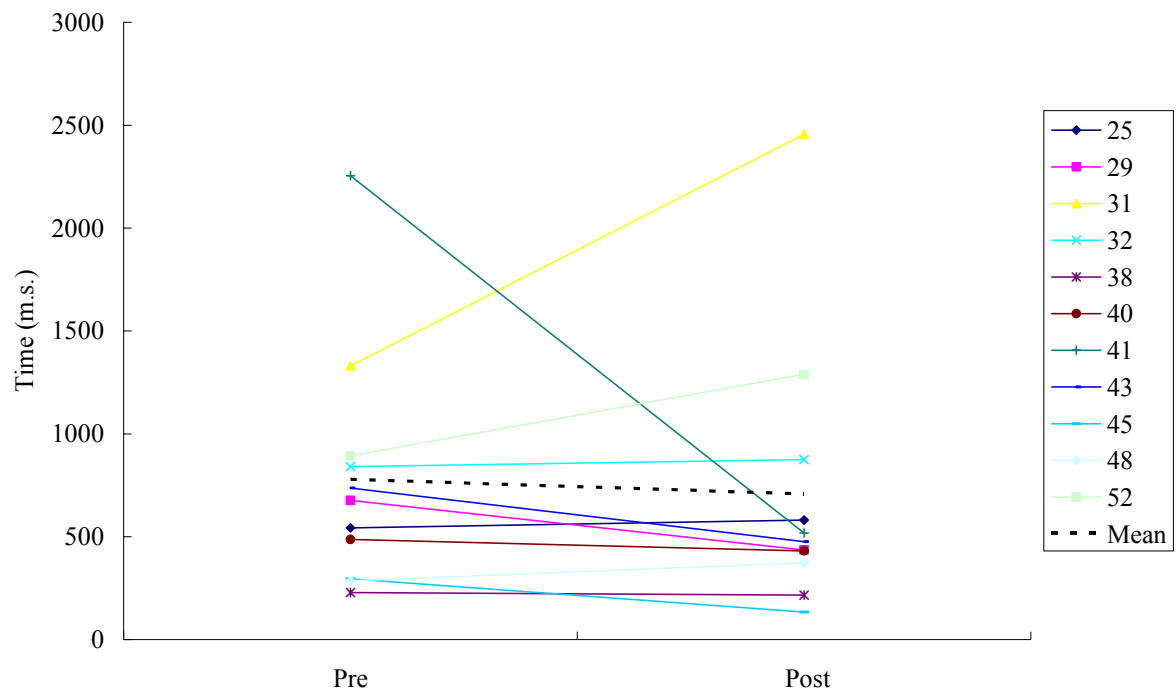
**4.3.d. Control Group- Time Required to Reach 60% of Maximum Force from an Onset Level of 10% of Maximum**



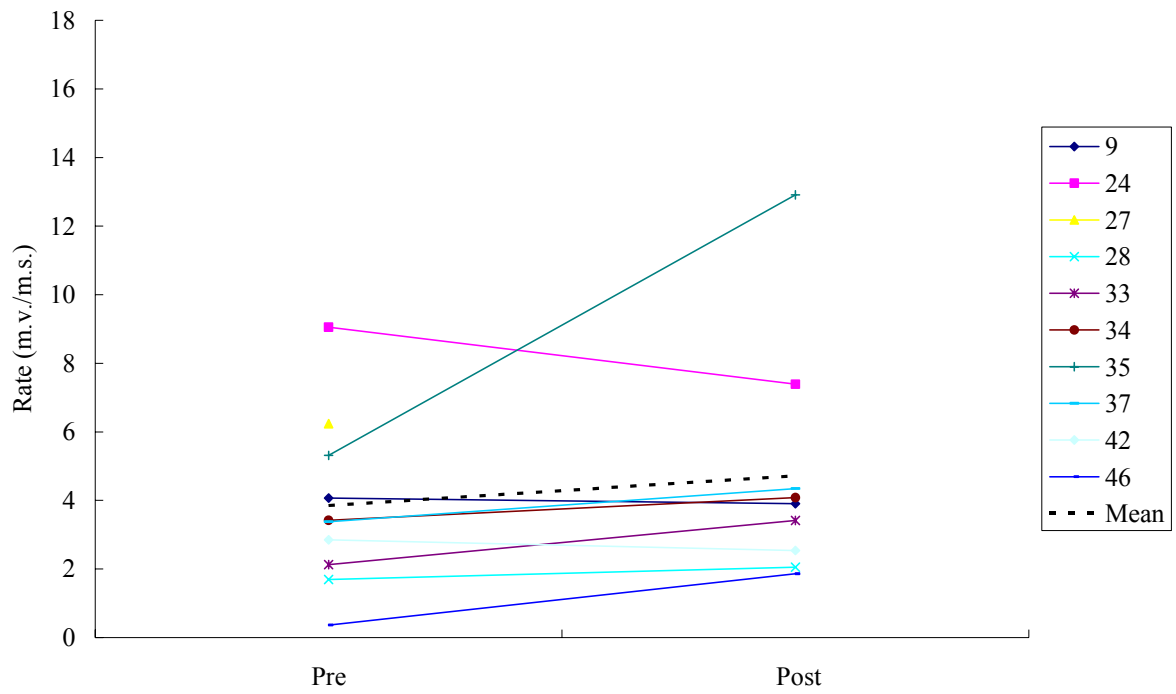
**4.3.e. Exercise Group- Time Required to Reach 90% of Maximum Force from an Onset Level of 10% of Maximum**



**4.3.f. Control Group- Time Required to Reach 90% of Maximum Force from an Onset Level of 10% of Maximum**

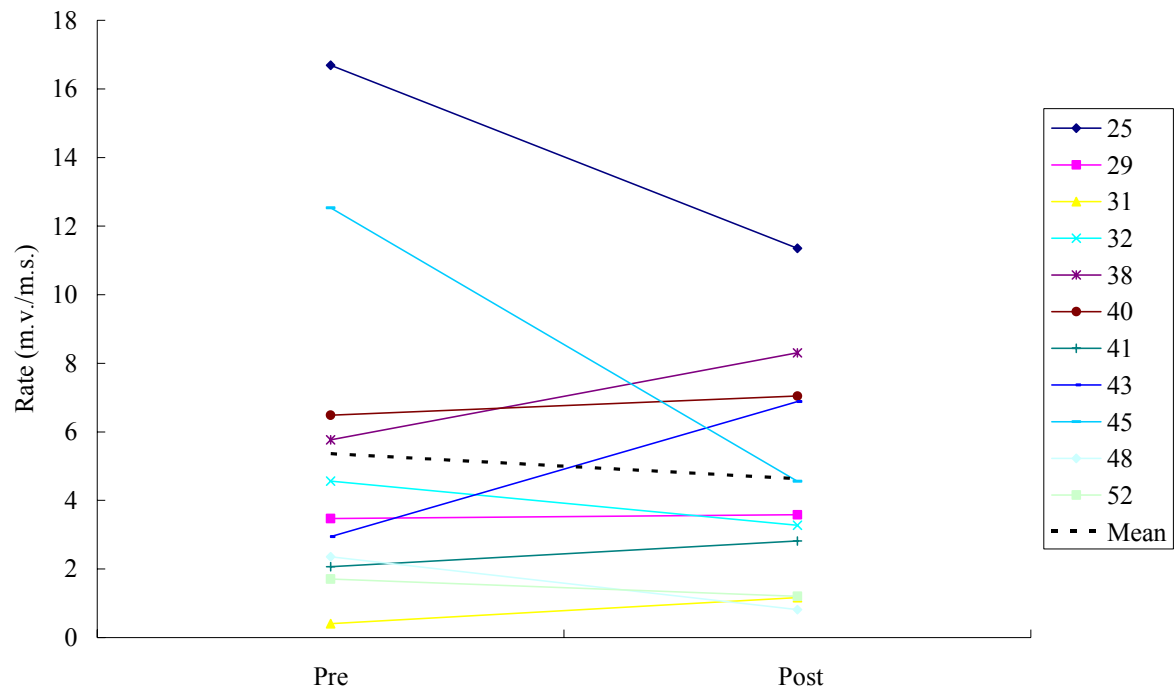


**4.3.g.** Exercise Group- The Average Slope of the Initial Phase of the Force-Time Curve at 50 ms

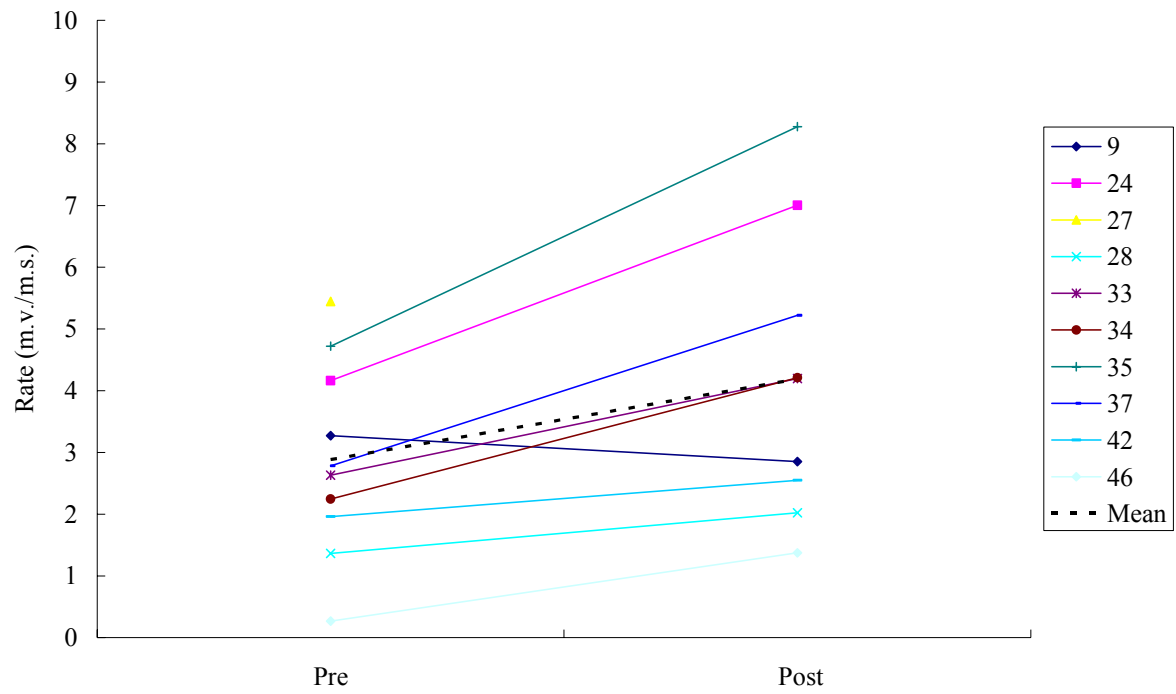




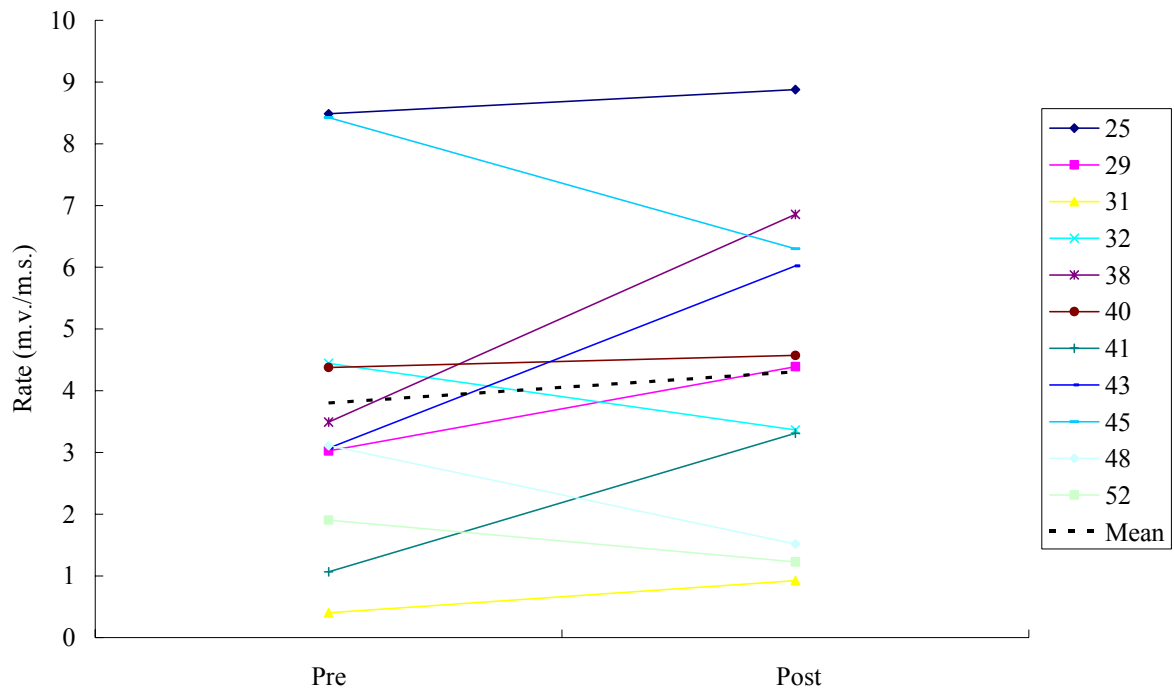
**4.3.h. Control Group- The Average Slope of the Initial Phase of the Force-Time Curve at 50 ms**



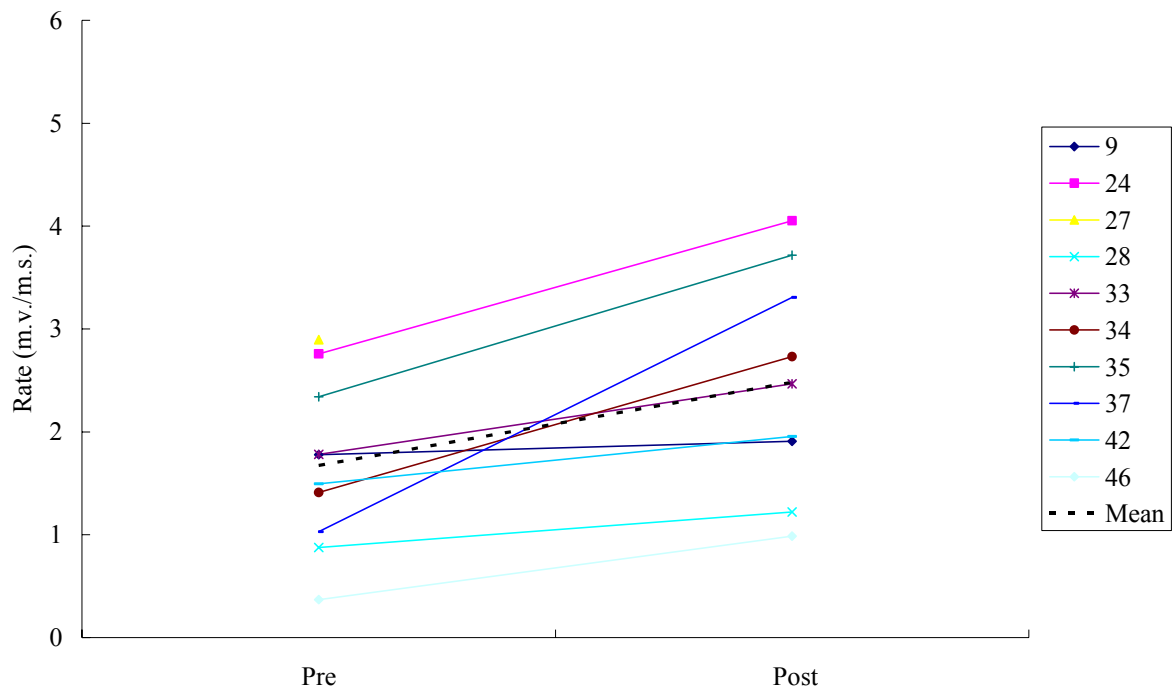
**4.3.i. Exercise Group- The Average Slope of the Initial Phase of the Force-Time Curve at 100 ms**



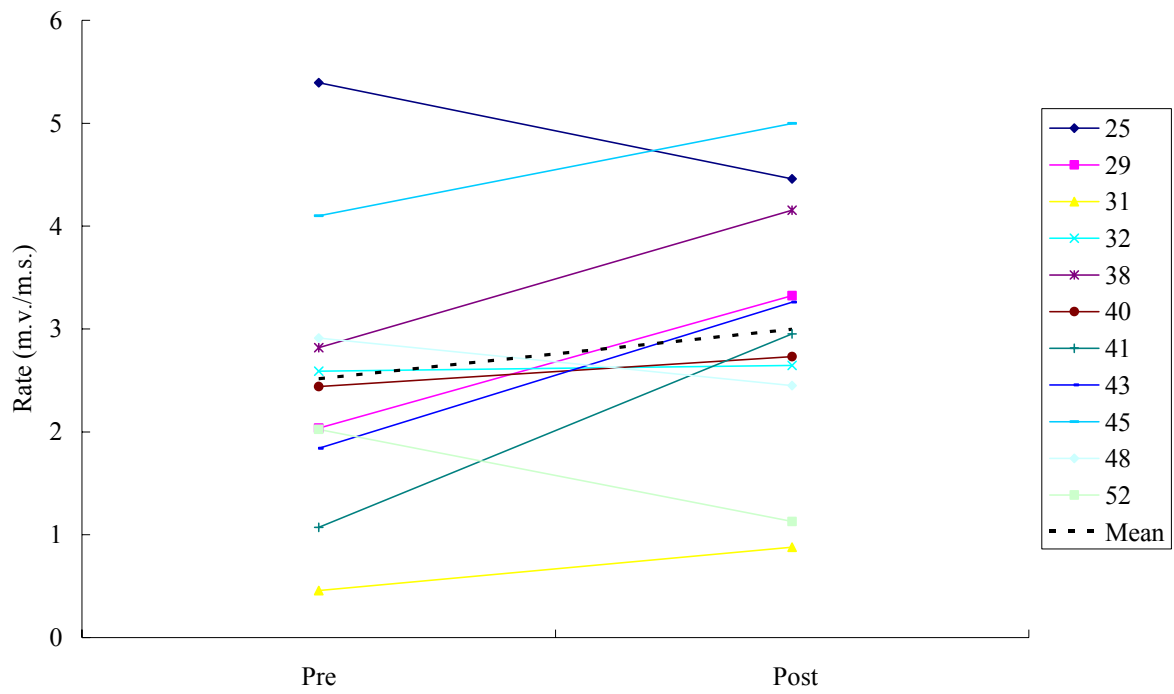
**4.3.j. Control Group- The Average Slope of the Initial Phase of the Force-Time Curve at 100 ms**



**4.3.k. Exercise Group- The Average Slope of the Initial Phase of the Force-Time Curve at 200 ms**

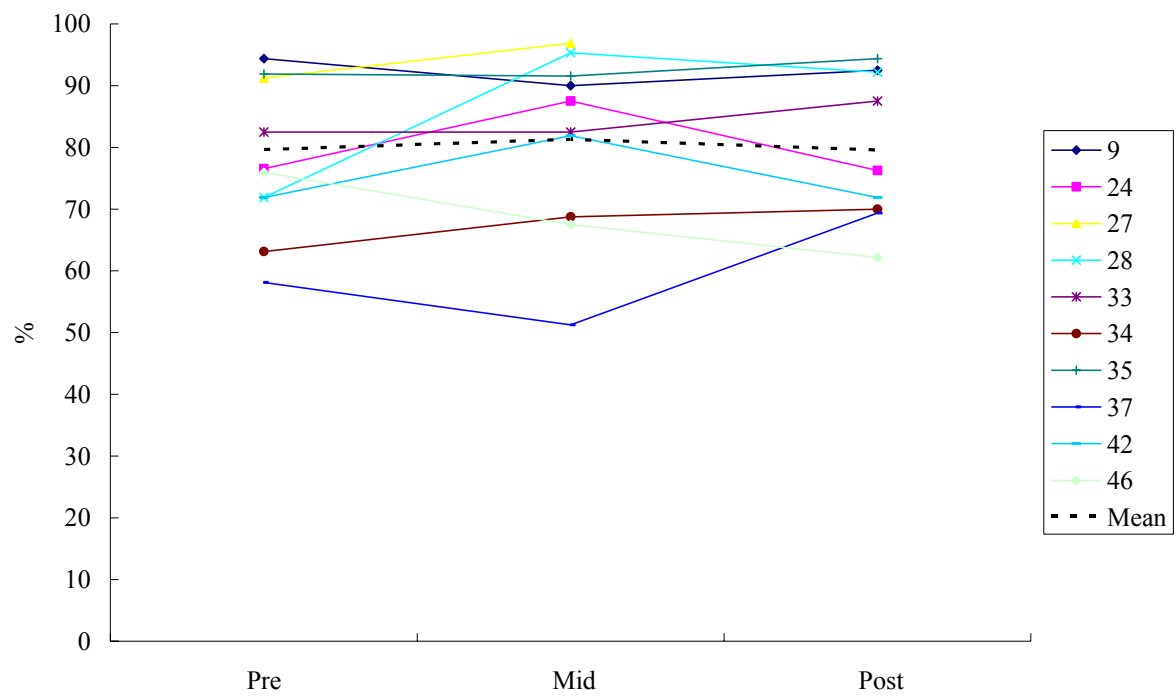


**4.3.1. Control Group- The Average Slope of the Initial Phase of the Force-Time Curve at 200 ms**

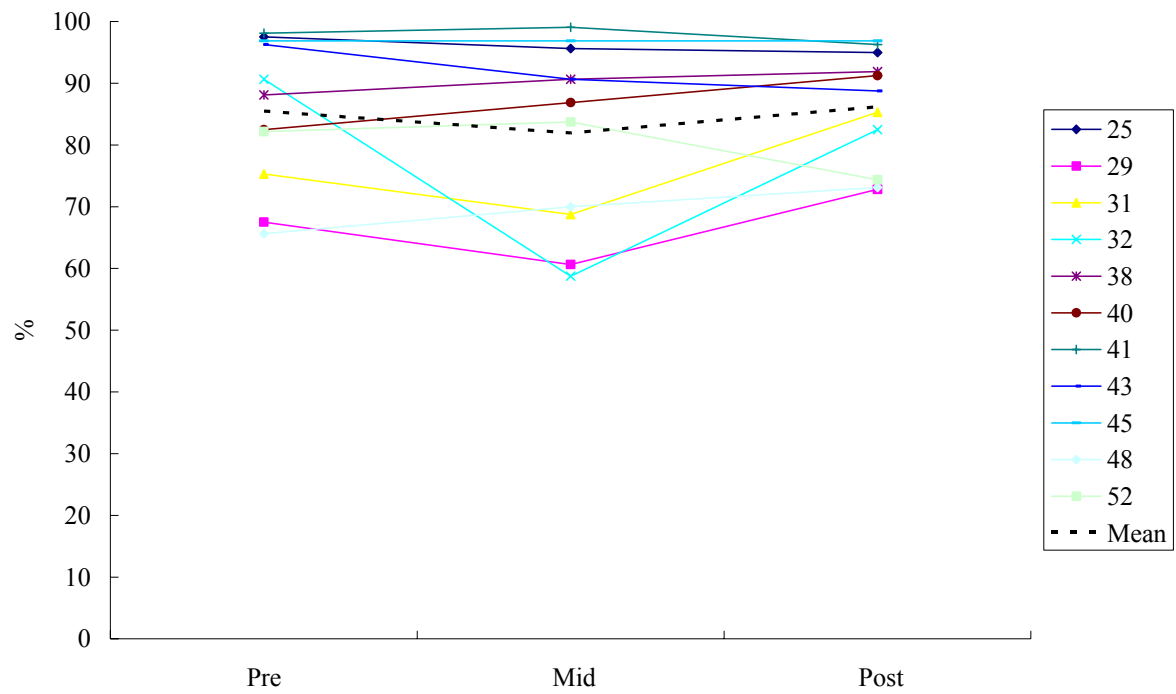


**Figure 4.4.** Scores of Balance Confidence and Clinical Balance Tests for Individual Subjects at Pre- and Post-Intervention Test Sessions. X axis is the Time of Testing

