AN ABSTRACT OF THE THESIS OF

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Abstract approved:

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Falls are a common problem among older adults, including those who are relatively healthy and living independently. Exercise has been recommended as an intervention to reduce falls by slowing and/or reversing age-related declines in balance, strength, and mobility. However, it remains unclear which types or combinations of programs are most effective. The objective of this study was to investigate whether exercise programs performed by healthy older adults were associated with superior balance, strength, and functional mobility measures that are pertinent to fall prevention.

This study compared three distinct groups: participants of a balance- and strength-focused training program (i.e., Better Bones and Balance®), participants engaged in a general walking program, and sedentary individuals. Balance was measured using the Sensory Organization Test composite score and sensory ratios. Isometric strength of the lateral hip stabilizers (i.e., abductors and adductors) was measured in terms of maximum voluntary contraction and rapid torque production. Rapid torque measures included contractile impulse and rate of torque development evaluated at 0-100 ms and 0-300 ms from contraction onset. Functional mobility was measured by the time to complete the Four Square Step Test.

Hip abduction contractile impulse (0-300 ms) was 1.905 Nm*s and 1.539 Nm*s higher for the Better Bones and Balance (BBB) group compared to the walking and sedentary groups, respectively. No differences were found among the groups for any of the hip adduction torque measures or Sensory Organization Test balance scores. The BBB group completed the Four Square Step Test faster than the walking and sedentary groups by 0.90 s and 1.06 s, respectively. In conclusion, participation in the balance- and strength-focused training program was associated with superior performance in some measures of strength and functional mobility that may be important for fall prevention.

Evaluating Balance and Strength of Older Women in Exercise Programs

by
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APPROVED:

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Melanie Dinger, Author

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CHAPTER 1

GENERAL INTRODUCTION

A fall occurs at least once per year in approximately one-third of community-dwelling adults over the age of 65 (Blake et al., 1988). Hip fracture is one of the most serious fall-related injuries, considering that approximately 25% of those injuries result in death within the following year (Johnell & Kanis, 2005; Kanis et al., 2003). Lateral falls are of particular concern because the risk of experiencing a hip fracture increases 3.3 to 5.7 fold relative to falls occurring in the sagittal plane (Greenspan et al., 1994; Nevitt & Cummings, 1993). Age-related declines in balance, muscle strength, and mobility are intrinsic risk factors that may be partially responsible for the higher fall rates observed in older individuals.

A recent model proposed by Horak et al. (2009) suggests that there are six interacting components of balance: (1) biomechanics, (2) verticality and limits of stability, (3) anticipatory postural adjustments, (4) reactive postural responses, (5) sensory orientation, and (6) stability in gait. These components are based on specific neurophysiological systems which may require different methods of training and evaluation (Horak et al., 2009). The sensory orientation component is responsible for establishing awareness of the body's position in space. In order to do this, the temporoparietal cortex of the central nervous system integrates somatosensory, visual, and vestibular inputs and shifts reliance to those sensory systems that have provided accurate information. Declines in these contributing systems can occur with age, even in the absence of known pathologies (Horak, Shupert, & Mirka, 1989). Through use of computerized dynamic posturography, less stability has been observed in older adults in comparison to younger adults (Cohen, Heaton, Congdon, & Jenkins, 1996), especially during conditions requiring greater reliance on vestibular input (Whipple, Wolfson, Derby, Singh, & Tobin, 1993).

Rapid declines in muscle torque and power have been observed in individuals over the age of 50, but power has been found to decline at higher rates, especially in individuals above age 65 (Macaluso & De Vito, 2004). Reduced muscle power has been associated with impaired functional performance in tasks such as stair climbing, rising from a chair, and walking (Macaluso & De Vito, 2004) and may also be associated with falls (Skelton, Kennedy, & Rutherford, 2002). Explosive power is the product of muscle torque and movement speed, and thus, rapid generation of muscle torque is an important contributor (Ratamess et al., 2009). Age-related declines in maximal torque production and rate of torque development have been observed in the lateral hip stabilizers (Johnson, Mille, Martinez, Crombie, & Rogers, 2004; Murray & Sepic, 1968) and likely contributes to lateral instability and higher fall rates observed in older individuals (Hilliard et al., 2008).

Rapid stepping is an aspect of functional mobility that is important for balance recovery. Older individuals have demonstrated longer step times relative to the young in response to perturbation during side and forward balance recovery (Mille, Johnson, Martinez, & Rogers, 2005; Rogers, Hedman, Johnson, Cain, & Hanke, 2001). More importantly, longer step times have been observed in fallers relative to non-fallers during forward balance recovery (Mille et al., 2005) and voluntary stepping (Brauer, Burns, & Galley, 2000). While the implications are not fully understood, a longer step time means a longer period of single leg support, which may further increase the challenge to lateral stability.

Exercise has been recommended as an intervention to reduce falls by slowing and/or reversing age-related declines in balance, strength, and mobility (Rose, 2008; Sherrington et al., 2008). Some interventions have adopted a general approach that simply increases physical activity, such as a walking program; others have been tailored to address specific risk factors, such as balance and/or strength training activities (Rose, 2008). Recent meta-analyses provide strong evidence that exercise can reduce falls by 14 to 37% in older adults (Chang et al., 2004; Gillespie et al., 2009; Sherrington et al., 2008). However, it remains unclear which types or combinations of programs are most effective, especially in relatively healthy individuals.

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CHAPTER 2

EVALUATING BALANCE AND STRENGTH OF OLDER WOMEN IN EXERCISE PROGRAMS

2.1 Introduction

A fall occurs at least once per year in approximately one-third of community-dwelling adults over the age of 65 (Blake et al., 1988). Hip fracture is one of the most serious fall-related injuries, considering that approximately 25% of those injuries result in death within the following year (Johnell & Kanis, 2005; Kanis et al., 2003). Lateral falls are of particular concern because the risk of experiencing a hip fracture increases 3.3 to 5.7 fold relative to falls occurring in the sagittal plane (Greenspan et al., 1994; Nevitt & Cummings, 1993). The growing population of older adults continues to make prevention of falls and fractures a relevant public health concern.

Exercise interventions are recommended to reduce falls by slowing and/or reversing balance, strength, and mobility declines associated with increasing age (Rose, 2008; Sherrington et al., 2008). Some interventions have adopted a general approach that simply increases physical activity, such as a walking program, while others have been tailored to address specific risk factors, such as balance and/or strength training activities (Rose & Hernandez, 2010). Recent meta-analyses provide strong evidence that exercise can reduce falls by 14 to 37% in older adults (Chang et al., 2004; Gillespie et al., 2009; Sherrington et al., 2008). However, it remains unclear which types or combinations of programs are most effective, especially in relatively healthy individuals (Rose & Hernandez, 2010).

While it is generally agreed upon that balance training is effective for fall prevention (Gillespie et al., 2009; Sherrington et al., 2008), there are multiple components of balance, requiring specific methods of training and measurement (Horak, Wrisley, & Frank, 2009). One important aspect of balance is sensory orientation, which establishes awareness of the body's position in space. In order to do this, the central nervous system integrates somatosensory, visual, and vestibular inputs and shifts reliance based on the accuracy of the information. Declines in these contributing sensory systems can occur with age, even in the absence of known pathologies (Horak, Shupert, & Mirka, 1989). Information regarding the effects of specific exercise programs on this crucial aspect of balance in healthy older adults is generally lacking.

In theory, strengthening muscles of the lower extremity should reduce falls, but the effectiveness of resistance training programs remains unclear. This may be due to differing training protocols in regards to the muscle groups targeted, intensity, volume, or speed of movement. Many exercise programs have focused on strengthening lower extremity muscles (e.g. knee and hip flexors and extensors) but may not have concurrently targeted the important lateral stabilizers. Reduced hip abductor and adductor torque production has been observed in older individuals (Johnson, Mille, Martinez, Crombie, & Rogers, 2004; Murray & Sepic, 1968) and likely contributes to greater lateral instability and incidence of falls (Hilliard et al., 2008). Rapid torque production of these muscles may be more relevant to fall prevention than maximum torque production. Because balance recovery occurs very quickly, there may not be enough time to generate maximum torque (Schultz, 1995). Although not yet reported for hip abductors and adductors, other muscle groups require more than 300 ms to generate maximum torque (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002), and the time may be even longer for older adults relative to the young (Mille, Johnson, Martinez, & Rogers, 2005). Studies of balance recovery suggest that the time critical period for producing lateral hip torque may be within 300 ms (Mille et al., 2005; Rogers, Hedman, Johnson, Cain, & Hanke, 2001). Exercise interventions associated with greater rapid torque development, especially in the lateral hip stabilizers, may be more effective in preventing falls.

Stepping rapidly is an aspect of functional mobility that is crucial for fall prevention and impairment may be associated with increasing age. Older individuals have demonstrated longer step times during side and forward balance recovery relative to the young (Mille et al., 2005; Rogers et al., 2001). More importantly, fallers have demonstrated longer step times relative to non-fallers during forward balance recovery (Mille et al., 2005) and also during voluntary stepping (Brauer, Burns, & Galley, 2000). The Four Square Step Test evaluates this aspect of functional mobility by measuring the time to complete a multi-directional stepping sequence. It has previously differentiated non-fallers, single-fallers, and multiple-fallers in a population of healthy older adults, and longer times have been associated with greater fall frequency (Dite & Temple, 2002). Exercise interventions that are associated with faster stepping performance may be more effective in preventing falls.

The objective of this study was to investigate whether exercise programs performed by healthy older adults were associated with superior balance, strength, and functional mobility measures that are pertinent to fall prevention. Specifically, this study compared participants of a balance- and strength-focused training program (i.e., Better Bones and Balance®), participants of a general walking program, and a group of sedentary individuals. The overall goal was to illuminate key differences based on the sensory orientation component of balance, rapid and maximum torque production of the lateral hip stabilizers, and rapid multi-directional stepping.

2.2 Methods

2.2.1 Participants

A total of 43 healthy, community-dwelling, adult women between the ages of 64 and 75 years were included in this study. Individuals were eligible to participate if they were able to perform normal activities of daily living (e.g., bathing and dressing) and could walk without a cane or walker. Individuals were excluded if they had diagnosed balance impairments, were currently taking four or more prescription medications or medications known to affect balance, had documented peripheral neuropathy, were currently undergoing cancer treatment or had received treatment within the past year, or had experienced a hip fracture or lower-extremity joint replacement. Participants also met the inclusion criteria for one of the following three groups:

- Balance and Strength Training Group (Better Bones and Balance®)

  - Considers Better Bones and Balance® (BBB) to be her primary form of physical activity.
  - Attended BBB classes for 2.5 hours each week, on average, during the previous six months.
  - Did not take any breaks from BBB classes that exceeded a total of four weeks during the previous six months. This included the scheduled two-week break between class terms.
- Walking Group
  - Considers walking to be her primary form of physical activity.
  - Walked for fitness for 2.5 hours each week, on average, in minimum bouts of 10 minutes, during the previous six months.
  - Walked at an intensity that noticeably increased breathing and/or heart rate throughout each walking session.
  - Did not take any breaks from walking that exceeded a total of four weeks during the previous six months.
- Sedentary Group
  - Performed, on average, less than one hour of physical activity each week during the previous six months that noticeably increased breathing and/or heart rate.

Recruitment occurred mainly by (1) posting fliers at local businesses and public places visited by seniors, (2) contacting individuals who had previously expressed interest in research participation through the OSU Center for Healthy Aging

Research LIFE Registry, and (3) giving brief presentations to organized groups (e.g., Better Bones & Balance® classes, religious organizations, local senior center classes, knitting groups, etc.). During the period of recruitment, at least one presentation was given to each Better Bones & Balance® class that was offered through Linn-Benton Community College. The study was approved by the Oregon State University Institutional Review Board, and all subjects provided informed consent (Appendix 2) prior to participation.

2.2.2 Procedures

Individuals came to the Sports Medicine and Disabilities Lab at Oregon State University for testing. Written consent was obtained upon arrival and prior to testing. The screening questionnaire (Appendix 3) was initially completed by phone, and eligibility was re-confirmed at the test session. Next, the participant filled out a health history questionnaire which ascertained recent fall history, comorbidities, and current medications (Appendix 4). Leg dominance was determined using a ball-kick test. Height and weight were measured with shoes removed. The individual then performed balance, strength, and functional mobility tests, with the same order occurring for all participants.

2.2.2.1 Sensory Organization Test

The Sensory Organization Test (SOT) using computerized dynamic posturography represents a gold standard for measuring sensory contribution to balance control (Mancini & Horak, 2010). The SOT was performed using a SMART Balance Master® System (Neurocom International Inc., Clackamas, Oregon) to measure ability of the central nervous system to reweight sensory input (i.e., somatosensory, visual, and vestibular) in response to missing or misleading information. The participant removed her shoes and was positioned in a safety harness attached securely to the equipment's structural frame (Figure 1). The participant's feet were properly aligned on the force platform according to her height. Instructions were given to stand quietly while looking straight ahead and to keep her arms at her sides. During the test, the participant's goal was to stand as steadily as possible without stepping or falling. Center of gravity sway was measured by the force platform during six unique conditions (Table 1). The first was a baseline condition in which all sensory information was available and accurate. As the conditions progressed, sensory information was systematically altered by asking the participant to keep her eyes closed, allowing the platform to rock, and/or allowing the wall enclosure around the participant (i.e., "visual surround") to move.

Three trials of each condition were performed, with each trial lasting 20 seconds. The testing order was sequential (i.e., all three trials of condition one were performed followed by all three trials of condition two, etc.). If the participant fell, took a step, or touched the wall, frame, or harness straps to regain balance, the trial was marked as a loss of balance. If the participant's feet moved slightly from the proper position but no step was taken, the trial was discarded and repeated. A maximum of five trials per condition was performed.

Each trial received an equilibrium score, which indicated the amount of anterior-posterior sway relative to the expected limits of stability. The equilibrium score was calculated by the Neurocom software using the following equation

$$Equilibrium\ score = \frac{12.5° - (\theta_{max} - \theta_{\min})}{12.5°} \times 100$$

where 12.5º represents the normal limits of sway and $(\theta_{max} - \theta_{min})$ is the participant's maximum sway amplitude during the trial. Equilibrium scores may range from zero to 100, with 100 representing high stability (i.e., no sway) and zero representing a loss of balance. Condition averages, referred to as $C1^{ES}$ through $C6^{ES}$, were calculated as the average of the three equilibrium scores. Three sensory ratios were calculated based on a specific condition average relative to the baseline (i.e., Condition 1) average. The somatosensory (SOM), visual (VIS), and vestibular (VEST) ratios measured ability to shift reliance and effectively use input from the somatosensory, visual, and vestibular systems, respectively. A higher ratio (closer to 1.0) indicated more effective use of the sensory system when other sensory inputs were missing or misleading. The composite equilibrium score, representing an overall balance score, was also reported. A higher composite score (closer to 100%) indicates greater stability. Table 2 presents the calculation for each measured variable.

2.2.2.2 Four Square Step Test

The Four Square Step Test measured an individual's ability to transfer weight and to step rapidly in multiple directions (Dite & Temple, 2002) through a grid of four squares (Figure 2) The grid was constructed from one-inch diameter PVC piping. Each square was approximately one square meter. The grid was wrapped in blue painter's tape to provide contrast against the white lab floor. It was secured to the floor at the four ends with clear packaging tape.

Prior to testing, a gait belt was secured around the participant's waist, which was held only in the event that the participant began to appear unstable during the test. A researcher demonstrated the step sequence. The participant was allowed to position herself, standing anywhere within the first square. She was asked to step as quickly as possible without contacting the grid, first in a clockwise direction and then in a counterclockwise direction (Figure 3). The participant was asked to remain facing forward during the step sequence if possible. Both feet were required to make contact with the floor in each square before moving to the next square. The test was scored by the time taken to complete the entire sequence.

One practice trial and two timed trials were completed. A trial was repeated if the subject failed to complete the sequence successfully or made contact with the grid. A maximum of five trials was performed. The faster of the two successful timed trials was used for analysis.

2.2.2.3 Hip Strength Measurement

Isometric hip abductor and adductor strength of the dominant leg were measured using a Biodex System 3 Dynamometer (Biodex Medical Systems Inc., Shirley, New York). The individual stood facing the dynamometer (Figure 4) with the dynamometer's axis of rotation aligned to the hip joint center of the participant's dominant leg. The attachment of the dynamometer was secured just above the knee and the femur was positioned at 15 degrees of abduction (Johnson et al., 2004).

The testing order for the muscle groups was randomly determined in advance of testing. The participant was instructed to "push" (i.e., abduct) or "pull" (i.e., adduct) against the attachment, depending on which muscle group was being tested. Once the participant was in proper position, she was to remain at rest in the position until the verbal cue was given to contract. The researcher began recording data approximately 1 second prior to verbal instruction to ensure that a baseline resting value could be established. When the verbal cue was given, the participant pushed or pulled as hard and fast as she could. To promote maximal effort, the participant received verbal encouragement from the researcher and real-time visual feedback of her force generated across time.

Three trials were performed for each muscle group. Each trial lasted approximately 5 seconds with 60 seconds of rest between trials. A trial was repeated if the individual did not maintain proper alignment (i.e., noticeable trunk rotation occurred in the frontal plane or gross misalignment of the hip joint center and the axis of rotation was observed), there was an initial countermovement (i.e., the individual pushed or pulled the wrong way initially), or there was a recording error. No more than five trials were collected per muscle group. After completion of the first muscle group, the individual was given the opportunity to rest for approximately 5 minutes. The individual was encouraged to walk around or to sit comfortably in a chair. Following the break, the individual was repositioned for testing of the other muscle group.

Torque data were recorded using a BIOPAC data acquisition system interfaced with AcqKnowledge Software (BIOPAC Systems, Inc; Goleta, CA) at a sampling frequency of 2000 Hz. The data were further processed using a customized MATLAB program (version R2011b, MathWorks, Natick, MA). The MATLAB program is documented in Appendix 5.

The torque data from each trial were digitally low-pass filtered using a fourth-order, zero lag, Butterworth filter with a cutoff frequency of 8 Hz. Abduction of a dominant right leg or adduction of a dominant left leg required the data to be reversed (i.e., multiplied by negative one). The torque data was then “zeroed” by removing the initial static offset due to the resting weight of the participant’s leg. Maximum voluntary contraction (MVC) was recorded as the peak torque during a trial. Rapid torque production measures (i.e., rate of torque development [RTD] and contractile impulse) from the onset of contraction to specified time points were calculated. The onset of contraction was defined as the point in time at which the torque reached a small percentage (i.e., 2.5%) of the MVC (Aagaard et al., 2002). RTD was defined as the average slope of the torque-time curve over a specified time interval (Aagaard et al., 2002). RTD was calculated using the following equation.

$$RTD = \frac{Torque_{final} - Torque_{onset}}{time_{final} - time_{onset}}$$

Impulse was defined as the area under the torque-time curve over a specified time interval. Impulse is given by the following integral equation.

$$\int_{t=onset}^{t=final} Torque\, dt$$

The integral was approximated using the trapezoidal summation technique (Chapra & Canale, 1998). A representative torque-time curve is shown in Figure 5 to illustrate MVC, RTD, and impulse. RTD and impulse were evaluated across 0-100 ms and 0-300 ms time intervals.

Trials were excluded if a 500 ms baseline just prior to contraction onset could not be determined. Large initial counter-movement (i.e., initial fluctuation with amplitude greater than the onset torque) was the most common reason that a baseline resting value could not be established. Figure 6 shows an example of an acceptable and unacceptable hip strength trial for one participant. Trials were also excluded if the individual did not maintain the contraction for approximately 5 seconds. For each strength measure, the highest value of the three trials was used for statistical analysis

(Andersen, Andersen, Zebis, & Aagaard, 2010), since maximum capability was of greater interest than average performance.

2.2.3 Statistical Analysis

Subject characteristics and measured outcome variables of the balance and strength testing were compared among the three groups using R, version 2.12.1 (The R Foundation, Vienna, Austria) unless otherwise noted. Assumptions of the statistical tests were checked prior to conducting any group comparisons. The Levene test (Kuehl, 2000) and residuals plots were used to assess homogeneity of group variances. Normal quantile-quantile plots were used to assess normality. Variables were log transformed if transformation improved normality or homogeneity of variances assumptions.

Subject characteristics were compared among group using one of three methods: (1) One-way analysis of variance (ANOVA) when data met the assumptions of homogenous variance and normal distribution, (2) the non-parametric Kruskal-Wallis test when data deviated from normal distribution, and (3) Welch's one-way ANOVA when variances were not homogeneous. Post hoc testing was performed when a difference among groups was detected using (1) The Tukey HSD test when group variances were homogeneous or (2) The Games-Howell test when group variances were not homogeneous. The Games-Howell test was performed using SPSS Statistical Software version 19 (IBM, Armonk, New York).

Group differences for balance and strength measures were evaluated using linear regression analysis. Linear regression was selected over one-way ANOVA to allow for more precise estimates by partitioning error sums of squares to covariates that may have influenced the response variable. Previous researchers have suggested that sensory orientation balance measures (Cohen, Heaton, Congdon, & Jenkins, 1996) and strength of the lateral hip stabilizers (Johnson et al., 2004) decline with age. It has also been suggested that individuals with greater body mass may possess more muscle mass than smaller individuals, which could bias strength measures (Jaric, Mirkov, & Markovic, 2005; Jaric, 2002). It was unclear how body mass might influence the Four Square Step Test times, since greater body mass may be an advantage due to association with greater muscle strength or a disadvantage due to greater force required to accelerate or decelerate the body while changing directions. The full models are shown below. Indicator variables, *BBB* and *Walk*, were used to represent the *Group* variable. The Better Bones and Balance® group is represented by {*BBB* = 1 and *Walk* = 0}, the Walking group is represented by {*BBB* = 0 and *Walk* = 1}, and the Sedentary group is represented by {*BBB* = 0 and *Walk* = 0}.

Full Model for SOT Variables:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_3 Age + \beta_5 BBB \times Age + \beta_6 Walk \times Age$$

Full Model for FSST Variable:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_3 Age + \beta_4 Mass + \beta_5 BBB \times Age + \beta_6 Walk \times Age + \beta_7 BBB \times Mass + \beta_8 Walk \times Mass$$

Full Model for Hip Strength Variables:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_3 Age + \beta_4 Mass + \beta_5 BBB \times Age + \beta_6 Walk \times Age + \beta_7 BBB \times Mass + \beta_8 Walk \times Mass$$

The full model for each variable was systematically reduced to a final model by conducting F-tests to determine significant variables (p-value < 0.05). The final regression models are presented in Appendix 6 along with corresponding coefficient and ANOVA output tables. Group models based on the final model were used to determine group differences. When interactions were not present, 95% confidence intervals were calculated, indicating whether group differences were significant. If the final model included *Group* only (i.e. age and/or mass were not significant), the presence of a group difference was tested using a one-way ANOVA or Welch's one-way ANOVA, dependent on whether group variances were homogeneous.

