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Effect of Augmented Eccentric Training in Older Adults

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Effect of Augmented Eccentric Training in Older Adults

A Thesis
Presented to
The Faculty of
Western Washington University

Accepted in Partial Completion
of the Requirements for the Degree
Master of Science

Jennifer Lee Estep

May, 2015

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MASTER'S THESIS

Signature: Jennifer Lee Estep

Date: May 15, 2015

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Abstract

The purpose of this study was to investigate the effect of a six week augmented eccentric load program on the rate of force development (RFD), center of pressure (COP) in quiet standing and single-foot balance, and performance in the five-time-sit-to-stand test (STS-5) in older adults. Eighteen moderately active older adults, aged sixty years or older, participated in this study. Subjects were separated into two groups; one group added augmented eccentric training in addition to resistance training (AEL) and a resistance training only group (RT). The AEL group participated in a six-week AEL training program that consisted of six lower extremity body exercises. The eccentric phase of each exercise movement was augmented beginning with no weight and increasing by five percent weekly up to 20 percent body weight. AEL group improved the time to complete the clinical STS-5 fall risk assessment test by -2.21 ± 1.50 s, p = 0.03. There was no significant change in time to complete the clinical STS-5 fall risk assessment test for RT. Those in the AEL group demonstrated a significant increase in the RFD moving from 785 ± 176 $N \cdot s^{-1}$ to 1041 ± 187 $N \cdot s^{-1}$ (p = 0.02) during a chair rising task compared to the RT which did not demonstrate a significant change. RT improved in the anterior-posterior (A-P) excursion for quiet standing, 0.075 ± 0.07 m to 0.001 ± 0.00 m, medial-lateral (M-L) excursion of right foot, 0.24 ± 0.19 m to 0.03 ± 0.04 m, and in A-P excursion of the left foot, 0.21 ± .19 m to 0.13 ± 0.01 m, p < .008. AEL showed significant improvements in M-L and anterior-posterior (A-P) excursion in the right foot during the quiet standing from 0.075 ± 0.07 m to 0.003 ± 0.01 m and 0.157 ± 0.11 to 0.005 ± 0.01. AEL also showed improvements in the M-L excursion for the right foot and the A-P excursion values for the left foot compared to baseline, 0.457 ± 0.20 m to 0.012 ± 0.00 m, p =0.002 and 0.465 ± 0.15 m to 0.013 ± 0.01 m, p = 0.0001. Therefore, a six-week AEL training program may be beneficial exercise prescription for older adults.

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Chapter I

The Problem and Its Scope

Introduction

Diminished muscle power is largely accepted as a main factor in decreased activities of daily living (ADL) as well as in an increased risk for falling in older adults. The ability to perform ADLs is important in older adults as it has been demonstrated to increase longevity and promote independence (Penninx, Messier, Regeski, Williamson, DiBari, Cavazzini, et al., 2001). Frailty in older adults is associated with a decrease in ability to perform ADLs. Assessments of function and frailty in older adults are important and give evaluators a good indication of the risks associated with aging including the risk of falling.

Increased risk of falling in older adults may be due to a number of factors which include: progressive declines in concentric muscle actions, loss of sensory motor integration, and age-related sarcopenia (Joshua, Souza, Unnikrishnan, Mithra, Kamath, Acharya, & Venugopal 2014). The loss of concentric muscle actions is greater than eccentric muscle actions with aging in older adults (Frontera, Hughes, Fielding, Fiatarone, Evans, and Roubenoff, 2000). Most importantly, eccentric muscle force output is retained in older adults which may help to prevent falls because of the brake-like function of eccentric muscle actions (LaStayo, Ewy, Pierotti, Johns, & Lindstedt, 2003). Therefore, the evaluation of both concentric and eccentric muscle strength power output in older adults is important for assessing the risk of falling.

Common clinical tests of function and risk of falling in older adults include the one-time sit-to-stand-test (STS-1) and the five-time sit-to-stand-test (STS-5). In the STS-2, older adults are asked to move from a sitting position to a standing position as fast as possible, with the arms crossed against the chest. Performances during these tests are related to muscle function domains in older adults which include: power, strength, rate of force development, and balance (Zech, Steib, Freiberger, & Pfeifer, 2011). Muscle function measurements are different between non-frail and pre-frail older adults and a decreased muscle function is associated with pre-frail older adults (Zech, Steib, Freiberger, & Pfeifer, 2011). The relationship between muscle function and frailty among older adults holds implications for the application of an exercise prescription that improves these domains of muscle function.

Along with the STS tests, frailty and risk of falling can also be assessed through a few other measurements. The rate of muscle force development (RFD) and center of pressure (COP) are among the measurements that can give evaluators a better understanding of an older adult's risk of falling (Houck, Kneiss, Bukata, Puzas, Clark, & Clark, 2011). The rate of force development during a task like standing up from a chair gives insight into how fast an older adult can produce the necessary muscle force to stand up. A greater rate of force development indicates generally stronger and healthier older adults and is also associated with maintained muscle power (Houck, Kneiss, Bukata, & Puzas, 2011). Center of pressure can be used to assess how well older adults have maintained stability with aging (Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). Both RFD and COP are variables that can be used as assessment tools for risk of fall and frailty in older adults.

In older adults, the rate of force development and peak muscle force output can be maintained or increased with resistance training (Schlicht, Camaione, & Owen, 2001). In athletic populations, a popular method for increasing muscle force is through the activation of the eccentric phase prior to performing a concentric muscle contraction. This phenomena has been attributed to non-contractile properties of muscle and a physiological mechanism referred to as the stretch shortening cycle (SSC) (Taube, Leukel, Lauber, & Gollhofer, 2012). Recently, research on the effect of the SSC on concentric muscle force production has led to the augmentation of the eccentric muscle load in order to further its effect. Research on eccentric overloading resulted in faster and more explosive concentric muscle movements along with increased muscle force and power output in healthy young adults (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002; Friedmann-Better, Bauer, Kinscherf, Vorwald, Klute, Bischoff, Muller, Weber, Metz, Kauczor, Bartsch, & Billeter, 2010). These data demonstrated that overloading the eccentric phase enhanced concentric muscle actions. However, this mode of training has not been investigated in older adults. Therefore the application of augmented eccentric load (AEL) training for older adults is needed to investigate the effect AEL has on the physiological and functional assessments involved with predicting increased risk of falling.

Purpose of the Study

Frailty in older adults results in increased risk of falling and therefore decreased independence. The loss of muscle mass and muscle strength are largely associated with increased frailty and risk of falling. However, muscle mass and strength can be retained with regular resistance training. Currently, overloading the eccentric phase of an exercise is practiced among strength and power athletes in order to increase concentric muscle force production, though this has not been investigated in older adults nor in long term training programs. Therefore, the purpose of this study was to investigate the effect of a six week augmented eccentric load program on the rate of force development, center of pressure, single-foot balance and performance during a one-time sit-to-stand test and five-time-sit-to-stand test in older adults.

Hypothesis

Neuromuscular adaptations due to eccentric muscle overloading after an augmented eccentric load program will improve domains of physical function in older adults which include: lower extremity rate of force development during a chair standing task, improved center of pressure excursion and therefore stability, and improved performance in the clinical five time sit-to-stand test.

Significance of the Study

This study is novel as it applies an athletic oriented method of muscle force development (augmented eccentric loading) to an older adult population. Increased performance on functional tests after a six week augmented eccentric loading (AEL) program may provide clinical implications for the prescription of long term AEL exercise programs with a goal to enhance the performance on functional tests. Additionally, AEL training may play a significant role in the improvement of physical function domains for older adults. These domains include balance, by improving center of pressure and stability, and improving lower extremity rate of force development, which is indicative of muscle power output needed to perform every day movements like standing up from a chair. Improvements in these domains of physical function hold promising applications for decreasing the risk of falling among older adults which may increase longevity and independence in this population.