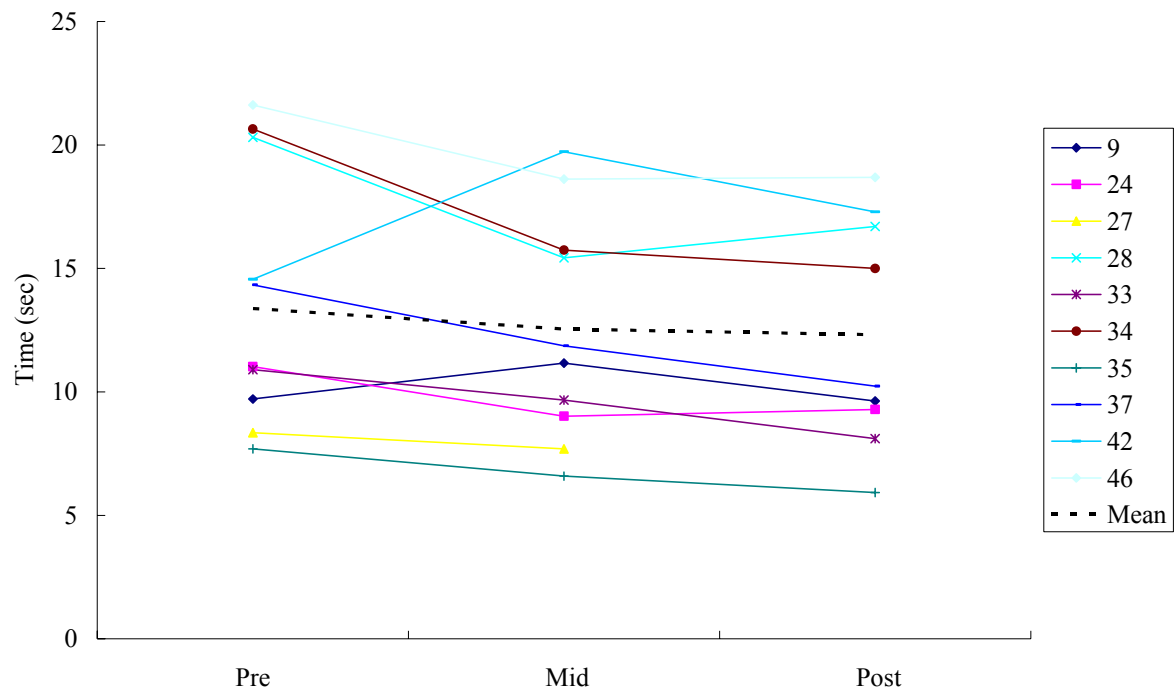
**4.4.a.** Exercise Group- Balance Confidence



#### 4.4.b. Control Group- Balance Confidence

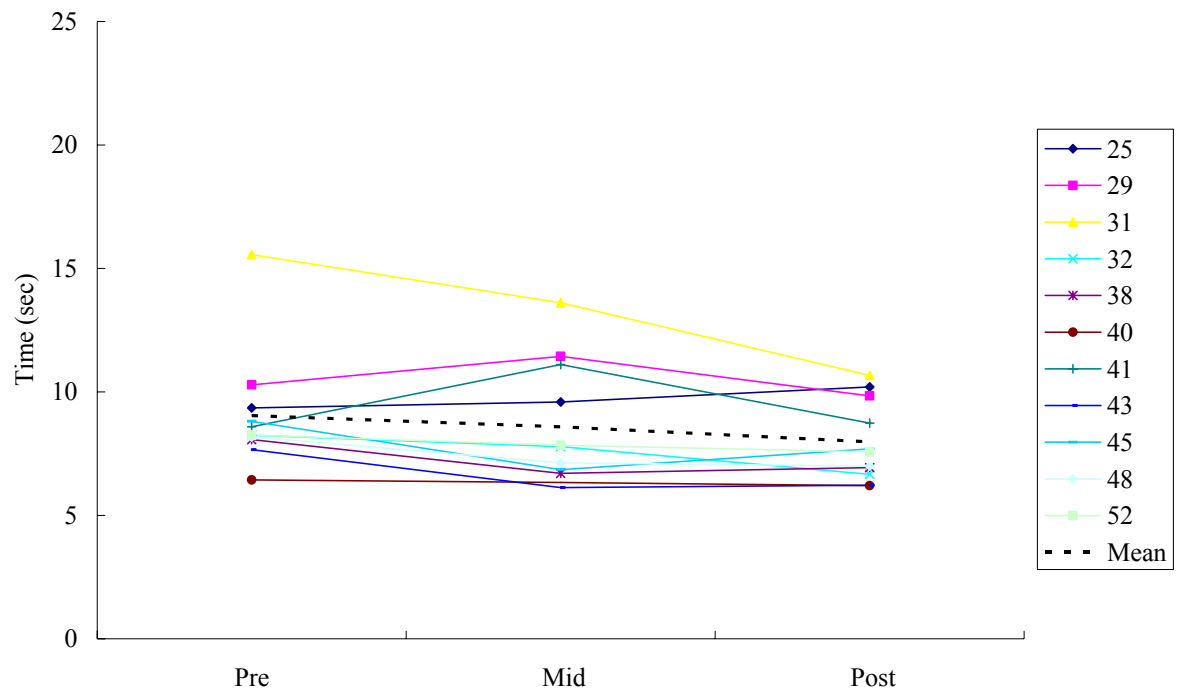


#### 4.4.c. Exercise Group- Four Square Step Test

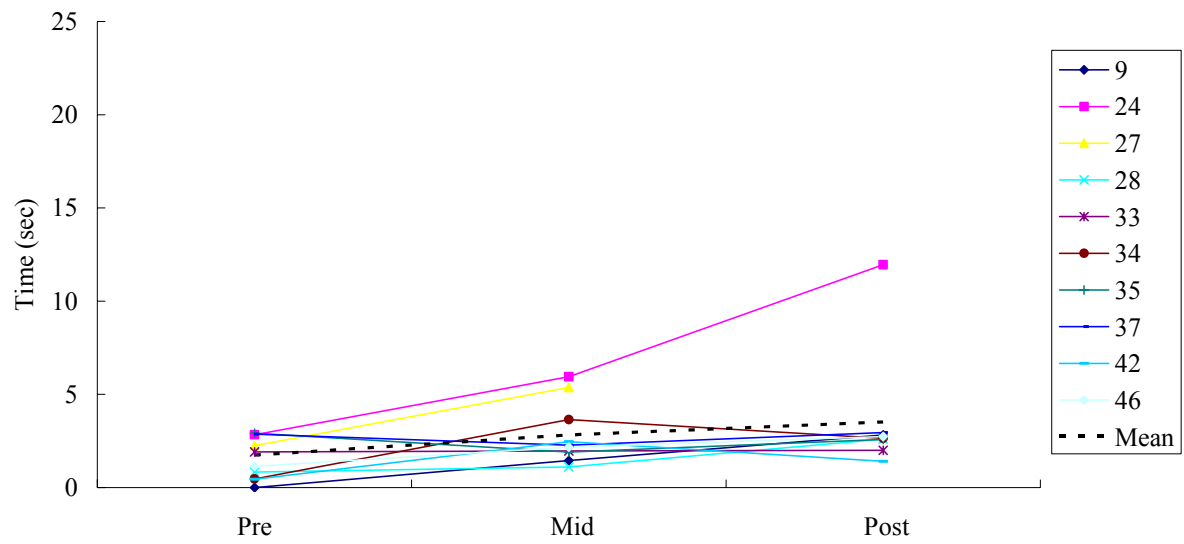




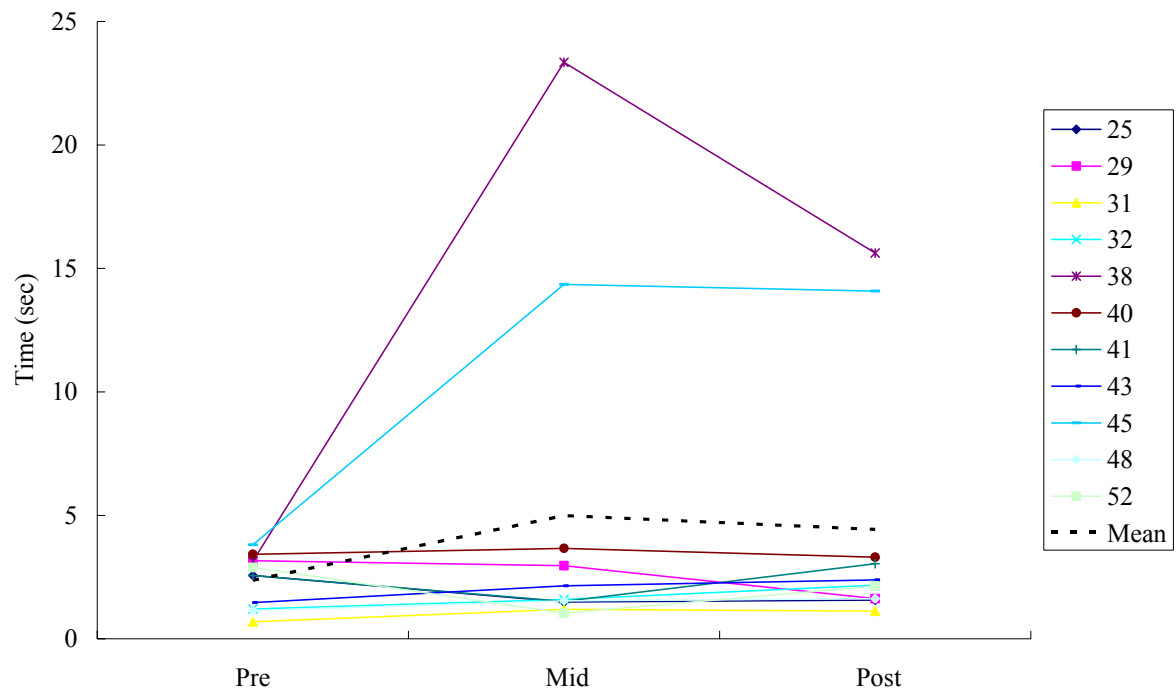
#### 4.4.d. Control Group- Four Square Step Test



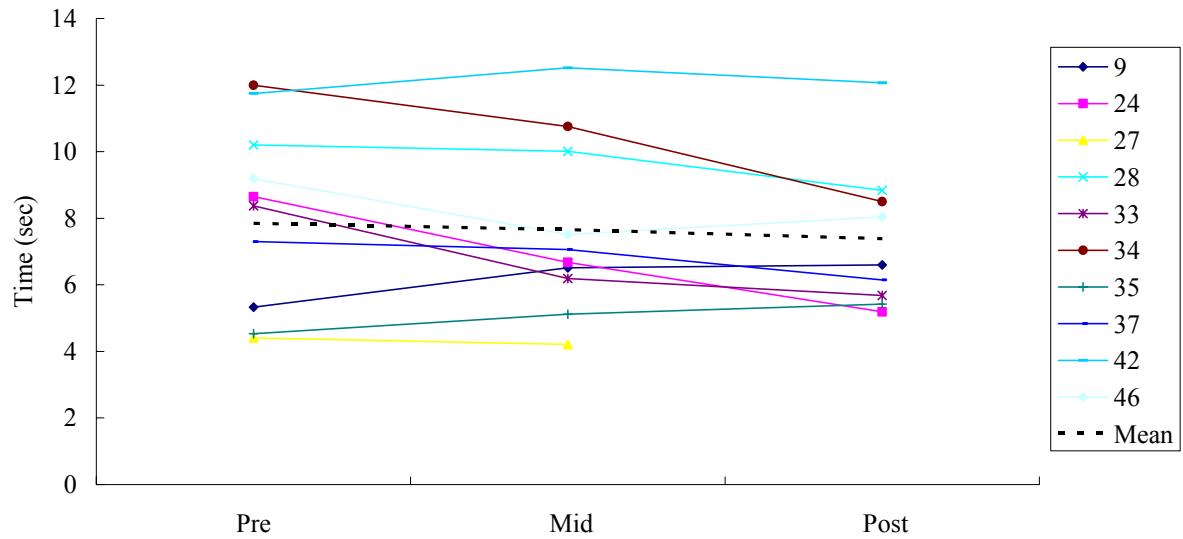
#### 4.4.e. Exercise Group- Single Limb Stance



#### 4.4.f. Control Group- Single Limb Stance

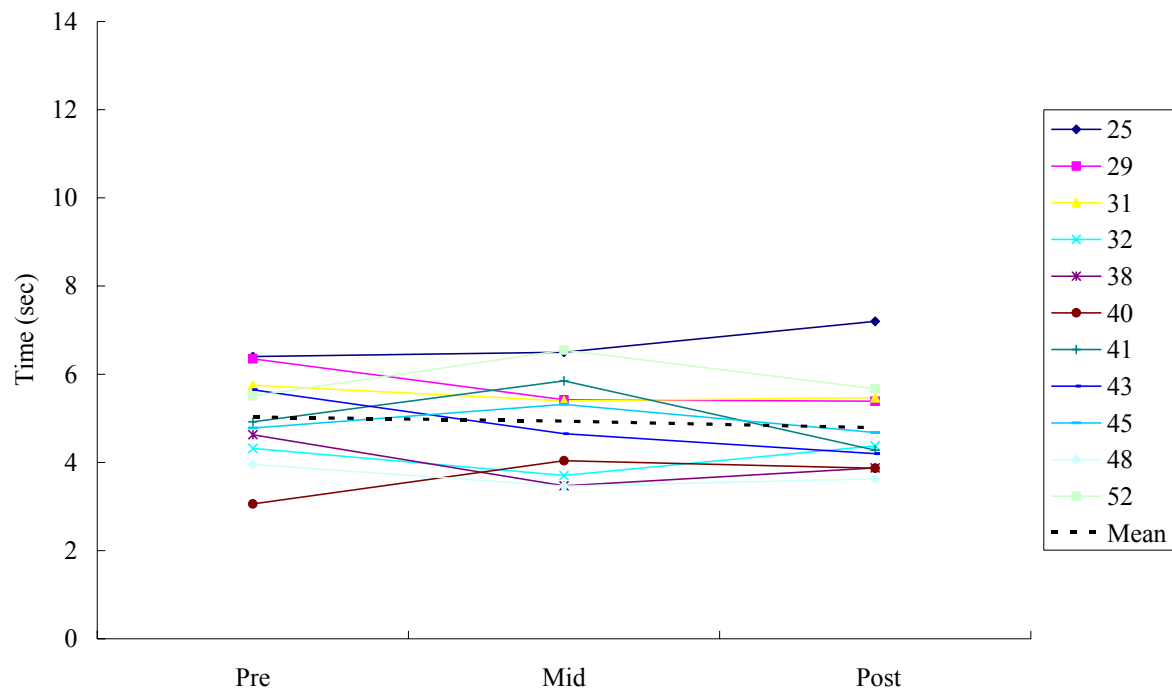


#### 4.4.g. Exercise Group- 360° Turn



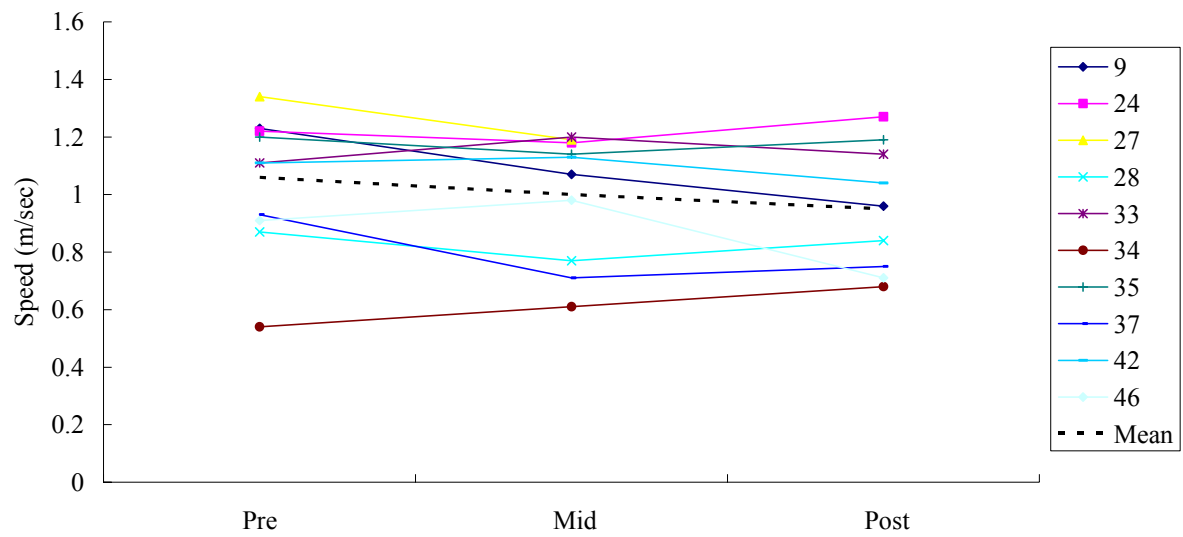
360° Turn was adapted from an item in Berg balance scale. This test was not performed in standardized procedures when it is rated as an isolated scale: subjects were asked to turn in one direction as quickly as possible completely around in one full circle.

#### 4.4.h. Control Group- 360° Turn

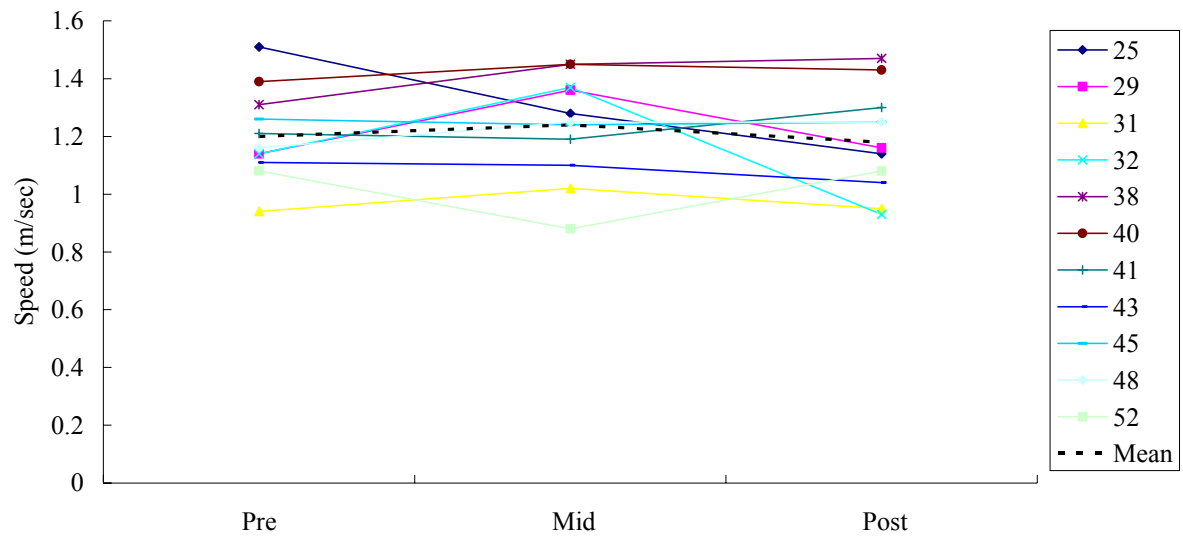


360° Turn was adapted from an item in Berg balance scale. This test was not performed in standardized procedures when it is rated as an isolated scale: subjects were asked to turn in one direction as quickly as possible completely around in one full circle.

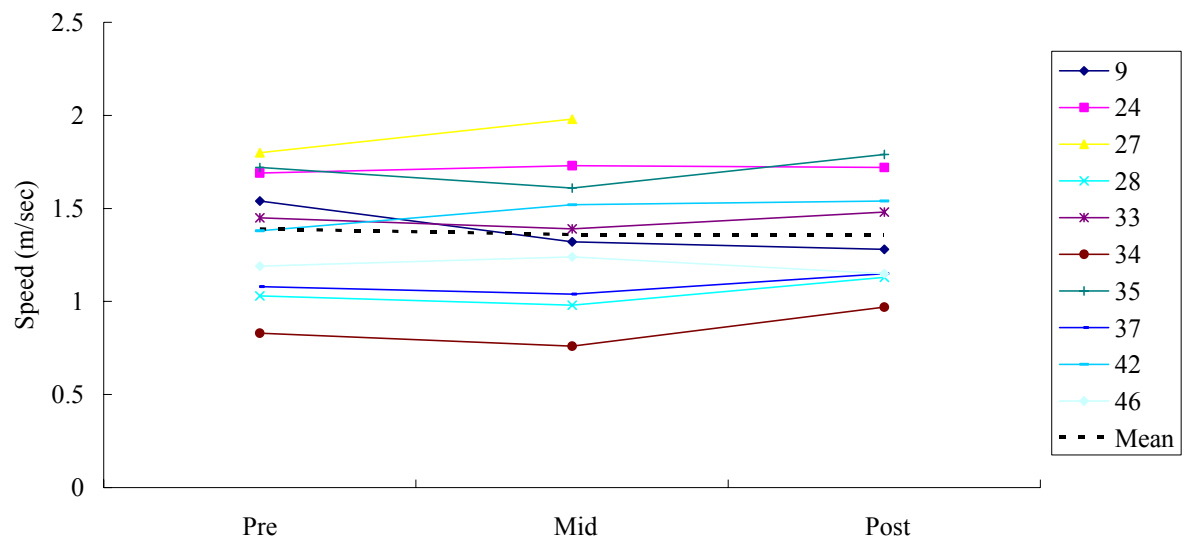
#### 4.4.i. Exercise Group- Self-Selected Speed Walking Test