2.3 Results

2.3.1 Subject Characteristics

Subject characteristics are presented in Table 3. No differences were found among groups for any of the variables except total physical activity performed in the previous 6 months. Figure 7 presents the average physical activity partitioned by type for each group. By group definition, the total physical activity performed by the sedentary group was significantly lower than the exercise groups ($p < 0.001$). No difference was found between the BBB and walking groups ($p = 0.12$). Although no difference was found among groups for the total number of falls experienced in the previous 12 months, the number of non-fallers, non-recurrent fallers, and recurrent fallers has been documented in Table 1 of Appendix 7.

2.3.2 Hip Strength

After accounting for age and mass, abduction contractile impulse from 0 to 300 ms was 1.905 Nm*s (95% CI: 0.645, 3.166) and 1.539 Nm*s (95% CI: 0.197, 2.880) higher in the BBB group compared to the walking and sedentary groups, respectively (Figure 8). No difference was found for RTD across the same time period (Figure 9).

After accounting for age, walking group abduction contractile impulse from 0 to 100 ms was 68.9% (95% CI: 55.3, 85.8) and 78.1% (95% CI: 62.5, 97.5) of the BBB and sedentary groups, respectively (Figure 8). Similarly, walking group abduction RTD from 0 to 100 ms was 67.5% (95% CI: 52.3, 87.0) and 72.4% (95% CI: 55.9, 93.6) of the BBB and sedentary groups, respectively (Figure 9).

After accounting for age and mass, a group by body mass interaction was found for abduction MVC. The interaction implies that for a given age, MVC increased with body mass in the BBB group but remained constant in the sedentary and walking groups (Figure 10). The time required to achieve abduction MVC did not differ among groups, and the median time was approximately 1000 ms. Average group abduction torque across contraction time is presented in Figure 11.

No differences among groups were found for any of the adduction variables (Figures 12, 13, and 14). The median time required to achieve adduction MVC was approximately 1800 ms. Average group adduction torque across contraction time is presented in Figure 15.

Group differences and 95% confidence intervals for hip strength variables are presented in Table 2 of Appendix 7.

2.3.3 Sensory Organization Test

No differences were found among groups for the SOT Composite Score (Figure 16) or Sensory Ratios (Figure 17). Age was not a significant term in any of the linear regression models. Table 3 of Appendix 7 presents group differences and 95% confidence intervals.

2.3.4 Four Square Step Test

After accounting for age, the BBB group completed the FSST 0.90 s (95% CI: 0.13, 1.66) and 1.06 s (95% CI: 0.27, 1.84) faster than the walking and sedentary groups, respectively. Average group times are presented in Figure 18. Table 4 of Appendix 7 presents group differences and 95% confidence intervals.

2.4 Discussion

The objective of this study was to investigate whether exercise programs performed by healthy older adults were associated with superior balance, strength, and functional mobility measures that are pertinent to fall prevention. Specifically, a balance- and strength-focused training program (i.e., Better Bones and Balance®), a general walking program, and a group of sedentary individuals were compared with outcomes focused on sensory orientation, torque production of lateral hip stabilizers, and rapid stepping. Results indicated that BBB participants demonstrated superior performance in some measures of hip abduction torque production and rapid stepping relative to the walking and sedentary groups. However, no differences were found among groups for hip adduction torque production and sensory orientation balance measures.

2.4.1 Hip Strength

We investigated whether participation in specific exercise programs was associated with greater torque production of lateral hip stabilizers, especially during time critical periods. Studies of balance recovery suggest that successful stepping occurs very quickly, i.e., within approximately 300 ms of step initiation (Mille et al., 2005; Rogers et al., 2001). It is in this period of single leg support when torque production of the lateral hip stabilizers may be especially important. There is some evidence suggesting that the time critical period may be even shorter, e.g., 100 ms, based on significant differences observed between younger and older individuals in the duration of hip torque production during lateral stepping. Younger individuals achieved peak hip abduction torque within approximately 100 ms of contraction onset compared to approximately 200 ms in older adults (Mille et al., 2005). The times to achieve maximum abduction and adduction torque in this study were approximately 1000 ms and 1800 ms, respectively, which are well outside of the proposed time critical period (i.e., < 300 ms). This supports the idea that maximum torque production may not be as relevant to fall prevention as measures of rapid torque production.

One major finding of the study was that the BBB group demonstrated greater hip abduction contractile impulse for 0-300 ms relative to the other two groups. A possible explanation is that BBB classes incorporate exercises that may strengthen the hip abductors by altering the base of support, such as step-ups and lunges. The largest of the hip abductor muscles, also with the greatest moment arm, is the gluteus medius (Neumann, 2010). An electromyography study measuring the gluteus medius muscle found greater activation during stair ascension (i.e., a step-up) compared with normal and fast-paced walking (Lyons, Perry, Gronley, Barnes, & Antonelli, 1983). In conjunction, Boudreau et al. (2009) found similar gluteus medius activation levels during a forward lunge and a step-up-and-over (i.e., similar to a step-up). Although walking requires contraction of the hip abductors for pelvic stabilization and counteracting the gravitational torque experienced during single leg stance (MacKinnon & Winter, 1993), the stimulus experienced by the walking group may not have been sufficient to increase contractile impulse relative to the sedentary group.

Although the BBB group demonstrated greater hip abduction contractile impulse from 0-300 ms, BBB did not differ from the sedentary group during the earlier 0-100 ms time period. This outcome may support the idea that early and late rapid torque production measures are influenced by different physiological parameters, as proposed by Andersen and Aagaard (2006). Similar results were found by Andersen et al. (2010), in which high-intensity resistance training increased late RFD but did not change early RFD. These studies have suggested that early time periods are partially influenced by muscle contractile properties (e.g. proportion of type IIX fiber type and cross-bridge cycling rates) and maximum muscle strength, while later time periods are more predominately influenced by maximum strength, which is controlled in part by muscle size. It is worth mentioning that, in the current study, body mass was a significant variable in the abduction linear regression models for the later 0-300 ms time period and for MVC, which occurred at approximately 1000 ms. However, body mass was not significant for the earlier 0-100 ms time period. By assuming that a strong positive correlation exists between body mass and muscle size (Akima et al., 2001; Jaric, 2002), then the significance, or lack of significance, of the body mass variable may also support the existence of different physiological influences on early and late rapid torque production measures. It appears that different types of training may be required to increase early and late phase rapid torque production. Although there is not enough information to make definitive recommendations, it has been suggested that resistance training with the intention of maximal acceleration would generate gains in the early-phase, while resistance training with slow and controlled movements may be more efficacious in the late-phase and in maximum muscle strength (Andersen et al., 2010). It is unknown why the walking group exhibited lower rapid torque production than the sedentary group for the earlier 0-100 ms time period but not for the 0-300 ms time period. However, the different outcomes observed for the earlier and later time intervals suggest that future studies are needed to clarify the most important time critical periods for hip abductor and adductor torque production during balance recovery.

It is noteworthy that no group differences were observed for hip abduction RTD during the 0-300 ms time period, despite differences that were observed for contractile impulse across the same time frame. Because contractile impulse captures the cumulative time history of the contraction (Aagaard et al., 2002; Suetta et al., 2004), it may be a more informative measure when the torque-time data during the period of interest is curvilinear. This point is illustrated by the average hip abduction curves (Figure 11) from 0 – 300 ms. The slopes (i.e., RTD) of the three groups appear to be very similar. In contrast, the area (i.e., contractile impulse) under the BBB curve appears to be considerably larger than the areas under the walking and sedentary curves. Contractile impulse has rarely been reported in the strength literature (Aagaard et al., 2002; Caserotti, Aagaard, Buttrup Larsen, & Puggaard, 2008; Suetta et al., 2004, 2007), potentially because an integral is more challenging to compute than a slope. However, the importance of rapid torque production is starting to gain more attention in the field of fall prevention, and contractile impulse has been recommended as the single most important strength parameter (Aagaard et al., 2002).

Although rapid torque development may be more pertinent to fall prevention, maximum torque has been the more commonly reported strength measure in the literature. In our study, abduction MVC increased with body mass for the BBB group and remained constant for the walking and sedentary groups, as indicated by the significant interaction presented in Figure 10. It is possible that BBB participants possessed a higher percentage of lean leg mass relative to overall body mass. Although lean leg mass was not measured in the current study, Shaw and Snow (1998) found that nine months of participation in BBB increased lean leg mass by 3.5% over sedentary controls. Less lean leg mass has been associated with more severe functional and mobility impairments, which have been linked to higher fall rates (Reid, Naumova, Carabello, Phillips, & Fielding, 2008). Shaw and Snow (1998) also reported that BBB participants increased isokinetic hip abduction strength by 30.3%, while no change was observed in the controls group. It is difficult to directly compare this result to our study due to the difference in measurements (e.g., isokinetic versus isometric) and data analysis (i.e., accounting for the effects of body size).

The lack of group differences for the adductor strength variables was an unexpected finding, as it was hypothesized that the BBB group would generate greater adductor torque relative to the walking and sedentary groups. This was not the case, and it is not possible to fully explain these results. However, a contributing factor might have been the testing position. While the adductors may also serve important functional roles as flexors and extensors of the hip in the sagittal plane (Neumann, 2010), they were tested purely in the frontal plane. Neither of the exercise groups may have trained the adductor muscles in pure adduction. Although a study has not yet been found that directly links hip adductor torque production in the frontal plane to falls, the contribution to lateral stability during ambulation (MacKinnon & Winter, 1993) and the significant declines observed in older individuals (Johnson et al., 2004) suggest that it may be a relevant factor.

The differences in hip abductor and adductor torque-time production with age (Johnson et al., 2004; Mille et al., 2005) and the impact of lateral instability on falls (Hilliard et al., 2008; Mille et al., 2005; Rogers et al., 2001; Rogers & Mille, 2003) has been gaining recent attention. Additionally, the measurement of rapid torque production during time critical periods is a relatively new concept to fall prevention literature. In this study, the BBB group demonstrated greater hip abduction torque relative to the walking and sedentary groups during a 0-300 ms time frame. However, the BBB group did not differ from the sedentary group during an earlier time frame of 0-100 ms. Early and late torque production measures may require different methods of training, and the differing results emphasize the need for studies to clarify the most important time critical periods for hip abductor and adductor torque production during balance recovery. Increasing rapid torque production of the lateral hip stabilizers may be an important component of effective fall prevention exercise programs, and the relationship with falls should continue to be an area of focused research.

2.4.2 Sensory Organization Test

We investigated whether participation in specific exercise programs was associated with ability of the central nervous system to reweight sensory input in response to missing or misleading information. To our knowledge, this is the first study to compare SOT sensory ratios among older adults who have engaged in specific exercise programs or a sedentary lifestyle. No differences were found among the groups for any of the SOT outcome variables.

Previous studies have reported superior balance performance in both BBB and walking participants when compared to controls. While this may appear in contrast with the results of the current study, it is likely that the tests evaluated different components of balance and therefore cannot be directly compared to the SOT results. The balance model proposed by Horak et al. (2009) suggests that there are six interacting components: (1) biomechanics, (2) verticality and limits of stability (3) anticipatory postural adjustments (4) reactive postural responses, (5) sensory orientation, and (6) stability in gait. Our study specifically focused on the sensory orientation component. Rooks et al. (1997) found that eight months of self-paced walking (i.e., three times per week for 45 minutes) resulted in superior tandem stance but no difference in one-leg stance with eyes open and closed compared to controls. The inclusion of a lower extremity strength-trained group may provide some insight on these balance measures. The strength-trained group improved in tandem stance and one-leg stance with eyes open and closed relative to controls. This may indicate that these measures are, in part, assessing strength, which is considered a biomechanical component of balance (Horak et al., 2009). McNamara (2010) found that BBB participants performed superiorly on one-leg stance, tandem walk, and timed-up-and-go relative to sedentary controls. According to Horak et al. (2009), one-leg stance also assesses anticipatory postural adjustment and the timed-up-and-go assesses stability in gait. In another study, Shaw and Snow (1998) found that BBB participants moved faster and more directly than sedentary controls during medial-lateral excursions of the Limits of Stability test. Limits of stability is another distinct balance component that differs from sensory orientation (Horak et al., 2009). A study has not been found that would enable direct comparison to the present SOT results.

A number of factors could have contributed to the lack of group differences in Sensory Organization Test scores. These include, but are not limited to, insufficient training stimuli, ceiling effects, self-selection to groups or to study participation, and sway measures used. The SOT scores were based on conditions in which visual and/or somatosensory inputs were altered, and it is possible that the exercise groups were not sufficiently challenged in this manner. An alternative explanation is that all three groups performed superiorly and reached an upper limit of capability. A third explanation involves limitations of a cross-sectional study design. Individuals self-selected group membership as well as participation in the study. Although the criteria for participation excluded for diagnosed balance problems, some individuals may have had problems that were not officially diagnosed. These individuals may have chosen to engage in a physical activity program in response to noticeable declines in their balance. Additionally individuals may have volunteered for the study based on concern regarding their own health. An improvement to this study would be an experimental design in which sedentary individuals are randomly assigned to each of the three treatment groups and differences between pre- and post-intervention measurements are compared. A fourth explanation for the lack of group differences involves the type of sway measure used. The importance of sway measures in the medial-lateral direction (e.g., amplitude and velocity) for differentiating groups such as recurrent fallers and non-recurrent fallers has been recently reported (Bigelow & Berme, 2011). Currently, the SOT standard output of each trial involves only the maximum anterior-posterior sway amplitude.

Information is generally lacking regarding the effects of specific exercise training on the sensory orientation component of balance in older adults. While some researchers have reported SOT composite scores (Carter et al., 2002; Woo, Hong, Lau, & Lynn, 2007), studies focusing on the effectiveness of specific sensory systems are particularly sparse. Although the SOT is currently considered a gold-standard for measuring sensory orientation (Mancini & Horak, 2010), incorporating lateral sway measures into the standard protocol may be an area of future research and development.

2.4.3 Four Square Step Test

The ability to step rapidly in various directions is important for recovering balance and, thus, preventing falls. One approach to evaluating this aspect of functional mobility is the FSST, and longer test time has been associated with higher fall frequency (Dite & Temple, 2002). In the present study, the mean BBB group time was significantly shorter compared to the walking and sedentary groups. Although statistically significant differences were observed, it is unclear whether these differences are clinically relevant. Dite & Temple (2002) reported median FSST times of 8.70 s, 12.01 s, and 23.59 s for non-fallers, single-fallers, and multiple-fallers, respectively. While statistical comparisons cannot be made, it appears that all three groups in the present study (see Figure 15) performed similarly to, or perhaps better than, the group of non-fallers.

To our knowledge, this is the first study to compare FSST times among older adults who have engaged in specific exercise programs or a sedentary lifestyle. In addition to differentiating healthy fallers from non-fallers, the FSST is easy to administer and does not require expensive equipment. Future studies aimed at identifying beneficial exercise for fall prevention in healthy older adults should consider including the FSST as a functional mobility test.

2.4.4 Study Limitations

Participants were included in one of the two exercise groups if (1) they considered their primary form of physical activity to be either BBB classes or walking for fitness and (2) minimum weekly requirements were met. Imposing an upper limit or excluding for other physical activity would have severely reduced sample sizes of the present study. Therefore, it was assumed that the primary form of physical activity (i.e. either Better Bones and Balance or walking for fitness) was the greatest contributor to group performance. An experimental design may have reduced biases through random group allocation of sedentary individuals and encouragement to concurrently restrict other forms of physical activity. Despite the shortcomings of a cross-sectional study design, time spent in additional physical activities was documented and no difference was found between the BBB and walking groups for the amount of time engaged in physical activity. While an experimental design can reduce sampling bias, it may present logistical challenges. Healthy older sedentary individuals in this community were challenging to recruit. An experimental design would require three times the number of sedentary individuals for randomization to the groups. Additionally, some women participated in this study because it required only one hour of their time for testing. A cross-sectional design eliminates additional time dedicated to receiving treatments.

Another study limitation may have occurred in the methods used for testing hip torque production. Previous studies have found that hip abductor and adductor strength depend on joint position, with greater strength occurring when muscles are in an elongated position. Thus, greater hip abduction strength occurs in the anatomically neutral position (i.e., 0 degrees), while greater adduction strength occurs at 25 to 30 degrees of abduction (Johnson et al., 2004; Murray & Sepic, 1968). A midrange test position of 15 degrees of abduction was selected for this study, due to challenges presented by both extremes. A position of greater hip abduction may not have been as functionally relevant to balance recovery and may have also produced greater measurement variability due to the more challenging standing position. In a more functional neutral position, space constraints for the attachment between both legs was a concern, especially since leg size can vary among participants. Thus, it is unclear whether other tested positions could have resulted in different outcomes.

2.5 Conclusions

The BBB group demonstrated greater hip abduction contractile impulse during a period of time that has been suggested to reflect balance recovery. The ability to generate greater torque within this time-critical period may improve lateral stability during a rapid step response and, in effect, reduce falls. Future studies are needed to clarify the most important time-critical periods for torque production of the lateral hip stabilizers and to directly link measures of rapid torque production with falls. The BBB group had a shorter mean time for the test of rapid multi-directional stepping, relative to the walking and sedentary groups. None of the groups demonstrated superior performance in hip adduction torque production or sensory orientation outcomes. In conclusion, participation in the balance- and strength-focused training program was associated with superior performance in some measures of strength and functional mobility that may be linked to successful balance recovery and fall prevention.

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FIGURES

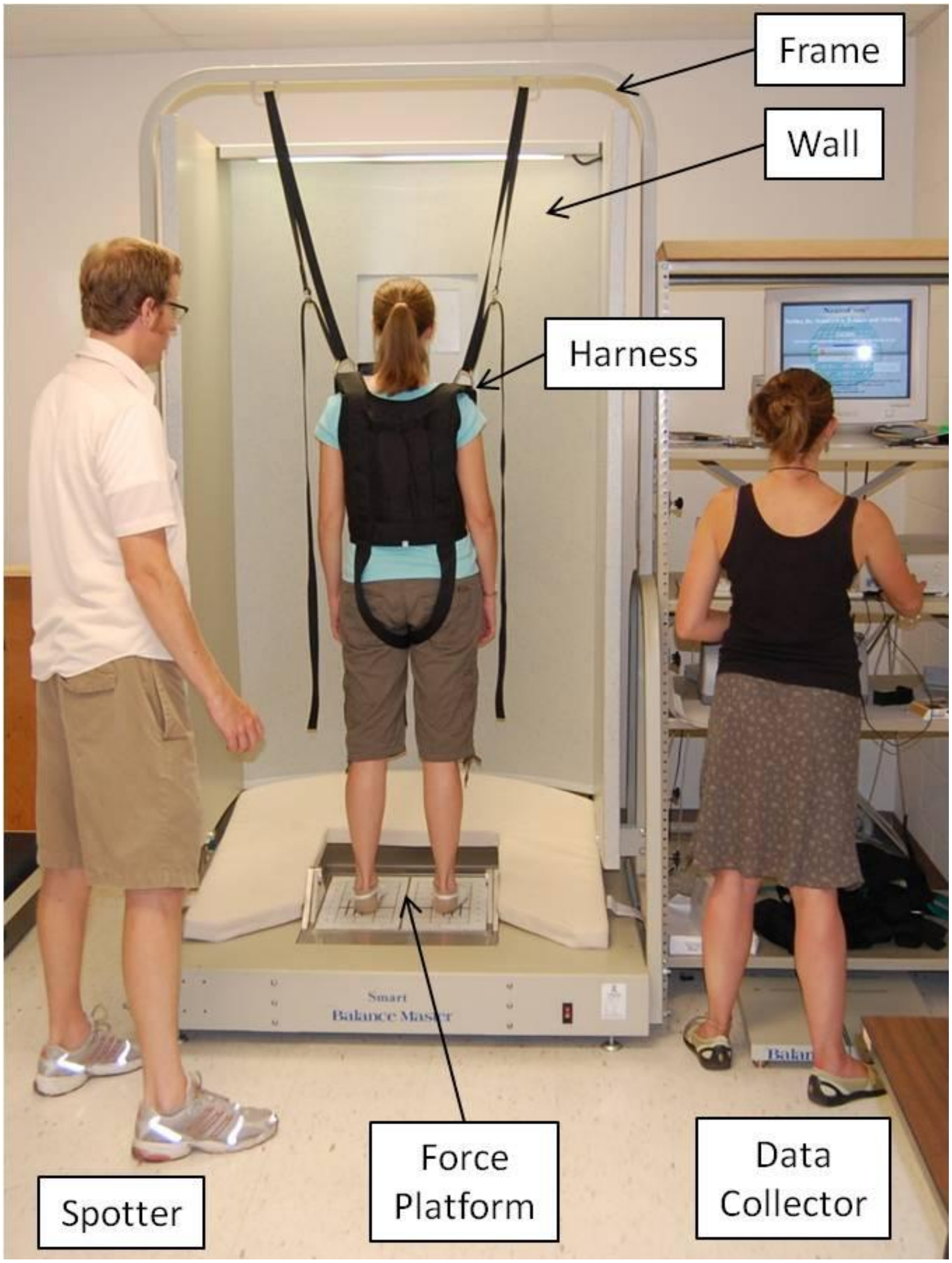


Figure 1: Sensory Organization Test setup. The participant removed her shoes and was positioned in a safety harness that attached securely to the frame. Her feet were properly aligned on the force platform. The force platform measured the participant's center of gravity sway. Some test conditions included sway of the force platform and/or the wall.