Limitations of the Study

1. All subjects were recruited from the Bellingham and Blaine Senior Centers and the WWU Mature Adult Training Program and therefore had resistance training experience prior to intervention.
2. All participants reported moderately active lifestyles defined as having previous resistance training for at least 2 times per week for the last 6 month.
3. Participants were aged 60 years or older; therefore these results may not be applicable to the general public or younger subjects.
4. Exercises performed were modified to coincide with ACSM's general safety guidelines for exercise prescription in older adult population.
5. Lower extremity rate of force development was measured only during a standing task, therefore, this AEL training may not yield the same results for other activities of daily living.
6. Specific muscle activation patterns were not measured and limit the results to an overall improvement in dynamic movement. This limitation did not allow for comparison to direct muscle electromyography of the muscles involved in standing from a chair.

Definition of the Terms

Activities of daily living (ADL)	Instrumental activities needed to be self-reliant in the community (Huang, et al 2010)
Aging	An accumulation of biological events that take place over a span of time (ACSM, 2014)
Augmented eccentrics	Increasing the stress of the eccentric muscle action by adding additional load (Moore, Weiss, Schilling, Fry, & Li, 2007).
Center of Pressure	Distribution of reaction forces between the body and the supporting surface. The force can then be summed into a single net force acting a single point (Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998).
Concentric muscle action	The shortening phase of muscle fibers due to increasing muscle tension (Neumann, 2010)
Eccentric muscle action	Lengthening phase of muscle fibers due to an opposing force that is greater than the force generated by the muscle (Neumann, 2010).
Frailty	Clinical syndrome in which three or more of the following criteria were present: unintentional weight loss (10 lbs in past year), self-reported exhaustion, weakness (grip strength), slow walking speed, and low physical activity (Fried et al, 2001)
Isometric muscle action	Activation of a muscle or muscle group(s) which generates force without producing movement of the skeletal system (Neumann, 2010).
Muscle quality	Loss of strength per unit of muscle mass (Goodpaster, et al, 2006)
Older adults	Persons 60 years and older (Institute of Gerontology, 2014)
Power	The product of force produced by a muscle and the velocity at which the muscle shortens (Orr, Vos, Singh, Ross, Stavrinos, & Fiatorone-Singh, 2006)
Rate of force development	The rate at which a muscle force is developed in the early phase of a muscle contraction (Aagaard, Simonsen, Andersen, Magnusson, & Poulsen, 2002)
Sarcopenia	The loss of muscle mass due to aging, disuse, poor nutrition or malabsorption, or other physiological causes, such as abnormal thyroid function (Crus-Jentoft, et al., 2010).
Sit to Stand	Upward movement transferring the center of gravity (Yamada, Demura, & Takahashi, 2013)
Sit to stand test (STS)	Functional tests used to evaluate risk of falling in older adults based on how many fast the subject can stand up from a chair (Strassmann, et al, 2013)
Torque	A moment of force causing rotation about an axis. When referring to muscle actions, it could be expressed as concentric torque, eccentric torque and isometric torque, depending on the nature of the muscle action (Harman, 1993)

Chapter II

Review of Literature

Introduction

The regular pattern of human movement involves a combination of eccentric, isometric and concentric muscle actions. As people age, muscle actions decrease in strength due to a natural degeneration of muscle mass. As muscle strength declines with aging, older adults have an increased risk of falling that is associated with loss of independence and frailty. Retention of lower extremity strength with aging may be beneficial in preventing falls in older adults. This is especially important to note because older adults have more retention of eccentric muscle strength compared to concentric or isometric strength (Klass, Baudry, & Dachateau, 2005). Research comparing the muscle forces from the different types of muscle actions has repeatedly demonstrated the eccentric (lengthening) muscle force is greater and more energy efficient than that of the concentric (shortening) muscle force (Power, Rice, Vandervoort, 2012). Therefore, older adults may be able to produce more muscle force with less work. The difference in muscle force output between the eccentric and concentric muscle actions has been attributed to the disparate physiological mechanisms by which these muscle actions are driven (Klass, Baudry, & Dachateau, 2005; Mueller, Breil, Vogt, Steiner, Lippuner, Popp, et al, 2009).

The activation of the eccentric muscle action immediately before a concentric muscle action has been well established as enhancing the consequent concentric muscle force output. This is an important finding as there is now research on the enhancement of concentric muscle actions through loading eccentric muscle action first (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002). However, most research has focused on the effects of loading the eccentric muscle phase on the one repetition maximum in the athletic population. Currently, there is little research on the effect augmented eccentric loading (AEL) has on muscle function among older adults. Therefore, this chapter will focus on the current literature with respect to the increased risk of falling in older adults, functional tests used to assess the risk of falling, how the preservation of eccentric muscle action may aid in decreasing the consequences of age-related decreases in muscle function. Specific domains of muscle functions that will be assessed include rate of muscle force development during a standing task, muscle power, and balance through stability in center of pressure measurements. The mechanism through which eccentric muscle actions enhance concentric muscle strength will also be covered, including the stretch-shortening cycle, stored elastic energy, and implications for augmenting eccentric loads in both the young and old.

Risk of Falling in Older Adults

Prevalence of falls in older adults. Falls are both highly common and highly devastating in older adults. Each year, 30 percent of community dwelling older adults fall at least once (Rubenstein, 2006) and are two to three times more likely to fall again (Todd & Skelton, 2004). The percentage of older adults who fall is 40 to 50 percent higher in those living in long term care institutions. In 2010, seven million Medicare patients had received medical care for fall related injuries (Stevens, Ballesteros, Mack, Rudd, DeCaro, Adler, 2012). Fatalities and injuries from falls among older adults have continually increased from 2.6 million to over seven million in the past decade (Stevens, Ballesteros, Mack, Rudd, DeCaro, Adler, 2012). This continuing increase in falls among older adults is alarming as falls are accepted as the leading cause of injury related deaths and disability among older adults (Stevens, & Olson, 2000; Rubenstein, 2006; Stevens et al, 2012).

Consequences of falls in older adults. Older adults who fall have increased mortality, morbidity, immobility, and early admission into nursing homes (Rubenstein, 2006). Immobility is largely associated with decreased independence in older adults and is usually a consequence of hip fracture and other fall related fractures such as ankle are wrist fractures (Todd & Skelton, 2004). Between 2003 and 2007, 40% of hip fractures were a result of slipping and stumbling in older adults and were the highest reported consequence of falling (Hartholt et al, 2011). The most frequently reported injuries from falls in older adults include: skull and brain injuries, wounds to head and face, femur fractures, ankle fractures, and wrist fractures (Hortholt et al, 2011). Some consequences of falls are subsequent situations in which the injury has decreased the independence of older adults and increased their fear of falling, which both, in turn, increase the likelihood that the individual will fall again (Hartholt et al, 2011; Rubenstein, 2006; Stevens & Olson, 2000; Todd & Skelton, 2004). With such high injury rates related to falls, etiologies of falls among older adults has been well examined and established in being highly attributable to age-related degenerative processes of muscle mass known as sarcopenia.

Sarcopenia as the major risk factor for falls in older adults. The greatest risk factor for falls among older adults is age-related loss of muscle mass (sarcopenia) and subsequent loss of muscle function (Fielding et al, 2011; Rubenstein, 2006). Sarcopenia has been established as a reliable marker of frailty and is the most closely related risk factor to falls compared to other risk factors including: age, gender, sensory impairments, physical inactivity, diabetes, and body mass index (Landi, Liperoti, Russo, Giovannini, Tosato, Capoluongo, et al, 2012). In a five year study, Scott, Hayes, Sanders, Aitken, Ebeling, and Jones (2014) assessed the association between sarcopenia and risk of fall in community dwelling middle-aged and older adults. Sarcopenia increased from baseline to follow up from 15% to 46% across both genders. Women had a greater increase in the prevalence of sarcopenia than men from baseline to follow up (Scott, Hayes, Sanders, Aitken, Ebeling, & Jones, 2014). The Physiological Profile Assessment (PPA) was used to evaluate the risk of fall. The PPA evaluates vision, reaction time, proprioception, knee extension strength, and balance to assess risk of fall in older adults. Both men and women with sarcopenia had a significantly higher risk of falling when compared to men and women without sarcopenia at follow up according to PPA scores, however the specific data on PPA scores was not provided.