#### 4.4.j. Control Group- Self-Selected Speed Walking Test

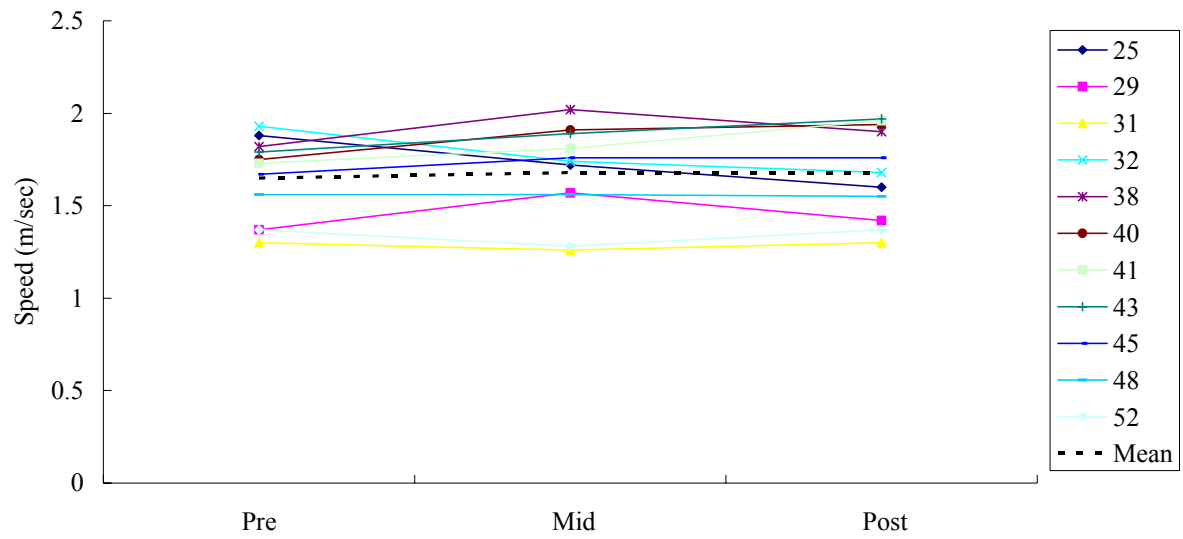


#### 4.4.k. Exercise Group- Maximal Speed Walking Test



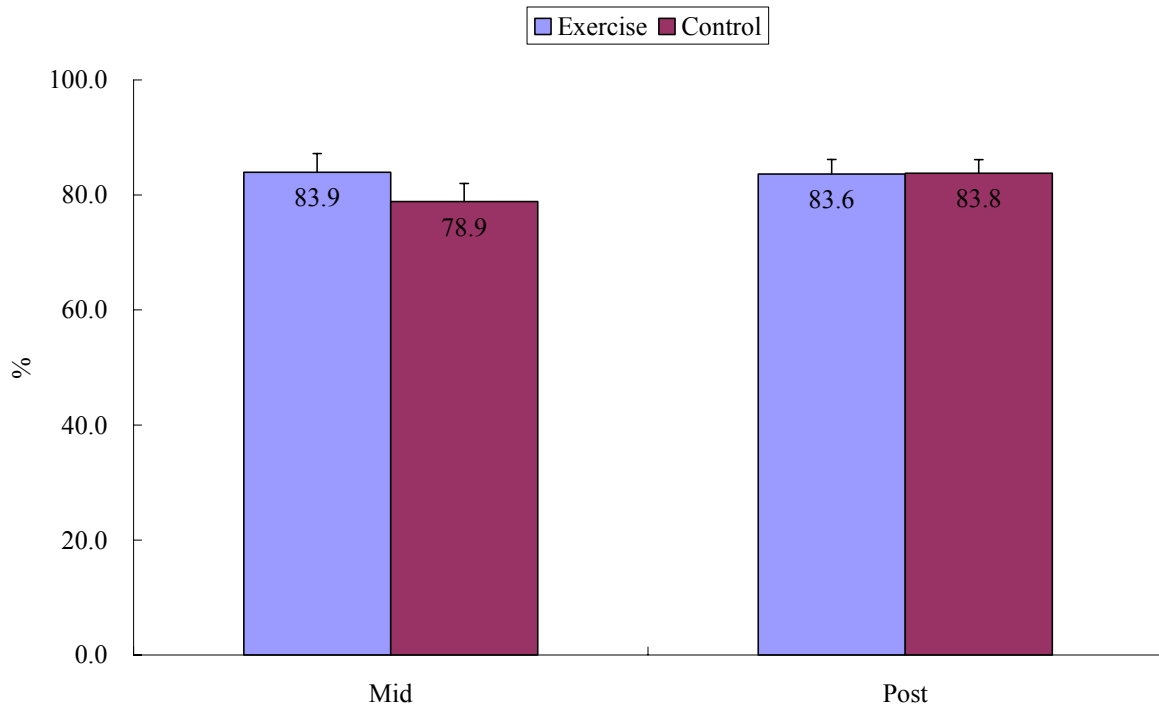


#### 4.4.1. Control Group- Maximal Speed Walking Test



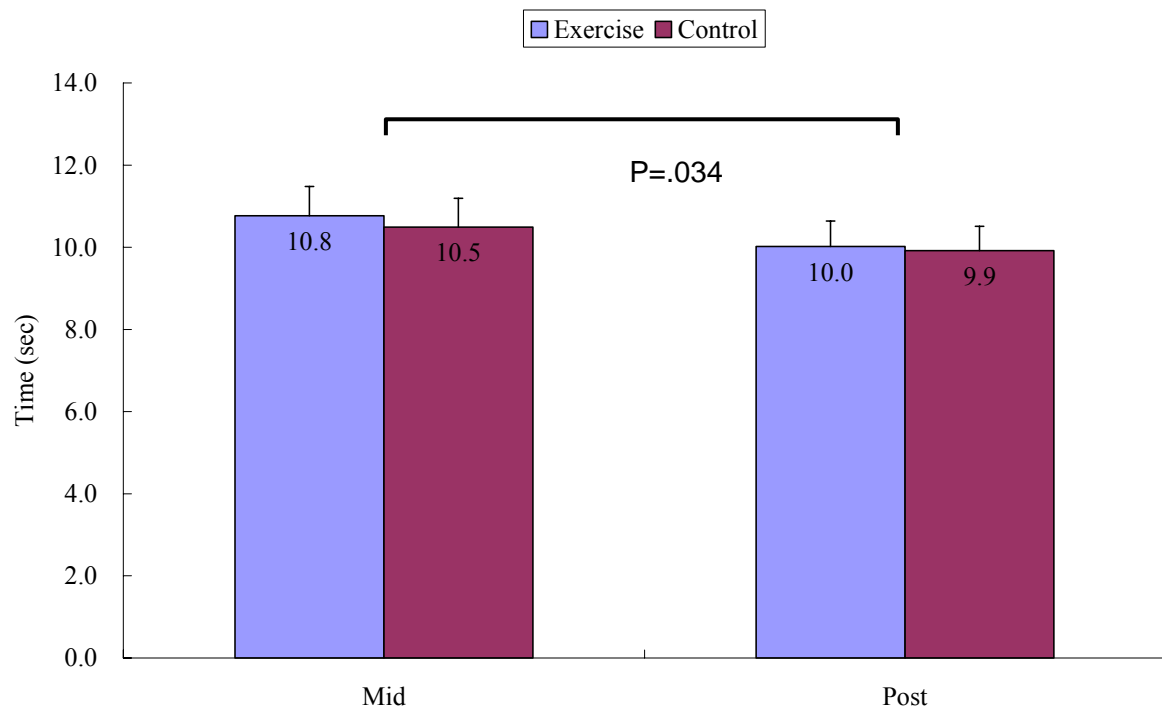
**Figure 4.5.** Model-Based Adjusted Means and Standard Errors of Balance Confidence and Clinical Balance Tests Estimated from Linear Mixed Models: Model-Based Adjusted Means and Standard Errors were Estimated from Linear Mixed Models Including the Participant Random Effect and the Fixed Covariates: Score at Baseline

**4.5.a.** Balance Confidence



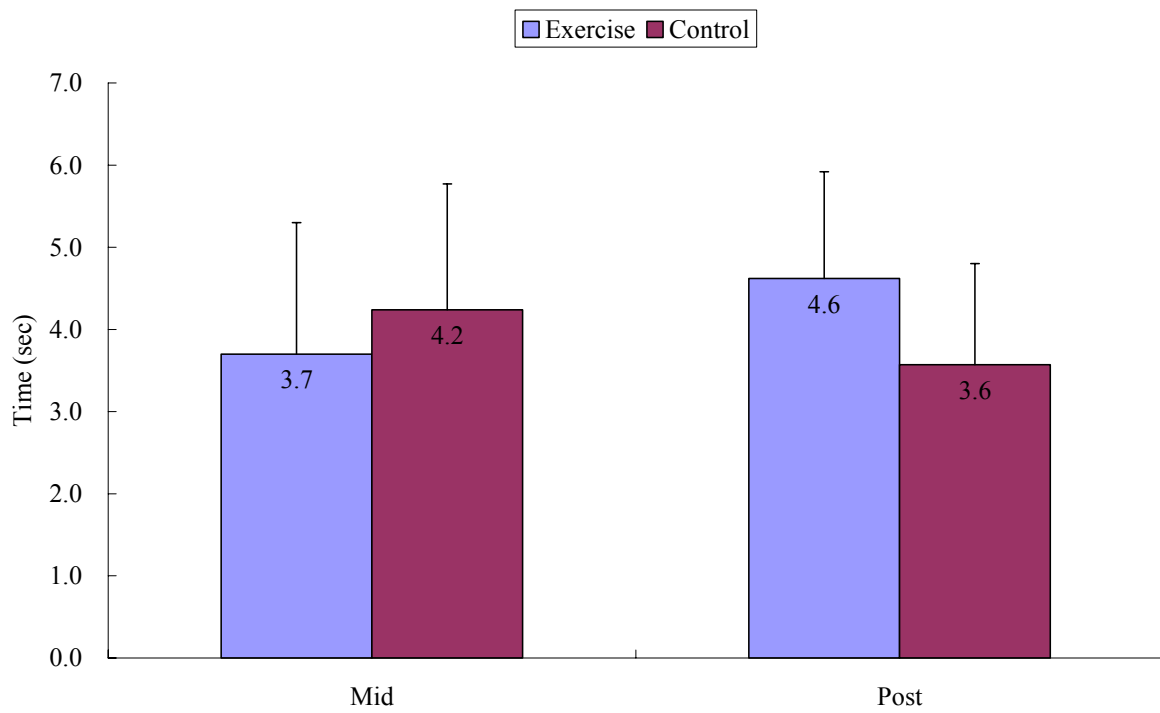
Group main effect:  $p=.498$ ; Time main effect:  $p=.282$ ; Group by time interaction:  $p=.218$ .

#### 4.5.b. Four Square Step Test



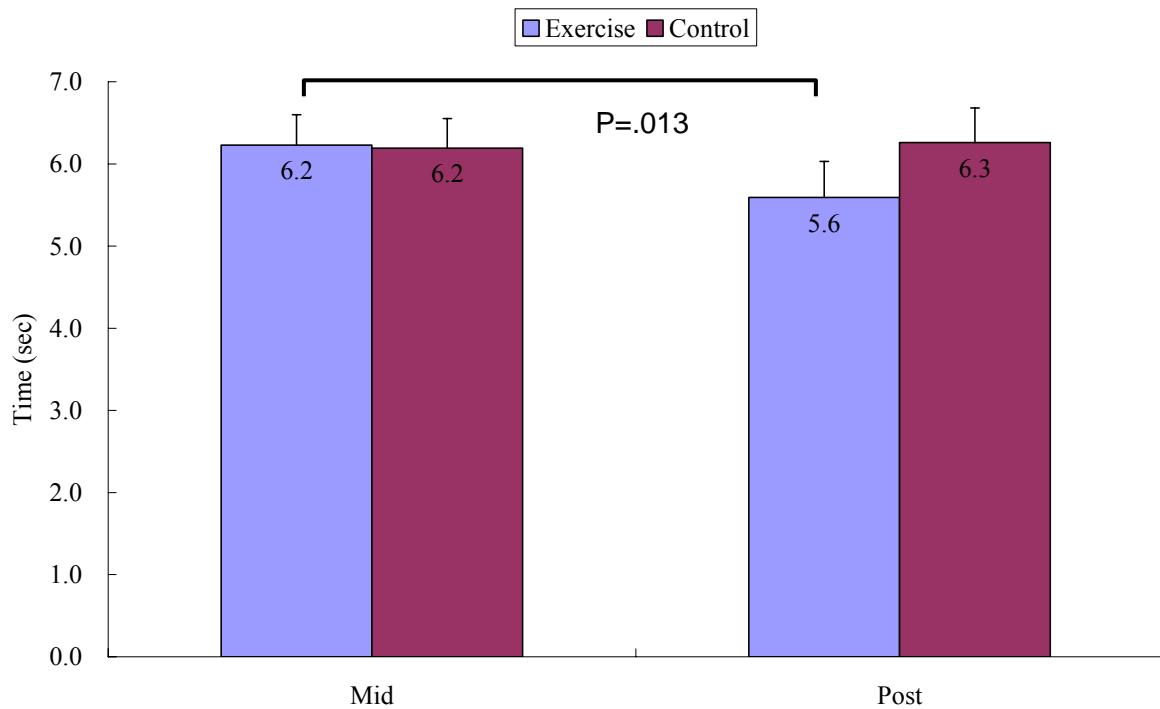
Group main effect:  $p=.844$ ; Time main effect:  $p=.034$ ; Group by time interaction:  $p=.763$ .

#### 4.5.c. Single Limb Stance



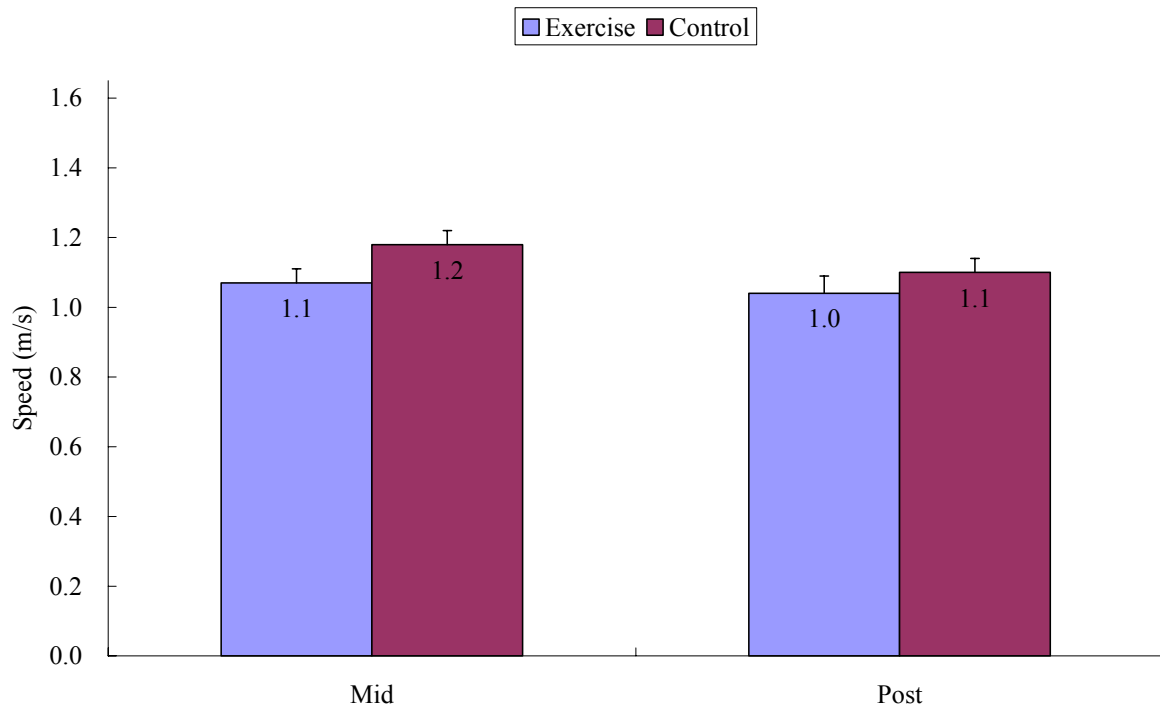
Group main effect:  $p=.899$ ; Time main effect:  $p=.814$ ; Group by time interaction:  $p=.142$ .

#### 4.5.d. 360° Turn



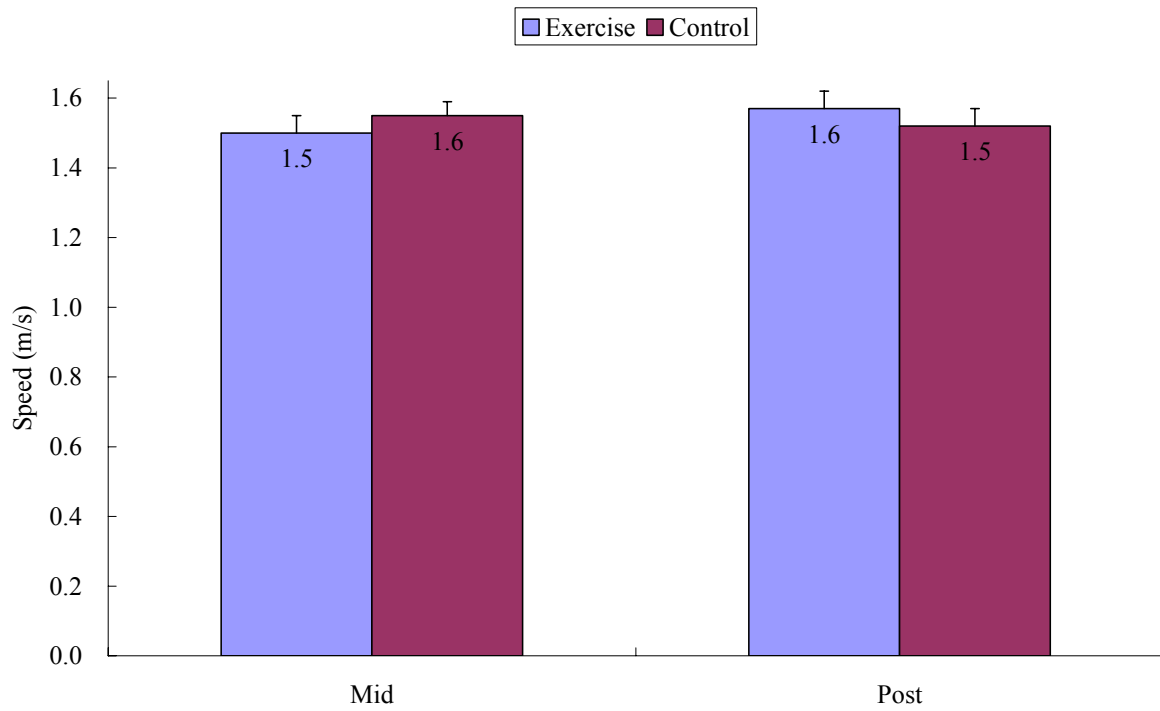
Group main effect:  $p=.601$ ; Time main effect:  $p=.102$ ; Group by time interaction:  $p=.043$ .  
360° Turn was adapted from an item in Berg balance scale. This test was not performed in standardized procedures when it is rated as an isolated scale: subjects were asked to turn in one direction as quickly as possible completely around in one full circle.

#### 4.5.e. Self-Selected Speed Walking Test



Group main effect:  $p=.132$ ; Time main effect:  $p=.143$ ; Group by time interaction:  $p=.418$ .

#### 4.5.f. Maximal Speed Walking Test



Group main effect:  $p=.999$ ; Time main effect:  $p=.407$ ; Group by time interaction:  $p=.065$ .

## **CHAPTER V**

### **SYNTHESIS**



## **SUMMARY OF FINDINGS**

The main purpose of this dissertation was to examine lateral trainer exercise as a novel intervention for improving lateral stability in older adults. Experimental findings are summarized by each of the three specific aims of the dissertation.

The first aim was to describe bilateral lower extremity kinematics and hip abductor muscle activity during exercise on the lateral trainer at self-selected and maximal speeds by older adults who are and are not at high risk of falls. Kinematic and electromyographic (EMG) data were collected in 20 older adults at high risk of falls and 22 older adults at low risk of falls.

Results were that older adults at high risk of falls showed less hip abduction/adduction angular displacement but similar EMG activity compared to older adults at low risk of falls. Subjects in both groups demonstrated higher normalized peak and root mean square (RMS) EMG during maximal speed compared to self-selected speed trials. Exercise at maximal speed was also characterized by slightly greater hip abduction/adduction angular displacement and hip and knee flexion/extension angular displacement than exercise at self-selected speed. The findings indicate that lateral trainer exercise performed at self-selected or maximal speeds may provide an adequate exercise stimulus for increasing hip abductor muscle strength. High velocity strength training principles can be applied in lateral trainer exercise for older adults.

The second aim was to compare hip abductor muscle activation characteristics during side leg raise, lateral step-up, and lateral trainer exercises performed by older adults. We hypothesized that the amplitude (normalized peak and RMS EMG) of hip abductor muscle activity during one repetition would be greater for lateral trainer exercises than for the other

two exercises. We also hypothesized that the amplitude of hip abductor muscle activity would be greater for performance at maximal as compared to self-selected speed.

Kinematic and EMG data were collected in a single session with 42 older adults.

The findings did not support our first hypothesis for Aim 2. The side leg raise exercise produced the highest muscle activity level (normalized peak and RMS EMG) of the hip abductor muscles bilaterally in one repetition. For all three exercises, performance at maximal speed produced higher peak and RMS EMG values than performance at self-selected speed. These results suggest that, of the three exercises included in this investigation, side leg raises in standing may be the most beneficial hip abductor strengthening exercise for healthy older adults.

Lateral trainer exercise does have some advantages, however. According to the ratings on the post-exercise questionnaire, participants thought that the lateral trainer exercise was interesting and would be likely to improve balance and/or hip muscle strength. The design of the lateral trainer may minimize demands for lower extremity control because the feet remain in contact with the footplates throughout the exercise and the exerciser can use the balance bar for support as needed. The decreased demands for lower extremity control may assist individuals with poor balance in focusing on the desired movement.

The third aim was to obtain preliminary data on the effects of a 10-week program of lateral trainer exercise using high velocity training principles on a) balance confidence, b) hip abductor muscle strength and rate of force development (RFD), and c) lateral stability in older adults at increased risk of falls. We hypothesized that older adults who participated in the exercise program would show greater balance confidence, greater hip abductor muscle strength and RFD, and better lateral stability than control group subjects.

The results showed that older adults who received lateral trainer exercise performed better than control group subjects on one dynamic balance test, a timed 360° Turn, but not on measures of hip abductor muscle strength or RFD, static balance, walking speed, or balance confidence. The lack of intervention effects for most measures may be attributable to a number of factors, including the following: the small sample size, which limited statistical power; the relatively high level of balance confidence and physical function of the older adults in the sample, which may have limited the potential for improvement; and possible inadequacies in the duration of the exercise intervention and/or in the level of resistance used.

## **STRENGTHS AND WEAKNESSES**

### **Strengths**

The projects included in this dissertation provide a solid basis for increasing our understanding of various hip abductor exercises and their effects on lateral stability in older adults. The sequence of the projects reflects a logical progression from understanding the kinematics and neuromuscular activation associated with the exercise, to comparison with other exercises, to implementation of the intervention with a group of older adults. The pilot testing completed as a part of this dissertation enabled identification of possible confounding variables, such as use of upper extremity support during exercise, and the need for further investigation to determine optimal exercise parameters.

Another important strength of the dissertation was the inclusion of older adults with varying levels of performance on the single limb stance test. Based on these test scores, the sample included individuals at high risk and those at low risk of falls. This enabled investigation of possible differences in lateral trainer exercise performance by the two groups,

as well as implementation of the exercise intervention with subjects who most likely would be targeted for such interventions, i.e., those in the high risk group.

One of the strengths of this dissertation is the use of questionnaires to solicit feedback from subjects about their opinions of the exercises in both projects. In addition to the laboratory measures, subject feedback can provide information about the acceptability of the exercises and potential barriers to participation in various exercise programs. Use of open-ended questions, semi-structured interviews, and/or focus groups would be likely to provide further insights in future studies.

### **Weaknesses**

Both projects had several weaknesses that should be addressed in future studies. The most significant weakness of the first project was the inconsistency of upper extremity support during performance of hip abductor exercises. The EMG results may have been influenced by changes in neuromuscular control and movement patterns associated with upper extremity support. Measurement and restriction of upper extremity support may provide further insights in future studies.

The method used for normalization of the EMG data may not have been appropriate for this age group. Maximal contraction has been criticized as an inaccurate means of normalization<sup>1</sup> and the stabilization provided by the researchers may not have been sufficient to enable the subjects to generate maximal effort. Our results may have been influenced by inability to obtain true maximal contraction on some MVIC trials. Submaximal effort may have occurred during MVIC testing if stabilization was not adequate or subjects were not able to produce maximal effort consistently. If so, the values of normalized EMG variables may be overestimated. In future studies, a normalization method using muscle activity

during dynamic tasks, such as walking, may be preferable.<sup>2,3</sup>

Furthermore, the assessments used to screen for falls risk may not have been the best screening tests for these projects. Single limb stance times (SLS; < 5 seconds considered at risk of falls) and the Four Square Step Test (FSST; > 15 seconds considered at risk of falls) were used to identify older adults at high risk of falls. Most subjects who were identified as being at high risk were classified on the basis of SLS scores, with only 4 subjects having FSST scores >15 seconds. SLS score may not have been a reliable indicator of increased risk of falls among the subjects included in our study. Standardized balance tests with well-established psychometric properties and multiple levels of task difficulty, such as the Berg Balance Scale should be included.