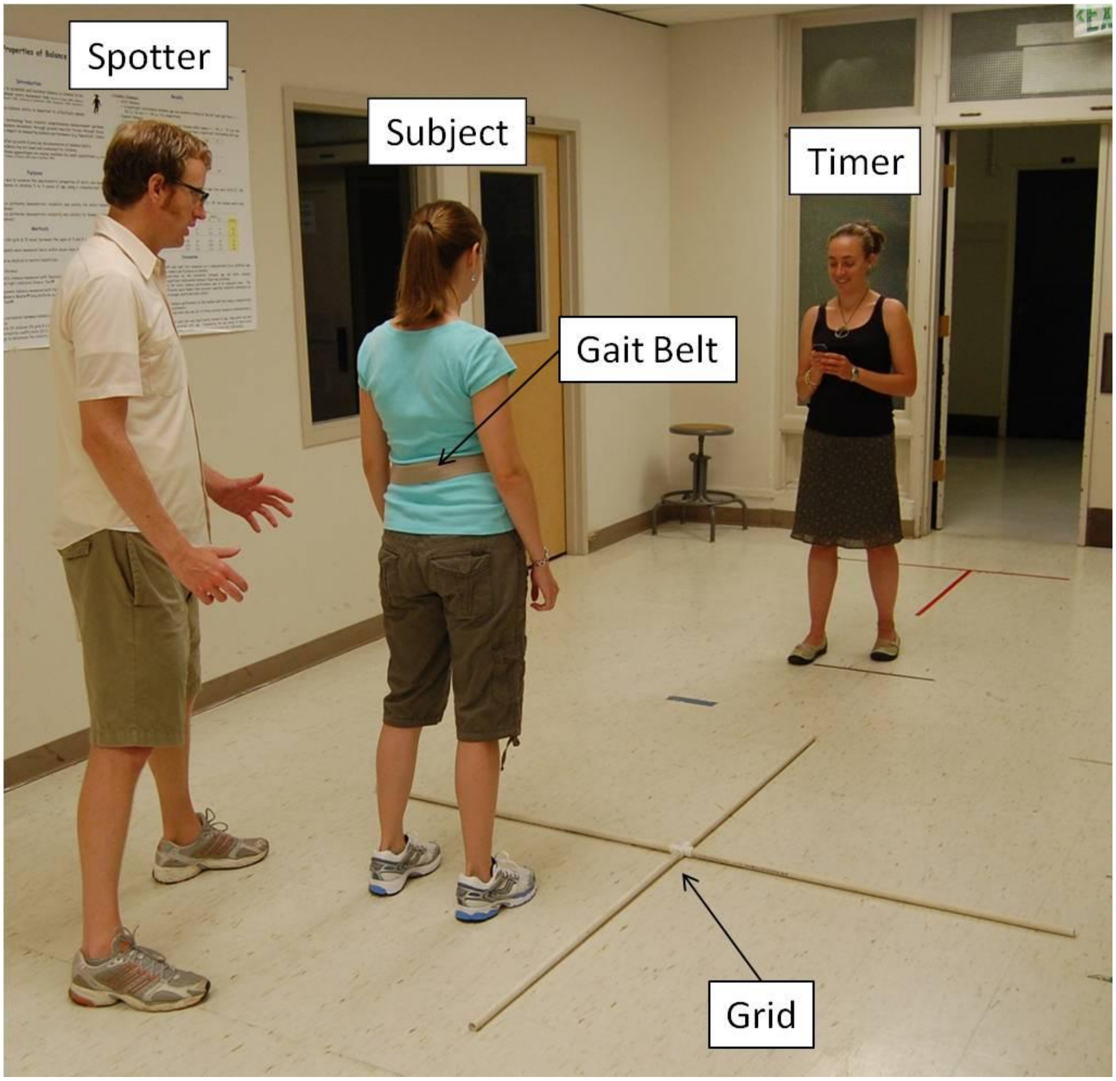


Figure 2: Four Square Step Test setup. The grid was secured to the floor at the ends with packaging tape. Although not shown here, the grid was wrapped in blue painter's tape to provide contrast against the white floor. One researcher timed the participant, while the other researcher served as a spotter. A gait belt was secured around the participant's waist in case the participant became unstable during the test.

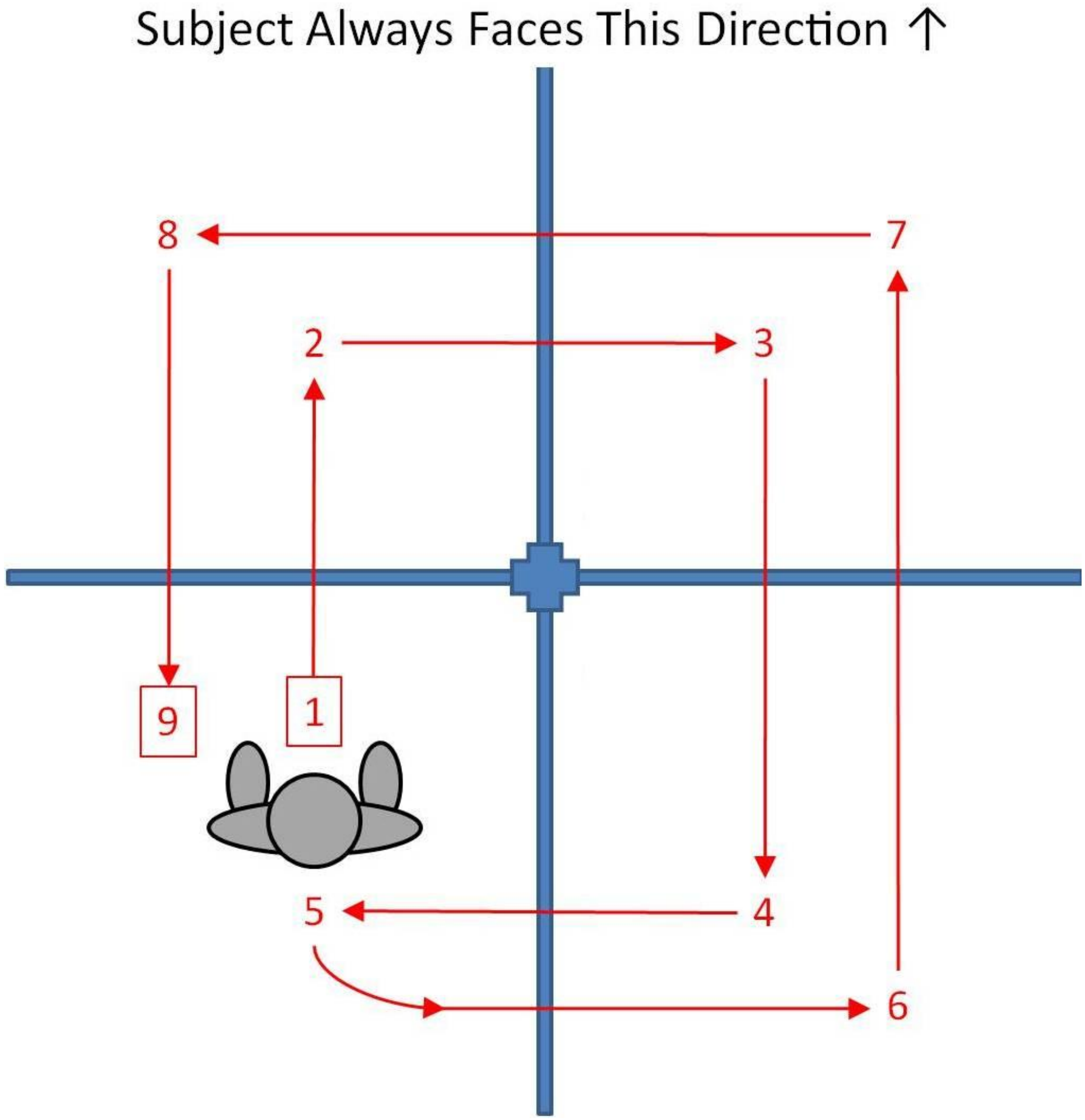


Figure 3: Four Square Step Test stepping sequence. The participant stepped around the grid, first in a clockwise direction and then in a counterclockwise direction. The numbers represent the order of the stepping sequence, beginning with position 1 and ending with position 9. At each position, both feet were required to touch down within the square before moving to the next position. The arrows represent the direction of travel. The participant is encouraged to remain facing in the same direction throughout the test. Numbers and arrows are included on the figure for reference only and are not present on the floor during the test.

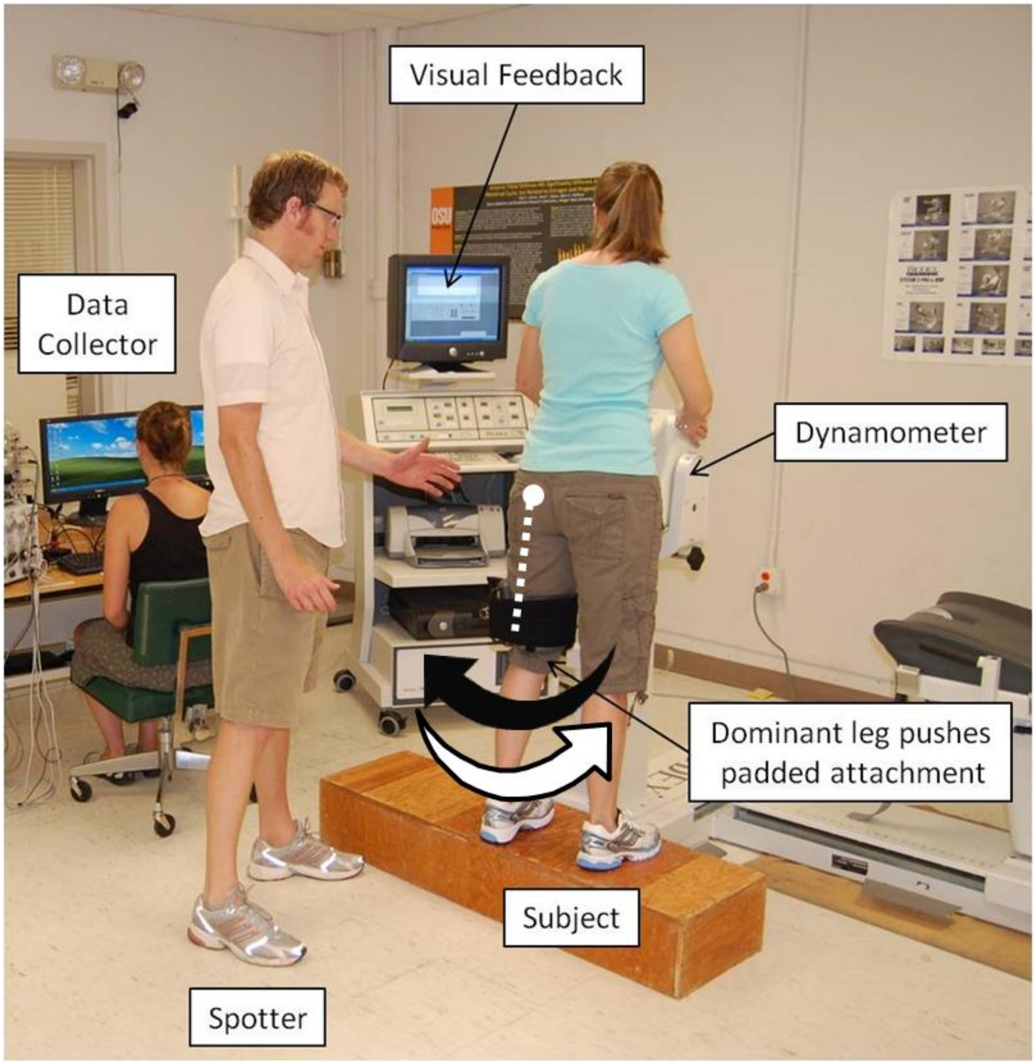


Figure 4: Hip strength measurement setup. The white circle and dotted line represent the hip joint center and femur, respectively, of the participant's dominant leg. Hip abduction (i.e., pushing the femur away from the centerline of the body in the frontal plane) is indicated by the direction of the black arrow. Hip adduction (i.e., pulling the femur toward the centerline of the body in the frontal plane) is indicated by the direction of the white arrow. Real-time visual feedback of the participant's torque produced across time was provided to help promote maximal effort.

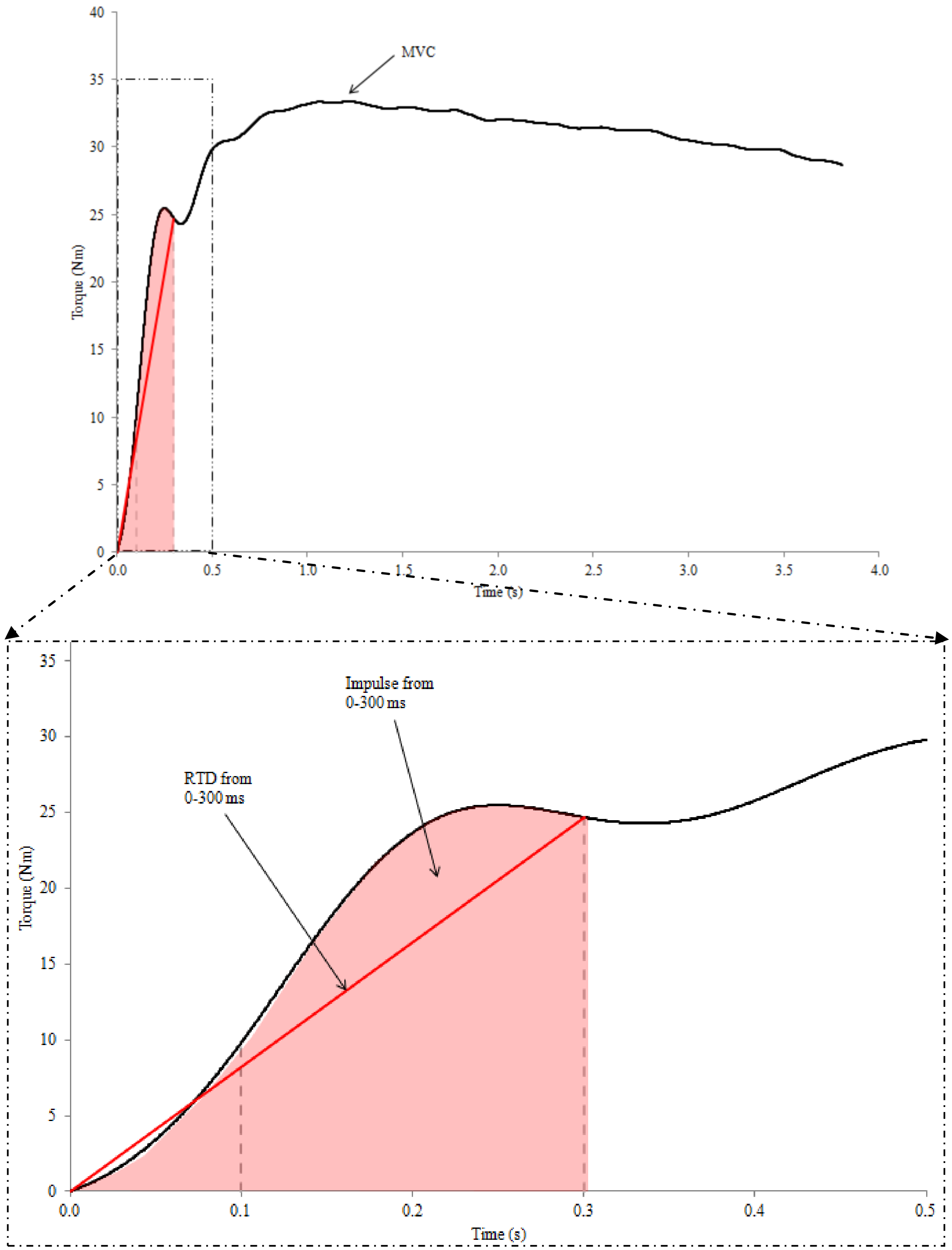
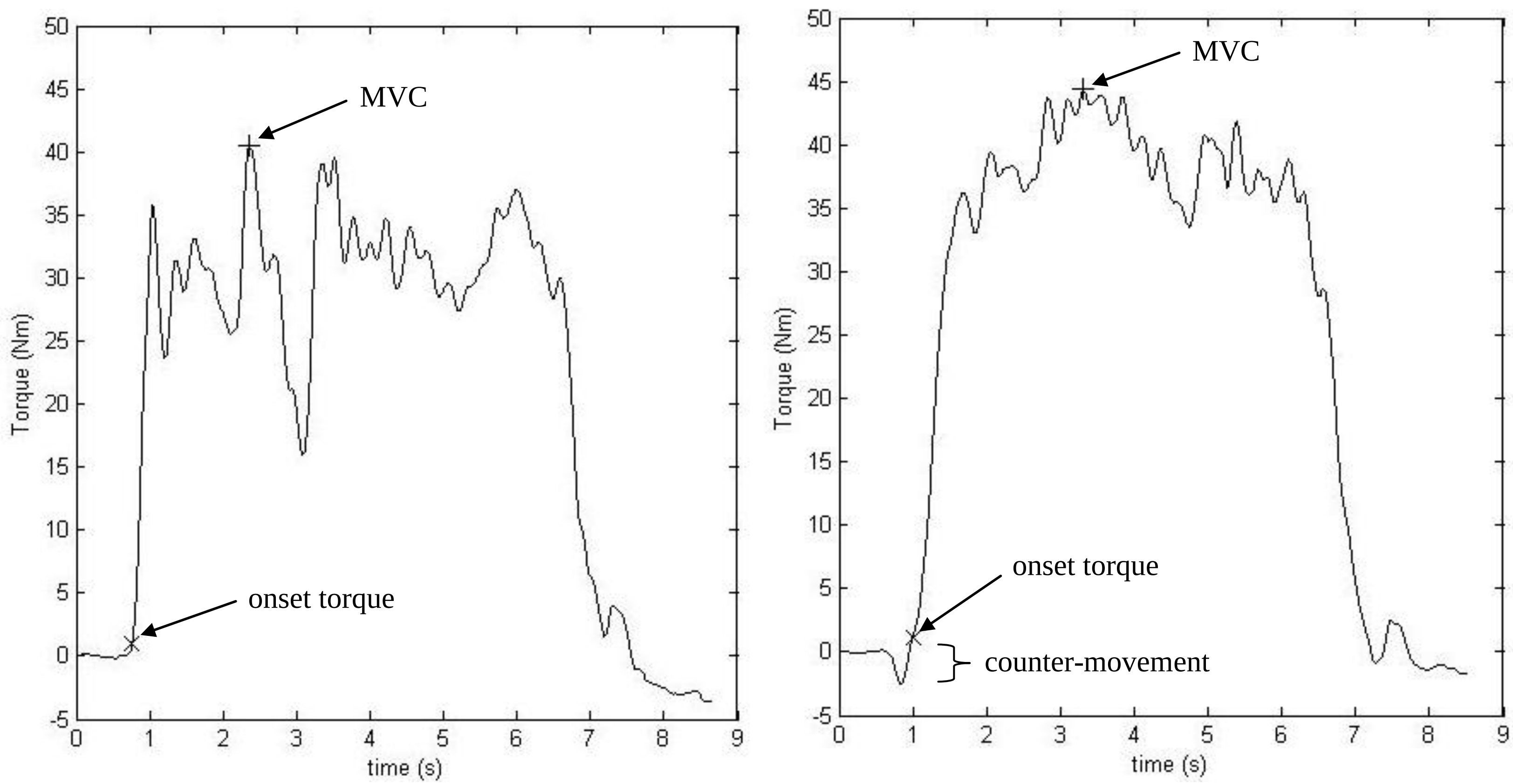


Figure 5: Representative torque-time curve. The upper panel shows the torque recorded across the full length of the trial. This includes the maximum voluntary contraction (MVC). The lower panel is an expansion of the initial 500 ms of the contraction. Contractile impulse is represented by the shaded area and rate of torque development (RTD) by the solid line for the 0-300 ms time period.



A) Acceptable Trial

B) Unacceptable Trial

Figure 6: Example of acceptable (A) and unacceptable (B) hip strength trials for one participant. The ‘x’ represents the onset torque and the ‘+’ represents the MVC. Trial (B) exhibits an initial counter-movement with amplitude that exceeds the value of the onset torque.

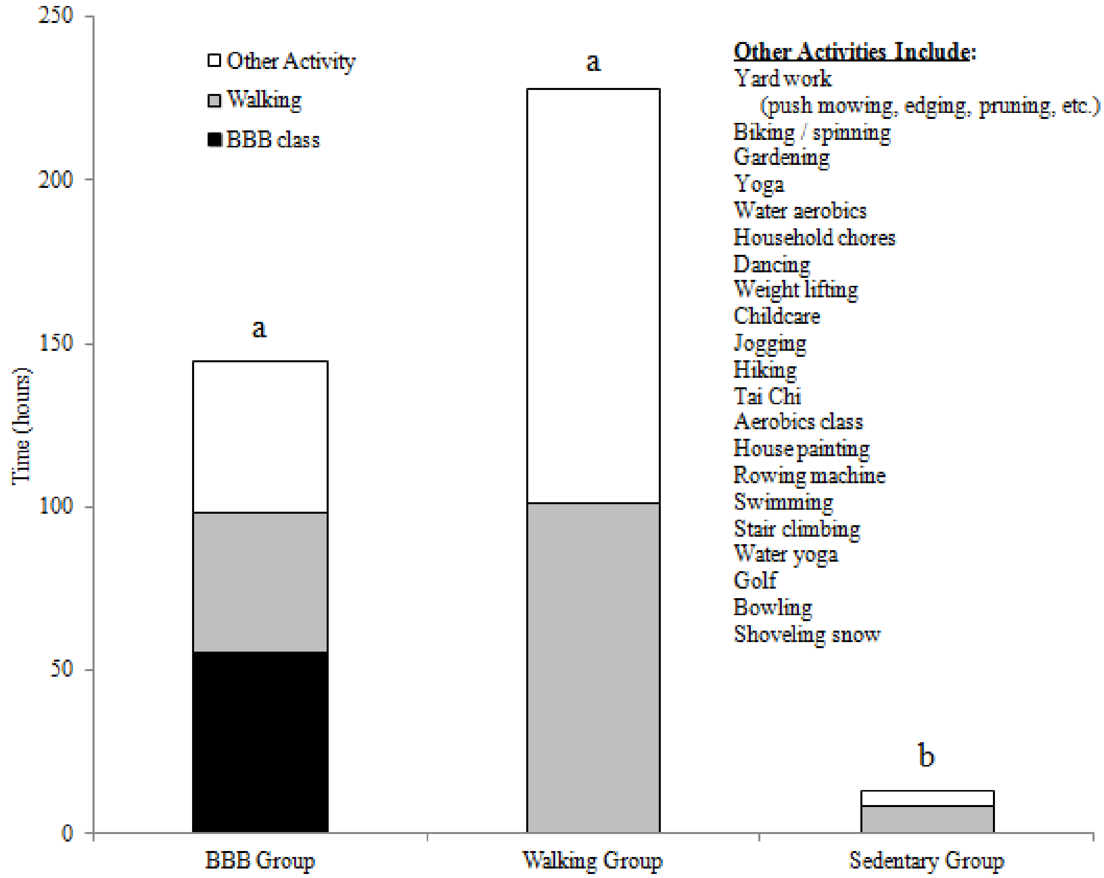


Figure 7: Average hours of physical activity by group during the six months prior to testing. The average physical activity is partitioned by type, with black representing Better Bones & Balance (BBB) class, grey representing walking, and white representing other physical activities. The other physical activities were documented during the screening process and are listed above. Groups with different letters indicate that the total amount of physical activity during the six months prior to testing was significantly different at α=0.05.