While there are other risk factors associated with the increased risk of fall in older adults, sarcopenia continues to be the leading predictor of falls in older adults. Though the decline of muscle mass and function are age-related, the decline in muscle quality (function) is lost more rapidly than muscle mass with aging (Goodpaster, Park, Harris, Krtichevsky, Nevitt, Schwartz, et al, 2006; Scott et al., 2014). However, recent research has provided evidence indicating retention of eccentric muscle function in older adults. This may be largely in part due to age-related accumulation of non-contractile properties which increase muscle stiffness. Increases in muscle stiffness have been well documented and may give older adults a mechanical advantage for producing eccentric muscle actions (Roig, Maclintyre, Eng, Narici, Maganaris, & Reid, 2010). This elucidates the need for eccentric training intervention studies that may contribute to the positive effects of resistance training programs. Those include improvements in the domains of muscle function in older adults such as rate of force development and balance. In order to begin designing eccentric resistance training programs for older adults, the mechanisms involved in the retention of eccentric strength in older adults must first be explored.

Preservation of Eccentric Muscle Function in Older Adults

While the loss of muscle mass and strength is a normal degenerative process of aging, recent research suggests that eccentric muscle strength is more preserved with aging compared to concentric or isometric muscle strength. In a 12 year longitudinal study, knee extensors and flexors (vastus lateralis and biceps femoris) along with elbow extensor and flexor strength was evaluated in older adults. The specific elbow extensors and flexors were not specified. Using an isokinetic dynamometers, strength was assessed from baseline and at follow up (12 years later). Frontera et al (2000) reported age-related declines in both knee and elbow flexors and extensors at both fast and slow velocities. However, the percent change per year in flexor strength in both the knee and elbow were greater, 29.8 %, than changes in extensor strength, 23.7 %. In fact, there was no change in the elbow extensors compared to baseline in either condition (Frontera, Hughes, Fielding, Fiatarone, Evans, and Roubenoff, 2000).

In a later study, Klass, Baudry, & Duchateau (2005) determined the association between age-related neural and muscular mechanisms and force declines in concentric, eccentric, and isometric muscle contractions in both young and old individuals. Using a motor-driven ergometer, the maximal voluntary contraction (MVC) of the tibialis anterior and the soleus were taken under isometric, concentric, and eccentric conditions. Stimulations of muscle actions were induced through electrical pulses from a costume-made stimulator. The peak torque, contraction time, and torque development were measured in all subjects. The MVC was recorded at different angular velocities (5, 25, 50, 75, and 100 degrees) through a 30 degree range of motion (Klass, Baudry, & Dachateau, 2005). The age-related deficit in torque was greater in the isometric and concentric actions (mean reduction 24.9 ± 1.4%, $p < 0.001$) compared to the eccentric actions across both genders. When compared to young women, older women did not differ significantly

($p > 0.05$) in absolute eccentric torque production. Additionally, elderly men and women produced higher relative torque (11 ± 1.4%, $p < 0.01$; 23.1 ± 1.5%, $p < 0.01$) for the eccentric actions compared to the young counterparts (Klass, Baudry, & Dachateau, 2005). An important finding was that there was no difference in muscle activation patterns across gender or age groups indicating that neural drive may not be responsible for the preservation of eccentric force production in older adults.

Based off emerging evidence of the maintenance of eccentric muscle strength, Powers, Rice, and Vandervoort, (2012) assessed residual force enhancement of the dorsiflexors in young and older adults. Powers et al (2012) stimulated concentric, eccentric, and isometric actions with two round carbon rubber electrodes at 10 Hz and 50 Hz in the tibialis anterior. During voluntary muscle actions, older men were similar to young men in activation and co-activation muscle patters, but were 13% ($p < 0.05$) weaker in producing isometric torque. Eccentric strength in older men was reported as being well maintained ($p < 0.05$) compared to the isometric and concentric muscle strength. Eccentric torque produced by older men was comparable to that produced by young men ($p>0.05$) (Powers, Rice, Vandervoort, 2012). At baseline, peak eccentric torque was 70% greater than baseline isometric and concentric contractions. Following stretch, isometric torque was higher in both young and old, and residual force enhancement was two and a half times greater in the older adult group than in the young group. These findings add to the inconclusive debate on the mechanisms that help to maintain eccentric strength in older adults. Therefore, there must be some non-contractile property of the muscle that is responsible for the maintenance of eccentric force development with aging. With evidence of the eccentric force preservation in older adults, the mechanism driving the retention is currently the focus of investigation.

Potential Mechanisms Preserving Eccentric Strength in Older Adults

Increased connective tissue and stiffness in muscle tendons. Understanding the mechanism by which eccentric strength is preserved with aging is important as it may benefit research on furthering the preservation of muscle strength in older adults. One of the current hypotheses on the underlying mechanisms involves the increase of muscle stiffness from the accumulation of non-contractile properties in the muscle fibers of older adults (Kent-Braun, Ng, & Young, 2000). The relationship between stiffness and muscle force enhancement is closely related to the stretching of activated fibers. The muscle force enhancement after stretching is referred to as residual force enhancement (RFE) (Kent-Braun, Ng, & Young, 2000; Rassier, & Herzog, 2005). In trying to understand how RFE works, Rassier and Herzog, (2005) investigated the relationship between force and stiffness in activated single muscle fibers of frogs after stretching. The individual muscle fibers were examined under four conditions: isometric contraction, stretch followed by contraction, and an enhanced state contraction where 2, 3-butanedione monoxime (BDM) (myosin inhibitor) was added to the Ringer solution during both isometric and stretch followed by contraction conditions. BDM is used in order to reduce force while not affecting stiffness. After contractions in each condition, Rassier and Herzog (2005) found that steady state isometric force after stretching of the fiber resulted in higher force production than the isometric contraction at all lengths. Myofibril stiffness was the greatest in the enhanced state, and force enhancement and increased stiffness accompanied each other. The application of BDM resulted in increased force enhancement in both stretch and isometric contractions. Additionally, lower frequencies in muscle activation did not result in enhanced force or stiffness of the individual muscle fibers (Rassier, & Herzog, 2005). The force enhancement in the stretch and enhanced state conditions was attributed to the increase of attached cross bridges after the stretch. Rassier & Herzog (2005) demonstrated that there is an association between increased muscle stiffness and force enhancement.

The muscle force enhancements seen with stretching muscle fibers prior to contractions was also studied in cats (Herzog & Leonard, 2002). They investigated force enhancements during ascending and descending after stretching the cat soleus muscle. Bipolar cuff-type electrodes were placed on the tibial nerve to stimulate the soleus using 30 Hz. The soleus tendon was then attached with sutures that would act as muscle pullers. Force-length relationship was then found by increasing the muscle length 2 mm at a time until the descending muscle was identified. Then force enhancements following stretching were assessed over four contractions: a reference isometric contraction at muscle length, a second isometric contraction at muscle length of -10 mm followed by stretching from -10 mm to -2 mm at 4 mm*s, followed by a 5 second isometric contraction at -2 mm, a third isometric contraction for 8 s at -10 mm of stretch, and a final isometric contraction at muscle length. Force enhancement following stretching was measured 3 seconds following stretching when the force curves had reached a steady-state.

Isometric contractions following stretching had greater steady-state active forces ($p <.05$) compared to isometric force at muscle length. All stretching tests at any speed had greater enhancement force 1.3 ± 1.1 N; 6.5% ($p <.05$) greater average isometric force than the force at initial muscle length. (Herzog & Leonard, 2002). During descending, there was a consistent passive force enhancements that were consistent with optimal muscle lengths. Additionally, over all of the stretching magnitudes ranging from 3 mm to 9 mm, passive force enhancements were responsible for up to 83.7% of the total force enhancements seen. For stretches 6 mm or greater, passive force enhancement accounted for more than 50 % of the total force enhancement seen after stretching. These data further support the role of passive force production from stretching of muscle fibers.