In the second project, one weakness was that physical activity and exercise levels were not evaluated for both groups during the study period. Subjects in the control group were asked to maintain their regular activity level during the study period; however, these subjects may have increased the amount of participation in regular physical and exercise activities and may have practiced the clinical balance tests. Research suggests that exercise and other types of physical activity can improve balance, muscle strength and functional activities and decrease the risk of falls.<sup>4-7</sup> In the future, quantitative measures of physical activity and exercise levels should be obtained for both the intervention and the control groups.

A second weakness was that most older adults who participated in the pilot intervention were from the same continuing care retirement community. They were living independently and were generally high functioning. The potential for improvement in our outcome measures may have been limited in this group of older adults. In future studies,

older adults should be recruited from different living environments, such as independent living and assisted living facilities, to include older adults with varied levels of functioning.

Third, subjects in the present study may have had deficits not only in the musculoskeletal system but also in the neuromuscular and sensory systems. A multifactorial-approach which uses interventions that target multiple risk factors should be applied in designing exercise interventions to improve lateral stability in older adults. Lateral trainer exercise could be considered a single-risk-factor exercise because this exercise focuses on hip abductor weakness. Interventions focused on a single risk factor such as decreased muscle strength, environmental hazards, or poor vision are effective in improving balance or preventing falls only when targeted to groups most at risk. In future studies, lateral trainer exercise may be combined with other types of training to achieve maximal strength and functional improvements.

## **FUTURE RESEARCH**

The findings of this dissertation raise several interesting questions for future research. Based on the findings and the strengths and weaknesses discussed above, three main directions for future studies should be considered. First, the effects of upper extremity support during exercise on lower extremity EMG activity should be investigated. Upper extremity support for balance is commonly recommended when exercise is prescribed for older adults. However, the influence of upper extremity support on neuromuscular control during hip abductor exercises is not clear. Second, older adults with greater functional limitations, such as patients with stroke or frail older adults, should be included in future intervention studies. Third, multifaceted exercise programs that include lateral trainer exercise should be investigated for their potential to achieve maximal strength and functional

improvements.

## References

1. DeLuca C. The use of surface electromyography in biomechanics. *J Appl Biomech* 1997; 13:135-63.
2. Winter DA, Yack HJ. EMG profiles during normal human walking: stride-to-stride and inter-subject variability. *Electroencephalogr Clin Neurophysiol* 1987; 67:402-11.
3. Benoit DL, Lamontagne M, Cerulli G, Liti A. The clinical significance of electromyography normalisation techniques in subjects with anterior cruciate ligament injury during treadmill walking. *Gait Posture* 2003; 18:56-63.
4. Carter ND, Kannus P, Khan KM. Exercise in the prevention of falls in older people: a systematic literature review examining the rationale and the evidence. *Sports Med* 2001; 31:427-38.
5. Gardner MM, Buchner DM, Robertson MC, Campbell AJ. Practical implementation of an exercise-based falls prevention programme. *Age Ageing* 2001; 30:77-83.
6. Lord SR, Caplan GA, Ward JA. Balance, reaction time, and muscle strength in exercising and nonexercising older women: a pilot study. *Arch Phys Med Rehabil* 1993; 74:837-9.
7. Shumway-Cook A, Gruber W, Baldwin M, Liao S. The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Phys Ther* 1997; 77:46-57.



## **Appendix A: Literature Review**

### **INTRODUCTION**

Lateral instability has been found to be associated with falls and fall-related injuries in older adults.<sup>1,2</sup> Falls most often involve lateral body motion, and hip fractures are most commonly associated with lateral falls.<sup>3-7</sup> Maintenance of lateral stability requires activation of appropriate muscle groups, primarily the hip abductors and adductors. An older adult who is unable to generate sufficient muscle force in the hip abductors and adductors in the time frame necessary to control the position of the center of mass (COM) relative to the base of support (BOS) will be at increased risk for falls.

Age-related and disease-related declines of sensory, nervous and musculoskeletal systems place older adults at risk for postural instability and falls. Decreased strength is known as a risk factor for impaired balance and falls in older adults; however, recent studies indicate that extremity muscle power is a better predictor of these outcomes than strength. Age-related declines in the capacity for explosive force generation by the leg extensor muscles are much greater than declines in maximal muscle strength. Muscle power is the product of muscle force and muscle contraction velocity. One important component of muscle power, the rate of muscle force development (RFD), is lower in older adults than in young adults. Decreased ability to develop muscle force rapidly may be related to impaired neuromuscular responses for controlling postural sway. Furthermore, the RFD (as measured during a maximal voluntary contraction) has been shown to be related to performance on clinical balance tests.<sup>8</sup> The RFD should be considered in assessment and treatment of older adults with balance deficits.

Previous researchers have studied exercise as a means of improving balance and preventing falls in older adults. Different types of exercise programs have been designed to address different risk factors for falls. Most fall prevention programs have focused on risk factors such as muscle weakness and poor balance. Recently, however, investigators have begun to turn their attention to new modes of exercise and the effects of exercise on RFD to improve balance and prevent falls in older adults.

The purpose of this review is to discuss the research on lateral instability and exercise interventions in older adults. Components important for control of lateral stability in older adults are discussed first, followed by a discussion of age-related system changes in postural control. In the final section, various types of exercise interventions designed to increase RFD and physical function are reviewed.

## **LATERAL INSTABILITY IN OLDER ADULTS**

Maintenance of postural balance is an important human movement function. In video observations conducted by Holliday et al<sup>9</sup>, older adults who fell were found to have difficulty controlling lateral responses. Older adults may be particularly vulnerable to lateral instability and falls. A number of studies have investigated the ability of older adults to control lateral body motion during volitional movement and when responding to external perturbations.

### **Lateral Instability during Volitional Tasks**

#### *Static Postural Control*

Maki et al<sup>2</sup> found that lateral spontaneous-sway amplitude in quiet standing with eyes closed was the best predictor of future falls risk in older adults. In this study, several balance tests were compared as predictors of risk of falls in an ambulatory and independent

elderly population. Falls were monitored prospectively over a one-year period in a sample of 100 older adults (mean age  $83 \pm 6$  years, range 62 – 96 years). The balance tests included measurements of: spontaneous postural sway, induced anterior-posterior sway, induced medial-lateral sway, anticipatory adjustments preceding volitional arm movements, timed one-leg stance, and performance on a clinical balance assessment scale. Moveable platforms were used to perturb balance in the induced-sway tests. The results suggested that control of lateral stability may be an important area for fall- preventative intervention.

Lord et al<sup>1</sup> also found that older adults with a history of falls had increased lateral sway on tests that challenge lateral stability. Maximal lateral sway in a near-tandem stability test with eyes open and closed and the necessity of taking a protective step in the near-tandem stability test with eyes closed were assessed in 156 community-dwelling older adults (mean age  $76.5 \pm 5.1$  years, range 63 – 90 years). Subjects with a history of falls not only had increased lateral sway both with eyes open and eyes closed and poorer visual acuity, proprioception, and quadriceps strength, but also were more likely to take a protective step in near-tandem position with eyes closed. Furthermore, the increased lateral sway was significantly related to impaired lower limb proprioception, quadriceps strength, and reaction time in the near-tandem position test with eyes open. Reduced proprioception, quadriceps strength, and age were found to be the best determinants of taking a protective step in the near-tandem position with eyes closed.

Although the results support the findings of the study by Maki et al<sup>2</sup> and indicate that clinical balance tests such as near-tandem can be used to identify older adults at risk of falls, the use of self-reported fall histories is problematic. Older adults may not be accurate in reporting the number of falls because of memory loss, different perceptions of what

constitutes a fall, and other factors.

### *Dynamic Postural Control*

Few studies have investigated lateral stability during dynamic movement. In a study of lateral reach and Step Test performance, Nitz et al<sup>10</sup> tested 366 community-dwelling women between 40 and 80 years of age. Laboratory tests including one leg stance and limits of stability were conducted using the Balance Master. Mean sway velocity during one-leg stance, movement velocity, reaction time and end-point center of gravity excursion in the lateral direction for the limits of stability test were analyzed. The results showed a significant decline in all measures between age cohorts in their 40s and those in their 60s. Significant declines in Step Test scores, one-leg stance times, and end-point excursion distances were found for subjects in their 70s compared to those in their 60s. The Step Test (stepping with the right leg) was highly negatively correlated with mediolateral sway during one-leg stance (standing on the left leg), indicating that individuals with less balance control performed worse on the Step Test. The study did not include measurement of falls.

Cho et al<sup>11</sup> examined the relationship between falls, physical function and dynamic clinical tests that challenge mediolateral stability in 167 mildly balance-impaired older adults (mean age  $78 \pm 7$  years, range 65 – 90 years). Maximal step length in different directions was correlated with scores on a variety of measures, including the Established Population for Epidemiologic Studies of the Elderly battery, Activities-specific Balance Confidence scale, Timed Up and Go, Performance Oriented Mobility Assessment, 6-minute walk, and peak maximum knee and ankle torque. The maximal step length score was also associated with the risk of being a frequent faller. Relationships between Rapid Step Test scores (time needed to step out and return in multiple directions as fast as possible) and these measures

were relatively modest. The results support the finding by Nitz et al<sup>4</sup> that performance on clinical tests that challenge mediolateral stability by reducing the base of support is correlated with falls in older adults.

During initiation of voluntary movements such as walking or stepping, the hip abductors of the swing foot and hip adductors of the stance foot contribute to the postural adjustments accompanying lateral weight transfer.<sup>12</sup> The anticipatory postural adjustment (APA) in the frontal plane shifts the center of pressure (COP) toward the swing foot, accelerating the COM toward the stance side and allowing the swing foot to be lifted.<sup>13</sup> Without APA, stability in the frontal plane could not be maintained. Joint torque produced by the hip abductors/adductors also serves an important role in stabilizing the pelvis and trunk in step execution and ongoing gait.

### **Lateral Stability during Reactive Movements**

Most falls and fall-related injuries occur during daily activities such as walking. Slips or trips while walking constitute 30% – 50% of all reported falls.<sup>14, 15</sup> Problems with lateral stability have been reported in several studies of reactive stepping (also called compensatory stepping) in older adults. Mediolateral movement of the COP and COM and impaired foot placement during reactive stepping by older adults with a history of falls suggest that lateral instability during reactive movements may be related to falls and fall-related injuries. Response to a sudden external force on the body or to displacement of the support surface requires an appropriate level of muscular effort, utilization of anticipatory and reactive postural control strategies, and processing of information from various sensory systems. These postural responses appear to differ from those involved in maintaining a position or performing a voluntary movement. Postural steadiness during quiet standing is

only slightly correlated with the ability to recover balance following a postural perturbation.<sup>16, 17</sup> Scores on volitional balance tests such as tandem gait do not correlate with mediolateral center of pressure measures during stepping reactions.<sup>8</sup> A comprehensive approach to fall prevention, therefore, requires an understanding of reactive as well as voluntary movement control.

### *Reactive Stepping*

Stepping reactions formerly were thought to come into play only when ankle and hip strategies failed to recover balance. However, we now know that stepping is a very common reaction, especially when the individual is unfamiliar with the perturbation.<sup>18, 19</sup> Stepping reactions have been observed during live and videotaped falls and near-falls in older adults. Problems in executing the stepping reaction appear to contribute to many falls.<sup>20</sup> Compared to young adults, older adults tend to have multiple and more laterally directed steps. Older fallers demonstrate greater lateral body motion toward the stepping side and more lateral foot placement during stepping reactions.<sup>18, 19, 21</sup> A better understanding of stepping reactions may facilitate development of new therapeutic approaches for detecting and treating instability and decreasing the risk of falls.

### *Anterior-Posterior Stepping Responses*

Luchies et al<sup>22</sup> used the technique of delivering a sudden backward pull at the waist to examine the biomechanics of stepping responses in 12 healthy young (mean age  $22.1 \pm 2.5$  years, range 19 – 26 years) and 12 older (mean age  $72.9 \pm 4.9$  years, range 65 – 80 years) adults. The disturbance was imposed by a backward waist pull controlled by a computer-released dropped weight and cable system. The dropped weights were always 20% of the individual's body weight. The height of each drop was set in relation to subject

height to correspond to various whole-body backward sways about the ankles (equivalent disturbance angles, or EDAs).<sup>22</sup> The lift-off time of the first step was earlier in the older than the young group (289 – 370 ms vs. 358 – 405 ms, respectively). The older group demonstrated a larger number of steps per trial, shorter first step duration, earlier landing time, smaller step height and shorter step length for the large disturbances. Lower extremity joint angles at step initiation were larger in the young, with significant differences in knee flexion and hip flexion on the stepping side and in hip flexion of the stance leg. There were no significant differences in joint angle excursion between the two groups.

Luchies et al<sup>22</sup> concluded that the multiple steps exhibited by the older adults represented a more conservative strategy than taking a single step. Age-related limitations of range of motion in older adults did not fully explain the observed differences in stepping responses. The authors suggested that the shorter step duration exhibited by older adults provided more opportunities for them to arrest energy and modify their responses. The authors did not offer an explanation for the earlier foot lift-off time in older compared to young subjects in this study. Age-related increases in reaction time would be expected to increase foot lift-off times. Perhaps the older adults were more fearful, and consequently prepared to step earlier than the young adults.

Thelen et al<sup>14</sup> compared stepping responses of 10 young (mean age 24.3 years, range 20-30 years, standard deviation (SD) not reported ) and 10 older (mean age 71.3 years, range 67 - 75 years, SD not reported) subjects. Subjects wore a padded pelvic belt attached to a horizontal lean-control cable that allowed them to maintain a forward leaning posture with knees and hips extended. The leaning angle was controlled by the cable, which was equipped with a load cell to detect the percentage of body weight supported when the subject

was in a forward leaning posture. In small lean trials, three different percentages of body weight (15, 20 and 25%) were supported. In maximal lean trials, the supported weight was incremented by 5% of body weight to determine the maximum lean angle from which the subject could successfully recover balance with a single step. The subjects were instructed to attempt to regain standing balance by taking a single step forward with the right foot.

Results revealed several differences between young and old adults in compensatory stepping.<sup>14</sup> In small lean trials, both young and old subjects completed a single step within 500 ms. Compared to the young subjects, the older subjects had significantly longer reaction times and took shorter steps at any given leaning angle. Step velocities were independent of age, but increased significantly with leaning magnitude. Weight transfer time was independent of age, but decreased with increasing leaning magnitude. In maximum leans, all young subjects were able to regain balance with a single step when the leaning magnitude was up to 35% of body weight. Only some older subjects were able to regain balance when the leaning magnitude was greater than 20% to 40% of body weight. The authors concluded that the source of the age-related decline in recovery abilities lies largely in the decrease of the maximum speed of movement of the lower extremity segments.<sup>14</sup>

Using a similar paradigm, Hsiao-Wecksler et al<sup>23</sup> compared stepping responses of 10 young (mean age  $28.0 \pm 4.0$  years, range 18 – 32 years) and 10 older (mean age  $75 \pm 3$  years, range 67 – 75 years) women subjects. Subjects maintain a forward leaning posture with knees and hips extended with a horizontal tether that attached at one end to an electromagnet and at the other end to a chest harness worn by the subject. Subjects were asked to step on a target on the floor located a horizontal distance of 15%, 25% and 35% of body height beyond



the anterior edge of the toes. A trial was considered successful if the subject took only one step to recover balance. The results showed that young subjects could recover balance at a greater release angle when step length increase from 15 to 25% of body height compared to older subjects (young: 36%, old: 31%) and from 25% to 35% of body height compared to older subjects (young: 23%, old: 6%). Young subjects could also recover balance from greater maximal release angles compared to older subjects for a given step length and the difference in recovery ability increased with increases in step length (by 21% at 15% of body height, 30% at 25% of body height and 51% at 35% of body height). At the two longer distances, young subjects stepped faster than older subjects by 50 to 100 ms. The authors concluded that the ability to recover balance in both young and older adults increased when step length increased. Young adults could recover balance from larger release angles by use of shorter step contact time and larger ankle plantarflexor and hip extensor torques in the stepping leg during step contact.

McIlroy et al<sup>24</sup> used an unpredictable moveable platform perturbation to study spatial and temporal characteristics in the control of stepping in five young adults (age range 22 – 28 years, mean and SD age not reported) and nine older adults (age range 65 – 81 years, mean and SD age not reported). The researchers reported that the time to lift the foot off the ground differed by less than 1 ms between young and older subjects and the time to place the foot on the ground differed by only about 10 ms. Although anticipatory adjustments occurred more frequently in the young subjects, the magnitude of the anticipatory postural activity was small in both age groups. The two groups also exhibited similar swing duration, swing velocity, step length, COM displacement, and average time of onset of swing-leg unloading, foot-off, and foot-contact.<sup>24</sup> An important finding was that the older subjects

tended to perform multiple steps and also to place the second and third steps more laterally. The authors concluded that older adults are able to generate rapid movement and do not appear to have reductions in musculoskeletal capacity severe enough to interfere with performance of rapid stepping reactions. The laterally directed second and third steps may result from lateral instability that occurs after the initial foot contact. The low frequency of anticipatory postural adjustments (APAs) in older subjects may reflect an age-related reduction in the sensitivity to peripheral sensory inputs and/or increase in central processing and nerve conduction time.<sup>25-27</sup>

In a subsequent study, the same group of researchers examined both gender and age differences in stepping responses in a sample of 10 young (mean age 25 years, SD not reported) and 10 older (mean age 73.7 years, SD not reported) adults.<sup>15</sup> Methodology was similar to the previous study, with subjects instructed to try to recover balance with a single step after being released from a forward lean. The mean maximum lean angle at which the older female subjects could recover balance was significantly smaller than that of older male subjects. The decreased abilities of older female subjects appeared to result from limitations in the maximum speeds of swing foot movement during recovery.<sup>15</sup>

Rogers et al<sup>21</sup> investigated differences in COM movement in response to a perturbation between 12 young adults (mean age  $31 \pm 7$  years), 20 older adult non-fallers (mean age  $71 \pm 5$  years) and 18 older adult fallers (mean age  $74 \pm 8$  years). Classification of fallers and non-fallers was based on self-reported history during the previous 12 months. The faller group showed longer first step duration compared to young and non-faller groups, and this longer step duration was associated with the extent of lateral COM movement at foot contact. Longer first-step duration may limit maximum stepping speeds and increase the

time spent in single-limb support, thereby increasing the risk of a fall. By the time of foot contact, individuals in the faller group had fallen farther sideways with greater velocity and more lateral foot placement compared to non-faller and young groups. The association between medial-lateral (M-L) COM movement and foot placement suggested that the stepping was adapted to match the lateral movement of the COM. Consistent with the work by Maki et al<sup>2</sup>, the authors concluded that the differences in controlling M-L body motion are likely to have implications for subsequent falls.

Some of the conflicting results reported by Luchies et al<sup>22</sup> and McIlroy and colleagues<sup>24</sup> may be attributed to methodological differences, including differences in instructions to the subjects. First, in the study by Luchies et al<sup>22</sup>, the perturbations were in predictable directions and were presented sequentially, which cannot imitate real-life situations and cannot elicit naive responses. Older subjects may have reached their stability limits earlier because they were less able to adapt their responses to take advantage of predictable features of the testing paradigm.

A second methodological difference was in the instructions given to the subjects and their responses to those instructions. Differing instructions may have affected lift-off times for the first step. Subjects step more frequently when they are encouraged to step. Furthermore, psychological factors such as fear of falling may contribute to earlier response initiation in older compared to young adults in some studies.<sup>28</sup>

A third methodological difference is the method of perturbation. Perturbations induced by release of a cable from a forward lean position involve changes in the location of the COM relative to the BOS prior to the perturbation. In this situation, subjects can anticipate the direction of the upcoming perturbation, resulting in long APAs and earlier step

initiation. In addition, gastrocnemius muscle groups are stretched due to the forward lean position, which can also result in shorter reaction times. Perturbations elicited by a backward waist pull act directly on the COM and can produce horizontal movement of the COM followed by a downward movement of the upper body. This type of perturbation can be easily used in clinical research and therapy as in the Postural Stress Test (PST) described by Wolfson et al.<sup>29</sup> Compared to the backward waist pull, perturbations produced by platform movements originate from the distal part of the segment which creates more downward movement around the hip joint on the COM. Moreover, moveable platform systems are very expensive for clinical assessments of balance.

#### *Medial-Lateral Stepping Responses*

Aging also appears to influence laterally directed compensatory stepping. In a study by Maki et al,<sup>30</sup> 10 young adults (mean age 24.0 years, range 20 – 30 years, SD not reported) and 10 older adults (mean age 69.0 years, range 65 – 73 years, SD not reported) either stood quietly or walked in place on a moveable platform. The platform was translated laterally at random intervals, producing an unexpected lateral perturbation. The older subjects tended to respond to the perturbation with multiple steps and extra limb movements. Both age groups used a side-step sequence more frequently than a cross-over step. Interestingly, when older adults used the cross-over step, they always executed additional steps or grasping reactions, and this was always associated with collisions between the swing and stance leg. In walk-in-place trials, both groups took at least one step to regain balance and the side-step sequence was the predominant pattern. Older adults commonly took more than two steps or exhibited grasping reactions during the side-step sequence as well as cross-over step reactions. Collisions between the two legs were very common in both groups, but more

frequent in older than younger adults.<sup>30</sup>

Mille et al<sup>31</sup> investigated lower extremity stepping response patterns, kinematics, and hip abduction torque during lateral protective stepping induced by a motor-driven waist-pull system in young (n=10, mean age=23 ± 1.4 years) and older (n=10, mean age=73.3 ± 6.3 years) adults. Subjects stood on two separate force platforms and the waist-pull system induced perturbations on either side of the body. In contrast to the results reported by Maki et al,<sup>30</sup> young adults tended to take a single lateral sidestep with the limb that was initially loaded passively by the waist pull, and older adults tended to take multiple cross-over steps, resulting in a greater number of inter-limb collisions. When loaded sidesteps were taken, older adults showed longer, slower and higher steps with greater lateral trunk movement than younger adults. Older adults also produced a higher level of stabilization hip abduction torque of the supporting leg during the single support phase, but produced this torque more slowly than younger adults.

The researchers suggested that the new BOS established by the initial stepping reaction in older adults might be insufficient to capture and arrest the motion of the COM, resulting in instability.<sup>32</sup> Reduction in the stability of the initial step and a consequent need to execute additional steps or arm reactions could be a result of errors or inadequacies in the planning or execution of the initial step.<sup>30</sup> The study by Maki et al<sup>30</sup> was the first to examine compensatory stepping behaviors in a dynamic situation (walking in place). However, COM movements during the task of walking in place may not be comparable to those associated with walking as a part of one's daily activities. In this study, the resultant moment combined the impact induced by the perturbation with the COM motion associated with walking in place, thereby complicating the analysis and interpretation of the responses.

## Summary

Measures of static and dynamic equilibrium are necessary for assessment of volitional balance control ability in older adults. Research shows that older adults have greater mediolateral sway than younger adults under both static and dynamic postural control conditions. Clinical balance tests that challenge mediolateral stability may be used to predict falls in older adults, especially in those with a history of falls. Age-related declines in physiological factors that affect voluntary postural control, such as lower limb proprioception, strength, and hip joint torque, are associated with poor lateral stability. These factors should be addressed in balance interventions for older adults.

Compensatory stepping is a prevalent reaction to balance disturbances in daily life. For both anterior-posterior and medial-lateral stepping reactions, increases in perturbation strength lead to multiple steps in young subjects as well as older subjects. Older adults may have difficulty executing compensatory steps of adequate size or using sensory feedback during stepping responses, thereby necessitating additional steps for balance recovery. Older adults, especially those with a history of falls, tend to exhibit multiple, laterally directed steps in response to A-P perturbations. They also have difficulty performing lateral compensatory stepping responses. This may reflect age-related changes in sensory, motor and integrative systems such as impairments in the ability to constrain COM displacement. These findings indicate that older adults have more M-L body motion than younger adults when recovering balance.