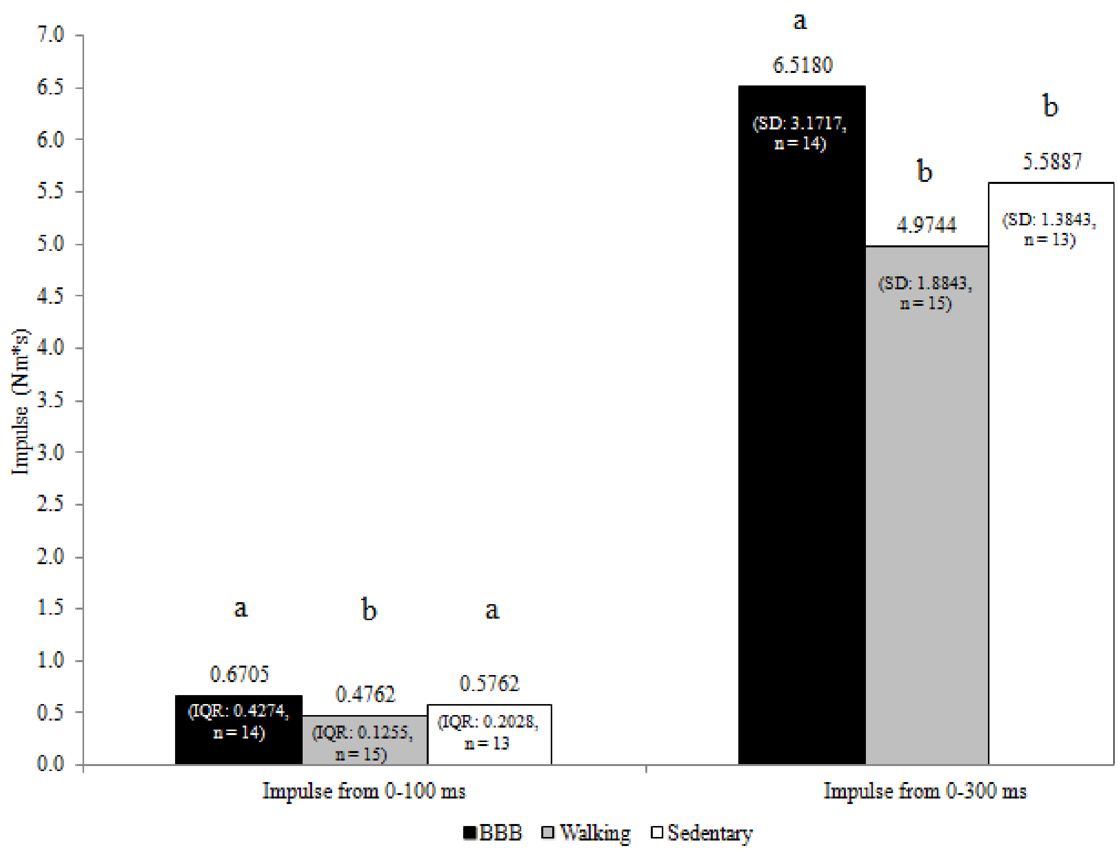


Figure 8: Hip abduction contractile impulse for 0-100 ms (left) and for 0-300ms (right). Impulse from 0-100 ms required a log transformation to meet model assumptions; thus, median values are presented along with interquartile ranges (IQR). Impulse from 0-300ms did not require a transformation; thus, mean values are presented along with standard deviations (SD). The number of participants in each group (n) has also been provided. Within each measure, groups with different letters are significantly different at α=0.05. Statistical comparisons were not made across measures.

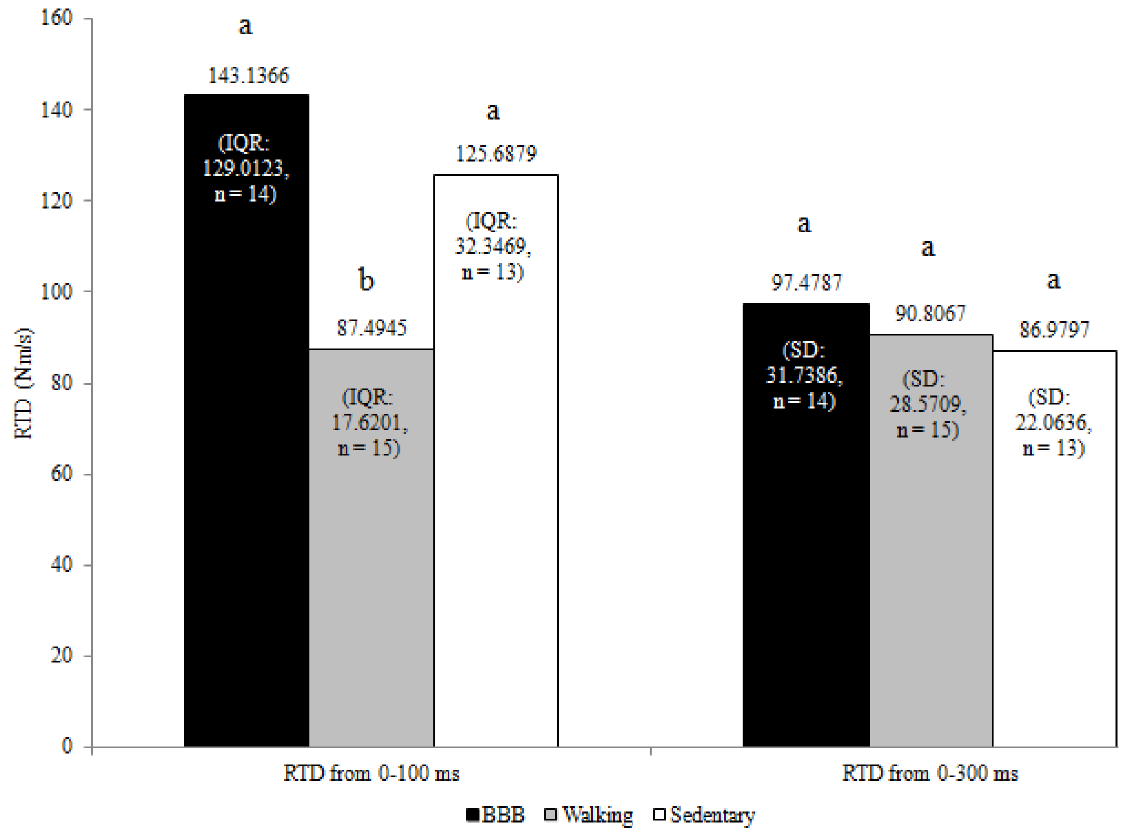


Figure 9: Hip abduction rate of torque development (RTD) for 0-100 ms (left) and for 0-300 ms (right). RTD from 0-100 ms required a log transformation to meet model assumptions; thus, median values are presented along with interquartile ranges (IQR). RTD from 0-300ms did not require a transformation; thus, mean values are presented along with standard deviations (SD). The number of participants in each group (n) has also been provided. Within each measure, groups with different letters are significantly different at α=0.05. Statistical comparisons were not made across measures.

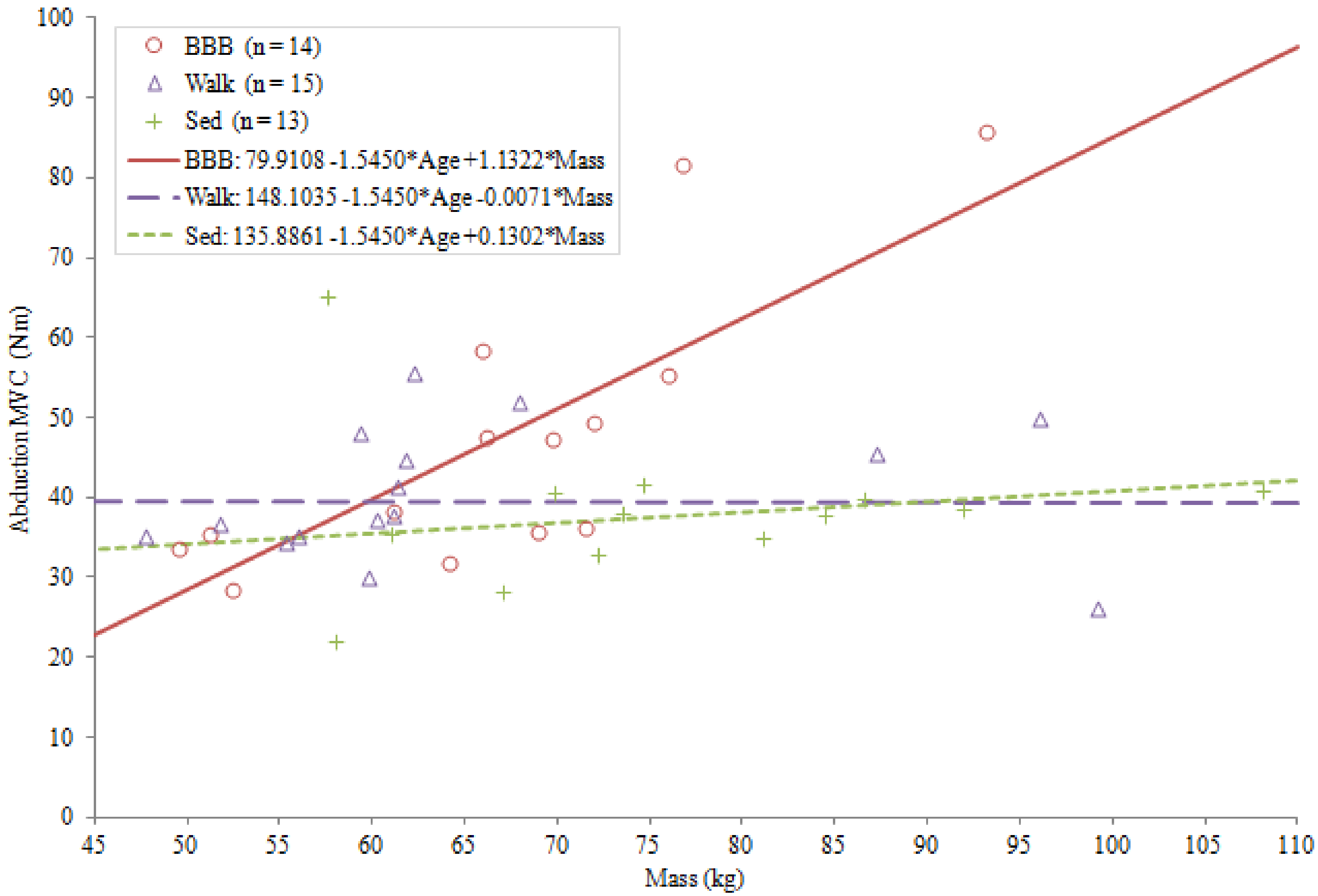


Figure 10: Hip abduction maximum voluntary contraction (MVC) as a function of body mass. Group linear models are presented for a base age of 70 years.

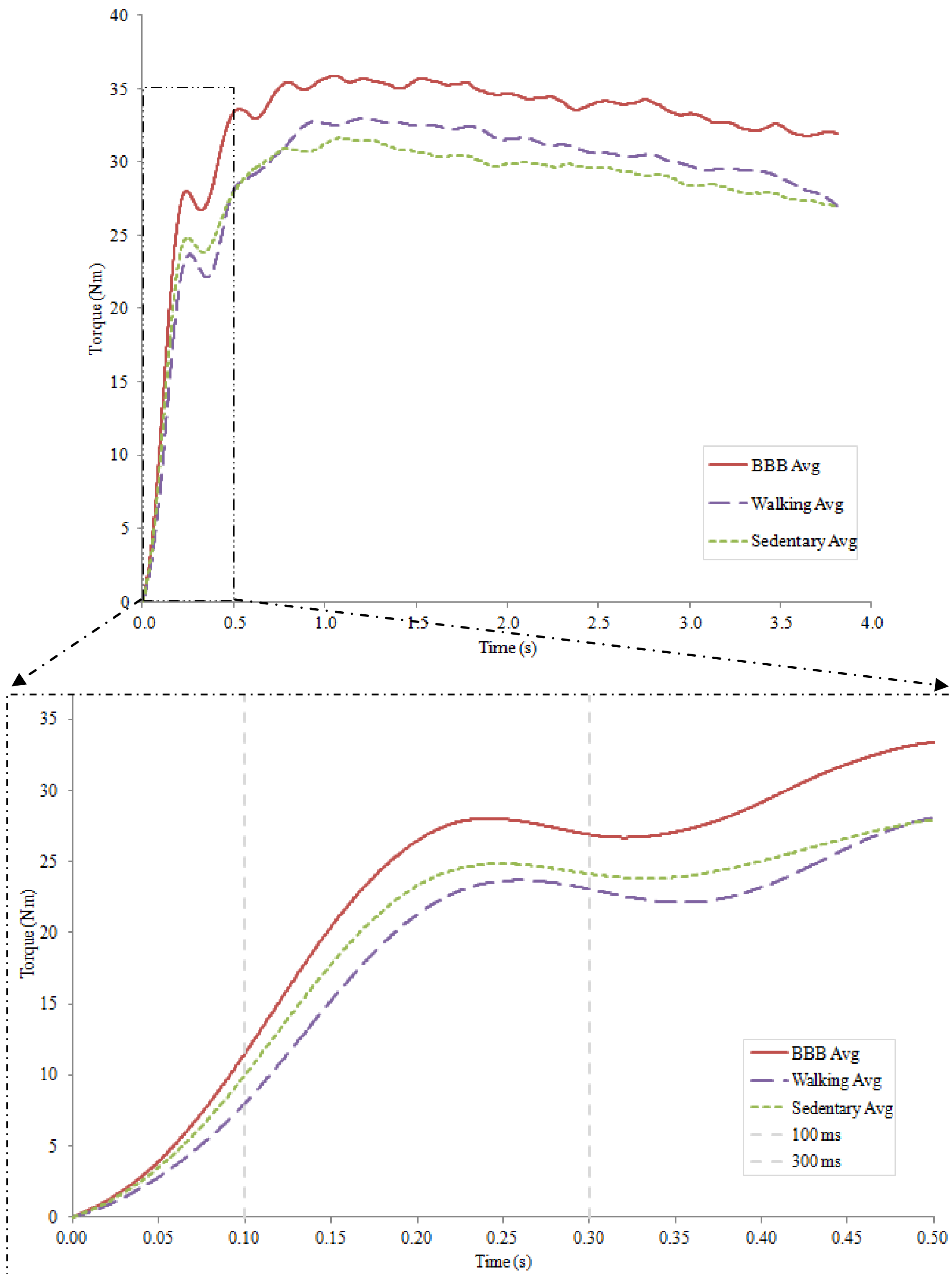


Figure 11: Average hip abduction torque-time curves by group. The upper panel shows the torque recorded across the full length of the trial. The lower panel is an expansion of the initial 500 ms of contraction. For clarity, the 100 ms and 300 ms time periods are indicated on the lower panel by light gray vertical dashed lines.

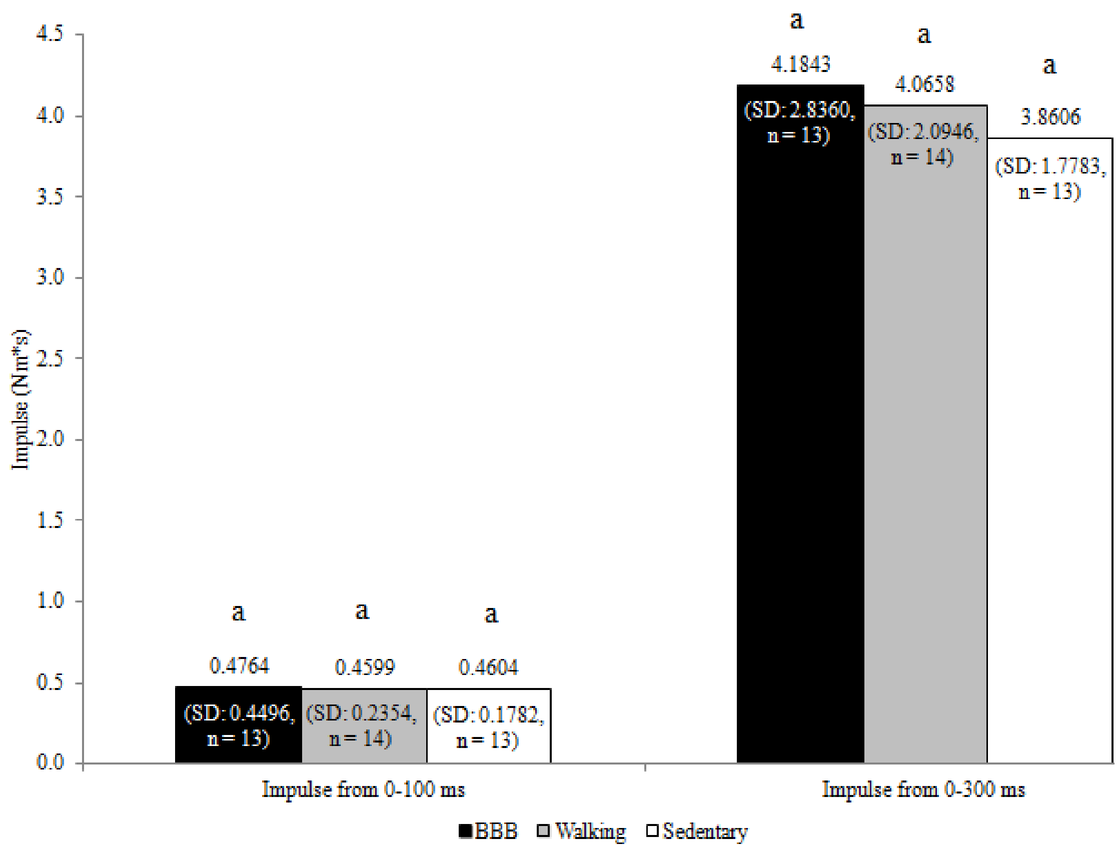


Figure 12: Hip adduction contractile impulse for 0-100 ms (left) and for 0-300ms (right). Mean values are presented along with standard deviations (SD) and number of participants in each group (n). Within each measure, groups with different letters are significantly different at α=0.05. Statistical comparisons were not made across measures.

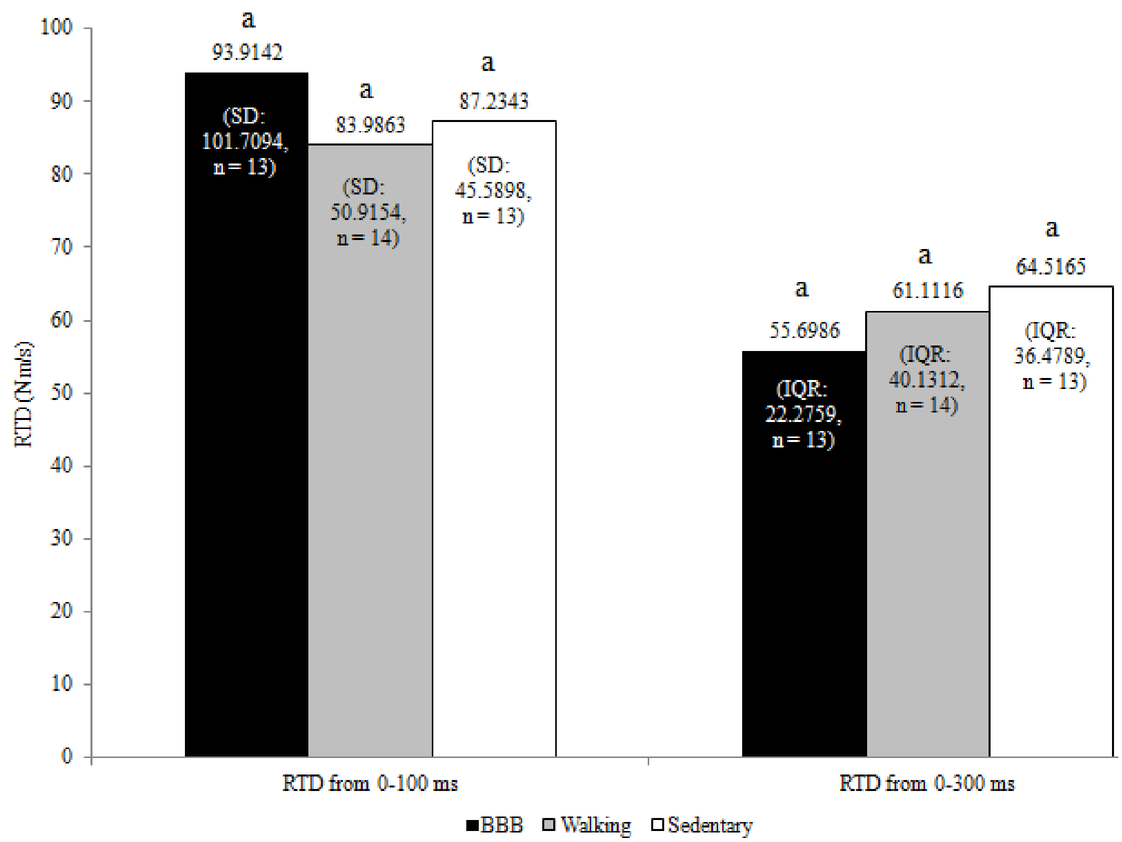


Figure 13: Hip adduction rate of torque development (RTD) for 0-100 ms (left) and for 0-300 ms (right). RTD from 0-100ms did not require a transformation; thus, mean values are presented along with standard deviations (SD). RTD from 0-300 ms required a log transformation to meet model assumptions; thus, median values are presented along with interquartile ranges (IQR). The number of participants in each group (n) has also been provided. Within each measure, groups with different letters are significantly different at α=0.05. Statistical comparisons were not made across measures.