Age-related accumulation of non-contractile properties increases muscle stiffness. In studies comparing young and old skeletal muscle components, non-contractile components of muscle increase with age. Kent-Braun, Ng, & Young (2000) compared contractile and non-contractile components in men and women. Using magnetic resonance imaging, contractile (muscle) and non-contractile (fat) properties of the right tibialis anterior was assessed. Younger men and women had larger cross sectional areas of contractile components compared to the older men and women. The young group had both smaller absolute and relative non-contractile cross sectional areas than older subjects. In fact, older subjects had a two to three fold greater cross sectional area of non-contractile components than the young subjects (Kent-Braun, Ng, & Young, 2000). Physical activity was also assessed in both young and old, and there was an inverse relationship found with percent of non-contractile components and physical inactivity. This observation is important, drawing light to the possibility of conserving contractile properties in older adults by increasing physical activity. This study also elucidates the decrease of contractile properties with aging along with the increase in non-contractile components.

Increases in connective tissue and the passive stiffening of muscles with aging was explored. In a review of literature on passive extensibility of skeletal muscle, Gajdosik, (2001) reported that increasing passive muscle stiffness along with length extensibility and increased muscle length (eccentric muscle action) results in optimal muscle function, the ability for the muscle to produce force per unit. Additionally, the increase in stiffness was largely associated with an increase in connective tissue in the cytoskeleton. These findings imply that older adults who have age related muscle stiffness may be able to use it to produce muscle force. This would be possible through a couple mechanism that enhance muscle force output. They include the stretch shortening cycle and stored elastic energy in tendons (DeVita, Helseth, & Hortobagyi, 2007; Taube, Leukel, Lauber, & Gollhofer, 2011).

Mechanisms of Eccentric Muscle Actions on Consequent Enhancements of Concentric

Stretch-shortening cycle. The eccentric phase of muscle occurs when the muscle lengthens in response to an opposing force that is greater than the force output of that muscle (DeVita, Helseth, & Hortobagyi, 2007). When the muscle lengthens, it serves to either slow down the movement of the body, as in walking downhill, or to resist the force of gravity while lowering weight. Mechanical energy decreases with lengthening muscle action because in muscle lengthening the force and displacement vectors are in opposite directions; this is referred to as negative work (DeVita, Helseth, & Hortobagyi, 2007). Typically, any energy that is absorbed during the lengthening phase is lost as heat unless it is immediately followed by a shortening contraction, in which case the energy can be used to enhance the concentric force (DeVita, Helseth, & Hortobagyi, 2007). The force production from this combination of muscle lengthening followed by a concentric contraction is known as the stretch shortening cycle (SSC) (Taube, Leukel, Lauber, & Gollhofer, 2011). Due to the increased force output from this combination, SSC exercises have been used in an attempt to improve muscle force and muscle power.

Stretch shortening cycle and muscle power production. In an eight week SSC exercise training program, functional performance and contractile properties were investigated in eight healthy men. The exercises included: static jumps with knees flexed, vertical countermovement jumps, drop jumps, double leg triple jumps, single-leg jumps, and single leg hurdle jumps (Malisoux, Francaux, Nielens, & Theisen, 2005). In order to assess the leg strength and power, each male performed a one repetition maximal force (1RM) of the leg extensors in a two-legged leg press before and after 24 sessions of SSC exercises. The contractile properties of the vastus lateralis was assessed by muscle biopsies before and after the SSC training program. Peak power was assessed in individual muscle fibers during a concentric muscle action. The 1RM in the leg press increased by 12 percent after 24 sessions of SSC training, and the peak power of type I, type IIa, and hybrid fibers IIa/IIx was enhanced by nine percent.

The potential to store and use elastic energy was also investigated in a study exploring the mechanical efficiency during repetitive vertical jumping. Eight jump trained males completed 30 repetitions of a static jump (SJ), and a countermovement jump (CMJ). Mechanical efficiency between the CMJ and the SJ was analyzed by comparing the force time curves, displacement time curves, and oxygen consumption (McCaulley, Cormie, Cavill, Nuzzo, Urbiztondo, & McBride, 2007). Over a total of 30 jumps, there was a significant difference ($P < 0.001$) of oxygen consumption in the CMJ (6.1 L/min) compared to the SJ (7.2 L/min). Energy cost per jump measured through the displacement time curve were also significantly different ($p < 0.05$) between the CMJ (5,405 J) and the SJ which required more work (6,176 J). The differences in the mechanical efficiency between the countermovement jump, and the static jump were attributed to the use of stored elastic energy created during the lengthening phase of the CMJ.

These studies suggest that the stretch shortening cycle enhances muscle force efficiently. Therefore further studies began to explore how to capitalize on the effect that the eccentric phase of the SSC has on force development in the concentric phase. It seems that there are underlying mechanical adaptations taking place during the eccentric phase of the SSC, one of which is the use of stored elastic energy.

Stored Elastic Energy. The elastic properties of tendons help to decrease the amount of mechanical energy needed to produce muscle force. Research on the behavior of animal tendons during muscle action has repeatedly demonstrated how stored elastic energy can enhance muscle force production (Astely & Roberts, 2011). The major concept is that the muscle tendon acts like a spring during muscle action. The elastic recoil of the tendon during a muscle contraction stores energy and converts it to kinetic energy in the following muscle contraction. To demonstrate this concept, Astley and Roberts (2011) investigated muscle fascicle activity and joint movement in frogs during a jump. Based off previous research which demonstrated that frogs used a “catapult like mechanism” during jumping to store and rapidly release elastic energy, Astely and Roberts (2011) hypothesized that there would be shortening of fascicles prior to joint movement followed by rapid joint movement without rapid muscle shortening. This would demonstrate that the enhanced muscle power output for jumping could be attributable to stored elastic energy in tendons. Plantaris muscle fascicle length change was tracked by implanting digitized markers within the muscle. Ankle joint length was measured by implanting bone markers into each of the bones of the ankle joint. Then, the relationship between the muscle and tendon unit length and joint angle at the ankle was used to evaluate their hypothesis that rapid joint movement would not be accompanied with muscle shortening.

Across all the jumps, fascicle shortening began prior to joint movement. This was the phase in which energy was stored from muscle contraction. Fascicle shortening was accompanied by large changes in both joint angle and angular acceleration with low muscle shortening activity. This angular change and acceleration without muscle shortening was attributed to the elastic recoil of the tendons during the jump, demonstrating how muscular force can be enhanced without a muscle contraction through the use of stored elastic energy (Astely and Roberts, 2011).

The use of stored elastic energy has also been demonstrated in human tasks such as walking, running, and jumping. In a study examining the relationship between fascicle length and tendon utilization of stored elastic energy, fascicle length during walking was studied in young males (Ishikawa, Komi, Grey, Lepola, Bruggemann, 2005). Subjects walked on a 10 m long force platform at normal walking cadence. Vertical and horizontal ground reaction forces were recorded as well as fascicle length using a high speed ultrasonographic apparatus. An optic fiber transducer for tendon stress was inserted transversely through the Achilles tendon to measure tendon stress. Electromyography was used to record muscle activation of the tibialis anterior (TA), medial gastrocnemius (MG), and the soleus muscle (SM) during walking. Walking was separated into four phases: brake I and II, push I and II. The tendon tissue of the medial gastrocnemius and the soleus muscle lengthened slowly during the standing phase and then quickly recoiled by the end of ground contact. The difference in behavior between the MG and SM was that while both initially lengthened, the MG remained isometric during the late-stance phase, while the SM continued to lengthen suggesting a catapult like action of energy transference during human walking. Another observation was that both the muscle tendon units along with the tendinous tissue of both the MG and SM lengthened slowly during the brake II and then quickly recoiled during the push II phase in all subjects. These observations suggest that in human walking, without spring-like action can still produce force due to the utilization of stored elastic energy through the slow lengthening and quick recoil behavior of the muscle tendon unit of muscle involved. This contributes to the evidence of alternative energy production from stored elastic energy.