Several researchers<sup>2, 30, 33</sup> have proposed that weakness, decline in the rate of force development of the hip stabilizers, problems with sensory detection, and inadequate biomechanical features of the first step or some combination of these factors<sup>34</sup> are potential

causes of lateral instability in older adults. The M-L foot placement achieved by hip abduction and adduction control during stepping appears to be one important component of frontal plane balance recovery.<sup>20, 21</sup> Further study is needed to identify critical elements that contribute to deficits in controlling lateral body motion during compensatory stepping.

## **AGE-RELATED SYSTEM CHANGES IN POSTURAL CONTROL**

### **Models of Postural Control**

In the traditional reflex model, postural responses to disequilibrium were thought to result from activation of reflex pathways by sensory stimulation.<sup>35</sup> Information flow was viewed as unidirectional from the sensory receptors to motor effectors, and the sensory stimulus alone was thought to shape the motor response to disequilibrium.<sup>36</sup> Postural control in humans is a complex behavior. The individual must predict, detect and encode many different types of information, select and adapt a corrective or protective response, and execute the response correctly to restore balance. In the systems model, the Central Nervous System (CNS) controls the location of the COM. Given the individual's biomechanical constraints, environmental context, sensory information and previous experience, the CNS attempts to optimally control position or movement of the COM.<sup>36</sup> Sensory information is required and used to detect instability of body motion and to generate appropriate postural responses by triggering preprogrammed "feedforward" reactions or by continuously updating ongoing "feedback" corrections when balance is disturbed.<sup>37</sup> The systems model provides a much better explanation of this complex behavior than the reflex model.

Based on the systems model, the CNS rapidly integrates visual, vestibular, and somatosensory information to generate motor responses that are appropriate to the balance

disturbance and the surrounding environment. Therefore, age-related changes in neural processing, nerve conduction, musculoskeletal mechanics or individual sensory systems may impact postural control in older adults. System changes resulting from disease states or from the side effects of medications may affect postural control as well.<sup>37</sup>

Two models of the effects of age on postural control were discussed by Horak et al.<sup>36</sup> One model is based on the view that instability is an inevitable aging effect resulting from widespread degeneration of the musculoskeletal, neuromuscular and sensory systems. In the alternative model, however, aging effects are considered too small to result in observable postural instability. Instead, older persons may develop specific pathologies that lead to accelerated degeneration in the neural and musculoskeletal systems. In this model, each individual may develop unique pathological changes and therefore unique patterns of postural dyscontrol.

### **Sensory systems**

#### *Visual system*

Visual cues provide useful information in maintaining postural control not only during movement but also in static situations.<sup>38</sup> Spatial frequency sensitivity, visual acuity, dark adaptation and contrast sensitivity decrease with age. Only one third of the light reaches the retina of people in their 60s compared to people in their 20s. Older people are more likely than young people to fall when peripheral vision is experimentally occluded and only focal vision is available.<sup>38</sup> However, older people demonstrate sway characteristics similar to those of young people when tested with eyes closed, suggesting that older people rely more on visual information for balance control.<sup>39</sup> These visual system changes may influence the ability to detect and discriminate obstacles in the environment and may place



older people at risk for falls.

### *Vestibular system*

Age-related changes in the vestibular system include a loss of labyrinthine hair cells, vestibular ganglion cells, and nerve fibers. However, the contribution of vestibular dysfunction to falls in older people is not clear. In studies of adults with vestibular loss, excess sway or falling occurs when balance is disturbed under conditions where visual and somatosensory inputs are reduced.<sup>39</sup> One of the vestibular system's functions is to stabilize the head. When the head is extended backward with eyes closed, postural sway increases in young and older adults because of the changes in vestibular organ orientation that alter vestibular feedback for maintaining posture.<sup>38</sup>

### *Somatosensory System*

Common somatosensory impairments associated with postural instability and falls in older adults are impaired position sense and decreased touch sensitivity. Somatosensory influences on postural control, especially in the lower extremities, are thought to be mediated through changes in muscle spindle activity, joint receptor activity, and cutaneous receptors.<sup>40</sup> Older adults have a higher rate of falls and increased sway when standing with eyes closed on foam or on a sway-referenced platform.<sup>41, 42</sup> However age-related changes in proprioception may be present and difficult to detect clinically.

Many studies show that alteration in one system increases dependence on other sensory systems. Older people may not be as efficient as young people in using vestibular information when somatosensory and visual inputs are altered. Compared to young adults, older adults tend to rely more on the visual system to maintain balance, particularly when experiencing sensory conflict.<sup>41-44</sup>

## **Nervous system**

A number of age-related changes that could impact postural control occur in the CNS, including loss of neurons, reduced branching and loss of dendrites, impaired cerebral metabolism, reduced cerebral perfusion, and altered transmitter metabolism.<sup>45</sup> Older adults exhibit a general slowing of information processing and a decrease in nerve conduction velocity that may delay and disrupt the generation of postural responses.<sup>37, 46</sup> Performance of tasks requiring CNS system processing is slowed and reaction time increases.<sup>25, 26, 47, 48</sup> Older adults may lose precise control over the speed at which responses can be made, make more errors when they move faster, and lose the ability to correct these errors.<sup>38, 49</sup>

## **Musculoskeletal System**

Reduction in muscle strength, particularly in the lower extremity, is often seen among older adults.<sup>50, 51</sup> Age-related decreases in the size and number of muscle fibers and number of motor neurons can increase the risk of falls.<sup>52, 53</sup> Peak muscle torque and power are reduced at the knee and ankle in fallers versus non-fallers.<sup>54</sup> Aging muscles also are more susceptible to fatigue than the muscles of young adults. Age-related increases in intrinsic muscle and connective tissue stiffness and degenerative changes in the joints may contribute to a decrease in flexibility and range of motion.<sup>50, 55</sup> Age-related increases in the time taken to produce a given level of force also may occur.<sup>38</sup> All of these changes may influence postural responses in older adults, particularly responses to sudden, large perturbations.<sup>2, 24, 38,</sup>

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### *Rate of Force Development*

It is well known that a decline in strength in older adults, especially in the lower extremities, can negatively affect functional abilities such as walking<sup>50, 57</sup> and can increase

risk for impaired balance and falls. Recent studies indicate that extremity muscle power is a better predictor of these outcomes than strength.<sup>58</sup> Muscle power is the product of muscle force and muscle contraction velocity. Declines in muscle power in the lower extremities with increased age occur faster than declines in muscle strength.<sup>59,64</sup> Muscle power in older adults is associated with their performance of activities such as walking, rising from a chair and climbing stairs.<sup>60-62</sup> Muscle power also is related to dynamic balance and postural sway in quiet standing.<sup>62-64</sup>

Age-related changes in the time needed to produce a required level of muscle force also may be important for postural control.<sup>56, 65</sup> The rate of muscle force development (RFD), is lower in older adults than in young adults.<sup>64</sup> Decreased ability to develop muscle force rapidly may be related to impaired neuromuscular responses for controlling postural sway.<sup>66</sup> Therefore, rate of muscle force development should be considered in assessment and treatment of older adults with balance deficits.

Bemben et al<sup>67</sup> examined age-related differences in maximal voluntary isometric contraction force-time characteristics including maximal force, time to maximal force, maximal rate of force increase, time to maximal rate of force increase, time to 50% of the force time curve and total impulse in 153 healthy men without disabilities. Subjects were distributed across age in 5-year intervals from 20 to 74 years. Three right upper extremity muscle groups (finger flexors, thumb abductors, and forearm extensors) and two right lower extremity muscle groups (ankle dorsiflexors and plantar flexors) were chosen to provide comparisons between large and small muscle groups and between upper and lower extremities. Significant differences in muscle force were reported between age groups for all muscles tested. Muscle force was highest for subjects in the 20- to 24-year-old group

and decreased with age, reaching the lowest values for subjects in the 70- to 74-year-old group. No significant differences were found between age groups in the time to maximal force for any of the muscle groups tested. The time required to reach 50% of maximal force did not differ between age groups for the finger flexors, thumb abductors, or ankle dorsiflexors. However, the younger groups (20 – 59 years of age) required less time to reach 50% of maximal force in forearm extension and ankle plantar flexion than the older age groups (60 – 74 years of age). Subjects between 55 and 74 years of age exhibited lower maximal rates of force production than subjects between 20 and 54 years of age.

Bemben et al<sup>67</sup> suggested that the decline in the rate of force production may be caused by fiber type changes, especially loss of type IIB fibers with increasing age.<sup>67, 68</sup> In this study, the researchers concluded that maximal force and the rate of force production showed a linear decline with increasing age, although the rate of decline was not consistent among the muscle groups tested. Larger muscle groups, however, such as the knee extensors and hip abductors, were not tested in this study and may show greater age-related differences in muscle force capabilities. Furthermore, the small number of subjects in each age group (an average of 14 subjects for each group) may not have been sufficient to reveal differences for all muscle groups.

Hakkinen et al<sup>65</sup> compared force production rates of the knee extensors during isometric contractions in 10 young men (mean age  $29.5 \pm 5.1$  years) and 10 older men (mean age  $61 \pm 4.4$  years). Subjects performed maximal voluntary contractions of the knee extensors on a Cybex dynamometer as fast as possible after a verbal command. The force produced during the early portion of the isometric force-time curves (0 – 100 ms) and the maximal rate of force development were greater in the young group than in the older group.

Times to produce submaximal force levels (30% and 90% of the maximum) also were shorter in the young group. The results support the idea that the rate of muscle force development decreases with increasing age. However, the researchers did not perform muscle biopsies to support their conclusions about changes in muscle fiber composition. We cannot exclude the possibility of aging effects on the rate of voluntary neural activation of the muscle.

### **Summary**

Age-related and disease-related declines of sensory, nervous and musculoskeletal systems place older adults at risk for postural instability and falls. The complex systems involved in postural control serve a common goal, that of regulating the relationship between the COM and the BOS. Appropriate models of postural control and specific training programs in older adults must include sensory, nervous, and musculoskeletal system function.<sup>37, 38</sup> Furthermore, rate of muscle force development should be considered in assessment and treatment of older adults with balance deficits.

### **RELATIONSHIP BETWEEN RATE OF FORCE DEVELOPMENT AND LATERAL STABILITY**

According to the studies by Hakkinen et al<sup>65</sup> and Bemben et al,<sup>67</sup> the rate of submaximal force development decreases with increasing age. Older adults need more time to generate a specific submaximal level of force. Performance of functional activities typically requires submaximal rather than maximal force levels.<sup>22, 69-71</sup> The ability to perform functional activities and react to balance disturbances may depend on one's ability to rapidly generate appropriate submaximal muscle forces, and this ability may be compromised in older adults.<sup>22, 70</sup>

Although Bellew<sup>72</sup> found no relationship between RFD of the quadriceps musculature and magnitude of postural sway in quiet standing in healthy older adults, results of other studies suggest that RFD affects lateral stability. Chang et al<sup>8</sup> examined the contribution of hip abductor RFD to lateral stability in community dwelling older adults. Hip abductor RFD was measured by handheld dynamometry, and static and dynamic stability were assessed by single limb stance and tandem gait tests. The authors found a significant relationship between hip abductor RFD, tested under voluntary conditions, and performance of these two clinical tests that challenge lateral stability. The results indicate the important role of RFD in control of movement, especially in the frontal plane.

## **EXERCISE INTERVENTIONS FOR OLDER ADULTS**

Interventions to improve balance and prevent falls can be categorized as single-risk-factor or multifactorial approaches. In single-risk-factor studies, interventions are focused on a single risk factor such as decreased muscle strength, environmental hazards, poor vision, or polypharmacy. These interventions are effective in improving balance or preventing falls only when targeted to groups most at risk. The multifactorial approach uses interventions that target multiple risk factors. This type of intervention is most effective when designed to address an older adult's individual impairments and circumstances.

Several types of exercise interventions for preventing falls and improving balance in older adults are reported in the literature. Exercises designed to address specific risk factors such as muscle weakness and poor balance are central to most fall prevention programs. Although previous researchers have emphasized movement in the sagittal plane and strengthening of muscles that produce sagittal plane movements (such as hip and knee flexors and extensors),<sup>73-75</sup> awareness of the critical role of the hip abductors and adductors

and other muscle groups that control stability in the frontal plane is increasing. In addition, researchers are becoming increasingly aware of the importance of the rate as well as the magnitude of force generation, and consequently are including RFD measures in their work. In this section, we will review the effects of different types of exercise training on neuromuscular characteristics, including RFD, that may affect balance and falls in older adults.

### **Effects of Exercise on Skeletal Muscle**

Sarcopenia, a main cause of muscle weakness, is the loss of muscle mass associated with aging and happens secondary to atrophy and motor unit loss due to injury.<sup>76</sup> Recent studies involving resistance exercise training indicate that sarcopenia in older adults can be reversed by training.<sup>77</sup> Resistance exercise increases contractile protein synthesis, resulting in an increase in myofiber cross-sectional area and muscle strength and RFD in aged muscle. The gains in muscle strength are due to both neural and muscular factors.

#### *Muscular Adaptation*

Numerous studies provide evidence that older muscles adapt to resistance training with increases in muscle cross-sectional area and volume. Myofiber hypertrophy was observed following a 2 – 3 days per week training program lasting 9 – 52 weeks, with increases in cross-sectional area ranging from 10% to 62%.<sup>78</sup> In older adults, hypertrophy has been observed in both type I and II fibers after training.<sup>79, 80</sup> In studies by Hasten et al<sup>81</sup> and Roth et al<sup>82</sup>, young and older adults demonstrated similar increases in protein synthesis rates and in muscle volume after resistance training. After resistance training, the percentage of type IIa myosin heavy chain isoforms in aged muscle increased, while the percentage of type IIb isoforms decreased.<sup>83</sup> The total amount of muscle mass gained in

response to resistance training is determined not only by the growth of each myofiber but also by the increase in number of myofibers in the muscle.

Intramuscular adaptations induced during a resistance training program lead to strength increases by increasing the force generating capacity of individual muscles.<sup>84, 85</sup> Increased muscle strength is also a result of enhancing the effectiveness of muscular coordination through motor learning. Individuals may learn to produce the movement with specific muscle recruitment patterns that are associated with optimal performance of the training tasks.<sup>86</sup> Therefore, increases in maximal contraction force, power, and RFD in response to specific types of training will reflect not only adaptations in muscle morphology and architecture, but also nervous system changes.<sup>87-89</sup>

#### *Neural Adaptation*

The nervous system plays an important role in development of muscle strength. Adaptation comprises changes in the neural activation of muscles occurring in both intramuscular and intermuscular coordination, including increased motoneuron firing rates, increased motor neural output in response to resistance training,<sup>89</sup> increased motoneuron excitability, decreased presynaptic inhibition, downregulation of inhibitory neural pathways and increased levels of central descending motor drive to agonist muscles.<sup>88, 90</sup>

One important neural system adaptation is an increase in efferent neural drive. Electromyographic (EMG) amplitude increases after resistance training in highly trained strength athletes. The increased EMG amplitudes may indicate changes in motor unit recruitment, firing frequency, or synchronization.<sup>91, 92</sup> In one study, maximal motor unit firing frequency was reported to increase in individuals receiving resistance training.<sup>89</sup> The frequency of motor unit action potentials during maximal voluntary contraction was greater



in trained elderly weight lifters compared to untrained age-matched individuals.

Training-induced increases in the maximal motor unit action potential firing frequency appear to occur in both young and older adults.

The RFD is enhanced with increases in motor unit firing frequency.<sup>93</sup> Increases in RFD have been observed in association with increases in EMG amplitude after resistance training. These increases can be seen in the initial phase of muscle contraction, suggesting that neural adaptation mechanisms, especially an increased incidence of discharge doublets, are important for the training-induced increase in RFD. The discharge doublets, in which the interpulse interval is less than 10 ms, may be observed in the firing pattern of single motor neurons at the onset of rapid muscle contraction.<sup>89</sup> It is possible that firing of discharge doublets at the onset of the contraction and during the phase of rising muscle force serves to enhance the initial generation of muscle contraction force to increase RFD.<sup>91</sup> Specific types of training, such as high-velocity resistance training, result in the greatest increases in the incidence of discharge doublets in individual motor units and also produce increases in RFD.<sup>89, 91</sup>

Motor unit synchronization also has been considered as a potential mechanism for modulating force development.<sup>94</sup> Adaptations in the patterns of muscle coordination that are specific to the particular training exercise are mediated by supraspinal mechanisms such as changes in the organization of the motor cortex and changes in the behavior of spinal cord circuitry.<sup>90, 95</sup>

### **Training to Enhance RFD in Older Adults**

Improvements in muscle strength, power, and RFD may be achieved by resistance training in older adults.<sup>92</sup> This type of training also can produce maintenance of or

improvements in functional abilities in this population.<sup>96</sup> Several studies have assessed the effects of resistance training interventions on muscle strength, power, and functional task performance.<sup>85, 97, 98</sup> RFD and muscle activation have been investigated in resistance and combined velocity/strength training programs in healthy adults and in older adults recovering from a period of immobilization.<sup>80, 84, 85</sup> Resistance training can increase RFD.<sup>92, 99</sup> Specific types of resistance training, such as high velocity resistance training, can increase maximal contraction force and maximal RFD.<sup>85, 100</sup> The mechanisms include not only adaptations in muscle morphology and architecture, but also nervous system adaptations.<sup>92</sup> A summary of studies of exercise interventions designed to improve RFD is presented in Table 1.

#### *Progressive Resistance Training*

Progressive resistance training is a traditional type of strengthening exercise for older adults. The training consists of several sets of movement repetitions at different percentages of the 1 repetition maximum (1 RM). The percentage of 1 RM is increased at various stages of training, and the 1 RM is re-assessed periodically.

Aagaard et al<sup>92</sup> investigated the effects of resistance training on RFD and efferent neural drive during maximal muscle contraction. Fifteen young men (mean age:  $23.3 \pm 3.7$  years) participated in 14 weeks (38 sessions) of heavy resistance strength training including hack squats, incline leg presses, knee extension exercises, hamstring curls and seated calf raises. The training loads started from 10 – 12 RM (lower loading) to 4 – 6 RM (very heavy loading). RFD (slope of force-time curve), impulse (time-integrated force), EMG signal amplitude (mean) and rate of EMG rise (slope of EMG-time curve) were examined during maximal isometric quadriceps femoris contraction. The results showed maximal isometric

muscle voluntary contraction (MVC) and RFD, determined within time intervals of 30, 50, 100 and 200 ms after the onset of contraction, increased after training. Normalized RFD (from 0 to 1/6 MVC) increased 15% after training. EMG amplitude and rate of EMG rise in the early contraction phase (200 ms) also increased 22 – 143% and 41 – 106% respectively. The results suggested RFD and impulse were increased after resistance training, and could be explained by enhanced neural drive.<sup>92</sup>

In another study by Maganaris et al,<sup>99</sup> resistance training was performed by 18 older adults (mean age in exercise group: 74 years, control: 67 years, SD not reported for either group). Exercise sessions were held 3 times a week using isotonic resistance leg-extension and leg-press machines at an intensity of 80% of the 5 RM. The isometric rate of torque development of the knee extensors was calculated from the torque-time curve over 100 ms after the onset of torque development. A 27% increase in the rate of torque development was found in older adults after exercise training. The results supported the findings by Aagaard et al<sup>88</sup> and indicated that resistance exercise can improve RFD in both young and older adults.

### *High-velocity Resistance Training*

The greatest increases in RFD have been reported following specific types of resistance training, such as high-velocity resistance training.<sup>89, 91</sup> High-velocity resistance training involves a movement speed requirement. Participants are asked to generate the muscle force as fast and as hard as they can at different percentages of 1 RM. The level of resistance is increased periodically during the training. This type of exercise has been shown to be effective in increasing both muscle strength and RFD.

Training effects in improving RFD have been demonstrated for young adults.<sup>101</sup> Hakkinen et al<sup>85</sup> conducted a 24-week resistance training program involving “explosive exercise” of major upper and lower body muscle groups in old (10 males: mean age  $42 \pm 2$  years; 11 females: mean age  $39 \pm 3$  years) and older (11 males: mean age  $72 \pm 3$  years; 10 females: mean age  $67 \pm 3$  years) adults. During explosive exercise training, subjects were instructed to perform the movements “explosively” (rapid muscle actions). The training load was increased periodically. RFD was defined as the greatest increase in force over a given 50 ms period at any portion of the curve. Increases in maximal knee extensor RFD measures under isometric conditions were observed in both groups.

In another study by Hakkinen et al<sup>79</sup>, a similar, but shorter (10-week), progressive strength training program was performed by young and older men. RFD was defined in the same manner as in the previous study by Hakkinen et al<sup>85</sup>. Interestingly, maximal peak force increased after training in both young and old groups (15.6% and 16.5%, respectively), but the isometric knee extensor RFD did not change in either group. One possible explanation is that the effects of training on RFD are only apparent with a longer training period for the multi-exercise program. Another possibility is that exercise effects were underestimated, because only the knee extensor muscles were tested for RFD, and the training included exercises for several other muscle groups. The frequency and intensity of exercise specific to the knee extensors was not indicated in either study.

Effects of high-velocity resistance training have also been reported for older adults recovering from bed rest. Suetta et al<sup>102</sup> studied older adults with long-term unilateral lower extremity disuse resulting from osteoarthritis who were scheduled for hip replacement surgery. Subjects were randomly assigned to 3 exercise groups for a 12-week intervention

after the operation: standard rehabilitation, standard rehabilitation plus strength training and standard rehabilitation plus electrical muscle stimulation. The strength training was held 3 times per week and focused on the quadriceps of the operated limb including knee extension in sitting, leg-press and knee-extension machines. The subjects in the strength training group were asked to perform the exercise as rapidly as possible in the concentric phase and at a slow speed in the eccentric phase. RFD was defined as the average slope of the initial phase of the force-time curve at 30, 50, 100 and 200 ms relative to the onset of muscle contraction. Significant increases in maximal isometric knee extensor strength, RFD variables, and impulse were observed in the strength training group. The results again supported the effect of high velocity training in improving RFD in older adults. In contrast to the studies by Hakkinen et al<sup>79,85</sup>, the exercise training focused only on the knee extensors and therefore may better reflect the effects of training on RFD.

Another difference between these studies is the manner in which RFD is defined and calculated. The RFD definition used by Hakkinen et al<sup>79,85</sup> is the greatest increase in force over a given 50 ms period at any portion of the curve and thus at any phase of the muscle contraction. However, the time allowed for force production in explosive movements is typically short (less than 200 ms). Furthermore, RFD during various time intervals from the onset of the muscle contraction may be affected by several physiological parameters, such as muscle fiber type and myosin heavy chain composition, muscle cross sectional area, maximal muscle strength, and neural drive to the muscle.<sup>103</sup> Hakkinen et al<sup>79, 85</sup> did not indicate which portion of the force-time curve was used for calculation of the RFD value. The RFD curve may change after training, so that the portion of the curve used for RFD calculation

may not be consistent with that used at pre-intervention. The phase of muscle contraction at which the training effect occurred is unclear.

In the study by Suetta et al<sup>102</sup>, RFD was calculated as the average slope of the initial phase of the force-time curve at 30, 50, 100 and 200 ms relative to the onset of muscle contraction. This calculation indicated the ability of individuals to generate muscle force in a fixed time interval in the initial stage of the force-time curve. Another method of calculating RFD, used by Aagaard et al<sup>92</sup>, is to determine the slope of the force-time curve from 0 to 1/6 of maximal voluntary muscle contraction. RFD values calculated in this manner indicate the time required to generate a submaximal muscle force from the onset of muscle contraction. These two calculations can provide a better understanding of changes associated with training.