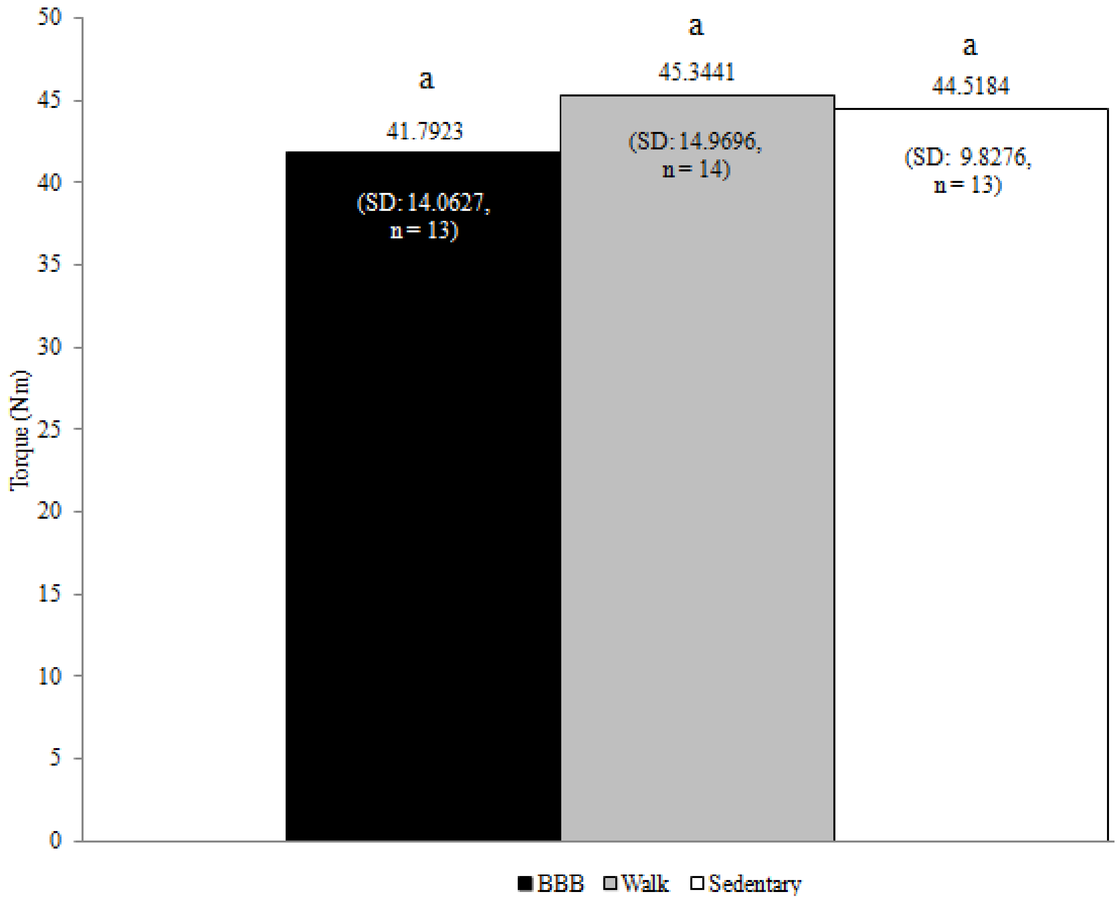


Figure 14: Hip adduction maximum voluntary contraction (MVC). Mean values are presented along with standard deviations (SD) and number of participants in each group (n). Groups with different letters are significantly different at α=0.05.

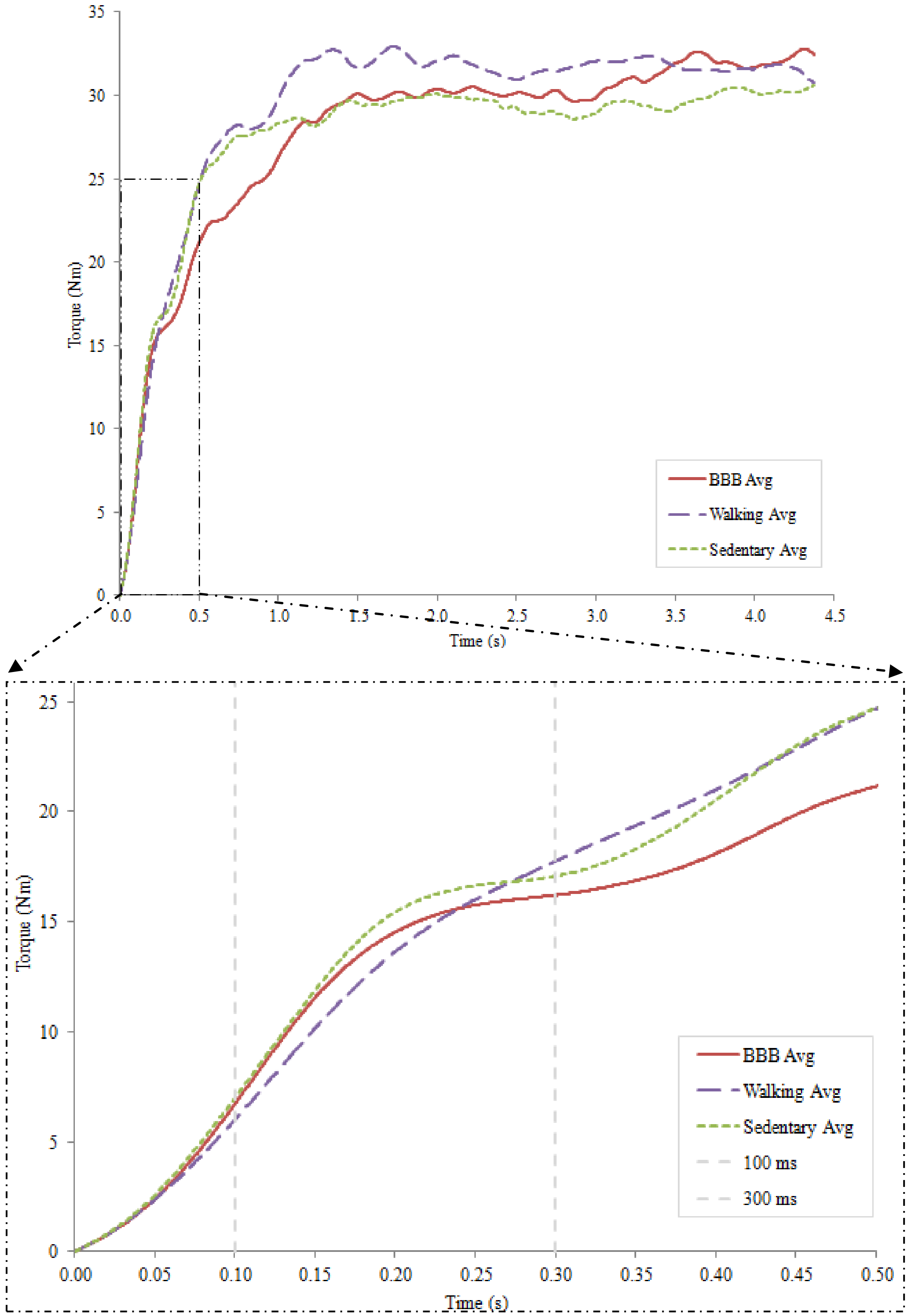


Figure 15: Average hip adduction torque-time curves by group. The upper panel shows the torque recorded across the full length of the trial. The lower panel is an expansion of the initial 500 ms of contraction. For clarity, the 100 ms and 300 ms time periods are indicated on the lower panel by light gray vertical dashed lines.

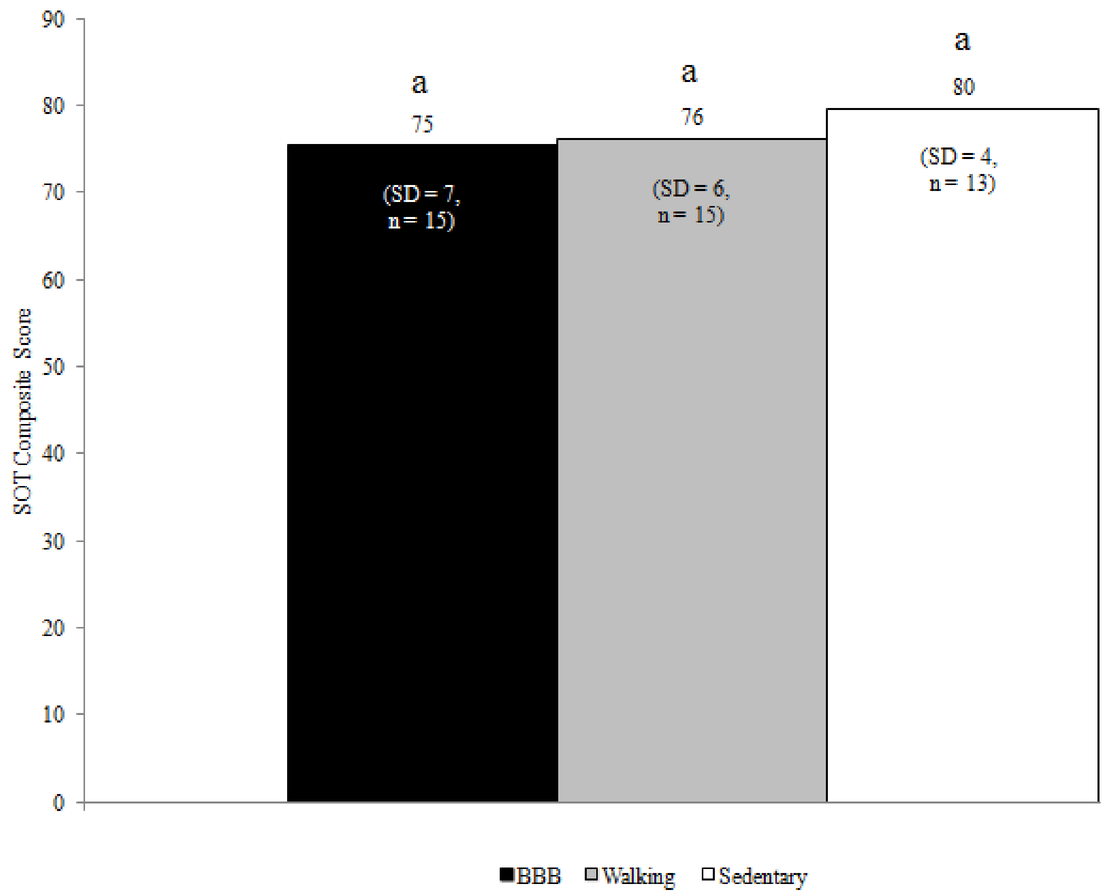


Figure 16: Sensory Organization Test composite scores. Mean values are presented along with standard deviations (SD) and number of participants in each group (n). Higher mean scores indicate greater stability. Groups with different letters are significantly different at α=0.05.

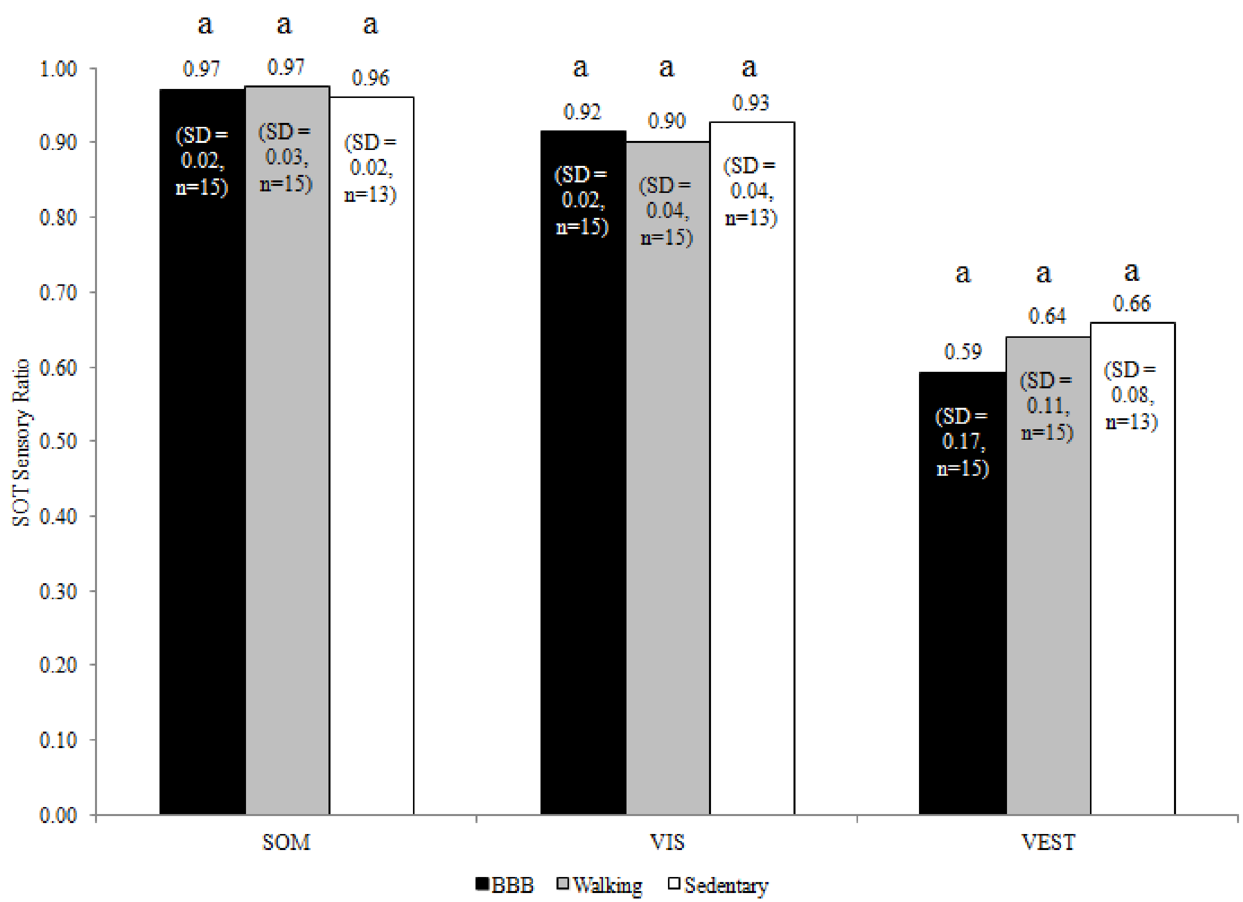


Figure 17: Sensory Organization Test sensory ratios. Three ratios are presented. Each ratio indicates effective use of the specified sensory system: somatosensory (SOM), visual (VIS), or vestibular (VEST). Mean values are presented along with standard deviations (SD) and number of participants in each group (n). Higher mean scores indicate greater stability. Within each measure, groups with different letters are significantly different at α=0.05. Statistical comparisons were not made across measures.

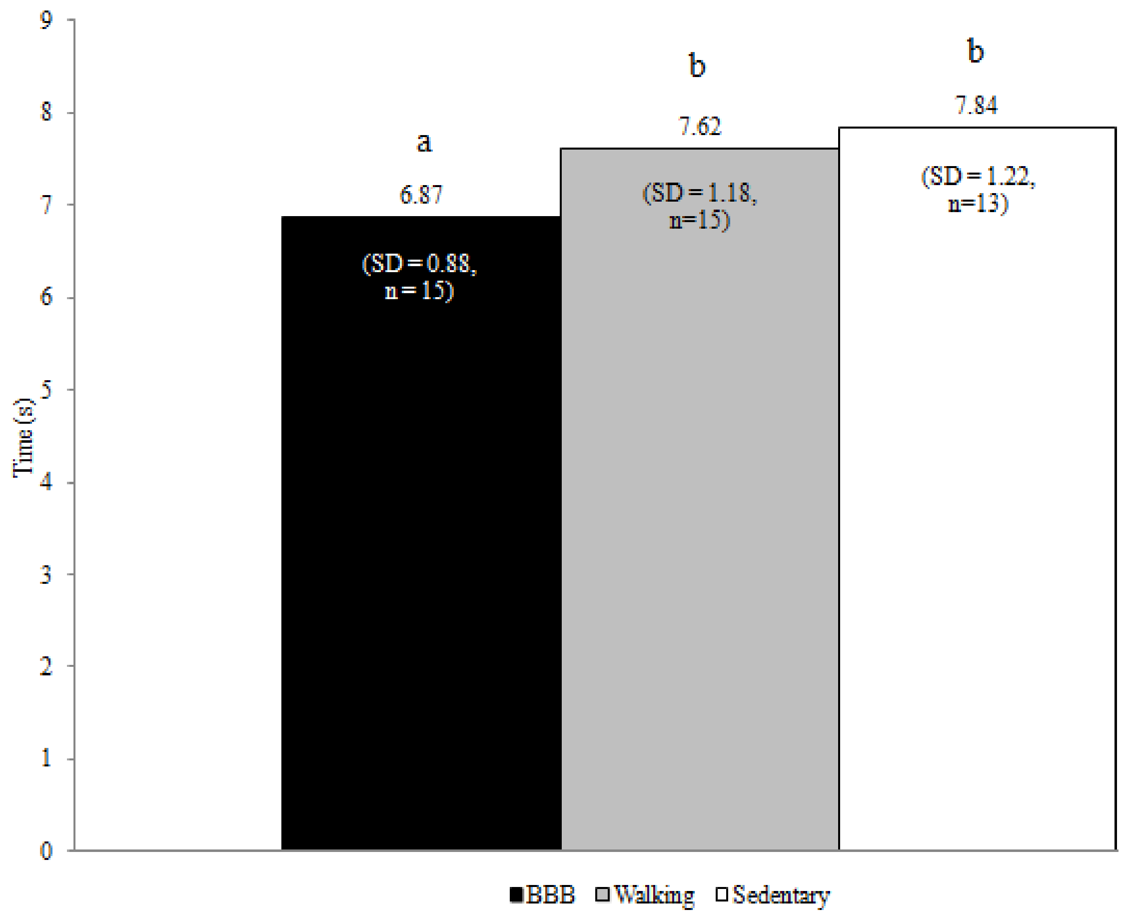


Figure 18: Four Square Step Test times. Mean values are presented along with standard deviations (SD) and number of participants in each group (n). Lower mean scores indicate superior performance. Groups with different letters are significantly different at α=0.05.

TABLES

Table 1: Six Sensory Organization Test conditions. This information has been provided by Natus® Medical Inc. (2011). The first condition is a baseline condition in which all sensory information is available and accurate. As conditions progress, sensory information is systematically altered by asking the participant to keep eyes closed, allowing the platform to sway, and/or allowing the wall enclosure around the participant (i.e., "visual surround") to sway.

Condition	Eyes	Visual Surround	Support Surface
1	Open	Fixed	Fixed
2	Closed	Fixed	Fixed
3	Open	Sway-referenced *	Fixed
4	Open	Fixed	Sway-referenced *
5	Closed	Fixed	Sway-referenced *
6	Open	Sway-referenced *	Sway-referenced *

* Movement of the platform and visual surround is referred to as sway-referenced because it occurs in direct response to the movement of the individual's center of gravity. Sway occurs in the anterior-posterior direction only.

Table 2: Sensory Organization Test equations. This information has been provided by Natus® Medical Inc. (2011). These equations show how the composite and sensory ratio scores are calculated from the equilibrium scores of the individual trials.

Condition	Trial	Equilibrium Score	Condition Average	Composite Equilibrium Score	Somato-sensory Ratio	Visual Ratio	Vestibular Ratio
1	**1**	$ES_{1,1}$	$C1^{ES} = (ES_{1,1} + ES_{1,2} + ES_{1,3}) / 3$	Composite = $(C1^{ES} + C2^{ES} + ES_{3,1} + ES_{3,2} + ES_{3,3} + ES_{4,1} + ES_{4,2} + ES_{4,3} + ES_{5,1} + ES_{5,2} + ES_{5,3} + ES_{6,1} + ES_{6,2} + ES_{6,3}) / 14$	SOM = $C2^{ES} / C1^{ES}$	VIS = $C4^{ES} / C1^{ES}$	VEST = $C5^{ES} / C1^{ES}$
1	**2**	$ES_{1,2}$					
1	**3**	$ES_{1,3}$					
2	**1**	$ES_{2,1}$	$C2^{ES} = (ES_{2,1} + ES_{2,2} + ES_{2,3}) / 3$				
2	**2**	$ES_{2,2}$					
2	**3**	$ES_{2,3}$					
3	**1**	$ES_{3,1}$	$C3^{ES} = (ES_{3,1} + ES_{3,2} + ES_{3,3}) / 3$				
3	**2**	$ES_{3,2}$					
3	**3**	$ES_{3,3}$					
4	**1**	$ES_{4,1}$	$C4^{ES} = (ES_{4,1} + ES_{4,2} + ES_{4,3}) / 3$				
4	**2**	$ES_{4,2}$					
4	**3**	$ES_{4,3}$					
5	**1**	$ES_{5,1}$	$C5^{ES} = (ES_{5,1} + ES_{5,2} + ES_{5,3}) / 3$				
5	**2**	$ES_{5,2}$					
5	**3**	$ES_{5,3}$					
6	**1**	$ES_{6,1}$	$C6^{ES} = (ES_{6,1} + ES_{6,2} + ES_{6,3}) / 3$				
6	**2**	$ES_{6,2}$					
6	**3**	$ES_{6,3}$					

Table 3: Subject characteristics presented by group. The group mean ± standard deviation is provided when the data did not require transformation. The group median (interquartile range) is provided when log transformation was required. A significant difference among groups is indicated by a p-value that is < 0.05.

Subject Characteristics	BBB (n = 15)	Walking (n = 15)	Sedentary (n = 13)	P-Value
Age (y)	70 ± 3	69 ± 3	70 ± 3	p = 0.67 †
Mass (kg)	69.0 (9.9)	61.2 (7.5)	73.5 (17.4)	p = 0.10 ‡
Height (m)	1.62 ± 0.08	1.62 ± 0.06	1.60 ± 0.05	p = 0.46 †
Total Physical Activity (hours in prior 6 months)	145 ± 100	228 ± 121	13 ± 24	p < 0.001 §
Falls (# in previous 12 months)	0 (0)	0 (1)	0 (0)	p = 0.36 ‡
Fall Worry (Likert Scale, 1 to 7, 1=no worry, 7=extremely worried)	1 (1)	2 (2)	1 (0)	p = 0.09 ‡
Comorbidities (#) *	1 (1)	2 (1)	2 (2)	p = 0.11 ‡

*Comorbidities include secondary diseases or conditions that may be associated with falls or fall-related injuries. See the Health History Questionnaire (Appendix 4) for documented comorbidities. The total number of comorbidities was recorded for each participant. The median number of comorbidities by group is presented above.

† One-way analysis of variance (ANOVA) was used to test for equality of means.

‡ Kruskal-Wallis Test was used to test for equality of means.

§ Welch's Test was used to test for equality of means.

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APPENDICES

APPENDIX 1

LITERATURE REVIEW

1.1 Introduction

A fall occurs at least once per year in approximately one-third of community-dwelling adults over the age of 65 (Blake et al., 1988). Hip fracture is one of the most serious fall-related injuries, considering that approximately 25% of those injuries result in death within the following year (Johnell & Kanis, 2005; Kanis et al., 2003). Lateral falls are of particular concern because the risk of experiencing a hip fracture increases 3.3 to 5.7 fold relative to falls occurring in the sagittal plane (Greenspan et al., 1994; Nevitt & Cummings, 1993). The growing population of older adults continues to make prevention of falls and fractures a relevant public health concern.

Multiple systems are engaged to maintain upright posture. Three sensory systems (i.e., somatosensory, visual, and vestibular) contribute to balance by gathering information about an individual's environment and their orientation relative to the environment. The sensory information is integrated within the central nervous system, which then directs the muscles of the trunk and lower extremity to generate coordinated movements that control the center of gravity relative to the base of support. Responses to postural disturbance include generating reactive ankle and hip torque or stepping if the disturbance is large. Age-related declines in balance, muscle strength, and mobility may be partially responsible for the high fall rates observed in older adults, and exercise has been recommended as an intervention to combat these impairments.