The existence of stored elastic energy was also explored during isolated plantar flexion exercises in men. In vivo muscle fiber behavior was studied during both static and counter movement ankle plantar flexion (Kawakami, Muraoka, Kanehisa, & Fukunaga, 2002). Subjects lied supine on a sliding table where a weight training apparatus was attached to the trunk. A force plate was then place onto the footplate of the apparatus where the subjects placed the ball of the right foot while maintaining full knee extension. Joint angle of the right ankle was measured and electromyography (EMG) was used to record muscle activation of the medial and lateral gastrocnemius and the soleus muscle. Subjects performed a maximal unilateral plantar flexion movement with and without a counter movement. The force at the ball of the foot, joint angle, and EMG were recorded. Achilles' tendon force was measured by plotting the muscle tendon unit power against the fascicle length during both conditions. For the countermovement conditions, the maximal Achilles tendon force was greater (4055 ± 655 N) compared to the static condition (3081 ± 667 N), the maximal angular velocity in the plantar flexion phase was also higher (138 ± 95. 3 deg*s) compared to the static condition (271 ± 86.2 deg*s), however there was no significant difference in muscle activation amplitudes (Kawakami, Muraoka, Kanehisa, & Fukunaga, 2002). A major finding of this study was that the muscle tendon unit length increased in the dorsiflexion phase with no change in muscle fiber length in later phases in the countermovement condition. Additionally the countermovement condition resulted in significantly greater mean power and force, as well as angular velocity at the ankle joint. This is further evidence of stored elastic energy contributing to greater muscle force and power output while requiring less work by first activating the muscle tendon unit through a countermovement.

These data along with the enhancements seen with the SSC could be applied to older adult exercise prescriptions. This is especially important to investigate as the loss of muscle strength and function is age-related and associated with an increased risk of falls in older adults (Rubenstein, 2006; Scott, Hayes, Sanders, Aitken, Ebeling, & Jones, 2014).

Assessment of Function in Older Adults

Muscle strength assessments in older adults. Muscle performance tests are used to assess function in older adults. In a cross sectional study, the relationship of upper and lower extremity strength and functional limitations were assessed in older men. Muscle strength to muscle mass was used to find muscle quality and functional limitations were found using self-reports and lower extremity performance tests which included: five time sit to stand test and the six meter walking speed test (Hairi, Cumming, Naganathan, Handelsman, Couteur, Creasey, et al., 2010) Upper extremity strength was measured by taking the mean of two grip strength trials using a Jamar dynamometer. Lower extremity strength was found through the use of a spring gauge on each leg separately for one trial. Men with self-reported functional limitations had lower lean leg mass (15.5 ± 2.7 kg/m^2) compared to those who did not have self-reported functional limitations (16.4 ± 2.3 kg/m^2). Those who had self-reported functional limitations also had lower grip strength (29.6 ± 7 kg) compared to those who did not report functional limitations (35.2 ± 7.3 kg). Lower extremity strength was also lower in the self-reported functional limitation group than in the no limitation group, 25.7 ± 7.3 kg, 31.5 ± 7.8 kg respectively. Mean muscle strength, muscle mass, and muscle quality decreased with increasing age, a common finding in literature (Graf, Judge, Ounpuuu, & Thelen, 2005; Hairi, Cumming, Naganathan, Handelsman, Couteur, Creasey, et al., 2010; Ondoer, Penninx, Feruci, Fried, Furalnik, & Pahor, 2005).

Additionally, compared to upper extremity muscle performance tests, quadriceps strength and lower extremity muscle force performance had a stronger relationship with functional limitations and disability (crude prevalence ratio = 2.23, 95% CI = 1.97-2.53) Functional limitations and disability were defined as having answered yes to any of the Katz activity of daily living (ADL) questions. The Katz ADL questions included: do you need help with personal care needs, walking across a room, bathing, dressing, and getting out of bed (Hairi, Cumming, Naganathan, Handelsman, Couteur, Creasey, et al., 2010). These data suggest that there seems to be a specific relationship with lower body strength and functional limitations that needs further investigation.

Ondoer, Penninx, Feruci, Fried, Furalnik, and Pahor (2005) assessed physical performance measures of the upper and lower extremities in predicting disability in women. Upper extremity performance was evaluated using: putting-on-blouse-test, Purdue pegboard test, and grip strength of dominant hand. For lower extremity performance tests, the four meter walking speed, sit to stand test, and the standing-balance test were used to evaluate performance. Disability outcomes were measured every 6 months over 3 years and included assessments on: activities of daily living (ADLs), walking across a room for lower extremity disability, and lifting 4.5 kilograms for upper extremity disability. Compared to upper extremity, lower extremity tests were significantly associated with catastrophic ADL disability. Catastrophic disability was defined as having difficulty performing two of the following assessments: performing ADLs, walking across a room, and lifting 4.5kg. All of the lower extremity tests and only the putting-on-blouse test were significant predictors of mobility disability, and only the lower extremity tests were significantly associated with the onset of catastrophic mobility disability.

Graf, Judge, Ounpuuu, and Thelen (2005) assessed lower extremity joint power and low physical performance in older adults. Fifty-two elderly adults were divided into two groups, healthy and low performance (LP) groups. Each group underwent kinematic tests for gait and speed, and joint power tests of the ankle-flexor (tibialis anterior muscle) power. Kinematic tests for gait were measured over 3 trials where subjects walked at a comfortable speed, and over 3 trials at a "fast as they could without running" speed. The joint power tests were found through the joint power time histories during the stance and swing phase of gait. Compared to the healthy group, the LP group had a significantly lower ankle power output (2.13 ± 0.58 W/kg, $p < .001$) during walking at a comfortable gait. Additionally, those in the LP group had greater coronal and transverse pelvis rotation as well as reduced hip extension in late stance. These findings suggest that an intervention for increasing muscular function of the quadriceps and ankle flexors like the tibialis anterior muscle in older adults is important. Increasing lower extremity performance could has an inverse relationship with the risk of falling and disability in older adults. The association with decreased lower extremity performance and increased risk of fall may also be evaluated through a simple and reliable functional test known as the five times sit to stand test.

One-time sit to stand test (STS-1). Rising from a chair is an important task of daily living that can become more difficult with aging. With decreasing ability to rise from a chair without support, there is a decrease in independence and an increase in risk of falling in older adults. Therefore, the one-time sit to stand test (STS-1) is a simple and common field test used in to assess function, risk of falling, and frailty in older adults (Gross, Stevenson, Charette, Pyka, & Marcus, 1998). The action of moving from a sitting position to a standing position requires the upward shifting of the center of mass (COM) (Yamada, Demura, & Takahashi, 2013). Furthermore, this action requires trunk flexion with knee extension and can be used as an evaluation test to assess lower limb strength and balance in older adults (Yamada, Demura, & Takahashi, 2013). The ability for an older adult to transfer the COM quickly and forcefully during a STS-1 requires greater lower extremity strength.

The minimum amount of muscle strength and speed has been investigated among different studies to provide evidence for pre-frail and frailty in older adults. Using three-dimensional coordinates the kinematics of rising from a chair was investigated in 11 older adults. A total of 110 chair rises were assessed and the relationship between the time it took to stand up and muscle strength was examined (Yoshioka, Nagano, Hay, & Fukashiro, 2009). This relationship was assessed by measuring peak hip and knee joint moments during the chair rise test. The amount of strength that needs to be done to stand in 1.5 was 1.8 Nm/kg, and the minimum of strength required to rise from a chair in 2- 3 seconds was 1.54 Nm/kg. These findings imply that older adults who take longer than 2.5 seconds to rise from a chair have been may have low balance and therefore an increased risk of falling (Janssen, Bussman, Stam, 2002; Mourey, Grishin, Athis, Pozzo, & Stapley, 2000; Yoshioka, Nagano, Hay, & Fukashiro, 2009).

Rate of force development during sit to stand test. In order to measure lower extremity strength and function during a STS-1, force plates that record ground reaction forces are commonly used to measure variables like rate of force development which is the time that is required to produce force and is measured by finding the slope of the vertical ground reaction force (Chang, Mercer, Giuliani, & Sloane, 2005; Janssen, Bussmann, & Stam, 2002). Force platforms measure horizontal and vertical component of applied force as well as center of foot pressure (Mourey, Grishin, Athis, Pozzo, & Stapley, 2000). This allows investigators to measure how effective older adults are in performing tasks like standing up from a chair. Additionally, rate of force development elucidates lower extremity movement strategies that may be associated with deficits in function in older adults (Houck, Kneiss, Bukata, & Puzas, 2011).