#### *Non-Resistance Training*

RFD also can be improved after non-resistance training. Gruber et al<sup>104</sup> studied the effects of specific sensorimotor training conducted two times per week for 4 weeks in young adults. The exercise program consisted of balance exercises including use of wobble boards, soft support surfaces, and a two-dimensional free moving platform. The researchers examined maximal and average RFD of the leg extensor muscles in different intervals after onset of the maximum isometric muscle contraction. Maximal isometric RFD, but not maximal static leg press strength, increased significantly in the subjects who received the training. In contrast to the results seen with classical training programs,<sup>92</sup> the increase in RFD was accompanied by increased EMG activity of the knee extensors. Enhancement of neuromuscular activation (measured in force and EMG) occurred in the early phase of muscular action (100 ms). The results indicated that the increases in neural

drive during the initial phase of force development might reflect an increase in motoneuron firing rate and might be related to an alteration of the motoneuron recruitment threshold.<sup>105</sup> The researchers suggested that the gains in neural drive might result from both supraspinal and spinal adaptations, and that sensorimotor training might influence proprioceptive afferent effects. It should be noted that the training activities not only involved sensorimotor training but also provided opportunities to perform rapid movements for maintaining balance. The principle of specificity may apply in this situation, as the subjects became better at generating muscle force rapidly as needed for balance.

### **Exercise Programs to Improve Function in Older Adults**

Resistance training programs have produced improvements in balance, gait, and the performance of functional tasks such as climbing stairs and rising from a chair. However, generalization of the effects of resistance training to functional task performance appears limited to those tasks that are most similar to the training exercise. In the previous section, evidence for increases in RFD after high-velocity resistance exercise was summarized; however, the extent to which these increases transfer to improved performance of functional tasks is unknown. Few researchers have examined the effects of exercise, especially high velocity exercise, on balance or physical function in older adults. A summary of studies of exercise interventions designed to improve physical function is provided in Table 2.

Henwood et al<sup>106</sup> conducted a high-velocity progressive resistance training program to improve physical performance in 24 community dwelling healthy older adults. Fourteen older adults (mean age  $69.9 \pm 6.5$  years) participated in the training twice a week for 8 weeks. The program consisted of exercises for major upper and lower body muscle groups using fitness machines. During exercise, the subjects were asked to move as fast as

possible. Subjects who exercised showed improvement in isotonic muscle strength, knee extensor power and physical performance including timed floor rise to standing, timed 6-meter walk, timed repeated chair rise and the number of lift- and-reach movements (seated subjects lifted a box up and down to a shelf in front of them) performed in 30 seconds. Similar results were found in a study by Capodaglio et al<sup>107</sup> of high-velocity resistance exercise combined with flexibility, Tai-Chi, and a home exercise program. Subjects had improved timed-task performance of activities such as chair rise, get up and go, and stair climbing, and improved flexibility and balance after a year long exercise program.

High-velocity resistance training can also improve physical function in older adults with physical limitations. In an investigation by Miszko et al<sup>108</sup>, power training was compared with strength training in improving whole-body physical function in older adults. The researchers also examined the relationship between changes in power and muscle strength and changes in physical function. Thirty-nine community-dwelling older adults were assigned to a power (n=11, mean age  $72.3 \pm 6.7$  years) or strength training (n=13, mean age  $72.8 \pm 5.4$  years) group that exercised 3 times per week for 16 weeks or to a control group (n=15, mean age  $72.4 \pm 7.2$  years). After the training, physical function was significantly better in the power training group than in the strength training or control groups. Maximal strength was greater in the strength training group than in the control group. Power did not differ between groups. The results suggests that power training focusing on movement speed may be more effective than strength training for improving function in community-dwelling older adults.

Results of the studies reviewed above suggest that the principle of specificity of training may apply to training to improve physical function in older adults. High-velocity



training can improve performance of physical function tasks that require rapid movement, and strength training can improve performance of physical function tasks that require maximal muscle strength. According to the specificity principle, intervention with functional activities may also improve physical function. In a study by Kyrolainen et al<sup>109</sup>, 23 young males (13 in training group, mean age  $24 \pm 4$  years; 10 in control group, mean age  $25 \pm 2$  years) participated in a 15-week power training program with explosive muscle contraction. The exercise program consisted of leg extensor exercises incorporating a variety of jumping and hopping activities. Maximal RFD was determined by calculating the steepest slope of the force production curve over a 5 ms period. The results showed that maximal isometric RFD of the knee extensors increased during the first 10 weeks; furthermore, explosive force production measured as knee moment and power increased significantly and vertical jump height in the drop jump test increased. However, the maximal voluntary isometric force and EMG activity of the knee extensors remained the same. The results indicated that the effect of functional training combined with explosive muscle contraction could improve RFD and also enhance performance in jumping.

Effects of different resistance levels during power training (high velocity training) in balance and muscle performance were investigated in a study by Orr et al<sup>110</sup>. One hundred twelve community-dwelling healthy older adults ( $69.0 \pm 6.0$  years) were randomized to one of three exercise groups, training at 20% (Low: 28 subjects,  $69.4 \pm 5.8$  years), 50% (Med: 28 subjects,  $68.1 \pm 4.5$  years) or 80% (High: 28 subjects,  $69.0 \pm 6.4$  years) of maximal strength or to a control group (28 subjects,  $67.6 \pm 6.0$  years). The training program included 3 sets of 8 repetitions of 5 exercises using pneumatic resistance machines: horizontal leg press, knee extension, knee flexion, seated row and seated chest press. The exercise groups were

asked to exercise twice per week for 10 weeks. The subjects were instructed to perform as rapidly as possible in concentric phase and slowly in eccentric phase. Resistance was increased throughout the study based on the subject's maximal strength (evaluated every week). The control group was asked to maintain their current level of physical activity during the study period. Balance was evaluated by measures of sway in quiet standing and muscle performance was evaluated by measures of dynamic muscle strength, muscle power and velocity, muscle endurance and body composition. After training, the greatest improvement in balance was seen in the Low group. The greatest improvement in muscle strength and endurance was seen in the High group. The exercise groups did not differ in muscle power. According to these results, high velocity and high load resistance exercise may be required for optimal improvements in muscle strength and endurance but high velocity and low load resistance exercise could induce improvement not only in muscle strength and endurance but also balance.

Effects of different speed requirements during high velocity training are unclear. To compare effects of different movement velocities during training, Sayers et al<sup>111</sup> conducted high-velocity and low-velocity resistance training with 30 older women for 16 weeks. The training program included bilateral leg press and knee extension exercises using strength training equipment. Subjects were randomized to either a high-velocity group (n=15, mean age  $73.2 \pm 1.2$  years, instructed to complete the concentric phase of each repetition as fast as possible), or a low-velocity group (n=15, mean age  $72.1 \pm 1.3$  years, instructed to complete the concentric phase of each repetition over a 2-second interval). After training, knee extensor strength and power, dynamic balance (measured by forward and backward tandem walking), and timed stair climbing were improved in both groups. There were no

significant differences between groups, except in knee extensor power (high velocity > low velocity group).

In contrast to the results of the studies by Henwood et al<sup>106</sup> and Miszko et al<sup>108</sup>, high-velocity resistance training did not improve functional performance in a group of healthy high-functioning older adults studied by Earles et al<sup>100</sup>. Forty-three retirement community volunteers over the age of 70 years participated in a 12-week randomized trial comparing high-velocity resistance training with a self-paced walking program. In the power group (n=18, mean age  $77 \pm 5$  years), subjects performed high-velocity leg exercises 3 times a week combined with 45 minutes of moderate, nonresistance (e.g., walking) exercise weekly. In the walking group (n=22, mean age  $78 \pm 5$  years), subjects performed moderate intensity exercise 30 minutes daily, 6 days a week. The only improvements observed were in peak hip and knee extensor power and strength in the power group. There was no significant improvement in functional task performance measured by the Short Physical Performance Battery in either group after training. Inclusion in this program of a moderate, nonresistance exercise similar to endurance training may have interfered with explosive strength development.<sup>101</sup>

Hakkinen et al<sup>101</sup> examined the effects of a 21-week concurrent strength and endurance training program (twice per week for each exercise, SE) compared to strength training (twice a week, S) in 26 men (SE: n=11, mean age  $38 \pm 5$  years; S: n=16, mean age  $37 \pm 5$  years). The strength training included major upper and lower limb muscle groups with explosive muscle contraction, whereas the endurance training included walking or use of a bicycle ergometer. After 21 weeks of training, the 1 RM and maximal isometric force increased 21 – 22% in both groups. Integrated EMG (iEMG) of the vastus lateralis increased

26% and 29% in S and SE groups respectively. The cross-sectional area of the quadriceps femoris and mean fiber areas of types I, IIa and IIb also increased in both groups after training. The magnitudes of the increases were not significantly different between the two groups. However, maximal isometric RFD and iEMG of the vastus lateralis during the first 500 ms of rapid isometric action increased in the S group only. The results suggest that the addition of concurrent endurance training to a strength training program may interfere with explosive strength development, possibly because of less improvement in rapid voluntary neural activation.

Compared to traditional exercise training, functional activities are included in few exercise intervention studies to improve RFD and physical performance. In a recent study, de Vreede et al<sup>112</sup> examined the effects of a functional-task exercise program compared with a resistance exercise program on the ability of community-living older people to perform daily tasks. A total of 98 healthy women aged 70 and older were randomly assigned to the functional-task group (n=33, mean age  $74.7 \pm 3.5$  years), resistance exercise group (n=34, mean age  $74.8 \pm 4.0$  years) or a control group (n=31, mean age  $73.0 \pm 3.2$  years).

Functional task performance (Assessment of Daily Activity Performance), isometric knee extensor strength, handgrip strength, isometric elbow flexor strength and leg extensor power were measured at baseline, at the end of training and 6 months after training. Functional performance scores increased significantly in the function group compared to the exercise and control groups at the end of training. Not surprisingly, isometric knee extensor and elbow flexor strength increased significantly in the resistance group compared to the other two groups. At the 6-month follow-up, the increases in functional task performance were sustained in the function group. The results showed that functional-task exercise was more

effective than resistance exercise for improving functional performance in healthy older adults. This type of training may help older adults in maintaining an independent lifestyle. The researchers suggested that the inconsistent results of previous studies<sup>113, 114</sup> of the effects of resistance exercise on functional-task performance in older adults could be explained by the principle of training specificity.

### **Summary**

Studies show that different types of strength training including resistance training, high-velocity training, power training and sensori-motor training can improve RFD in adults. Resistance exercise increases myofiber cross-sectional area and muscle strength and RFD in aged muscle. The gains in muscle strength are due to both neural and muscular factors. Several studies suggest that neural adaptation mechanisms, especially an increased incidence of discharge doublets and motor unit synchronization, are important for training-induced increases in RFD. Specific types of training, such as high-velocity resistance training, result in the greatest increases in the incidence of discharge doublets in individual motor units and produce increases in RFD. High-velocity resistance training is also associated with improvements in balance and physical performance in older adults with and without physical limitations. Research also suggests that exercise training that focuses on speed of movement may be more effective than resistance training for improving physical function in older adults.

### **CONCLUSION**

Impaired lateral stability affects static and dynamic balance control in older adults. Maintenance of lateral stability requires activation of appropriate muscle groups, primarily the hip abductors and adductors. Decreased ability to develop muscle force rapidly may be

related to impaired neuromuscular responses for controlling postural sway. Muscle groups such as the hip abductors and adductors must generate force rapidly and with precise coordination for stability during performance of volitional and reactive movements.

Exercise programs designed for older adults have been shown to improve muscle strength and physical function. However, these programs typically emphasize hip and knee flexors and extensors rather than muscles that produce movement in the frontal plane. High-velocity resistance training, a type of exercise that emphasizes speed of movement, has been shown to improve lower extremity muscle RFD and gait speed in older adults. Further research is needed to determine optimal exercise protocols for increasing hip muscle RFD and to investigate relationships between RFD and balance and functional ability in older adults with balance deficits.

**Table 1.** Summary of Exercise Intervention to Improve Rate of Force Development

Authors	Population	Subjects (n, gender, age)	Training (duration, freq, type, muscles)	RFD measures	Results
<b>Young</b>					
Aagaard et al <sup>92</sup>	Young adults	15 male (23.3±3.7)	14 weeks, 38 sessions, progressive resistance training, lower extremity muscles.	RFD: Average slope of the moment-time curve over time intervals of 0-30, -50, -100, -200 after onset. Normalized RFD: the slope of the moment-time curve when normalized relative to peak isometric moment (calculated from onset of contraction to the level of 1/6, 1/2 and 2/3 MVC)	Increase in isometric knee extensor RFD in all time intervals. Increase in normalized RFD (0-1/6 MVC) and the time from onset to 1/6 MVC decreased.
Hakkinen et al <sup>101</sup>	Community dwelling adults	16 male (37±5) in S 11 male (38±5) in SE	21 weeks, 2 times/week, S: heavy resistance training with explosive exercise, upper and lower muscle groups, SE: plus endurance training, bicycling ergometer or walking.	The greatest increase in force over a given 50 ms period at any portion of the curve	Increase in max. isometric RFD of knee extensor and flexor in S but not in SE
Kyrolainen et al <sup>109</sup>	Young recreationally active men	13 (24±4) in exercise 10 (25±2) in control	15 weeks, 2 times/week, power training, leg extensors (jumps squats, jump, hops)	The steepest application point of the force curve by each 5 ms.	Increase in max. isometric RFD in knee extensors, but not in plantaflexors
Gruber et al <sup>104</sup>	Young	5 male (31.4±5.8) 12 female (27.8±6.5)	4 weeks, 2 times/week, sensorimotor training, postural stabilization tasks, knee muscles	Max. RFD: max. slope of the force time curve after onset. Sub max. RFD: mean slope of the force-time curve	Increase in max. isometric RFD but not in the time to reach max. RFD. Increase in sub max RFD in

				(0-30, 50, 100, 200, 300, 400, 500 after onset)	0-30, 0-50 only.
<b>Older</b>					
Maganiaris et al <sup>99</sup>	Community dwelling older adults	9 (mean age:74) in strength training 9 (mean age:67) in control non-exercise	14 weeks, 3 times/week, isotonic resistance device for leg-extension and leg-press	Rate of torque development: slope of the torque-time relationship over the first 100 ms after the onset of torque development	Increase in knee isometric extensor RTD in exercise group.
Hakkinen et al <sup>85</sup>	Community dwelling old and older adults	10 male (42±2) 11 female (39±3) 11 male (72±3) 10 female (67±3)	24 weeks, heavy resistance training with explosive exercises, upper and lower body	The greatest increase in force over a given 50 ms period at any portion of the curve.	Increase in max. isometric RFD of knee extensor in all groups.
Hakkinen et al <sup>79</sup>	Community	10 male (61±4) 8 male (19±5)	10 weeks, 3 times/week, heavy resistance training with explosive exercise, upper and lower muscle groups	The greatest increase in force over a given 50 ms period at any portion of the curve.	No changes in max. isometric RFD of knee extensor within groups
Hakkinen et al <sup>115</sup>	Community dwelling older adults	10 female (64±3)	21 weeks, 2 times/week, combination of heavy resistance and explosive exercises, main upper and lower muscle groups	The greatest increase in force over a given 50 ms period at any portion of the curve	Increase in max. isometric RFD of knee extensor.
Suetta et al <sup>102</sup>	Bed-rest, hip OA, THR scheduled	11 (71) in ST 10 (69) in ES 9 (69) in SR	12 weeks ST: 3 times/week, strength training, resistance training and explosive movement, quadriceps.	Average slope of the initial phase of the force-time curve at 30, 50, 100 and 200 ms relative to the onset of the contraction. Normalized RFD: slope of the force-time	Increase in peak isometric knee extensor RFD in ST (0-30, 0-50, 0-100, 0-200 intervals). Increase in normalized RFD in ST (only 0-30 ms)



			ES: 1 hour/day, electrical stimulation, quadriceps. SR: 1 hour/day, standard rehabilitation, 15 PT hip exercises.	curve normalized relative to CSA.	
Barry et al <sup>116</sup>	Community	8 young (26.3±4.6) 8 older (68.8±7.5)	4 weeks, progressive resistance training with high-velocity movement, elbow flexors	Max. RTD Mean rate of torque development: calculated over time intervals of 0- 30, 50, 100 and 200 ms relative to the onset of the torque production.	Increase isometric elbow flexion and supination RTD in both groups after training.

RFD: rate of force development, MVC: maximal voluntary contraction, Max: maximal, RTD: rate of torque development, OA: osteoarthritis, THR: total hip replacement

**Table 2.** Summary of Exercise Intervention to Improve Physical Function in Older Adults

Authors	Population	Subjects (n, gender, age)	Training (duration, freq, type, muscles)	Physical Function	Results
Schlicht et al <sup>117</sup>	Community dwelling older adults	12 (72±6.3) in exercise 12 in control	8 weeks, 3 times/week, resistance training, 6 lower body exercises	Strength, max. walking speed, one-leg blind balance, 5 repetition sit-to-stand	Increase strength after exercise in exercise group. Improved max. walking speed in exercise group compared to control group.
Miszko et al <sup>108</sup>	Community dwelling older adults below average lower extremity extensor power	13 (72.8±5.4) in strength 11 (72.3±6.7) in power 15 (72.4±7.2) in control RCT	16 weeks, 3 times/week. Strength: 8 upper and lower body exercises and squats. Power: 8 upper and lower body exercise and jump squat at 40% 1 RM and as fast as possible. Control: 3 lectures	Continuous scale physical functional performance (CS-PFP), maximal strength, anaerobic power	Greater CS-PFP in power group after training. Greater maximal strength in Strength group compared to control group. No difference between groups for peak anaerobic power
Sayers et al <sup>111</sup>	Older women with preexisting functional limitation	15 (73.2±1.2) in high-velocity group 15 (72.1±1.3) in low-velocity group RCT	16 weeks, 3 times/week. Resistance training, leg press and knee extension. High-velocity: required to complete the movement as fast as possible in 1 s. Low-velocity: concentric-maintain-eccentric in 2-1-2 sec	Psychosocial outcome (MMSE, Geriatric Depression Scale, Physical Activity Scale). Functional outcome (balance: tandem walking, chair-rise time, stair climb time, habitual and max. gait speed) Disability Outcome (SF-36)	Dynamic balance, stair-climb time, self-reported disability, physical functioning, physical and mental health improved after training. No difference between groups.
Capodaglio et al <sup>107</sup>	Community dwelling older adults.	28 (15 female, 76.4±3.6) in exercise	52 weeks, 2 times/week, strength training (concentric over 2 sec, eccentric over 3	Muscle function (max. isometric knee extensor, ankle plantar flexor	Significant improvement in MF and FA in training females.

		20 (11 female, 77.2±3.4) in control	sec), flexibility exercise, Tai-Chi, home program (Theraband exercises)	strength), Functional ability (functional reach, chair rise time, bed rise time, 6-min walk, chair climbing time, get-up and go, one leg standing), physical activity	Improved FA in training males.
De Vreede et al <sup>112</sup>	Community dwelling older adults.	33 females (74.7±3.5) in function group 34 female (74.8±4.0) in Resistance group 31 females (73±3.2) in Control group.	12 weeks, 3 times/week. Functional-task program: daily tasks (moving with a vertical and horizontal component, carry an object and changing between lying-sitting-standing position) Resistance exercise training: major upper and lower body muscle groups that are important for daily task performance.	Physical function performance (Assessment of Daily Activity Performance (ADAP), Timed Up and Go), muscle function (isometric knee extensor elbow flexor strength, handgrip strength, leg extensor power)	ADAP increased significantly in function group compared with resistance or control group. ADAP in resistance group did not change significantly compared with control group. Isometric knee extensor and elbow flexor strength increased significantly in the resistance group compared with the function and control group. ADAP score in the function group was sustained at 6- mon follow-up.
Henwood et al <sup>106</sup>	Community dwelling older adults.	14 (69.9±6.5) in exercise group. 10 (71.3±5.6) in control group. NOT RCT	8 weeks, 2 times/week. Exercise group: high-velocity progressive resistance training in major upper and lower body muscle groups exercises using equipment, move as fast as possible	Dynamic isotonic muscle strength of upper and lower body, lower-limb muscle power (peak, isotonic, functional), physical performance (chair rise, 6m walk, 6m	Dynamic muscle strength and knee extensor power increased in exercise group after training, Significant improvement in floor rise, usual 6m walk, repeated chair rise and lift and reach

				backwards walk, floor rise to standing, lift and reach)	was seen in exercise group.
Orr et al <sup>110</sup>	Community dwelling older adults.	28 (69.4±5.8, 17 female) in Low (20% of 1RM) group 28 (68.1±4.5, 17 female) in Med (50% of 1RM) 28 (69.0±6.4, 17 female) in High (80% of 1RM) 28 (67.6±6.0, 17 female) in Control group	10 weeks, 2 times/week. Exercise group: high-velocity progressive resistance training in horizontal leg press, knee extension, knee flexion, seated row and seated chest press using pneumatic resistance machines, move as fast as possible	Balance (static balance body sway in computerized force platform), muscle performance (dynamic muscle strength, muscle power and velocity, muscle endurance and body composition)	Most balance improvement was seen in the LOW group. Most muscle strength and endurance improvement was seen in High group. No difference between exercise groups in muscle power.

## BIBLIOGRAPHY

1. Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. *J Am Geriatr Soc* 1999; 47:1077-81.
2. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J Gerontol* 1994; 49:M72-84.
3. Cumming RG, Klineberg RJ. Fall frequency and characteristics and the risk of hip fractures. *J Am Geriatr Soc* 1994; 42:774-8.
4. Greenspan SL, Myers ER, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *Jama* 1994; 271:128-33.
5. Hayes WC, Myers ER, Morris JN, Gerhart TN, Yett HS, Lipsitz LA. Impact near the hip dominates fracture risk in elderly nursing home residents who fall. *Calcif Tissue Int* 1993; 52:192-8.
6. Robinovitch SN, Hayes WC, McMahon TA. Prediction of femoral impact forces in falls on the hip. *J Biomech Eng* 1991; 113:366-74.
7. Smeesters C, Hayes WC, McMahon TA. Disturbance type and gait speed affect fall direction and impact location. *J Biomech* 2001; 34:309-17.
8. Chang SH, Mercer VS, Giuliani CA, Sloane PD. Relationship between hip abductor rate of force development and mediolateral stability in older adults. *Arch Phys Med Rehabil* 2005; 86:1843-50.
9. Holliday PJ, Fernie GR, C.I. G, Griggs GT. Video recording of spontaneous falls of the elderly. In: Gray BE, ed. *Slips, stumbles, and falls*. Vol. 1103. Philadelphia: American society for testing and materials, 1990:7-16.
10. Nitz JC, Choy NL, Isles RC. Medial-lateral postural stability in community-dwelling women over 40 years of age. *Clin Rehabil* 2003; 17:765-7.
11. Cho BL, Scarpace D, Alexander NB. Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. *J Am Geriatr Soc* 2004; 52:1168-73.
12. Rogers MW, Pai YC. Organization of preparatory postural responses for the initiation of lateral body motion during goal directed leg movements. *Neurosci Lett* 1995; 187:99-102.
13. Elble RJ, Moody C, Leffler K, Sinha R. The initiation of normal walking. *Mov Disord* 1994; 9:139-46.