1.2 Current Physical Activity Guidelines for Older Adults

Recent guidelines have been published by the American College of Sports Medicine and the American Heart Association regarding the recommended physical activity for older adults (Chodzko-Zajko et al., 2009; Garber et al., 2011; Nelson et al., 2007). Generally, these guidelines recommended weekly doses of aerobic, resistance, flexibility, and balance training to improve or maintain general health. Specifically, aerobic activity was recommended for at least 30 minutes per day on five days per week at a moderate intensity (i.e., noticeable increase in breathing and heart rate) or 20 minutes per day on three days per week at a vigorous intensity (i.e., large increase in breathing and heart rate) (Chodzko-Zajko et al., 2009; Nelson et al., 2007). Muscle-strengthening activities that include progressive weight-bearing and resistance exercises using the major muscle groups were recommended on at least two nonconsecutive days per week (Chodzko-Zajko et al., 2009; Nelson et al., 2007). Although balance training was recommended, Nelson et al. (2007) suggested that the preferred type, frequency, and duration remained unclear. Despite the growing public health concern, information within these guidelines regarding physical activity aimed at fall prevention was limited. Chodzko-Zajko et al. (2009) recommended multimodal exercise which includes strength and balance training, and cited examples such as lower body strengthening, walking over difficult terrain, and tai chi. Garber et al.

(2011) recommended resistance training for older individuals that emphasized the development of power rather than strength alone, since it has been suggested that fall risk is more closely related to lower extremity declines in power. Neuromotor exercise training (i.e., functional fitness training), which incorporates balance, coordination, agility, and proprioceptive training, was also recommended (Garber et al., 2011). These guidelines are very general in regards to the type, intensity, and volume of physical activity that is beneficial for fall prevention. Additionally, they do not address the varying degrees of health found within the older adult population (e.g. relatively healthy versus frail). Finally, some of the recommendations appear to be in contrast to the results of exercise intervention studies (e.g. walking), or beneficial effects on falls have not been consistently demonstrated (e.g. resistance training). Understanding the important fall risk factors and the exercise interventions that are most beneficial in specific older adult populations continues to be an area of needed research.

1.3 Exercise Intervention Studies

Numerous studies have been conducted to determine whether exercise programs can reduce falls. Results have been mixed, which may be due in part to small sample sizes, varying program characteristics (e.g., exercise type, intensity, and volume), and diverse study populations (e.g., healthy, frail, specific pathologies). Recent meta-analyses have provided strong evidence that exercise can reduce falls by 14 to 37% in older adults (Chang et al., 2004; Gillespie et al., 2009; Sherrington et al., 2008). However, it remains unclear which types or combinations of programs are most effective, especially in relatively healthy individuals.

Gillespie et al. (2009) and Sherrington et al. (2008) sought to determine the impact of specific exercise types on fall rates. Gillespie et al. (2009) found that interventions which included multiple exercise types were more effective in reducing fall rates than single exercise interventions. Tai chi, which may consist of both strength and balance components, reduced fall rates by 37%. Gait, balance, and functional training reduced fall rates by 27%, while strength training alone had no effect. Similarly, Sherrington et al. (2008) found that balance training reduced fall rates by approximately 25%, while strength training had no effect. It was also suggested that programs which did not include a walking component were more effective (Sherrington et al., 2008). Classification of individual studies in terms of exercise type is a monumental challenge. While it is important to acknowledge these efforts, results may be biased due to the definitions of balance, strength, and walking. Balance is a term that is often used in a general sense, but there are multiple components of balance that may require specific methods of training and measurement. Similarly, strength training outcomes are specific to factors such as the muscle groups targeted, intensity, and contraction velocity. Finally, the definition of walking used by Sherrington et al. (2008) is very broad. A better definition may be based on the physical activity guidelines for aerobic exercise in older adults (Chodzko-Zajko et al., 2009). Thus, the conclusions of Gillespie et al. (2009) and

Sherrington et al. (2008) regarding the effects of specific exercise types for fall prevention deserve closer attention.

1.4 Balance Training

While it is generally agreed upon that balance training is effective for fall prevention (Gillespie et al., 2009; Sherrington et al., 2008), a challenge to this field and body of literature is that definitions of balance are broad and inconsistent. The balance model proposed by Horak et al. (2009) suggests that there are six interacting components: (1) biomechanics, (2) verticality and limits of stability, (3) anticipatory postural adjustments, (4) reactive postural responses, (5) sensory orientation, and (6) stability in gait. Gillespie et al. (2009) combined gait, balance, and functional training into one inclusive category that comprised a wide variety of activities. Sherrington et al. (2008) classified balance training in terms of three criteria: movement of the center of mass, narrowing of the base of support, and minimizing upper limb support. This definition may represent some balance components (e.g., anticipatory postural adjustments) but may not encompass others (e.g., sensory orientation). The effectiveness of interventions may become more clear if exercise programs are developed and evaluated in terms of specific and clearly-defined balance components, such as those proposed by Horak et al. (2009).

One important aspect of balance is sensory orientation, which establishes awareness of the body’s position in space. In order to do this, the central nervous system integrates somatosensory, visual, and vestibular inputs and shifts reliance based on the accuracy of the information. Declines in these contributing sensory systems can occur with age, even in the absence of known pathologies (Horak, Shupert, & Mirka, 1989). The Sensory Organization Test (SOT) using computerized dynamic posturography represents a gold standard for measuring sensory contribution to balance control (Mancini & Horak, 2010). A force platform measures the anterior-posterior sway of the center of gravity during six unique and progressively challenging conditions. The conditions may interrupt vision (i.e., requiring eyes to be closed or allowing the surrounding enclosure to sway) and/or somatosensation (i.e., allowing the platform beneath the feet to sway). Less stability has been observed in older adults in comparison to young adults, especially for conditions that challenge both somatosensory and visual systems (Whipple, Wolfson, Derby, Singh, & Tobin, 1993). However, information regarding the effects of specific exercise programs on sensory orientation in healthy older adults is generally lacking. A few exercise intervention studies have compared SOT overall composite scores (Carter et al., 2002; Woo, Hong, Lau, & Lynn, 2007), but comparisons of specific sensory ratios have not been found. Since the effective use of each of the three sensory systems may be trained uniquely, the specific sensory ratios may be more informative measures of sensory orientation than the overall composite score.

1.5 Resistance training

In theory, strengthening muscles of the lower extremity should reduce falls, but the effectiveness of resistance training programs remains unclear. This may be due to differing training protocols, such as muscle groups targeted, intensity, or speed of movement. Exercise intervention programs often incorporate multiple types of training (e.g. balance and strength), making it difficult to decipher individual contributions. Few studies have been found in which resistance training was performed as the single exercise intervention by relatively healthy older adults. One such study of postmenopausal women found that progressive lower extremity resistance training (i.e., mini-squats, mini-lunges, hamstring curls, calf raises, and gluteus maximus extensions on a mat) resulted in improved postural sway but no differences for falls relative to controls (Liu-Ambrose et al., 2004). It is possible that small sample sizes may have impacted this result, since fall outcomes were not the primary goal of the study. Alternatively, the training stimulus may have been insufficient to reduce falls. No differences were found between groups for quadriceps strength or ankle dorsiflexion strength, and due to lack of measurement, it is unclear whether the training stimuli were sufficient to improve strength in other lower extremity muscle groups relative to the control group. In another study, Woo et al. (2007) found no differences between resistance-trained individuals (using medium-strength resistance bands for hip abduction, heel raises, hip flexion, hip extension, and squatting ankle dorsiflexion) and controls for number of falls. Again, no difference was found between groups for quadriceps strength, and due to lack of measurement, it is unclear whether the training stimuli were sufficient to improve strength in other lower extremity muscle groups relative to the control group. Rooks et al. (1997) studied the effects of resistance training (stair climbing with weighted vests, unilateral seated knee extension, and standing ankle plantar flexion with increasing weight) on fall risk factors in healthy older adults but did not report on falls outcomes. At the completion of the 10-month intervention, resistance-trained individuals outperformed controls in tandem stance, one-legged stance, and stair climbing times, which are considered balance and functional performance measures. Knee extension strength was also greater in the resistance-trained individuals, but strength of other lower extremity muscle groups was not measured. While the effect on falls is not clear, it appears that resistance training in healthy older adults can improve some measures that are considered fall risk indicators.

The current physical activity guidelines for older adults (Chodzko-Zajko et al., 2009) recommend engaging in progressive weight-bearing or resistance training exercises involving the major muscle groups at least two days per week. Some resistance training interventions included in the meta-analyses lacked sufficient detail regarding targeted muscle groups (e.g., Barnett et al. (2003), Campbell et al. (2005), Mulrow et al. (1994), Nowalk et al. (2001)). In some weight-bearing exercises, the muscles activated may not have been fully understood. Other studies focused on muscles that act in the anterior-posterior direction but may not have concurrently targeted the important lateral stabilizers (e.g. Latham et al. (2003); Schoenfelder (2000); Suzuki et al., (2004)). Reduced hip abductor and adductor torque production has been observed in older individuals (Johnson, Mille, Martinez, Crombie, & Rogers, 2004; Murray & Sepic, 1968) and likely contributes to lateral instability and incidence of falls (Hilliard et al., 2008). Additionally, the ability to generate torque rapidly in these muscles may be highly relevant to fall prevention, more so than the traditional measure of maximum torque production. Studies of balance recovery suggest that successful stepping occurs very quickly, i.e., within approximately 300 ms of step initiation (Mille, Johnson, Martinez, & Rogers, 2005; Rogers, Hedman, Johnson, Cain, & Hanke, 2001). It is in this period of single leg support when torque production of the lateral hip stabilizers may be especially important. There is some evidence that the time critical period may be even shorter (e.g., 100 ms), based on significant differences observed between younger and older adults in the duration of hip torque production during lateral balance recovery (Mille et al., 2005). While the time to achieve maximum torque has not been reported for hip abductors and adductors, other muscle groups require more than 300 ms (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002), and the time may be even greater for older adults relative to the young (Mille et al., 2005). Exercise interventions associated with greater rapid torque development, especially in the lateral hip stabilizers, may be more effective in preventing falls and could represent a missing link between resistance training and fall prevention.

1.6 Walking

The effectiveness of walking programs on falls remains unclear. The meta-analysis by Sherrington et al. (2008) reported that exercise intervention programs that did not include a walking component were more effective at reducing fall rates. The authors proposed that walking may expose individuals to greater risk (e.g., slips or trips) or that time spent walking may have taken the place of other more beneficial forms of training in time-limited programs. It is also possible that the outcome was related to how walking was defined in the study. Sherrington et al. (2008) incorporated a very broad definition, classifying programs as having a walking component if any walking program or practice was mentioned. Twenty-seven studies met this criterion. In 10 of these studies, the walking component may have been more appropriately classified as balance or gait training (e.g. walking on toes, walking sideways, tandem walk, etc.) rather than fitness walking. The physical activity guidelines for older adults recommends at least 150 minutes of moderate intensity aerobic exercise per week, and states that walking is the most common form of aerobic activity. Eight of the 27 studies fell considerably short of 150 minutes per week. The walking component was ill-defined in 14 of the original studies. Only one intervention study measuring fall outcomes was found in which walking approached a recommended weekly dose. Ebrahim et al. (1997) found that women who walked briskly for 120 minutes each week experienced a higher percentage of falls in the first year of participation and a similar percentage of falls in the second year compared to a placebo group. While this outcome would suggest that walking may not be beneficial as a fall prevention program, all women recruited for the study had a recent history of upper limb fracture, and thus, may represent a higher risk population. It has been suggested that exercise may be associated with increased fall rates in higher risk older adult populations (Sherrington et al., 2008). Other studies have supported the merit of walking for reducing fall risk and fracture. Rooks et al. (1997) found that 135 minutes per week of self-paced walking improved some measures of balance and functional ability compared to controls during a 10-month intervention, but fall outcomes were not measured. Feskanich et al. (2002) conducted a 12-year longitudinal study of postmenopausal women, reporting that at least 4 hours of walking per week was associated with a 41% lower risk of hip fracture compared with less than 1 hour per week. Walking for 2 to 3 hours per week, which brackets the minimum recommended dose of aerobic exercise, approached a statistically significant reduction of 25% in hip fracture risk. Additionally, an average and brisk pace reduced the risk by 49% and 65%, respectively, relative to an easy pace. It is unknown from this study whether lower hip fracture rates resulted from fewer falls, superior femoral bone mineral density (BMD), or perhaps some other factor or combination of factors related to physical activity. Some studies have suggested that walking has a beneficial effect on femoral BMD (Coupland et al., 1999; Ebrahim et al., 1997), while one study found no effect (Nelson, Fisher, Dilmanian, Dallal, & Evans, 1991). Walking may improve some balance and functional performance measures (Roberts, 1989; Rooks et al., 1997), but it has not been associated with improved muscle performance measured by leg extension power (Ebrahim et al., 1997), maximum knee extension strength (Krall & Dawson-Hughes, 1994; Nelson et al., 1991; Rooks et al., 1997), or maximum knee flexion strength (Nelson et al., 1991). The effects of walking on strength measures of other lower extremity musculature, including the lateral hip stabilizers, have not been studied. Since walking is the most common form of physical activity among older adults (Siegel, Brackbill, & Heath, 1995; Yusuf et al., 1996), a better understanding of the impact on falls and fall risk factors is warranted. Studies should include healthy, community-dwelling older adults and programs of sufficient length to meet the current physical activity guidelines for aerobic exercise.

1.7 Better Bones and Balance

Better Bones and Balance (BBB) is a community-based program designed to prevent falls and fractures by increasing muscle strength, improving balance, and preventing bone loss. Classes are typically taught in 50 minute sessions, three times per week. The class is based on five core exercise components: (1) chair stands and squats, (2) stepping, (3) forward and side lunges, (4) toe raises and heel drops, and (5) stomps and jumps. Balance tasks emphasize reducing the base of support (e.g., standing on one leg, standing on toes), altering the location of the body's center of gravity (e.g., weight shifts), strengthening postural muscles (e.g., abdominals, gastrocnemius, upper and lower back muscles), and altering sensory input (e.g., standing on compliant surfaces, closing one eye). Previous studies have reported superior performance on some balance and strength measures for BBB participants relative to controls. Shaw and Snow (1998) found that BBB participation improved lateral stability (i.e., movement time and path sway), lower extremity muscle power, and peak isokinetic strength of hip abductors, knee extensors, and ankle plantarflexors. McNamara (2010) found that BBB participants performed better on one leg stance, tandem walk, timed up and go, and timed chair stands. Sensory orientation balance measures have not been evaluated. Although peak isometric hip abduction strength has been measured previously, rapid torque production during time-critical periods may be more pertinent to fall-prevention, and has not yet been assessed.

1.8 Functional Mobility

Stepping rapidly is an aspect of functional mobility that is crucial for fall prevention and impairment may be associated with increasing age. Older individuals have demonstrated longer step times during side and forward balance recovery relative to the young (Mille et al., 2005; Rogers et al., 2001). More importantly, fallers have demonstrated longer step times relative to non-fallers during forward balance recovery (Mille et al., 2005) and also during voluntary stepping (Brauer, Burns, & Galley, 2000). The Four Square Step Test evaluates this aspect of functional mobility by measuring the time to complete a multi-directional stepping sequence. It has previously differentiated non-fallers, single-fallers, and multiple-fallers in a population of healthy older adults, and longer times have been associated with greater fall frequency (Dite & Temple, 2002). Exercise interventions that are associated with faster stepping performance may be more effective in preventing falls.

1.9 Conclusion

Age-related declines in balance, muscle strength, and mobility may be partially responsible for the high fall rates observed in older adults. Exercise has been recommended as an intervention to combat these impairments. Understanding the important fall risk factors and the exercise interventions that are most beneficial for specific older adult populations continues to be an area of needed research. The objective of this study was to investigate whether exercise programs performed by healthy older adults were associated with superior balance, strength, and functional mobility measures that are pertinent to fall prevention. Specifically, this study compared participants of a balance- and strength-focused training program (i.e., Better Bones and Balance®), participants of a general walking program, and a group of sedentary individuals. The overall goal was to illuminate key differences based on the sensory orientation component of balance, rapid and maximum torque production of the lateral hip stabilizers, and rapid multi-directional stepping.

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APPENDIX 2

Informed Consent Document

OSU Oregon State University
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WRITTEN CONSENT FORM

Project Title:	Evaluating Balance and Strength of Older Women in Exercise Programs
Principal Investigator:	Sam Johnson, PhD, ATC
Student Researcher:	Melanie Dinger
Version Date:	1/13/12

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

We want to measure balance and strength in older women who participate in exercise programs and those who do not. Poor balance and strength increase risk of falling. We know that balance and strength may be improved by exercise, but we are not sure about which type is best. We will compare individuals in a balance and strength training program, individuals who walk, and individuals who are less active. Up to 125 individuals may be invited to take part in this study. This study is being conducted for the completion of a student's Master's Thesis.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a woman between the ages of 65 and 75 years of age, or within one year of this age range, and you have indicated that you meet ALL of the following requirements:

1) I am able to do normal activities of daily living (for example, bathing and dressing),
2) I walk without a cane or walker,
3) I have no diagnosed balance problems,
4) I am not taking medications with side effects that affect my balance,
5) I am currently taking less than four prescription medications,
6) I have not been diagnosed with peripheral neuropathy (tingling, burning, or loss of feeling in the feet),
7) I am not currently undergoing cancer treatment and have not undergone

treatment within the past year,

8) I have never experienced a hip fracture,

9) I have never experienced a hip, knee, or ankle joint replacement,

10) I belong to ONLY ONE of the following three groups (Better Bones & Balance, Walkers, or Controls):

   a. **Better Bones & Balance**
      i. I consider Better Bones & Balance to be my primary form of physical activity;
      ii. I have participated in an average of three Better Bones & Balance classes each week for the past six months; and
      iii. Other than scheduled breaks between terms, I have not missed more than six classes.

   b. **Walkers**
      i. I consider walking for fitness to be my primary form of physical activity;
      ii. I have walked for at least 2.5 hours each week in bouts of 10 minutes or more during the past six months;
      iii. My walking was generally at a level of intensity that noticeably increased my breathing and/or heart rate; and
      iv. I have not missed more than a total of four weeks of walking during the past six months.

   c. **Controls: Individuals who are less physically active**
      i. I have performed less than one hour per week of physical activity that noticeably increased my breathing or heart rate during the past six months.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

Testing will occur in the Sports Medicine Laboratory. This is located in the Women's Building on the campus of Oregon State University. Your involvement will last for approximately a little over an hour. The following is a brief description of the testing session:

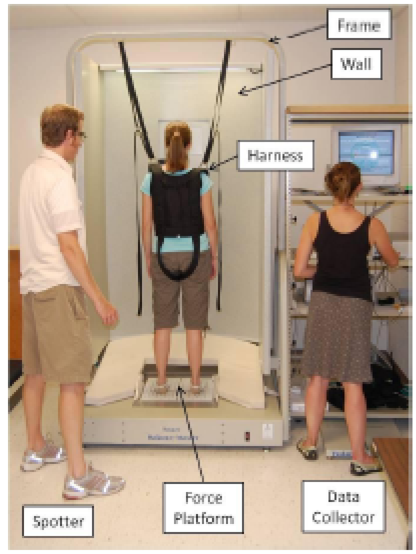
- **Read and sign informed consent form (~10 minutes)**

- **Complete Screening & Health History Questionnaires (~10 minutes)**

- **Determination of leg dominance, height, and weight (~5 minutes)**

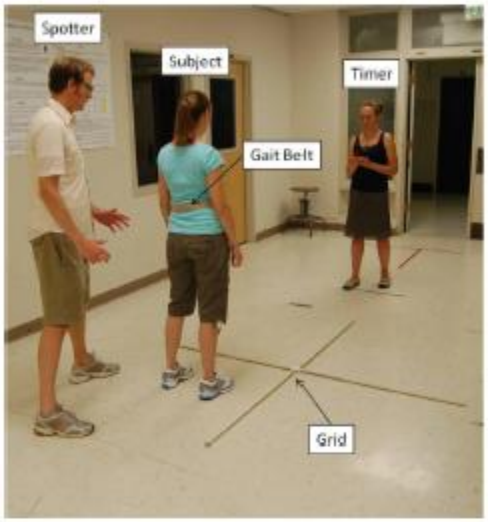
- **Standing Balance test (~15 minutes)**

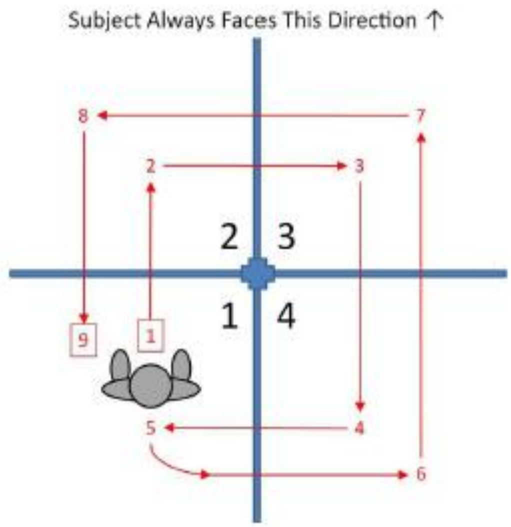
  You will be positioned securely in a safety harness and asked to stand on a platform. Your feet will be positioned by the researcher so that we can measure how much your body sways during six different test conditions. During some conditions, we will ask you to keep your eyes open while on others we will ask you to keep your eyes closed. Additionally, the platform may rock forward and backward and/or the wall around you might move. Your goal is to try to stand as steadily as possible without stepping or falling. You will perform three trials, lasting 20 seconds each, for each of the six conditions. If your feet move during the test, you may be asked to repeat a trial. If you lose your balance the harness will prevent you from falling.



- **Dynamic Balance Test (~10 minutes)**

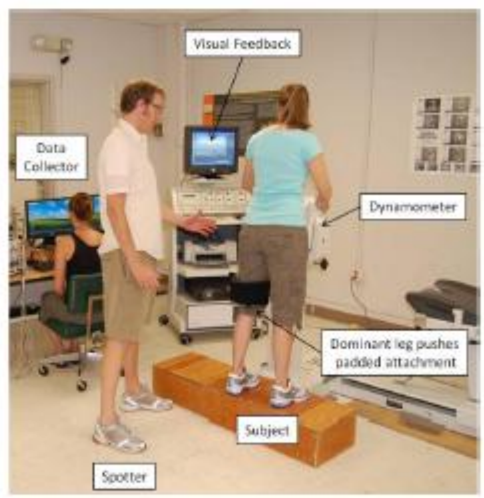
  This test requires quick stepping over 1-inch high stationary objects. You will be asked to step forward, sideways, and backward as quickly as you can in sequence that we will show you. One researcher will time you while another researcher will remain close to you in case you lose your balance. You will also wear a gait belt that will help the researchers in attempting to prevent a fall if you do lose your balance.