In a study comparing standing from chair strategies between older adults with hip fractures to healthy adults, rate of force development (RFD) and vertical ground reaction forces (vGRF) were assessed. Community dwelling elderly subjects participated in functional and balance assessments. The tests included gait speed, BERG balance test, and a self-report measure of functional mobility (Houck, Kneiss, Bukata, & Puzas, 2011). Subjects performed a sit to stand movement on a force plate and the RFD and vGRF were measured. A custom made force plate seat was used to determine arm impulse which was defined as the area under the vGRF starting at the first 5 N in force and ending when below 5 N. This allowed investigators to determine the vertical upper extremity contribution during a STS task. For vGRF variables, RFD was measured in N/s and the lower extremity contribution during a STS was used to measure symmetry. Lower extremity symmetry during a STS was found by measuring the area between the vGRF of the injured side and the vGRF of the uninjured side, where a higher area suggested greater asymmetry. The results showed that the arm impulse was significantly higher in the hip fracture group (CI of 0.02 (n*s)/kg to .98 (N*s)/kg) compared to the control group and the difference between the groups was .35 N*s/kg. There was a moderate correlation (r =-0.443) between greater arm impulse and lower self-reported function and gait speed. This suggested that movement strategies during STS tests using RFD and vGRF as assessment variables were associated with performance during functional and self-reported measures of fall risk.

In a similar study, the validity of using rate of force development during a sit to stand task was evaluated in healthy older adults. Subjects were asked to rise from a chair with their arms crossed across the chest and with feet shoulder width apart. Subjects also performed leg press, static balance test, and the YMCA functional capacity test (Ritchie, Trost, Brown, & Armit, 2005). There was a significant correlation (r =.68, p < .05) between the sit to stand test and the 1RM for leg press. The sit to stand test was both reliable and valid measurement of lower body strength and function. Similar to RFD in a sit to stand task, the center of pressure is another variable that can be measured through force plates and used to evaluate balance and function in older adults.

Balance, risk assessment and improvements with resistance training in older adults. For older adults maintaining muscle strength and function are important in decreasing their risk of falling. Among these muscle functions, balance is a critical function to maintain as it is a predictor of falls in older adults (Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). Balance in older adults is assessed by measuring medial-lateral and anterior-posterior displacement of center of pressure on a force plate. In a study investigating the association between balance and recurring falls in older adults, balance was assessed in 439 older adults. Subjects performed four balance tests: eyes open, eyes closed, eyes open, and with eyes closed. The average medial-lateral and anterior-posterior sway were averaged separately for eyes open and eyes closed conditions. Subjects were asked to stand looking straight ahead with feet comfortably spaced and arms at their sides for 30 seconds. Recurrent fallers were significantly associated with poor balance (OR = 3.8; 95% CI: 1.9 – 7.7) compared to non-fallers (OR = 2.9; 95% CI: 1.3-6.5). Medial-lateral sway had the greatest predictive value for identifying recurrent falls (AUC = .67; 95% CI: 0.57 – 0.77). Eyes-open-medial-lateral-sway had stronger predictive value for identifying recurrent falls (AUC = .67) compared to anterior-posterior-sway (AUC = .61) (Stel, Smit, Pluijim, & Lips, 2003).

The ability to maintain balance has been defined as having postural steadiness that can be assessed using center of pressure in older adults (Champagne, Prince, Bouffard, & Lafond, 2012). In a case control study, postural steadiness was assessed in 15 older women with low back pain. Subjects stood straight with eyes open on a force plate and the center of pressure (COP), speed and frequencies of total power from 0 to 4 Hz were used to assess postural steadiness (Champagne, Prince, Bouffard, & Lafond, 2012). Frequencies were used because of the relationship between visual, vestibular, and proprioception and frequency bands of COP. Subjects also completed fall-related self-efficacy tests and fear of avoidance questionnaires. Postural unsteadiness was related to fall-related self-efficacy (93.5%) compared to the control group (79.5%). Low back pain levels, and fear of avoidance in older women with low back pain and postural unsteadiness was also higher compared to the control group, 43.8%, and 33.4% respectively.

Similar results were found on postural control in a group of 225 community dwelling older adults (Delbaere, Crombez, Vanderstraeten, Willems, & Cambier, 2004). In order to assess the relationship between lower extremity strength, postural control, and avoidance of activities in older adults, each subject underwent a series of evaluations. Fall history was attained prior to testing and again at 1 year. The Dutch modified survey of activities and fear of falling elderly scale (SAFFE) was used to measure fear-related avoidance of activities. Physical frailty was measured through a performance based test where subjects were timed during eating, picking up a coin, and ascending and descending stairs. Postural control was measured by having subjects stand on a force plate and COP and body sway were recorded. With muscle performance was measured by having each subject perform a maximal isometric contraction of the knee and ankle extensors and flexors, though specific muscles were not defined. Fear of falling was related to

COP ($r = 0.33$; $P < 0.001$) and specifically to excursion in the forward direction ($r = 0.31$; $p < 0.001$). SAFFE scores were strongly correlated with both past falls ($r = 0.33$; $P <0.001$) and future falls ($r = 0.30$; $p <0.001$). This is important because fear of falling was predictive of falls and recurrent falls in this population. Therefore, maintenance of balance and stability is important as its variables are related to increased risk of falling and may be improved with resistance training interventions.

Decreased stability due to aging is an imperative factor contributing to mobility limitations in older adults (Bean, Herman, Kiely, Frey, Leveille, Fielding, & Frontera, 2004). Interventions for preventing loss of stability include resistance training programs that are both functional and task specific. A study on community dwelling older women used velocity exercises specific to task to evaluate changes in leg power, balance, and mobility from a resistance training program. Twenty-one women aged 70 or older were randomized into either a progressive resistance program or a control exercise group (Bean, Herman, Kiely, Frey, Leveille, Fielding, & Frontera, 2004). The progressive resistance group (InVest) trained with weighted vests and performed exercises specific to mobility tasks at fast velocities. The control group performed slow-velocity and low resistance exercises. The training program was done three times per week for 12 weeks and all subjects underwent muscle power, balance and physical performance tests. The InVest exercises included: chair stand, toe raises, pelvic raises, step ups, seated triceps dips, and chest press done in three sets of ten repetitions each. The InVest group was instructed to perform the concentric phase as quickly as possible. The weight of the vest was increased progressively by 2% body mass. Measurements of mobility and balance included: standing balance test, 2.4 meter walk, and the five times sit-to-stand test. Tests were scored on a 0 to 4 scale for a maximum of 12 points determining highest level of performance. Muscle strength were measured through a one repetition maximum (1RM) leg press. Muscle power was measured with the same leg press exercise at eight intensities, ranging from 40-90 percent of the 1RM, performed as fast as possible.

Compared to baseline measurements, the InVest group had leg power increases between 12% and 36%. The InVest group also reached statistical significance ($p < .001$) at all levels between 60 -90% 1RM. The InVest group had significantly greater improvements in the chair stand time ($p < .001$), gait speed ($p < .006$), and balance stance time ($p < .028$) compared to control group. Specific data on the actual change in times and speed was not available. These data demonstrated improvements in balance stance time which is commonly used to evaluate fall related injury risk. Those in the InVest group improved in the balance stance time by 50%, a meaningful change that should prompt further research on balance and stability improvements following resistance training programs.