14. Thelen DG, Wojcik LA, Schultz AB, Ashton-Miller JA, Alexander NB. Age differences in using a rapid step to regain balance during a forward fall. *J Gerontol A Biol Sci Med Sci* 1997; 52:M8-13.
15. Wojcik LA, Thelen DG, Schultz AB, Ashton-Miller JA, Alexander NB. Age and gender differences in single-step recovery from a forward fall. *J Gerontol A Biol Sci Med Sci* 1999; 54:M44-50.
16. Mackey DC, Robinovitch SN. Postural steadiness during quiet stance does not associate with ability to recover balance in older women. *Clin Biomech (Bristol, Avon)* 2005; 20:776-83.
17. Owings TM, Pavol MJ, Foley KT, Grabiner MD. Measures of postural stability are not predictors of recovery from large postural disturbances in healthy older adults. *J Am Geriatr Soc* 2000; 48:42-50.
18. McIlroy WE, Maki BE. Task constraints on foot movement and the incidence of compensatory stepping following perturbation of upright stance. *Brain Res* 1993; 616:30-8.
19. Maki BE, McIlroy WE. The role of limb movements in maintaining upright stance: the "change- in-support" strategy. *Phys Ther* 1997; 77:488-507.
20. Maki BE, McIlroy WE. Control of compensatory stepping reaction: Age-related impairment and the potential for remedial intervention. *Physiotherapy theory and Practice* 1998; 15:69-90.
21. Rogers MW, Hedman LD, Johnson ME, Cain TD, Hanke TA. Lateral stability during forward-induced stepping for dynamic balance recovery in young and older adults. *J Gerontol A Biol Sci Med Sci* 2001; 56:M589-94.
22. Luchies CW, Alexander NB, Schultz AB, Ashton-Miller J. Stepping responses of young and old adults to postural disturbances: kinematics. *J Am Geriatr Soc* 1994; 42:506-12.
23. Hsiao-Weckslar ET, Robinovitch SN. The effect of step length on young and elderly women's ability to recover balance. *Clin Biomech (Bristol, Avon)* 2007; 22:574-80.
24. McIlroy WE, Maki BE. Age-related changes in compensatory stepping in response to unpredictable perturbations. *J Gerontol A Biol Sci Med Sci* 1996; 51:M289-96.
25. Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc* 1994; 42:1110-7.
26. Salthouse TA, Somberg BL. Time-accuracy relationships in young and old adults. *J Gerontol* 1982; 37:349-53.

27. Pai YC, Patton J. Center of mass velocity-position predictions for balance control. *J Biomech* 1997; 30:347-54.
28. Myers AM, Powell LE, Maki BE, Holliday PJ, Brawley LR, Sherk W. Psychological indicators of balance confidence: relationship to actual and perceived abilities. *J Gerontol A Biol Sci Med Sci* 1996; 51:M37-43.
29. Wolfson LI, Whipple R, Amerman P, Kleinberg A. Stressing the postural response. A quantitative method for testing balance. *J Am Geriatr Soc* 1986; 34:845-50.
30. Maki BE, Edmondstone MA, McIlroy WE. Age-related differences in laterally directed compensatory stepping behavior. *J Gerontol A Biol Sci Med Sci* 2000; 55:M270-7.
31. Mille ML, Johnson ME, Martinez KM, Rogers MW. Age-dependent differences in lateral balance recovery through protective stepping. *Clin Biomech (Bristol, Avon)* 2005; 20:607-16.
32. Maki BE, Perry SD, Norrie RG, McIlroy WE. Effect of facilitation of sensation from plantar foot-surface boundaries on postural stabilization in young and older adults. *J Gerontol A Biol Sci Med Sci* 1999; 54:M281-7.
33. Pai YC, Naughton BJ, Chang RW, Rogers MW. Control of body center of mass momentum during sit-to-stand among young and elderly adults. 1994.
34. Smeesters C, Hayes WC, McMahon TA. The threshold trip duration for which recovery is no longer possible is associated with strength and reaction time. *J Biomech* 2001; 34:589-95.
35. Man'kovskii NB, Mints A, Lysenyuk VP. Regulation of the preparatory period for complex voluntary movement in old and extreme old age. *Hum Physiol* 1980; 6:46-50.
36. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: a review. *Neurobiol Aging* 1989; 10:727-38.
37. Maki BE, McIlroy WE. Postural control in the older adult. *Clin Geriatr Med* 1996; 12:635-58.
38. Alexander NB. Postural control in older adults. *J Am Geriatr Soc* 1994; 42:93-108.
39. Woollacott MH. Age-related changes in posture and movement. *J Gerontol* 1993; 48 Spec No:56-60.
40. Pykko I, Aalto A, Hytonen M. Effect of age on postural control. In: Amblard B, Berthoz A, Clarac F, eds. *Posture and Gait : Development, Adaptation, and Modulation*. New York: Elsevier, 1988:95-104.

41. Woollacott MH, Shumway-Cook A, Nashner LM. Aging and posture control: changes in sensory organization and muscular coordination. *Int J Aging Hum Dev* 1986; 23:97-114.
42. Manchester D, Woollacott M, Zederbauer-Hylton N, Marin O. Visual, vestibular and somatosensory contributions to balance control in the older adult. *J Gerontol* 1989; 44:M118-27.
43. Teasdale N, Stelmach GE, Breunig A. Postural sway characteristics of the elderly under normal and altered visual and support surface conditions. *J Gerontol* 1991; 46:B238-44.
44. Simoneau GG, Leibowitz HW, Ulbrecht JS, Tyrrell RA, Cavanagh PR. The effects of visual factors and head orientation on postural steadiness in women 55 to 70 years of age. *J Gerontol* 1992; 47:M151-8.
45. Lipsitz LA, Goldberger AL. Loss of 'complexity' and aging. Potential applications of fractals and chaos theory to senescence. *Jama* 1992; 267:1806-9.
46. Stelmach GE, Worringham CJ. Sensorimotor deficits related to postural stability. Implications for falling in the elderly. *Clin Geriatr Med* 1985; 1:679-94.
47. Grabiner MD, Jahnigen DW. Modeling recovery from stumbles: preliminary data on variable selection and classification efficacy. *J Am Geriatr Soc* 1992; 40:910-3.
48. Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc* 1991; 39:1194-200.
49. Rabbit P. How old and young subjects monitor and control responses for accuracy and speed. *Br J Psychol* 1979; 70:305-311.
50. Vandervoort AA, Chesworth BM, Cunningham DA, Paterson DH, Rechnitzer PA, Koval JJ. Age and sex effects on mobility of the human ankle. *J Gerontol* 1992; 47:M17-21.
51. Larsson L, Grimby G, Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol* 1979; 46:451-6.
52. Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people. Results of two population- based studies. *Arch Intern Med* 1989; 149:1628-33.
53. Lipsitz LA, Jonsson PV, Kelley MM, Koestner JS. Causes and correlates of recurrent falls in ambulatory frail elderly. *J Gerontol* 1991; 46:M114-22.
54. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *J Am Geriatr Soc* 1987; 35:13-20.



55. Such CH, Unsworth A, Wright V, Dowson D. Quantitative study of stiffness in the knee joint. *Ann Rheum Dis* 1975; 34:286-91.
56. Hakkinen K, Hakkinen A. Muscle cross-sectional area, force production and relaxation characteristics in women at different ages. *Eur J Appl Physiol Occup Physiol* 1991; 62:410-4.
57. Brown M, Sinacore DR, Host HH. The relationship of strength to function in the older adult. *J Gerontol A Biol Sci Med Sci* 1995; 50 Spec No:55-9.
58. Skelton DA. Effects of physical activity on postural stability. *Age Ageing* 2001; 30 Suppl 4:33-9.
59. Metter EJ, Conwit R, Tobin J, Fozard JL. Age-associated loss of power and strength in the upper extremities in women and men. *J Gerontol A Biol Sci Med Sci* 1997; 52:B267-76.
60. Bassey EJ, Fiatarone MA, O'Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. *Clin Sci (Lond)* 1992; 82:321-7.
61. Bean JF, Kiely DK, Herman S, et al. The relationship between leg power and physical performance in mobility- limited older people. *J Am Geriatr Soc* 2002; 50:461-7.
62. Bean JF, Leveille SG, Kiely DK, Bandinelli S, Guralnik JM, Ferrucci L. A comparison of leg power and leg strength within the InCHIANTI study: which influences mobility more? *J Gerontol A Biol Sci Med Sci* 2003; 58:728-33.
63. Izquierdo M, Aguado X, Gonzalez R, Lopez JL, Hakkinen K. Maximal and explosive force production capacity and balance performance in men of different ages. *Eur J Appl Physiol Occup Physiol* 1999; 79:260-7.
64. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol A Biol Sci Med Sci* 2000; 55:M192-9.
65. Hakkinen K, Kraemer WJ, Newton RU. Muscle activation and force production during bilateral and unilateral concentric and isometric contractions of the knee extensors in men and women at different ages. *Electromyogr Clin Neurophysiol* 1997; 37:131-42.
66. Izquierdo M, Ibanez J, Gorostiaga E, et al. Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiol Scand* 1999; 167:57-68.

67. Bemben MG, Massey BH, Bemben DA, Misner JE, Boileau RA. Isometric muscle force production as a function of age in healthy 20- to 74-yr-old men. *Med Sci Sports Exerc* 1991; 23:1302-10.
68. Campbell MJ, McComas AJ, Petito F. Physiological changes in ageing muscles. *J Neurol Neurosurg Psychiatry* 1973; 36:174-82.
69. Viitasalo JT, Komi PV. Force-time characteristics and fiber composition in human leg extensor muscles. *Eur J Appl Physiol Occup Physiol* 1978; 40:7-15.
70. Schultz AB. Muscle function and mobility biomechanics in the elderly: an overview of some recent research. *J Gerontol A Biol Sci Med Sci* 1995; 50 Spec No:60-3.
71. Wojcik LA, Thelen DG, Schultz AB, Ashton-Miller JA, Alexander NB. Age and gender differences in peak lower extremity joint torques and ranges of motion used during single-step balance recovery from a forward fall. *J Biomech* 2001; 34:67-73.
72. Bellew JW. A correlation analysis between rate of force development of the quadriceps and postural sway in healthy older adults. *J Geri Phys Ther* 2002; 25:11-15.
73. Rantanen T, Guralnik JM, Izmirlian G, et al. Association of muscle strength with maximum walking speed in disabled older women. *Am J Phys Med Rehabil* 1998; 77:299-305.
74. Brown M, Holloszy JO. Effects of walking, jogging and cycling on strength, flexibility, speed and balance in 60- to 72-year olds. *Aging (Milano)* 1993; 5:427-34.
75. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther* 1993; 73:254-62; discussion 263-5.
76. Doherty TJ. Invited review: Aging and sarcopenia. *J Appl Physiol* 2003; 95:1717-27.
77. Thompson LV. Skeletal muscle adaptations with age, inactivity, and therapeutic exercise. *J Orthop Sports Phys Ther* 2002; 32:44-57.
78. Hunter GR, McCarthy JP, Bamman MM. Effects of resistance training on older adults. *Sports Med* 2004; 34:329-48.
79. Hakkinen K, Newton RU, Gordon SE, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol A Biol Sci Med Sci* 1998; 53:B415-23.
80. Hakkinen K, Kraemer WJ, Newton RU, Alen M. Changes in electromyographic activity, muscle fibre and force production characteristics during heavy

- resistance/power strength training in middle-aged and older men and women. *Acta Physiol Scand* 2001; 171:51-62.
81. Hasten DL, Pak-Loduca J, Obert KA, Yarasheski KE. Resistance exercise acutely increases MHC and mixed muscle protein synthesis rates in 78-84 and 23-32 yr olds. *Am J Physiol Endocrinol Metab* 2000; 278:E620-6.
  82. Roth SM, Ivey FM, Martel GF, et al. Muscle size responses to strength training in young and older men and women. *J Am Geriatr Soc* 2001; 49:1428-33.
  83. Williamson DL, Godard MP, Porter DA, Costill DL, Trappe SW. Progressive resistance training reduces myosin heavy chain coexpression in single muscle fibers from older men. *J Appl Physiol* 2000; 88:627-33.
  84. Hakkinen K, Alen M, Kallinen M, Newton RU, Kraemer WJ. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. *Eur J Appl Physiol* 2000; 83:51-62.
  85. Hakkinen K, Kallinen M, Izquierdo M, et al. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *J Appl Physiol* 1998; 84:1341-9.
  86. Carroll TJ, Riek S, Carson RG. Neural adaptations to resistance training: implications for movement control. *Sports Med* 2001; 31:829-40.
  87. Aagaard P, Andersen JL, Dyhre-Poulsen P, et al. A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. *J Physiol* 2001; 534:613-23.
  88. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *J Appl Physiol* 2002; 92:2309-18.
  89. Van Cutsem M, Duchateau J, Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol* 1998; 513 ( Pt 1):295-305.
  90. Barry BK, Carson RG. The consequences of resistance training for movement control in older adults. *J Gerontol A Biol Sci Med Sci* 2004; 59:730-54.
  91. Aagaard P. Training-induced changes in neural function. *Exerc Sport Sci Rev* 2003; 31:61-7.
  92. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol* 2002; 93:1318-26.

93. Nelson AG. Supramaximal activation increases motor unit velocity of unloading shortening. *J Appl Biomech* 1996; 12:285-291.
94. Semmler JG. Motor unit synchronization and neuromuscular performance. *Exerc Sport Sci Rev* 2002; 30:8-14.
95. Carroll TJ, Riek S, Carson RG. The sites of neural adaptation induced by resistance training in humans. *J Physiol* 2002; 544:641-52.
96. Fiatarone MA, Evans WJ. The etiology and reversibility of muscle dysfunction in the aged. *J Gerontol* 1993; 48 Spec No:77-83.
97. Harridge SD, Kryger A, Stensgaard A. Knee extensor strength, activation, and size in very elderly people following strength training. *Muscle Nerve* 1999; 22:831-9.
98. Hakkinen K, Pakarinen A, Newton RU, Kraemer WJ. Acute hormone responses to heavy resistance lower and upper extremity exercise in young versus old men. *Eur J Appl Physiol Occup Physiol* 1998; 77:312-9.
99. Maganaris CN, Narici MV, Reeves ND. In vivo human tendon mechanical properties: effect of resistance training in old age. *J Musculoskelet Neuronal Interact* 2004; 4:204-8.
100. Earles DR, Judge JO, Gunnarsson OT. Velocity training induces power-specific adaptations in highly functioning older adults. *Arch Phys Med Rehabil* 2001; 82:872-8.
101. Hakkinen K, Alen M, Kraemer WJ, et al. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *Eur J Appl Physiol* 2003; 89:42-52.
102. Suetta C, Aagaard P, Rosted A, et al. Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. *J Appl Physiol* 2004; 97:1954-61.
103. Andersen LL, Aagaard P. Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *Eur J Appl Physiol* 2005:1-7.
104. Gruber M, Gollhofer A. Impact of sensorimotor training on the rate of force development and neural activation. *Eur J Appl Physiol* 2004; 92:98-105.
105. Grabiner MD. Maximum rate of force development is increased by antagonist conditioning contraction. *J Appl Physiol* 1994; 77:807-11.
106. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology* 2005; 51:108-15.

107. Capodaglio P, Capodaglio EM, Ferri A, Scaglioni G, Marchi A, Saibene F. Muscle function and functional ability improves more in community-dwelling older women with a mixed-strength training programme. *Age Ageing* 2005; 34:141-7.
108. Miszko TA, Cress ME, Slade JM, Covey CJ, Agrawal SK, Doerr CE. Effect of strength and power training on physical function in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci* 2003; 58:171-5.
109. Kyrolainen H, Avela J, McBride JM, et al. Effects of power training on muscle structure and neuromuscular performance. *Scand J Med Sci Sports* 2005; 15:58-64.
110. Orr R, de Vos NJ, Singh NA, Ross DA, Stavrinou TM, Fiatarone-Singh MA. Power training improves balance in healthy older adults. *J Gerontol A Biol Sci Med Sci* 2006; 61:78-85.
111. Sayers SP, Bean J, Cuoco A, LeBrasseur NK, Jette A, Fielding RA. Changes in function and disability after resistance training: does velocity matter?: a pilot study. *Am J Phys Med Rehabil* 2003; 82:605-13.
112. de Vreede PL, Samson MM, van Meeteren NL, Duursma SA, Verhaar HJ. Functional-task exercise versus resistance strength exercise to improve daily function in older women: a randomized, controlled trial. *J Am Geriatr Soc* 2005; 53:2-10.
113. Keysor JJ, Jette AM. Have we oversold the benefit of late-life exercise? *J Gerontol A Biol Sci Med Sci* 2001; 56:M412-23.
114. King AC, Rejeski WJ, Buchner DM. Physical activity interventions targeting older adults. A critical review and recommendations. *Am J Prev Med* 1998; 15:316-33.
115. Hakkinen K, Pakarinen A, Kraemer WJ, Hakkinen A, Valkeinen H, Alen M. Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol* 2001; 91:569-80.
116. Barry BK, Warman GE, Carson RG. Age-related differences in rapid muscle activation after rate of force development training of the elbow flexors. *Exp Brain Res* 2005; 162:122-32.
117. Schlicht J, Camaione DN, Owen SV. Effect of intense strength training on standing balance, walking speed, and sit-to-stand performance in older adults. *J Gerontol A Biol Sci Med Sci* 2001; 56:M281-6.

## **Appendix B. Recruitment Flyer and Campus-wide Emails**

### **RESEARCH STUDY CENTER FOR HUMAN MOVEMENT SCIENCE UNC-CHAPEL HILL**

#### **A novel exercise program is available for our senior residents!!!**

We are conducting a research study at the University of North Carolina at Chapel Hill designed to investigate hip muscle strength and balance in older adults. A lateral trainer (The Skier's Edge Company, Park City, Utah 84060) an exercise device currently used in athletic training and sport rehabilitation, will be used to try to improve force production of the hip muscles in older adults who are found to be at increased risk of falling.

- Older adults with and without balance problems will participate in one session of exercises for the hip muscles, including lateral trainer exercises and lateral step-ups. Participants will receive \$20 for participation in this session.
- Older adults whose balance test scores meet specific criteria will be invited to participate in a 10-week exercise program at the Center for Human Movement Science or University Physical Therapy in Hillsborough. Participants will receive \$40 for participation in two physical performance test sessions and up to \$200 for completing the exercise program.

#### Eligibility Criteria:

If you are

- 65 years of age or older,
  - in generally good health and able to perform physical exercise,
  - able to ambulate at least 50 feet without physical assistance,
  - have normal or corrected-to-normal vision and hearing and
- do not have musculoskeletal or cardiovascular disorders or diseases that would interfere with your participation.

Please contact James Chang, PT, MS at 919-966-9797 or 919-969-6691 or email [changsj@med.unc.edu](mailto:changsj@med.unc.edu) for more information.

**\*\*This advertisement and the study described have been reviewed and approved by the Biomedical IRB # 05-2185 Formerly 05-AHS-700 on December 09, 2005 \*\***

Campus-wide email (1<sup>st</sup>)

We are conducting a research study at the University of North Carolina at Chapel Hill designed to investigate hip muscle strength and balance in older adults. A lateral trainer (The Skier's Edge Company, Park City, Utah 84060) an exercise device currently used in athletic training and sport rehabilitation, will be used to try to improve force production of the hip muscles in older adults who are found to be at increased risk of falling.

- Older adults with and without balance problems will participate in one session of exercises for the hip muscles, including lateral trainer exercises and lateral step-ups. Participants will receive \$20 for participation in this session.
- Older adults whose balance test scores meet specific criteria will be invited to participate in a 10-week exercise program at the Center for Human Movement Science or University Physical Therapy in Hillsborough. Participants will receive \$40 for participation in two physical performance test sessions and up to \$200 for completing the exercise program.

Eligibility Criteria:

- If you are 65 years of age or older,
- in generally good health and able to perform physical exercise,
- able to ambulate at least 50 feet without physical assistance,
- have normal or corrected-to-normal vision and hearing and
- do not have musculoskeletal or cardiovascular disorders or diseases that would interfere with your participation.

Please contact James Chang, PT, MS at 919-966-9797 or 919-969-6691 or email [changsj@med.unc.edu](mailto:changsj@med.unc.edu) for more information.

This advertisement and the study described have been reviewed and approved by the Biomedical IRB # 05-2185 Formerly (05-AHS-700).

This email is sponsored by: Department of Allied Health Sciences

Campus-wide email (2<sup>nd</sup>)

We are conducting a research study at the University of North Carolina at Chapel Hill designed to investigate hip muscle strength and balance in older adults. A lateral trainer (The Skier's Edge Company, Park City, Utah 84060) an exercise device currently used in athletic training and sport rehabilitation, will be used to try to improve force production of the hip muscles in older adults who are found to be at increased risk of falling. One specific aim of the project is to compare amplitude and timing of lower extremity muscle activation and angular displacement of hip and knee joints during exercise on the lateral trainer and during performance of lateral step-up exercises.

We are looking for older adults with and without balance problems to participate in one session of exercises for the hip muscles, including lateral trainer exercises and lateral step-ups. Participants will receive \$20 for participation.

Eligibility Criteria:

- If you are 65 years of age or older,
- in generally good health and able to perform physical exercise,
- able to ambulate at least 50 feet without physical assistance,
- have normal or corrected-to-normal vision and hearing and
- do not have musculoskeletal or cardiovascular disorders or diseases that would interfere with your participation.

Please contact James Chang, PT, MS at 919-966-9797 or 919-969-6691 or email [changsj@med.unc.edu](mailto:changsj@med.unc.edu) for more information.

This advertisement and the study described have been reviewed and approved by the Biomedical IRB # 05-2185 Formerly (05-AHS-700).

This email is sponsored by: Department of Allied Health Sciences



## **Appendix C. Study Consent Forms**

### **University of North Carolina-Chapel Hill Consent to Participate in a Research Study Adult Subjects Biomedical Form**

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**IRB Study #** 05-2185 Formerly (05-AHS-700)  
**Consent Form Version Date:** 10/30/2006

**Title of Study:** Improving Lateral Stability in Older Adults at Risk of Falls

**Principal Investigator:** Shuo-Hsiu James Chang, PT, MS

**UNC-Chapel Hill Department:** Department of Allied Health Sciences

**UNC-Chapel Hill Phone number:** 966-9797

**Email Address:** changsj@med.unc.edu

**Faculty Advisor:** Vicki Mercer, PT, PhD

**Funding Source:** Section on Aging, American Physical Therapy Association; Injury Prevention Research Center, UNC-Chapel Hill; Smith Graduate Research Grant, UNC-Chapel Hill

**Study Contact telephone number:** 966-9797

**Study Contact email:** changsj@med.unc.edu

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#### **What are some general things you should know about research studies?**

You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

#### **What is the purpose of this study?**

The purpose of this research study is to investigate a new exercise program and evaluate if

we can improve the rate of force development of the hip muscles and balance in older adults. The exercise program involves use of a lateral trainer.

Older adults with and without balance problems will participate in a single test session to examine leg muscle activity and joint motion during lateral trainer exercises. All participants will then be tested to determine their eligibility for participating in a 10-week pilot exercise intervention. Those who are eligible will be assigned by chance to an exercise group or a control (no exercise) group.

You are being asked to be in the study because you are 65 years of age or older; in generally good health and able to perform physical exercise; and without musculoskeletal or cardiovascular disorders or diseases that would interfere with participation.

**Are there any reasons you should not be in this study?**

You should not be in this study if your weight is 200 lb or above, or you have any diagnosed neurological disease or disorders; terminal illness; joint replacement; acute back or extremity musculoskeletal problems (such as strains, sprains, or fractures), pain that will interfere with lower extremity exercises, unstable angina, myocardial infarction within the last six months, congestive heart failure within the last 12 months, unstable chronic obstructive pulmonary disease requiring 2 hospitalizations within the previous 12 months, uncontrolled hypertension, or uncontrolled diabetes mellitus.

**How many people will take part in this study?**

If you decide to be in this study, you will be one of approximately 50 people in this research study.

**How long will your part in this study last?**

You will participate in a single test session to examine leg muscle activity and joint motion that will last approximately 2 hours. If you are eligible to participate in the exercise program, you will attend two physical performance test sessions before and after the exercise program. These test sessions will last approximately 1 hour and 30 minutes. If you are in the exercise group, you will participate in an exercise intervention over a period of 10 weeks (2.5 months), with 3 sessions every week. Each exercise session will last approximately 45 to 60 minutes.

**What will happen if you take part in the study?**

**Screening and Baseline Testing**

You will be provided a private space for screening and baseline testing. You will complete a short questionnaire about your current health status and medical history. You will also complete the Six-Item Test, a cognitive screening test.