- **Hip muscle strength measurements (~15 minutes)**

This test requires you to be in a standing position with your dominant leg pushing away from <u>or</u> towards your body. You will be asked to push as hard and as fast as you can against a stationary pad for five seconds. This will be done three times in one direction <u>and</u> then three times in the opposite direction. You will receive a minute of rest between the three trials of a muscle group, but you will remain standing with the pad attached. Between muscle groups, you will receive five minutes of rest where you are encouraged to walk around or sit comfortably in a chair.



Future use of data:

It is not possible for us to know what studies we may do in the future. We ask that you give permission now for us to use your personal information without being contacted about each future study. Future use of your information will be limited to studies about exercise, falls and fall risk, balance, neuromuscular performance, and aging. If you decide later that you do not want your information stored for future use, you may contact Sam Johnson. See Section 12 for contact information.

______You may store my information for use in future studies.
Initials

______ You may not store my information for use in future studies.
Initials

Future contact:

We may contact you in the future for another similar study. You may ask us to stop contacting you at any time.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

All tests included in this study have been used before in clinical settings and in many other studies. To our knowledge, there have been no adverse consequences. We believe that the risks involved with being in this study are minimal and that we have taken the necessary steps to protect you. However, you may experience side effects from the study procedures that are not known to us. To the best of our knowledge, we have identified any potential risks and/or discomforts that you may experience as a result of being in this study. This information will help you decide whether to be in this study or not.

The test of standing balance may cause mild temporary discomfort, such as dizziness, nausea, or loss of balance. A safety harness will prevent you from falling if you lose your balance during the test. We will monitor your well being throughout the test and your willingness to continue. The test of dynamic balance could cause an unintentional trip or loss of balance. You will wear a gait belt and a trained researcher will be standing close to you to assist if you feel or appear unstable. Measurement of hip muscle strength may cause mild temporary discomfort, such as fatigue or soreness. A five minute rest will be provided between the two five-minute bouts of testing to minimize fatigue. Although it is unlikely, muscle soreness may occur in the days following testing. This is not considered an adverse consequence. If you feel uncomfortable and wish to stop testing for any reason, you may tell the researcher and end the test or the test session at any time.

We have procedures in place to protect your privacy. However, there is a small risk that we could accidentally disclose information that identifies you. Please see the section "WHO WILL SEE THE INFORMATION I GIVE?" for our procedures to minimize your risk.

6. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. You will be responsible for all costs associated with receiving medical treatment. Compensation will not be provided. If you think that you have been injured from being in this study, please report what happened to the student researcher and/or the principal investigator immediately. The information will be reported immediately to the Oregon State University Institutional Review Board (a committee that reviews and approves research studies).

7. WHAT ARE THE BENEFITS OF THIS STUDY?

This study is not designed to benefit you directly.

8. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study.

9. WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will be responsible for your own transportation to and from the testing site. The cost of visitor parking on campus will be covered by the researchers.

10. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

To help protect your privacy, your name and contact information will be stored on one "master" document. All other information that we collect about you will not be directly associated with your name. Instead, we will use a unique identification code. Your information will be safely stored, either on a researcher's password-protected computer, on a computer that is in the researcher's locked laboratory, or in a locked file cabinet available only to the research staff. If the results of this project are published, your identity will not be made public.

If your name was obtained from the LIFE registry, your participation will be reported back to the Center for Healthy Aging Research.

11. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

Participation in this study will be ended by the researcher if 1) you choose not to answer the screening questions or 2) we determine that you do not meet the requirements based on your answers. These questions are designed for your safety and for the integrity of the study design. For your convenience, we will screen you before you arrive at the test site. However, if your circumstances change between the initial screening and the test session, you will be dismissed from the study.

You will be asked to complete a health history questionnaire as part of your test session. Although we encourage your participation, you will not be dismissed from the study if you choose not to answer some of the questions.

12. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact Sam Johnson at (541) 737-6801 or by email at sam.johnson@oregonstate.edu. You may also contact Melanie Dinger at (541) 737-6899 or by email at dingerm@onid.orst.edu.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu.

13. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed): ______________________________

______________________________ ______________________________
(Signature of Participant) (Date)

______________________________ ______________________________
(Signature of Person Obtaining Consent) (Date)

Oregon State University	IRB Study # 5074	Expiration Date 10/24/2012

APPENDIX 3

Screening Questionnaire

SCREENING QUESTIONNAIRE

__________ _______________
Date Code

Please answer the following questions:

1. What is your age? ____ years

2. Are you able to take care of your own personal needs, such as bathing and dressing yourself?

   YES NO

3. Are you able to walk without the use of a cane or walker?

   YES NO

4. Do you currently have any diagnosed balance problems?

   YES NO

5. Are you taking any medications known to affect balance?
   (These may include benzodiazepines, sleeping medications, neuroleptics/antipsychotics, antidepressants, anticonvulsants, or class 1A antiarrhythmics.)

   YES NO

6. Are you currently taking 4 or more **prescription** medications?

   YES NO

7. Do you have documented peripheral neuropathy?

   YES NO

Date Code

8. Are you currently undergoing treatment for cancer or have you been treated for cancer during the past year?

YES NO

9. Have you ever experienced a hip fracture?

YES NO

10. Have you ever experienced a hip, knee, or ankle joint replacement?

YES NO

11. How would you describe your primary form of physical activity?

Circle one:

A.) Participation in Better Bones & Balance

B.) Walking for fitness

C.) Neither A nor B

If you answered A, please complete page 3.
If you answered B, please complete page 4.
If you answered C, please complete page 5.

______ ________
Date Code

PHYSICAL ACTIVITY: BETTER BONES & BALANCE

1. Have you been attending Better Bones & Balance classes three times per week, on average, for the previous six months?

   YES NO

2. Please indicate approximately how long, in years and months, you have been participating in the Better Bones & Balance program.

   ____ years ____ months

3. Did you take any unscheduled breaks from classes that exceeded a total of two weeks (i.e. six classes) during the previous six months?

   YES NO

4. Did you regularly participate in any other physical activities during the previous six months that ***noticeably increased your heart rate and/or breathing***?

   YES NO

   If YES, please list the activity, when you began the activity, the number of weeks in which you were engaged in the activity, and the approximate amount of time per week. *(Examples: strenuous household chores, yard work, swimming, bicycling,...)*

Activity	**Start Date**	**Length of participation (# of weeks)**	**Amount of time per week (minutes)**

STOP HERE!! PLEASE NOTIFY THE RESEARCHER BEFORE PROCEEDING.

__________ ________________
Date Code

PHYSICAL ACTIVITY: WALKING

1. During the previous six months, how much time did you spend, on average, each week walking for fitness at an intensity that noticeably increased your heart rate and/or breathing?

   ____ hours ____ minutes

2. Did you walk for more than 10 minutes at a time? YES NO

3. Were there any prolonged periods of time in which you did not walk for fitness during the previous six months?

   YES NO

   If YES, please approximate the total length of time. ____ weeks

4. Did you regularly participate in any other physical activities during the previous six months that ***noticeably increased your heart rate and/or breathing***?

   YES NO

   If YES, please list the activity, when you began the activity, the number of weeks in which you were engaged in the activity, and the approximate amount of time per week. *(Examples: strenuous household chores, yard work, swimming, bicycling,...)*

Activity	**Start Date**	**Length of participation (# of weeks)**	**Amount of time per week (minutes)**

STOP HERE!! PLEASE NOTIFY THE RESEARCHER BEFORE PROCEEDING.

Date ____________ Code ____________________

PHYSICAL ACTIVITY: CONTROLS

Did you regularly participate in any physical activities during the previous six months that ***noticeably increased your heart rate and/or breathing***?

YES NO

If YES, please list the activity, when you began the activity, the number of weeks in which you were engaged in the activity, and the approximate amount of time per week. *(Examples: strenuous household chores, yard work, swimming, bicycling, ...)*

Activity	Start Date	Length of participation (# of weeks)	Amount of time per week (minutes)

STOP HERE!! PLEASE NOTIFY THE RESEARCHER BEFORE PROCEEDING.

APPENDIX 4

Health History Questionnaire

HEALTH HISTORY QUESTIONNAIRE

____________ __________________
Date Code:

1. Have you fallen in the past year? YES NO

   If YES, please give an *approximate date and describe the reason for the fall*. Please indicate what you were doing at the time of the fall and if the fall occurred while exercising.

Date	Reason

2. Are you worried about falling? (Circle the appropriate number)

1	2	3	4	5	6	7
No	slightly		moderately		very	extremely

3. Do you currently have or have you ever had any of the following?

Check if YES		**Year of Onset**	**Current Symptoms? (circle one)**	
____	Diabetes	__________	YES	NO
____	Kidney disease	__________	YES	NO
____	Neurological disorder (*examples: Dementia, Parkinson's Disease, Fibromyalgia*)	__________	YES	NO

_________ Date ______________ Code

Check if YES		**Year of Onset**	**Current Symptoms? (circle one)**	
____	Vision impairment	________	YES	NO
____	Heart disease or heart trouble	________	YES	NO
____	Lung disease	________	YES	NO
____	Stroke	________	YES	NO
____	High blood pressure	________	YES	NO
____	Orthostatic Hypotension (*for example, blood pressure drops when standing up*)	________	YES	NO
____	Cancer	________	YES	NO
____	Osteoporosis	________	YES	NO
____	Arthritis	________	YES	NO
____	Back injury	________	YES	NO
____	Broken bones	________	YES	NO
____	Bone / joint surgery of lower extremity	________	YES	NO

If YES to any of the medical conditions listed, please briefly describe:

____

____

____

____

__________ _______________
Date Code

4. Please list all medications that you are currently taking. **Include prescriptions and over the counter medications**.

Medication	Dosage	For what condition

APPENDIX 5

Matlab Program for Processing Hip Strength Data

```
%==================================================================
%                    Main Program
%==================================================================
%Oregon State University
%
%Main program: RFD_Lateral_Hip_Muscles_20130121.m
%
clc                                         % Clear Command Window
clear;                                      % Clear items from workspace
clear all;
fclose('all');
close(gcf)

temporary_directory = pwd;                  % Returns the current folder
as a string to temporary_directory
fprintf(1,'\n\nProcessing\n\n');            % Writes data to text file.
File ID = 1 for std output to screen.

%==================================================================
%                    Program Information
%==================================================================

%-------------------subject information-----------------------------

subjects            = 1;            %number of subjects to process
conditions          = 1;            %number of conditions per subject
trials              = 1;            %trials per condition
startwithsubj       = 1;            %subject number to start with
startwithcond       = 1;            %condition number to start with
startwithtrial      = 1;            %trial number to start with

%-------------------File information--------------------------------

outputfile          = 'Output_s1c1t1.txt';
      %File name that dependent variables will be saved to
TimeTorqueFile      = 'TimeTorque_s1c1t1.txt';
      %File name that TimeForce data will be saved to
directory           = 'C:\Users\dingerm\Documents\MATLAB\work';
headers             = 0;
      %number of rows of text in data set
fs                  = 2000;
      %sample frequency (Hz)
fc                  = 8;
      %cutoff frequency for smoothing (Hz)
peakcol             = 2;
      %Number of columns in data set
precision           = 4;
      %output precision
PercentMaxT         = 0.025;
      %Percent of max torque to determine threshold for onset
points              = 500;
      %number of data points (x2)to calculate offset
LRinterval          = [50:50:400];  %in ms
```

```
splice                = 200
      %number of points to get rid of at beginning and end

%-------------------create figure-----------------------------------

bottomleftcornerx = 100;
bottomleftcornery = 100;
width             = 500;
height            = 500;

%bottom left corner (x,y) then width then height
figure('position', [bottomleftcornerx, bottomleftcornery, width,
height])

%===================================================================
%                   Main Processing Loop
%===================================================================

%counter
filenumber = 0;

for s = startwithsubj:(startwithsubj+subjects-1)
for c = startwithcond:(startwithcond+conditions-1)
for t = startwithtrial:(startwithtrial+trials-1)

    %update counter
    filenumber = filenumber+1;

    %Open a file
    [data, inputfileroot] = osu_open(s, c, t, directory, ['.txt'], …
            peakcol, inf, headers);

    %assign variables
    time = 0:1/fs:(length(data(splice:end-splice,1))-1)/fs;
    % Torque converted from ft-lbF to N-m
    % Note: 1 lbF = 4.44822161526 N
    % Note: 1 ft = 0.3048 m
    torque = data(splice:end-splice,1) * 4.44822161526 *0.3048;

    %=======================================================

    %plot data
    plot(time, torque, 'r')
    xlabel('time (s)')
    ylabel('Torque (Nm)')
    hold on

    %ask the user if the data need to be flipped:
    a= input('\n  Do the data need to be flipped? (1=yes, 0=no) \n');

    %flip if needed
```

```
if a == 1

%multiply by negative one
torque = torque*(-1);

%plot data flipped curve
plot(time, torque, 'b')

end

%if a == 0, then do nothing.

%========================================================
%smooth data
torque_smooth = my_filt(torque, fc, fs, 1);

%plot data
plot(time, torque_smooth, 'c')

%remove offset
%fprintf(1, '\n  Click on offset\n')
fprintf(1, '\n  Place cursor ~250 ms prior to contraction onset.
  … Click to determine offset.\n')
[x,y] = ginput(1);
%findx is a vector of indices in which time > x coordinate
findx = find(time > x);
start_offset = findx(1)-points;
%check to make sure search was not before beginning of array
if start_offset < 1
    start_offset = 1;
end

% Offset calculated using # points before & after input coord.
% However, if input coord is too close to beginning of curve,
% offset calculation starts at beginning of curve and uses fewer
% points for offset calculation. Fzero implies that the torque
% has been "zeroed" using the offset calc.
offset = mean(torque_smooth(start_offset:findx(1)+points));
Fzero = torque_smooth - offset;

hold off
plot(time, Fzero, 'g')
hold on

% Identify end of time with user input
fprintf(1, '\n  Click after end\n')
[x2, y] = ginput(1);
% tt is a vector of indices in which time < x2 coordinate
tt = find(time < x2);
end_t = tt(end);
```

```
% Identify force onset
% Added variable forceonset (percent of max force)
TorqueOnset = PercentMaxT.*max(Fzero);
tempstartforce = find(Fzero(1:end_t) > TorqueOnset);
startforce = tempstartforce(1);
endforce = tempstartforce(end);
plot(time(startforce:endforce), Fzero(startforce:endforce), 'm')

% Specify torque-time data to save.
% Start at onset torque and increment by 1/fs until arriving at
% the number of data points in the torque curve (Fzero).
TimeData(:,1) =
        … 0:1/fs:(length(Fzero(startforce:endforce,1))-1)/fs;
TorqueData (:,1) = Fzero(startforce:endforce);

%---------------Determine RTD (Avg, Max, & Instant)----------------
% MVC = max torque of torque-time curve
% TimeToMVC = time from torque onset to time of max torque (MVC)
% MaxRTD_MVC = avg RTD from torque onset to MVC
% MaxRTD_Peak1_Avg = avg RTD from torque onset to first peak.
% MaxRTD_Peak1_Inst = max first derivative of torque-time curve
% from torque onset to the first peak.
% RTDavg = change in Torque / change in Time
% (i.e., 0-50, 0-100, ..., 0-400 ms).
% RTDinst = 1st derivative (instantaneous) of torque-time curve
% at each specified time point (i.e., 50, 100,..., 400 ms)

plot(time(startforce:end), max(Fzero(startforce:end)), 'bo')

%find max torque and the associated index.
[MVC, PosMaxT] = max(Fzero);
MVC;

%find time from torque onset to max torque (MVC)
TimeToMVC = (PosMaxT-startforce)/fs;

% Avg RTD between torque onset and max torque (MVC)
MaxRTD_MVC = MVC/((PosMaxT-startforce)/fs);
plot([time(startforce) time(PosMaxT)], …
[Fzero(startforce) Fzero(PosMaxT)], 'y')

% Find avg RTD from torque onset to first peak.
% Also identify Torque at Peak 1 and Time at Peak 1.
for z = 1:(length(Fzero(startforce:end))-2)
    FirstDeriv(z) = ( Fzero(startforce+z+1) …
  - Fzero(startforce+z-1)) / (2*(1/fs));
end
% Find the index where the first derivative is negative.
% This will be the index immediately following the first peak.
% Note: Didn't use FirstDeriv==0 b/c may not ever be perfectly 0.
FirstIndex = find(FirstDeriv<0, 1);
% Use FirstIndex to find the time and torque at Peak 1.
```

```
% Note: Subtracted a total of 2 indices to determine Torque &
% Time at Peak1. One indice subtracted b/c FirstIndex didn't
% point to peak but to index immediately after peak.
% Another indice subtracted to account for startforce indice.
TorqueAtPeak1 = Fzero(startforce + FirstIndex -2);
TimeAtPeak1 = (FirstIndex-2)/fs;
MaxRTD_Peak1_Avg = …
   (TorqueAtPeak1 - Fzero(startforce)) / TimeAtPeak1;

% Find Max RTD defined as the max first derivative from torque
% onset to the first peak.
% Also Identify Torque at Max RTD, and Time of Max RTD.
[MaxRTD_Peak1_Inst, PosMaxRTD_Peak1] = …
    max(FirstDeriv(1:FirstIndex));
TorqueAtMaxRTD = Fzero(startforce + PosMaxRTD_Peak1 -1);
TimeAtMaxRTD = (PosMaxRTD_Peak1 - 1)/fs;

% Average RTD from torque onset to specific time defined by
% LRinterval.
for i = 1:length(LRinterval)

    finalforce = (LRinterval(i)*fs/1000) + startforce;
% LRinterval(i)*fs/1000 is the number of indices from torque
% onset to time of interest.

    RTDavg(i) = ( Fzero(finalforce) - Fzero(startforce) )/ ...
        (time(finalforce) - time(startforce));

    %this is just for plotting purposes
    fx = [time(startforce) time(finalforce)];
    fy = [Fzero(startforce) Fzero(finalforce)];

    %plot using different colors
    if i == 1
        plot(fx, fy, 'k')

        elseif i == 2
        plot(fx, fy, 'g')

        elseif i == 3
        plot(fx, fy, 'c')

        else
        plot(fx, fy, 'r')

    end

    % Instantaneous RTD at specific time defined by LRinterval.
    % Calculated using the central difference method.
    RTDinst(i) = ( Fzero(finalforce+1) …
        - Fzero(finalforce-1)) / (2*(1/fs));
```

```
        %------------------Determine Impulse-----------------------

        % CALCULATE IMPULSE (NEWTON-METER*SECONDS) FOR A SPECIFIC
        % TIME INTERVAL BY SUMMING THE AREAS OF THE TRAPEZOIDS
        % CREATED BY EACH SAMPLING CYCLE WITHIN THE TIME INTERVAL.

        % Calculate # of trapezoids during the time interval
        Trapezoids = finalforce - startforce;
        SumForces = Fzero(startforce) + Fzero(finalforce);
        for k = 1 : Trapezoids
            if k < Trapezoids
                SumForces = SumForces + 2*Fzero(startforce + k);
            end     %end if statement
        end     %end 'k' loop
        % Calculate area under curve
        Impulse(i) = SumForces./(2*fs);


    end     %end 'i' loop

    pause


    % Specify variables to save in output file.
    total(filenumber, :) = [s c t MVC TimeToMVC MaxRTD_MVC ...
        TorqueAtPeak1 TimeAtPeak1 MaxRTD_Peak1_Avg MaxRTD_Peak1_Inst
            ...TorqueAtMaxRTD TimeAtMaxRTD RTDavg RTDavg./MVC RTDinst
            ...RTDinst./MVC Impulse Impulse./MVC];
    % Specify data to save in TimeTorque file
    TimeTorqueData = [TimeData TorqueData];

    close(gcf)

    if conditions > 1 | trials > 1
        figure('position', [bottomleftcornerx, bottomleftcornery,…
            width, height])
    end

    clear data force force_smooth Fzero absforce time;

    fprintf(1, '\n ======================\n\n')
end %next trial
end %next condition
end %next subject


%======================================================================
%                    Save data and close program
%======================================================================
```

```
%save data
my_save(directory, outputfile, total, precision);

%save data
my_save_TimeTorque(directory, TimeTorqueFile, TimeTorqueData, …
      precision);

%change back to original directory
eval(['cd ' temporary_directory])

%clean house
%close(gcf);
fclose('all');
close(gcf);

%Tell user program is done processing
fprintf(1, '\ndone\n\n');

%clean up
%clear;

%======================================================================
%                   End Main Program
%======================================================================
```

```
%==================================================================
%                   Function: osu_open
%==================================================================
%function:  osu_open
%this function will run the commonly used commands to open a file.
%
%called as:
%   [data, inputfileroot] = osu_open(s, c, t, directory, datain,
columns, rows, headers)
%
%where
%   data          = returned data set
%   inputfileroot = file name processed
%   directory     = location of file
%   datain        = extension of file name
%   columns       = number of columns
%   rows          = number of rows
%   headers       = number of headers to get rid of

function [tempdata, inputfileroot] = osu_open(s, c, t, my_dir,
datain, columns, rows, headers);

    %create s?c?t? filename
    subj = int2str(s);
    cond = int2str(c);
    tri = int2str(t);

    f_name = ['s' subj 'c' cond 't' tri];
    fprintf(1,f_name); fprintf(1,'\n');
    inputfileroot = f_name;

    %create filenames
    inputfile    = [f_name datain];

    %set up commands for eval function
    %change to working directory
    eval(['cd ' my_dir ';']);

    %open the file
    %create substrings
    c = 'fid=fopen(''';
    d = ''',''rt'');';

    %create filename
    file_name = [c, inputfile, d];

        %open peak input file
    eval(file_name);

    %get rid of headers
    for h = 1:headers
        fgets(fid);
```

```
    end

    %read in data
    A = fscanf(fid, '%f', [columns rows]);
    tempdata = A';

%close files
fclose('all');
```

```
%======================================================================
%                   Function: my_filt
%======================================================================
%Fourth Order Zero lag Butterworth Filter
%
%Function called as:
%[smooth_data] = my_filt(rawdata, fc, fs, type)
%
%where
%fc = cutoff frequency
%fs = sample frequency
%type = type of filter
%   1 = low pass filter
%   2 = high pass filter
%====================================================

function [smoothed_data] = my_filt(raw_data,fc, fs, type)

warning off

%calculate wn
wn = 2*fc/fs;

%calculate butterworth coefficients (2nd order)
if type == 1
   [B,A]=butter(2,wn);
end
if type == 2
   [B,A]=butter(2,wn,'high');
end

%calculate smoothed data using a zero-phase lag routine
smoothed_data=filtfilt(B,A,raw_data);

warning on
```

```
%=====================================================================
%                   Function: my_save
%=====================================================================
%Function: my_save(directory, filename, data, precision)
%
%This function will save data to a specified file with a specified
%precision

function my_save(directory, filename, data, precision)

    %initialize variable
    all_column_info = [];

    %change directory
        temp = pwd;
        eval(['cd ' directory]);

    %open the file to write to
        fid=fopen(filename, 'w');

    %make quote notation
        q='''';

    %check the size of the data array
        [rows columns] = size(data);

    %Create the necessary write commands

        column_precision = int2str(precision);
        column_info = ['%5.' column_precision 'f'];

        for i = 1:columns
            all_column_info = [column_info ' ' all_column_info];
        end

    %transpose the output data array because the print command writes
    %column 1, then column 2, ...
        data=data';

    %create command line
        print_command = …
            ['fprintf(fid,' q all_column_info '\n' q ', data);'];

    %save data
        eval([print_command]);

    %close file
        fclose(fid);

    %change back to original directory
        eval(['cd ' t
```

```
%======================================================================
%                    Function: my_save_TimeTorque
%======================================================================
%Function: my_save_TimeTorque(directory, filename, data, precision)
%
%This function will save data to a specified file with a specified
%precision

function my_save_TimeTorque(directory, filename, data, precision)

    %initialize variable
    all_column_info = [];

    %change directory
        temp = pwd;
        eval(['cd ' directory]);

    %open the file to write to
        fid=fopen(filename, 'w');

    %make quote notation
        q='''';

    %check the size of the data array
        [rows columns] = size(data);

    %Create the necessary write commands

        column_precision = int2str(precision);
        column_info = ['%5.' column_precision 'f'];

        for i = 1:columns
            all_column_info = [column_info ' ' all_column_info];
        end

    %transpose the output data array because the print command writes
    %column 1, then column 2, ...
        data=data';

    %create command line
        print_command = …
            ['fprintf(fid,' q all_column_info '\n' q ', data);'];

    %save data
        eval([print_command]);

    %close file
        fclose(fid);

    %change back to original directory
        eval(['cd ' t
```

APPENDIX 6

Final Linear Regression Models

The final linear regression model for each dependent variable is presented along with the associated coefficient and ANOVA tables. If the final model included *Group* (BBB and Walk indicator variables) only, then the one-way ANOVA or Welch's one-way ANOVA output is presented instead.