High intensity strength training programs may also improve performance on balance tests. In a ten week high intensity strength training program, balance measurements were assessed in 27 balance-impaired older adults (Hess & Woollacott, 2005). The subjects were placed into either a control group that was instructed to not participate in any exercise programs, or the experimental group which participated in a ten week high intensity strength training program three times per week. Clinical measurements of functional balance included the Berg Balance Scale (BBS), Timed Up and Go (TUG) test, and the Activities-Specific Balance Confidence Scale (ABC) questionnaire (Hess & Woollacott, 2005). The strength training protocol consisted of tibialis anterior flexion exercises done on a Hammer strength tibial dorsiflexion machine for strengthening the tibialis anterior muscle (TA), a Maxicam machine was used for plantar flexors strengthening of the gastrocnemius muscle (GA), and knee extension/flexion strengthening exercises were performed on a Maxicam variable-resistance machine for quadriceps (QD) and hamstrings (HM) strengthening. Exercises were done for three sets of eight repetitions at 80% of their estimated one repetition maximum (1RM). All exercises were performed within a six second time limit, where two seconds were spent in the concentric phase and four seconds in the eccentric phase.

After the ten week strength training program, subjects in the experimental group and control group were assessed again. The 1RM strength for the TA increased significantly (p = .045; 15.6 ± 13.8 lb. to 26.8 ± 16.1 lb.) in the experimental group compared to control group (13.7 ± 3.7lb to 14.3 ± 2.3lbs). The GA 1RM also increased significantly in experimental group (P = .045; 45.5 ± 15.5 lb. to 94.2 ±24.6 lbs.) compared to control group (control group final GA 1RM was not given). Quadriceps 1RM increased significantly (p = .045) in experimental group moving from 60.3 ± 8.1 lbs. to 92.7 ± 12.4 lbs., while the control group decreased from 74.4 ± 27.1 lbs. to 70.8 ± 28.5 lbs. Hamstring 1RM also increased significantly in the training group (p =.045, 37.1 ± 12.9 lbs. to 66.7 ± 24.9 lbs.) compared to control group (39.0 ± 8.5 lbs. to 39.9 ± 9.5 lbs.). Mean GA strength was significantly correlated with the mean BBS scores (Pearson correlation coefficient = -0.1683, p =.014) where BBS scores increased with correlating increases in GA strength in the experimental group. Specifically, the mean BBS score for the experimental group increased from 48.8 ± 2.4 points to 51.2 ± 4.3 points of 56 possible points while the control group moved from 48.5 ± 2.8 to 49.5 ± 3.0 points. Additionally, there were significant changes in the TUG test where time decreased from 11.5 ± 2.4 s to 9.7 ± 2.5 s; p = .045) and ABC scale (increasing from 80.3 ± 15% to 88.3 ± 10.3%; p = .038) for the experimental group. The control group had a slight increase in TUG test moving from 11.2 ± 1.7 s to 11.8 ± 3.3 s and ABC scale scores were unchanged (81.1% ± 11.7 % to 81.2% ± 13.5%).

Overall, these data suggest that resistance training at high intensities may increase performance on balance tests, and balance retention seems to be correlated with muscle strength. Along with balance tests, functional tests like the five times sit-to-stand test are useful measurement tools used in risk of fall assessments for older adults.

Five-times sit to stand test. The assessment of overall function and risk of fall among older adults is commonly assessed using the sit to stand test (STS-1). The ability to stand up from a chair is an important factor that determines independence in older adults (Lord, Murray, Chapman, Munro, & Tiedman, 2002; Schlicht, Camaione, & Owen, 2001). The STS-1 has been used in clinical settings to measure the force generating capacity of lower extremity muscles and the risk of fall in older adults (Lord, Murray, Chapman, Munro, & Tiedman, 2002; Schlicht, Camaione, & Owen, 2001; Whitney, Wrisley, Marchetti, Gee, Redfern, & Furnamn, 2005). Although there are many variation of the STS-1, the 5-times STS (STS-5) is most commonly used and is among the best measures for predicting risk of fall compared to other functional mobility tests (Buatois, Milijkovic, Manckoundia, Gueguen, Miget, Vancon, et al., 2008;Tiedemann, Shimada, Sherrington, Murray, & Lord, 2008; Whitney, Wrisley, Marchetti, Gee, Redfern, & Furnamn, 2005). During a STS-5 test, subjects are instructed to move from a sitting position to a standing position as fast as possible, with their arms crossed against the chest five times in a row (Houck, Kneiss, Bukata, Puzas, Clark, & Clark, 2011; Tiedman, Shimada, Sherrington, Murray, Lord, 2008). The STS-5 test is timed, beginning from the initial sitting position and time is stopped when the subject is in the final seating position after the fifth stand.

The time it takes to complete standing tasks is association with frailty and therefore risk of falls for older adults. This was assessed by Millor, Lecumberri, Gomez, Martinez-Ramirez, & Izquierdo, (2013) in a chair rise study comparing older adults who were either healthy, pre-frail, or frail. Forty-seven subjects in; healthy, pre-frail, or frail groups performed a 30-s chair stand test. The subjects had to stand up and sit down from a chair as many times as they could within 30 seconds. A global reference system was used to assess kinematic data during each trial performed. The system had an XYZ reference frame where Z axis points vertically, the X lateral axis, and the Y anterior-posterior axis. These were used to assess the linear acceleration. The frail group took longer in the impulse phase of the chair rise that was significantly greater than that of the pre-frail group during the same phase ($p < 0.0001$). Additionally, when normalized for the entire length of the movement, the healthy group had a significantly smaller time ($P < 0.001$) than both pre-frail and frail group (no specific data was given for these groups). The greatest Z-velocity during the stand-up phase (about 1.2 m/s) and also during the sit-down phase (about 0.14 m/s) were both greater in the healthy group compared to pre-frail (about .08 m/s and .05 respectively) and frail (about .5 m/s and .05 m/s respectively) groups. There seems to be a relationship between time to stand and frailty in older adults. Studies have also focused on the relationship between fall risk increases with increase in the time it takes for subjects to complete the STS-5.

Reference values for the STS-5. There is no single concrete reference value that has been established universally for the prediction of fall risk from performance of STS-5. However, multiple studies suggest that a score of 12 seconds or more is closely associated with recurrent falls in older adults. In a study comparing standard clinical function tests of older adults, performance of the STS-5 as a predictor of falls was assessed (Buatois, Milijkovic, Manckoundia, Gueguen, Miget, Vancon, et al., 2008). Over 2,500 subjects over the age of 65 underwent three balance tests including the one-leg balance test (OBL), timed up and go test (TUG), and the five-times sit to stand (STS-5). At 18 and 36 months posttest, falls were recoded from a questionnaire. Out of the three tests, the STS-5 was the only test that was independently associated with an increased risk of falling and of recurrent falls (risk ratio 1.74, 95% confidence interval = 1.24- 2.45, p < .001) (Buatois, et al, 2008). The optimal cutoff time having the greatest sensitivity in predicting falls was 15 seconds (sensitivity = 55%). In addition, subjects who took 15 seconds or longer to complete the STS-5 had a 74% greater risk of falling compared to those who completed the test in less time (Buatois, et al., 2008).

Another study comparing mobility tests as predictors of falls in older people found similar findings. In defining cut-off points for the associated sensitivity and relative risk of falls in older adults, the STS-5 cut off value with the greatest sensitivity for relative risk of fall was 12 seconds or greater (sensitivity = 66%) (Whitney, Wrisley, Marchetti, Gee, Redfern, and Furnamn, 2005). An analysis of sensitivity and specificity was conducted for the STS-5 and the time representing the best sensitivity was 13 seconds (sensitivity = 66%).

In examining these data, the cutoff time of 12 seconds for predicting an increased risk of falls seems to be a reliable reference time. In order to improve this time, some interventions have been put into place for older adults, mainly resistance training programs.