You will be asked to perform two balance tests called the Four Square Step Test and Single Limb Stance. For Four Square Step Test, you will step forward, backward and sideways to the right and left over canes that create 4 squares on the floor. You will be asked to try to face forward and step as fast as possible. For Single Limb Stance, you will be asked to stand on one foot with your eyes open for more than 5 seconds. These tests will be used to determine whether you are in the low-risk or the high-risk group.

You will be asked to complete the Modified Physical Activity Readiness Questionnaire (PAR-Q), a short questionnaire about your health status. You will be asked to provide the contact information of your primary physician. We will send the study information, your PAR-Q, and a letter to your physician requesting medical approval for you to participate.

#### Muscle activity and Joint Motion Testing

You will be asked to come to our laboratory one time to perform several sets of exercises. For this session, you will need to wear a swimming suit or shorts and the shoes that you wear for exercise, i.e. rubber sole athletic shoes. The shorts will be provided for you if you do not have them. Measurements of your height, weight, and the length of your thigh will be recorded. You will perform lateral body movements on the lateral trainer and step-ups onto a step placed on one side of your body. The researchers will demonstrate the movement to you and you will have time to practice. Reflective markers will be placed at various points on your spine, pelvis, and legs. Transducers, devices that collect muscle activity signals, will be placed on your legs to record activity of hip abductor and adductor muscles. You will be given rest periods, and will be able to rest at other times as needed. You will complete a questionnaire about your opinions of and responses to the exercises.

**If you are in the low-risk group, your participation in the study will end after this session.**

#### Group Assignment

Individuals in the high-risk group will be eligible to participate in the exercise program. If you are in the high-risk group, you will draw a piece of paper from a container to determine whether you will be in the exercise group or the control (no exercise) group. Regardless of your group assignment, you will be asked to come to the Center for Human Movement Science for physical performance testing before, midway through, and after the intervention period.

#### Physical Performance Testing (before, midway through, and after the intervention period)

You will complete a balance confidence questionnaire. You will then perform the following 5 tests:

- Four Square Step Test (as described above)
- Timed 360-degree turn. You will turn as quickly as possible in a complete circle while standing.
- Standing on one leg. You will attempt to hold one foot off the floor for up to a minute at a time with your arms folded across your chest. This test will be performed on either leg you prefer.
- Ten meter walk. You will walk about 60 feet at your comfortable and fast speeds.
- Hip muscle strength and rate of force development. You will lie on your back on a therapy table with your arms across your chest. You will be asked to push one leg straight out to the side as fast and as hard as possible, and to maintain this for approximately 3 seconds. A member of the research team will provide resistance to the push, so that you will not actually move your leg. This test will be performed on either leg you prefer.

You will draw slips of paper from a container to determine the order in which you will perform these 5 tests. A researcher will demonstrate the tests to you. You will be asked to remove your shoes and socks for all tests except the walking test. You will repeat each test 3 times, and you will be given rest periods between tests and at other times as needed.

#### *Control Group*

If you are in the control group, you will be asked to continue your current activities and NOT to enroll in any other exercise programs or training while participating in this study. One of the researchers will contact you every week to ask about your activity level. At the completion of the study, you will have an opportunity to receive EITHER 1) a handout with exercises you can perform at home, OR 2) the same exercise program that the exercise group received. If you choose to receive the exercise program, it will be performed as described below for the exercise group, except that information about your performance related to the exercise program will not be included as part of the study. You will not complete any additional physical performance testing or receive any payment in association with your participation in the exercise program.

#### *Exercise Group*

If you are in the exercise group, you will be asked to come to one of our exercise sites, Carolina Meadows (continuing care retirement facility), University Physical Therapy in Hillsborough or the Center for Human Movement Science in UNC-CH, 3 times a week for 10 weeks. The schedule for all exercise sessions will be made before the intervention starts based on your schedule and the availability of the exercise sites. Each exercise session will last approximately 45 minutes. You will be asked to perform warm-ups for 5 to 10 minutes, several periods of exercise on the lateral trainer for 12 to 15 minutes and cool-downs at the end of each session.

The researchers will demonstrate the warm-ups, movements on the lateral trainer and cool-downs at the first session and as needed. Your resting heart rate and blood pressure will be determined and used to calculate your maximal heart rate. You also will be taught to use the Borg scale as a measure of the intensity of the exercise. You will be asked to indicate your Borg scale scores periodically during the exercise. You will be given rest periods as needed based on your heart rate and Borg scale responses and at your request.

You will practice the lateral body movement on the lateral trainer at your comfortable speed and resistance at the first three sessions. At the third session, you will be asked to perform 10 cycles of the lateral body movement on the lateral trainer as fast as you can to calculate the maximal speed. You also will be asked to perform the movements against maximal resistance for a brief period of time. Your maximal speed and resistance will be measured periodically during the exercise program. The intensity of your exercise program will be gradually increased based on your ability. You will complete a questionnaire about your opinions of and responses to the exercises.

#### **What are the possible benefits from being in this study?**

Research is designed to benefit society by gaining new knowledge. The benefits to you from being in this study may be improvements in: bilateral lower extremity muscle strength and rate of force development, balance in standing (including single limb stance), ability to step

over obstacles, and walking speed. This study may benefit society by increasing knowledge about interventions for lateral instability (and associated limitations in performance of standing activities and gait) in older adults with balance problems.

**What are the possible risks or discomforts involved with being in this study?**

There are no unusual risks associated with participation in this study beyond those encountered in a typical physical therapy examination and intervention program. Risks include the risk of breach of confidentiality with respect to your participation in the study, the risk of a loss of balance or fall, the risk of muscle fatigue or slight muscle soreness, and the risk of cardiovascular stress.

To minimize the possibility of a serious loss of balance or fall, one of the researchers will stand close to each subject to provide support using a gait belt or contact guarding during all physical performance testing and during performance of standing exercises. Foam mats will be placed around the lateral trainer as well. The lateral trainer includes a balance bar at chest height to provide upper extremity support as needed. You may experience muscle fatigue immediately after testing or exercise, but this should resolve in a few minutes with rest. You also may experience mild muscle soreness in association with testing and/or exercise. To minimize the risk of muscle soreness, isometric contractions will be used for strength testing and concentric contractions will be emphasized in the exercise program. These types of muscle contractions are less likely to produce muscle soreness than eccentric contractions. The exercise program will be progressed gradually. To avoid undue stress on the cardiovascular system, the Borg scale and the heart rate reserve (HRR) method will be used to provide safety guidelines during exercise. In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

**What if we learn about new findings or information during the study?**

You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

**How will your privacy be protected?**

You will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

You will be provided a private place for consent form review, screening and baseline testing. You will be given an identification code, and will be identified by the code rather than your name in all presentations and publications. All identifying information and the coding system will be stored in a secure place. Only the investigators will have access to the coding system.

**What will happen if you are injured by this research?**

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

**What if you want to stop before your part in the study is complete?**

You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have not received approval from your physician, have had an unexpected reaction, have failed to follow instructions, or because the entire study has been stopped.

**Will you receive anything for being in this study?**

You will receive \$20 for taking part in the single test session to examine leg muscle activity and joint motion.

If you are in the high-risk group, you will receive \$10 for each of the 3 physical performance test sessions you attend and (FOR THE EXERCISE GROUP ONLY) \$5 for each of the 30 exercise sessions you attend. If you attend more than 25 exercise sessions, you will also receive a \$50 bonus at the end of the study period.

**Will it cost you anything to be in this study?**

There will be no costs to you for participating. However, costs of transportation will be at your own expense.

**What if you are a UNC employee?**

Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

**Who is sponsoring this study?**

This research is partially funded by the Section on Geriatrics, American Physical Therapy Association; the Injury Prevention Research Center, the University of North Carolina at Chapel Hill and Smith Graduate Research Grant, the University of North Carolina at Chapel Hill. The research team is not being paid by the sponsor for doing the study. The researchers do not have a direct financial interest with the sponsor or in the final results of the study.

**What if you have questions about this study?**

You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

**What if you have questions about your rights as a research subject?**

**Subject's Agreement:**

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Signature of Research Subject
Date

Signature of Person Obtaining Consent	Date
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Printed Name of Person Obtaining Consent

**HIPAA Authorization for Use and Disclosure of Health Information for Research  
Purposes  
University of North Carolina-Chapel Hill**

IRB Study # 05-2185 Formerly (05-AHS-700)

UNC-Chapel Hill Principal Investigator (Researcher):

Shuo-Hsiu James Chang, PT, MS

Division of Physical Therapy, Department of Allied Health Sciences, 3000 Bondurant Hall,  
CB# 7135, UNC-Chapel Hill, Chapel Hill, NC 27599-7135

This is a permission called a “HIPAA authorization.” It is required by “The Health Insurance Portability and Accountability Act of 1996” (known as “HIPAA”) for us to get information from your medical records or health insurance records to use in this research study.

---

1. If you sign this HIPAA authorization form you are giving your permission for the following people or groups to give the researchers certain information (described in #2 below) about you:

Any health care providers or health care professionals or health plans that have provided health services, treatment, or payment for you such as physicians and clinics, including but not limited to the UNC Health Care System.

2. If you sign this HIPAA authorization form, this is the health information about you that the people or groups listed in #1 may give to the researchers to use in this research study: Information about diseases or disorders that may prevent you from participating in an exercise program, such as cardiopulmonary disease or musculoskeletal disorders.

3. The people or groups listed in #1 on this form may give this health information to the researcher listed at the top of this form (UNC-Chapel Hill Principal Investigator) or to another researcher working on this research study. This information may also be shared with, used by or seen by the sponsor of the research study, the sponsor’s representatives, officials of the IRB, and certain employees of the university or government agencies if needed to oversee the research study.

4. The HIPAA rules that apply to your medical records will not apply to your information in the research study records. The informed consent document describes the procedures in this research study to protect your personal information. You can also ask the researchers any questions about what they will do with your personal information and how they will protect your personal information in this research study.

5. If you want to participate in this research study, you must sign this HIPAA authorization form to allow the people or groups listed in #1 on this form to have access to the information about you that is listed in #2 on this form. If you do not want to sign this HIPAA authorization form, you cannot participate in this research study but not signing the



authorization form will not change your right to treatment, payment, enrollment or eligibility for medical services outside of this research study.

6. This HIPAA authorization will stop when the study is completed.

7. You have the right to stop this HIPAA authorization at any time. HIPAA rules are that if you want to stop this HIPAA authorization, you must do that in writing. You may give your written stop of this HIPAA authorization directly to the people or groups listed in #1 on this form or you may give it to the researcher and tell the researcher to send it to any person or group the researcher has given a copy of this HIPAA authorization. Stopping this HIPAA authorization will not stop information sharing that has already happened.

8. You will be given a copy of this signed HIPAA authorization.

\_\_\_\_\_  
Signature of Research Subject

\_\_\_\_\_  
Date

\_\_\_\_\_  
Print Name of Research Subject

***For Personal Representative of the Research Participant (if applicable)***

Print Name of Personal Representative: \_\_\_\_\_

Please explain your authority to act on behalf of this Research Subject:

\_\_\_\_\_

*I am giving this permission by signing this HIPAA Authorization on behalf of the Research Participant.*

\_\_\_\_\_  
Signature of Personal Representative

\_\_\_\_\_  
Date

## Appendix D. Screening Questionnaire (Telephone and In-Person Interview)

Date:

ID Number

### Screening Questionnaire

Name: \_\_\_\_\_ Gender: Male Female Date of birth: \_\_\_\_\_

Phone number: (1) \_\_\_\_\_ (2) \_\_\_\_\_

Address: \_\_\_\_\_

Contact person's name: \_\_\_\_\_ Phone number: \_\_\_\_\_

Weight: \_\_\_\_\_ (exclude if over 200 lb)

**\*\* Six-item test: ask volunteer to remember these three items: apple, table, penny\*\***

How much difficulty do you have in walking by yourself for at least 50 ft?

No Difficulty      Some Difficulty      **Unable to Do**

Have you ever had a hip or knee joint replacement? (exclude if Y)      Y      N

Do you have a terminal illness?(exclude if Y)      Y      N

Do you have a diagnosed neurological disorder such as stroke or Parkinson's disease?  
Y      N

If yes, please describe: (exclude if Y)

Are you limited in doing daily activities because of pain?      Y      N

If yes, please describe: (exclude if Y)

Are you limited in doing daily activities because of problems with your back or legs?  
Y      N

If yes, please describe: (exclude if Y)

Have you been limited in doing daily activities because of any cardiopulmonary disorder?

Y      N

If yes, please describe: **(exclude if have angina, myocardial infarction, congestive heart failure Heart failure within last 12 months, 2 or more hospital stay because of pulmonary diseases within last 12 months, Uncontrolled high blood pressure or high blood sugar.)**

With both eyes open, can you see light?      Y  
N

At the present time, would you say your eyesight, with glasses or contact lenses if you wear them is:

Excellent      Good      Fair      **Poor**      **Very poor**

Which statement best describes your hearing?

My hearing is good I have a little trouble hearing **I have a lot of trouble hearing**  
During the past 6 months, have you had difficulty with falling? Y N  
If yes, please describe how many times you have fallen and under what circumstances:

In the past 30 days, how often did you do physical activity or exercise? Y N  
Please describe:

### Medical History (after consent)

Have you had any surgeries? Y N  
If yes, please describe:

Are you currently taking any medications? Y N  
If yes, please list.

### Screening Tests (after consent)

#### Six Item Test:

ORIENTATION: What is the (day of the week) (month)(year)? \_\_\_\_/3

RECALL: Ask for the 3 objects repeated above.(apple, table, penny) \_\_\_\_/3  
(Give 1 point for each correct answer)

#### Four Square Step Test:

Trial 1:

Trial 2:

→At risk of falls: Y ( $\geq 15$  sec: High risk group) N ( $< 15$  sec: Low risk group)

Single Limb Stance: \_\_\_\_\_ sec, 1 trial only

→At risk of falls: Y ( $< 5$  sec: High risk group) N ( $\geq 5$  sec: Low risk group)

Subject in: **High Risk** (Either or Both)  
**Low Risk** (None)

Primary Physician contact information:

Name: \_\_\_\_\_ Location: \_\_\_\_\_

Phone number: \_\_\_\_\_ Address: \_\_\_\_\_

## Appendix E. Modified Physical Activities Readiness Questionnaire (PAR-Q)

Name	Date
------	------

Regular exercise is associated with many health benefits; however, any change of activity may increase the risk of injury. Completion of this questionnaire is a first step when planning to increase the amount of physical activity in your life. Please read each question carefully and answer every question honestly:

Yes	No	1) Has a physician ever said you have a heart condition and you should only do physical activity recommended by a physician?
Yes	No	2) When you do physical activity, do you feel pain in your chest?
Yes	No	3) When you were not doing physical activity, have you had chest pain in the past month?
Yes	No	4) Do you ever lose consciousness or do you lose your balance because of dizziness?
Yes	No	5) Do you have a joint or bone problem that may be made worse by a change in your physical activity?
Yes	No	6) Is a physician currently prescribing medications for your blood pressure or heart condition?
Yes	No	7) Are you pregnant?
Yes	No	8) Do you have insulin dependent diabetes?
Yes	No	9) Do you know of any other reason you should not exercise or increase your physical activity?

If you answered yes to any of the above questions, talk with your doctor BEFORE you become more physically active. Tell your doctor your intent to exercise and to which questions you answer yes.

If you honestly answered no to all questions you can be reasonably positive that you can safely increase your level of physical activity **gradually**.

If your health changes so you then answer yes to any of the above questions, you should notify the researchers and seek guidance from a physician.

Participant signature	Date
-----------------------	------

\* Adapted from [www.exrx.net](http://www.exrx.net)

## Appendix F. Request for Medical Approval Form

Dear Dr. \_\_\_\_\_,

One of your patients, (Patient's Name) , has expressed interest in participating in a research study we are conducting at the University of North Carolina at Chapel Hill. The study examines a novel exercise intervention, involving use of a ski simulator, which is designed to improve the rate of force development (RFD) of the hip muscles and lateral stability in older adults with impaired balance. A brief description of the study is provided below. If you believe there are no significant medical contraindications for the patient's participation, **please indicate your approval by signing the accompanying form.** The patient may return the form to me prior to his or her participation in our intervention. You may also mail the form using the accompanying stamped, self-addressed envelope.

Volunteers will be randomly assigned to either an exercise group or control (no exercise) group. Each volunteer's participation in the study will last for a total of approximately 10 weeks including two testing sessions (pre- and post- intervention). The exercise sessions will be scheduled three times a week with each session lasting a maximum of 45 minutes. The exercise and testing sessions will be conducted at the Center for Human Movement Science at UNC-Chapel Hill and/or at University Physical Therapy in Hillsborough, NC.

### Testing:

- Hip abductor muscle strength and rate of force development
- Four Square Step Test
- Single limb stance
- Timed 360° turn
- Ten-meter walk
- Balance confidence

### Intervention:

If your patient is in the exercise group, he/she will attend approximately 30 exercise sessions. The exercise program is designed to increase the strength and rate of force development of muscle groups that control movement in the frontal plane. It includes several periods of exercise on the Dynamic Edge® RPM™ machine (Skier's Edge Co., Park City, UT). The duration of each exercise period will be adjusted in accordance with the participant's abilities and tolerance, to a maximum of 12 consecutive minutes. Speed requirements and/or amount of resistance for each exercise will be increased gradually in accordance with the participant's abilities. The participants will perform warm-up and cool-down exercises such as stretching exercises and treadmill walking (or stationary bike riding). To avoid undue stress on the cardiovascular system, the Borg scale and the heart rate reserve (HRR) method will be used to provide safety guidelines during exercise.

The study has been approved by the Committee on the protection of the Rights of Human Subjects at The University of North Carolina at Chapel Hill. There are no unusual risks associated with participation in this study beyond those encountered in a typical clinical balance examination and intervention program.

### Control Group:

Subjects assigned to the control (no exercise) group will be asked to continue their

current activity levels and to refrain from enrolling in any other exercise programs or training during the time of their participation in this study.

Please do not hesitate to contact me at 966-9797 if you have any questions about the study. Thank you very much for your assistance.

Sincerely,

James Chang, PT, MS

(Patient's Name) has medical clearance for participation in the study "Improving Lateral Stability in Older Adults at Risk of Falls" being conducted by Shuo-Hsiu James Chang, PT, MS at the University of North Carolina at Chapel Hill.

---

Physician's signature

---

Date

## Appendix G. Post-Exercise Questionnaire for Project I

### Post-Exercise Questionnaire (Project I)

Please complete this questionnaire to give us feedback about the three hip muscle exercises you did today.

#### **Instructions:**

Use the following response codes to indicate your level of agreement or disagreement with each statement below. Circle the number corresponding to your response.

**1:** Strongly Disagree; **2:** Disagree; **3:** Neutral; **4:** Agree; **5:** Strongly Agree.

#### **Statements:**

- |  |   |   |   |   |   |
|--|---|---|---|---|---|
| 1. Lateral trainer exercise is easy to perform.  | 1 | 2 | 3 | 4 | 5 |
| 2. Side leg raise exercise is easy to perform.   | 1 | 2 | 3 | 4 | 5 |
| 3. Lateral step-up exercise is easy to perform.  | 1 | 2 | 3 | 4 | 5 |
| 4. Lateral trainer exercise is interesting.  | 1 | 2 | 3 | 4 | 5 |
| 5. Side leg raise exercise is interesting.   | 1 | 2 | 3 | 4 | 5 |
| 6. Lateral step-up exercise is interesting.  | 1 | 2 | 3 | 4 | 5 |
| 7. Regular lateral trainer exercise would improve my balance and/or hip muscle strength. | 1 | 2 | 3 | 4 | 5 |
| 8. Regular side leg raise exercise would improve my balance and/or hip muscle strength.  | 1 | 2 | 3 | 4 | 5 |
| 9. Regular lateral step-up exercise would improve my balance and/or hip muscle strength. | 1 | 2 | 3 | 4 | 5 |



## Appendix H. Telephone Interviews for Control Group

### Telephone Interviews for Control Group

Subject ID: \_\_\_\_\_.

To assess for adherence to the experimental protocol, contact control group subjects by phone once every week and ask the following:

**Question: Have you done any new physical activities or exercises in the past week that you were not doing before you enrolled in this study?**

Week 0 – Week 1 (date: \_\_\_\_\_) Y N

If yes, please describe and indicate the reason:

Week 1 – Week 2 (date: \_\_\_\_\_) Y N

If yes, please describe and indicate the reason:

Week 2 – Week 3 (date: \_\_\_\_\_) Y N

If yes, please describe indicate the reason:

Week 3 – Week 4 (date: \_\_\_\_\_) Y N

If yes, please describe and indicate the reason:

Week 4 – Week 5 (date: \_\_\_\_\_) Y N (5<sup>th</sup>-week assessment)

If yes, please describe and indicate the reason:

Week 5 – Week 6 (date: \_\_\_\_\_) Y N

If yes, please describe and indicate the reason:

Week 6 – Week 7 (date: \_\_\_\_\_) Y N

If yes, please describe and indicate the reason:

Week 7 – Week 8 (date: \_\_\_\_\_) Y N

If yes, please describe and indicate the reason:

Week 8– Week 9 (date: \_\_\_\_\_) Y N

If yes, please describe and indicate the reason:

Week 9 – Week 10 (date: \_\_\_\_\_) Y N (post-intervention

If yes, please describe and indicate the reason: assessment)

## **Appendix I. Borg (Rating of Perceived Exertion) Scale**

### **Borg Scale**

- 6 - 20% effort - Very, very light (Rest)
- 7 - 30% effort
- 8 - 40% effort
- 9 - 50% effort - Very light - gentle walking
- 10 - 55% effort
- 11 - 60% effort - Fairly light
- 12 - 65% effort
- 13 - 70% effort - Moderately hard - steady pace
- 14 - 75% effort
- 15 - 80% effort - Hard
- 16 - 85% effort
- 17 - 90% effort - Very hard
- 18 - 95% effort
- 19 - 100% effort - Very, very hard
- 20 - Exhaustion

## **Appendix J. Exercise program Feedback Questionnaire for Project II**

### Exercise Program Feedback Questionnaire (Project II)

Please complete this questionnaire to give us feedback about the exercise program.  
Place a check mark on the line at the point that best describes your answer.

1. How much did you enjoy this exercise program?

Not at all | \_\_\_\_\_ | Very interesting

2. How easy is this exercise for you to perform?

Very difficult | \_\_\_\_\_ | Very easy

3. How much did this exercise help your hip muscle strength?

Not at all | \_\_\_\_\_ | Very much

4. How much did this exercise help your balance?

Not at all | \_\_\_\_\_ | Very much

5. How likely would you be to continue this exercise if the ski simulator was available for your use?

Not likely at all | \_\_\_\_\_ | Very likely

6. Other comments/suggestions:

## Appendix K. Activities-specific Balance Confidence (ABC)

### Balance Confidence

The Activities-specific Balance Confidence (ABC) Scale\*

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

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

“How confident are you that you will not lose your balance or become unsteady when you...

...walk around the house? \_\_\_\_%

...walk up or down stairs? \_\_\_\_%

...bend over and pick up a slipper from the front of a closet floor \_\_\_\_%

...reach for a small can off a shelf at eye level? \_\_\_\_%

...stand on your tiptoes and reach for something above your head? \_\_\_\_%

...stand on a chair and reach for something? \_\_\_\_%

...sweep the floor? \_\_\_\_%

...walk outside the house to a car parked in the driveway? \_\_\_\_%

...get into or out of a car? \_\_\_\_%

...walk across a parking lot to the mall? \_\_\_\_%

...walk up or down a ramp? \_\_\_\_%

...walk in a crowded mall where people rapidly walk past you? \_\_\_\_%

...are bumped into by people as you walk through the mall? \_\_\_\_%

... step onto or off an escalator while you are holding onto a railing? \_\_\_\_%

... step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? \_\_\_\_%

...walk outside on icy sidewalks? \_\_\_\_%

\*Powell, LE & Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol Med Sci* 1995; 50(1): M28-34