Sensory Organization Test

Composite Score:

$$\bar{y} = \beta_0 + \beta_1 BBB + \beta_2 Walk$$

```
Analysis of Variance Table

Response: y
          Df  Sum Sq Mean Sq F value Pr(>F)
Group      2  136.83  68.415  1.8704 0.1673
Residuals 40 1463.08  36.577
```

SOM Ratio:

$$\bar{y} = \beta_0 + \beta_1 BBB + \beta_2 Walk$$

```
Analysis of Variance Table

Response: y
          Df    Sum Sq     Mean Sq F value  Pr(>F)
Group      2 0.0014401 0.000720048 0.94004 0.39907
Residuals 40 0.0306390 0.000765974
```

VIS Ratio:

$$\bar{y} = \beta_0 + \beta_1 BBB + \beta_2 Walk$$

```
        One-way analysis of means (not assuming equal variances)

data:  y and Group
F = 1.4819, num df = 2.00, denom df = 24.34, p-value = 0.247
```

VEST Ratio:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk$$

```
Analysis of Variance Table

Response: y
          Df  Sum Sq  Mean Sq F value Pr(>F)
Group      2 0.03290 0.016450  0.9999 0.3769
Residuals 40 0.65806 0.016452
```

Four Square Step Test:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_3 Age$$

```
Call:
lm(formula = y ~ BBB + Walk + Age)

Residuals:
      Min        1Q    Median        3Q       Max
-1.715630 -0.572189  0.007811  0.529093  2.774615

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
β0 = (Intercept) -1.970288   3.677738 -0.5357 0.595185
β1 = BBB         -1.057177   0.388104 -2.7240 0.009602 **
β2 = Walk        -0.161045   0.387573 -0.4155 0.680038
β3 = Age          0.140799   0.052614  2.6761 0.010836 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.0211 on 39 degrees of freedom
Multiple R-squared: 0.26943,    Adjusted R-squared: 0.21323
F-statistic: 4.7942 on 3 and 39 DF,  p-value: 0.0061476


Analysis of Variance Table

Response: y
          Df  Sum Sq Mean Sq F value   Pr(>F)
BBB        1  7.1892 7.18924 6.89529 0.012284 *
Walk       1  0.3401 0.34006 0.32616 0.571206
Age        1  7.4665 7.46655 7.16126 0.010836 *
Residuals 39 40.6626 1.04263
```

Hip Torque Production

Abduction RTD from 0-100 ms:

$$Median\ (\log y) = \beta_0 + \beta_1\ BBB + \beta_2 Walk + \beta_3 Age$$

```
Call:
lm(formula = y ~ BBB + Walk + Age)

Residuals:
      Min        1Q    Median        3Q       Max 
-1.228884 -0.164906 -0.004169  0.187532  0.562834 

Coefficients:
             Estimate Std. Error t value  Pr(>|t|)    
β0 = (Intercept) 10.758185   1.212947  8.8695 8.581e-11 ***
β1 = BBB          0.069990   0.129394  0.5409   0.59173    
β2 = Walk        -0.323490   0.127282 -2.5415   0.01524 *  
β3 = Age         -0.085066   0.017353 -4.9021 1.802e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.33533 on 38 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared: 0.45714,    Adjusted R-squared: 0.41428 
F-statistic: 10.667 on 3 and 38 DF,  p-value: 3.1747e-05


Analysis of Variance Table

Response: y
          Df  Sum Sq  Mean Sq  F value     Pr(>F)    
BBB        1 0.32139 0.321387  2.85812   0.099102 .  
Walk       1 0.57477 0.574770  5.11148   0.029577 *  
Age        1 2.70212 2.702123 24.03023 1.8019e-05 ***
Residuals 38 4.27298 0.112447
```

Abduction Impulse from 0-100 ms:

$$Median\ (\log y) = \beta_0 + \beta_1\,BBB + \beta_2 Walk + \beta_3 Age$$

```
Call:
lm(formula = y ~ BBB + Walk + Age)

Residuals:
      Min        1Q    Median        3Q       Max 
-0.476976 -0.088056 -0.019114  0.065359  0.438490 

Coefficients:
              Estimate Std. Error t value  Pr(>|t|)    
β0 = (Intercept)  3.7287563  0.5911745  6.3074 2.158e-07 ***
β1 = BBB          0.1276293  0.0630649  2.0238   0.05007 .  
β2 = Walk        -0.1331331  0.0620357 -2.1461   0.03832 *  
β3 = Age         -0.0448114  0.0084577 -5.2983 5.211e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

Residual standard error: 0.16344 on 38 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared: 0.52135,    Adjusted R-squared: 0.48356 
F-statistic: 13.797 on 3 and 38 DF,  p-value: 3.082e-06 


Analysis of Variance Table

Response: y
          Df   Sum Sq  Mean Sq  F value    Pr(>F)    
BBB        1 0.265129 0.265129  9.92574 0.0031725 ** 
Walk       1 0.090602 0.090602  3.39191 0.0733321 .  
Age        1 0.749844 0.749844 28.07219 5.211e-06 ***
Residuals 38 1.015029 0.026711                       
```

Abduction RTD from 0-300 ms:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_3 Age + \beta_4 Mass$$

```
Call:
lm(formula = y ~ BBB + Walk + Age + Mass)

Residuals:
     Min       1Q   Median       3Q      Max 
-58.4900 -12.0017  -1.2022  11.2017  39.9424 

Coefficients:
             Estimate Std. Error t value  Pr(>|t|)    
β0 = (Intercept) 322.38421   87.28549  3.6934 0.0007108 ***
β1 = BBB          18.41197    9.29885  1.9800 0.0551745 .  
β2 = Walk          8.95756    9.25178  0.9682 0.3392319    
β3 = Age          -4.12736    1.20762 -3.4178 0.0015495 ** 
β4 = Mass          0.68870    0.26676  2.5817 0.0139278 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 

Residual standard error: 23.329 on 37 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared: 0.35322,    Adjusted R-squared: 0.28329 
F-statistic: 5.0515 on 4 and 37 DF,  p-value: 0.0023774 


Analysis of Variance Table

Response: y
          Df   Sum Sq Mean Sq  F value    Pr(>F)   
BBB        1   666.24  666.24  1.22418 0.2756832   
Walk       1   102.00  102.00  0.18741 0.6675911   
Age        1  6601.19 6601.19 12.12934 0.0012923 **
Mass       1  3627.39 3627.39  6.66513 0.0139278 * 
Residuals 37 20136.64  544.23                      
```

Abduction Impulse from 0-300 ms:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_3 Age + \beta_4 Mass$$

```
     Call:
     lm(formula = y ~ BBB + Walk + Age + Mass)

     Residuals:
          Min        1Q    Median        3Q       Max
     -2.67372 -1.08931 -0.11167  1.12160  4.10678

     Coefficients:
                  Estimate Std. Error t value  Pr(>|t|)
β0 = (Intercept) 35.273170   6.212727  5.6776 1.717e-06 ***
β1 = BBB          1.538483   0.661865  2.3245   0.02570 *
β2 = Walk        -0.366799   0.658515 -0.5570   0.58087
β3 = Age         -0.474870   0.085955 -5.5247 2.765e-06 ***
β4 = Mass         0.044958   0.018987  2.3678   0.02323 *
     ---
     Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

     Residual standard error: 1.6605 on 37 degrees of freedom
       (1 observation deleted due to missingness)
     Multiple R-squared: 0.53815,    Adjusted R-squared: 0.48822
     F-statistic: 10.778 on 4 and 37 DF,  p-value: 6.8069e-06


     Analysis of Variance Table

     Response: y
               Df   Sum Sq Mean Sq  F value     Pr(>F)
     BBB        1  14.7811 14.7811  5.36093   0.026242 *
     Walk       1   2.6279  2.6279  0.95311   0.335268
     Age        1  86.0014 86.0014 31.19175 2.2913e-06 ***
     Mass       1  15.4579 15.4579  5.60642   0.023233 *
     Residuals 37 102.0158  2.7572
```

Abduction MVC:

$$\bar{y} = \beta_0 + \beta_1 BBB + \beta_2 Walk + \beta_3 Age + \beta_4 Mass + \beta_7 BBB \times Mass + \beta_8 Walk \times Mass$$

```
Call:
lm(formula = y ~ BBB + Walk + Age + Mass + BBB * Mass + Walk *
    Mass)

Residuals:
      Min        1Q    Median        3Q       Max
-14.78452  -4.47431  -0.65685   4.00518  24.54256

Coefficients:
             Estimate Std. Error t value  Pr(>|t|)
β0 = (Intercept) 135.88615   33.55036  4.0502 0.0002699 ***
β1 = BBB         -55.97539   20.72537 -2.7008 0.0105876 *
β2 = Walk         12.21739   17.62494  0.6932 0.4927664
β3 = Age          -1.54495    0.48118 -3.2108 0.0028359 **
β4 = Mass          0.13018    0.18205  0.7151 0.4792961
β7 = BBB:Mass      1.00205    0.28773  3.4826 0.0013525 **
β8 = Walk:Mass    -0.13730    0.24151 -0.5685 0.5733091
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 8.9342 on 35 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared: 0.59595,    Adjusted R-squared: 0.52669
F-statistic:  8.604 on 6 and 35 DF,  p-value: 8.9306e-06


Analysis of Variance Table

Response: y
          Df   Sum Sq  Mean Sq  F value     Pr(>F)
BBB        1  601.864  601.864  7.54023 0.00946285 **
Walk       1   44.624   44.624  0.55905 0.45963654
Age        1 1241.995 1241.995 15.55988 0.00036636 ***
Mass       1  662.860  662.860  8.30440 0.00671404 **
BBB:Mass   1 1543.497 1543.497 19.33714 9.7485e-05 ***
Walk:Mass  1   25.800   25.800  0.32322 0.57330909
Residuals 35 2793.712   79.820
```

Adduction RTD from 0-100 ms:

$$\bar{y} = \beta_0 + \beta_1 BBB + \beta_2 Walk + \beta_3 Age$$

```
     Call:
     lm(formula = y ~ BBB + Walk + Age, subset = c(-7))

     Residuals:
          Min       1Q   Median       3Q      Max
     -75.2865 -30.3805  -2.8786  19.1188 109.5432

     Coefficients:
                 Estimate Std. Error t value Pr(>|t|)
β0 = (Intercept) 593.5204   178.1389  3.3318 0.002005 **
β1 = BBB          12.2681    18.0360  0.6802 0.500727
β2 = Walk         -4.1261    17.6087 -0.2343 0.816061
β3 = Age          -7.2646     2.5496 -2.8493 0.007202 **
     ---
     Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '

     Residual standard error: 45.71 on 36 degrees of freedom
       (2 observations deleted due to missingness)
     Multiple R-squared: 0.19004,    Adjusted R-squared: 0.12254
     F-statistic: 2.8155 on 3 and 36 DF,  p-value: 0.052875


     Analysis of Variance Table

     Response: y
               Df  Sum Sq  Mean Sq F value    Pr(>F)
     BBB        1   613.9   613.89 0.29381 0.5911308
     Walk       1    71.1    71.11 0.03403 0.8546704
     Age        1 16963.2 16963.17 8.11857 0.0072024 **
     Residuals 36 75219.4  2089.43
```

Adduction Impulse from 0-100 ms:

$$\bar{y} = \beta_0 + \beta_1 BBB + \beta_2 Walk + \beta_3 Age$$

```
        Call:
        lm(formula = y ~ BBB + Walk + Age, subset = c(-7))

        Residuals:
              Min        1Q    Median        3Q       Max
        -0.323254 -0.117116 -0.039260  0.095778  0.443334

        Coefficients:
                      Estimate Std. Error t value  Pr(>|t|)
β0 =    (Intercept)  2.7065260  0.7486791  3.6151 0.0009114 ***
β1 =    BBB          0.0407916  0.0758013  0.5381 0.5937933
β2 =    Walk        -0.0043749  0.0740054 -0.0591 0.9531862
β3 =    Age         -0.0322291  0.0107154 -3.0077 0.0047793 **
        ---
        Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

        Residual standard error: 0.19211 on 36 degrees of freedom
          (2 observations deleted due to missingness)
        Multiple R-squared: 0.20194,    Adjusted R-squared: 0.13543
        F-statistic: 3.0364 on 3 and 36 DF,  p-value: 0.041492

        Analysis of Variance Table

        Response: y
                  Df   Sum Sq  Mean Sq F value    Pr(>F)
        BBB        1 0.002317 0.002317 0.06277 0.8035909
        Walk       1 0.000002 0.000002 0.00004 0.9948694
        Age        1 0.333872 0.333872 9.04647 0.0047793 **
        Residuals 36 1.328628 0.036906
```

Adduction RTD from 0-300 ms:

$$Median\ (\log y) = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_4 Mass$$

```
        Call:
        lm(formula = y ~ BBB + Walk + Mass, subset = c(-7))

        Residuals:
             Min       1Q   Median       3Q      Max
        -0.78185 -0.25615 -0.09370  0.27203  0.88806

        Coefficients:
                    Estimate Std. Error t value  Pr(>|t|)
β0 =    (Intercept) 3.3555373  0.4002387  8.3838 5.515e-10 ***
β1 =    BBB         0.1156037  0.1696632  0.6814   0.50000
β2 =    Walk        0.1907273  0.1675967  1.1380   0.26263
β4 =    Mass        0.0100686  0.0050525  1.9928   0.05391 .
        ---
        Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

        Residual standard error: 0.41592 on 36 degrees of freedom
          (2 observations deleted due to missingness)
        Multiple R-squared: 0.10753,    Adjusted R-squared: 0.033161
        F-statistic: 1.4459 on 3 and 36 DF,  p-value: 0.24559


        Analysis of Variance Table

        Response: y
                  Df  Sum Sq  Mean Sq F value   Pr(>F)
        BBB        1 0.00560 0.005604 0.03239 0.858178
        Walk       1 0.05779 0.057790 0.33406 0.566876
        Mass       1 0.68698 0.686980 3.97119 0.053908 .
        Residuals 36 6.22768 0.172991
```

Adduction Impulse from 0-300 ms:

$$\bar{y} = \beta_0 + \beta_1 BBB + \beta_2 Walk + \beta_3 Age$$

```
        Call:
        lm(formula = y ~ BBB + Walk + Age, subset = c(-7))

        Residuals:
             Min       1Q   Median       3Q      Max
        -2.35122 -1.37537 -0.41972  0.76430  4.68378

        Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
β0 =    (Intercept) 18.39132    6.97364  2.6373  0.01226 *
β1 =    BBB          0.48404    0.70606  0.6855  0.49739
β2 =    Walk         0.17999    0.68933  0.2611  0.79550
β3 =    Age         -0.20850    0.09981 -2.0890  0.04384 *
        ---
        Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

        Residual standard error: 1.7894 on 36 degrees of freedom
          (2 observations deleted due to missingness)
        Multiple R-squared: 0.1129,     Adjusted R-squared: 0.038976
        F-statistic: 1.5272 on 3 and 36 DF,  p-value: 0.22405


        Analysis of Variance Table

        Response: y
                  Df   Sum Sq  Mean Sq F value   Pr(>F)
        BBB        1   0.4142  0.41419 0.12935 0.721206
        Walk       1   0.2838  0.28381 0.08863 0.767634
        Age        1  13.9729 13.97293 4.36374 0.043843 *
        Residuals 36 115.2740  3.20205
```

Adduction MVC:

$$\bar{y} = \beta_0 + \beta_1\, BBB + \beta_2 Walk + \beta_4 Mass$$

```
Call:
lm(formula = y ~ BBB + Walk + Mass)

Residuals:
     Min       1Q   Median       3Q      Max 
-18.4200  -8.0083  -1.3828   6.2766  25.9725 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
β0 = (Intercept) 15.29937   11.09038  1.3795 0.176245
β1 = BBB          0.82666    4.70127  0.1758 0.861407
β2 = Walk         4.58015    4.64401  0.9863 0.330593
β4 = Mass         0.38520    0.14000  2.7514 0.009232 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 11.525 on 36 degrees of freedom
  (2 observations deleted due to missingness)
Multiple R-squared: 0.18666,    Adjusted R-squared: 0.11888
F-statistic:  2.754 on 3 and 36 DF,  p-value: 0.056585

Analysis of Variance Table

Response: y
          Df  Sum Sq  Mean Sq F value    Pr(>F)
BBB        1   87.30   87.304 0.65729 0.4228471
Walk       1    4.60    4.596 0.03460 0.8534796
Mass       1 1005.50 1005.497 7.57011 0.0092317 **
Residuals 36 4781.69  132.825
```

APPENDIX 7

Supplemental Tables

Table 1: Number of individuals experiencing zero falls (i.e., non-fallers), one fall (i.e., non-recurrent fallers), or two falls (i.e., recurrent fallers) during the 12 months prior to testing.

Number of Falls	**BBB (n=15)**	**Walking (n=15)**	**Sedentary (n=13)**
0	12	9	11
1	1	6	2
2	2	0	0

Table 2: Group differences and 95% confidence intervals for hip strength variables. If the variable required log transformation, then the value becomes a factor. Boldfaced values indicate significant results.

Hip Strength Variable	Log Transform	BBB-Walking	BBB-Sedentary	Walk-Sedentary
Abduction				
RTD, 0-100 ms (Nm/s)	YES	**1.4821 (1.1495, 1.9110)**	1.0725 (0.8253, 1.3937)	**0.7236 (0.5592, 0.9363)**
Impulse, 0-100 ms (Nm*s)	YES	**1.4516 (1.1657, 1.8078)**	1.1335 (0.9041, 1.4211)	**0.7808 (0.6251, 0.9753)**
RTD, 0-300 ms (Nm/s)	NO	9.4544 (-8.2556, 27.1644)	18.4120 (-0.4293, 37.2532)	8.9576 (-9.7883, 27.7034)
Impulse, 0-300 ms (Nm*s)	NO	**1.9053 (0.6447, 3.1658)**	**1.5385 (0.1974, 2.8795)**	-0.3668 (-1.7011, 0.9675)
MVC (Nm)	NO	Interaction	Interaction	Interaction
Adduction				
RTD, 0-100 ms (Nm/s)	NO	16.3943 (-19.6076, 52.3962)	12.2681 (-24.3106, 48.8468)	-4.1261 (-39.8382, 31.5860)
Impulse, 0-100 ms (Nm*s)	NO	0.0452 (-0.1061, 0.1965)	0.0408 (-0.1129, 0.1945)	-0.0044 (-0.1545, 0.1457)
RTD, 0-300 ms (Nm/s)	YES	0.9276 (0.6703, 1.2838)	1.1226 (0.7957, 1.5836)	1.2101 (0.8614, 1.7000)
Impulse, 0-300 ms (Nm*s)	NO	0.3041 (-1.1053, 1.7134)	0.4840 (-0.9479, 1.9160)	0.1800 (-1.2180, 1.5780)
MVC (Nm)	NO	-3.7535 (-12.7574, 5.2504)	0.8267 (-8.7080, 10.3613)	4.5802 (-4.8383, 13.9986)

Table 3: Group differences and 95% confidence intervals for Sensory Organization Test variables. Boldfaced values indicate significant results.

SOT Scores	**BBB-Walking**	**BBB-Sedentary**	**Walking-Sedentary**
Composite	-0.8000 (-5.2633, 3.6633)	-4.2154 (-8.8471, 0.4163)	-3.4154 (-8.0471, 1.2163)
SOM Ratio	-0.0033 (-0.0238, 0.0171)	0.0106 (-0.0106, 0.0318)	0.0139 (-0.0073, 0.0351)
VIS Ratio	0.0127 (-0.0143, 0.0397)	-0.0145 (-0.0425, 0.0135)	-0.0271 (-0.0551, 0.0009)
VEST Ratio	-0.0473 (-0.1420, 0.0473)	-0.0658 (-0.1640, 0.0324)	-0.0185 (-0.1167, 0.0798)

Table 4: Group differences and 95% confidence intervals for Four Square Step Test times. Boldfaced values indicate significant results.

	BBB-Walking	**BBB-Sedentary**	**Walking-Sedentary**
FSST Score (s)	**-0.90** **(-1.66, -0.13)**	**-1.06** **(-1.84, -0.27)**	-0.16 (-0.95, 0.62)