Resistance training improves muscle function and performance on functional tests in older adults. Age-related decreases in muscle strength and mass increase the risk of falls in older adults. Resistance training can help attenuate the age-related decrease in muscle strength and therefore decrease the risk of falls. In an eight week study, Schlicht, Camaione, and Owen (2001) measured the effect of a strength training program on performance of functional tests including the STS-5. Twenty-four moderately active, community dwelling adults aged 60 years and older were recruited to participate in an eight week intense strength training program set at

75% of the 1RM for each exercise. Prior to the training program, performance measurements were taken for muscle strength, walking speed, one-legged blind balance test, and the five repetition sit to stand test (STS-5) (Schlicht, Camaione, & Owen, 2001). The strength training sessions took place three days a week over an eight week period. The exercises consisted of leg extensions, inner thigh press, outer thigh press, glute press, leg press, and ankle press. Each exercise was done for two sets of 10 repetitions. For the first two weeks, subjects were allowed to use self-selected weight for familiarization and development of proper technique. For the final six weeks, the loads were set at 75% of the 1 repetition maximum, and the load was increased at the end of two week blocks as strength increased. Functional tests were measured again at mid-intervention and post-intervention. The STS-5 was significantly better at both mid-and post-intervention compared to pre-intervention scores ($p < .017$), however the actual times recorded for the task were not provided.

The effect of a 12 week heavy lower extremity resistance training program on muscle force, strength, and power was investigated. Sixty-five home dwelling women were divided into old (60 -65 years) and very old (80-89 years) groups for this study (Caserotti, Aagaard, Larsen, & Puggaard, 2008). Explosive lower limb muscle power, leg extensor performance on a power rig, rate of force development, and maximal muscle strength during a countermovement jump were measured. The strength training program took place twice a week for 12 weeks with at least two days between sessions. Exercises for the training program consisted of bilateral knee extensions, horizontal leg press, hamstring curl, calf rise, and inclined leg press performed for four sets at 8-10 repetitions. The load was set at 75-80% 1RM in order to promote heavy resistance that has been found to increase muscle cross sectional area, muscle strength, and muscle power output in both old and very old adults (Caserotti, Aagaard, Larsen, & Puggaard, 2008). In post-test measurements, both the old and young group had significant improvements in explosive lower limb muscle power during the counter movement jump (CMJ) where the old group improved by 18% and the very old group improved by 10%. Rate of force development increased by 21%, maximal strength during a maximal voluntary contraction increased by 18%, and impulse increased by 51% compared to pre-test. This study demonstrated that a low volume with heavy resistance training protocol significantly improved muscle function in older women. Therefore, it seems that a low volume, moderate intensity resistance program is an appropriate prescription for adults over 60 years of age.

Muscle Function Domains Affecting Physical Performance in Older Adults.

Lower extremity rate of force development affects physical performance in older adults. Muscle rate of force development (RFD) is the measurement of a muscle’s ability to generate force quickly at the beginning of a movement, like when standing up from a chair (Aagaard, Simonsen, Andersen, Magnusson, & Poulsen, 2002). With aging, there is a trend for muscles to experience a decrease in RFD that is associated with the age-related atrophy of muscle (Fielding et al, 2011; Rubenstein, 2006). This combination of muscle mass and function loss is in large part associated with the increased risk of falling in older adults (Goodpaster, Park, Harris, Krtichevsky, Nevitt, Schwartz, et al, 2006; Scott et al., 2014). However, resistance training programs may aid in increasing and maintaining RFD.

The effect of strength training on lower extremity RFD, muscular strength, and body composition was examined in 24 older men between the ages of 70 and 80 (Lovell, Cuneo, & Gass, 2010). The men were separated into either a strength training (ST) group or a non-training control group. The ST group participated in a 16 week training program followed by a four week de-training period. The strength training was done three times per week for 25 minute sessions on an incline squat machine, starting at 50% of the one-repetition max (1RM) done at three sets of 10 repetitions for the first two weeks. Then the program progressively increased to 70-90% 1RM done at three sets of eight repetitions. Prior to training, RFD was measured in both groups by performing a maximum isometric contraction in squat position onto a force platform. Sampled at 1000 Hz, the maximum force was taken as the highest value recorded during each trial from the start of the contraction up to 500 ms. The RFD was then calculated from the maximum force that occurred over the force-time curve (Lovell, Cuneo, & Gass, 2010). These measurements were taken pre-test and post-test and also every four weeks through to the four week de-training period in both groups. Changes in leg strength did not significantly change but did decrease over the 16 week period in the control group (724 N ± 65 N to 711 N ± 58 N). In comparison, the ST group had significant ($p < .05$) increases in leg strength, increasing from 702 N ± 42 N at week 0 to 878 N ± 55 N by week 16. Additionally, leg strength remained significantly greater after the four week de-training period in the ST group (746 N ± 43 N, $p < .05$) compared to week zero, while the control group, though the change was not significant, continued to decline from week zero to week 20 (724 N ± 65 N to 706 N ± 63 N). Rate of force development significantly increased in the ST group from 926 Ns ± 125 $N\cdot s^{-1}$ at week zero, to 1106 $N\cdot s^{-1}$ ± 140 $N\cdot s^{-1}$at week 16, and remained elevated at 1014 $N\cdot s^{-1}$± 128 $N\cdot s^{-1}$by the end of week 20 compared to week zero. The control group had no significant changes ($p > .05$) from week zero (895 $N\cdot s^{-1}$ ± 87 $N\cdot s^{-1}$) to week 16 (882 $N\cdot s^{-1}$ ± 83 $N\cdot s^{-1}$) although there was a decrease in RFD. The differences in leg strength and RFD between the ST group and control group did not only demonstrate that resistance training may help to increase muscle force and RFD, but also, those who participated in resistance training were better able to retain strength gains and

RFD even after a de-training period. This holds strong implications for the beneficial effects that resistance training has on aging muscle function.

Rate of force development effect on balance in older adults. Maintenance of muscle rate of force development (RFD) in itself is important and may also contribute to the retention of other important muscle functions such as stability. As aforementioned, instability is associated with an increased risk of falls, and recurrent falls in older adults (Bean, Herman, Kiely, Frey, Leveille, Fielding, & Frontera, 2004). The relationship between RFD and balance was assessed in a group of 30 community-dwelling older adults (Chang, Mercer, Giuliani, & Sloane, 2005). Three main associations were investigated pertaining to RFD; first, the relationship between hip abductor RFD and lateral stability during stepping, second, RFD and scores on one-leg standing test (OLS), and third, the variance in OLS scores and tandem gait test scored that can be accounted for from the hip abductor RFD measurements along with lateral stability during stepping (Change, Mercer, Giuliani, & Sloane, 2005). All subjects underwent a series of tests beginning with the one leg standing test where subjects stood barefoot with arms folded across the chest and given instructions to slowly raise the right leg. Once the subjects achieved unilateral stance they were timed until the moment of compensation from either the lifted foot touching the ground, or if the arms moved from the starting position. Next a tandem gait test was performed where subjects were timed while walking heel to toe along a 20 foot strip of tape without stepping off of the tape and while walking as fast as possible. RFD and peak force of the hip abductors were measured by mounting a dynamometer on a wooden block against a wall, while keeping the contralateral leg in neutral position, the subjects pushed the dominant leg straight toward the wall as fast as possible. Subjects were also instructed to maintain a maximal effort until told to stop, and peak force values were recorded. RFD was defined as the time it took in milliseconds for the force signal to move from 10% to 60% and then to 90% of the maximum force recorded. A postural stress test was given where subjects stood barefoot on a force plate and posture was stressed by strapping a waist belt to each subject. The waist belt had a rope attached to a pulley system that was four feet behind the subject's waist line where it was connected to a support used for holding weights. The weight was set at 4.5% of the subject's body weight and was unexpectedly released causing posterior perturbations that increased by 1.5% over eight trials. The number of steps taken in response to each perturbation was recorded.

The Pearson product-moment correlation coefficient was used to assess the relationships between the aforementioned outcome variables and RFD. There was a significant positive correlation ($r = 0.352$, $p < .05$) between peak force and center of pressure (COP) displacement from perturbation at 4.5% body weight, and also at 6.0% body weight ($r = .421$, $p < .05$). For predicting OLS scores, age along with RFD accounted significantly to an increase in variance, R^2 change = .314 for age, and R^2 change = .097 for RFD ($p < .05$). In predicting tandem gait scores, addition of weight and RFD accounted for a significant increase in the variance explained (R^2 change = .118 for weight, and R^2 change = .105 for RFD; $p < .05$) (Change, Mercer, Giuliani, & Sloane, 2005). These data demonstrated the contribution of RFD and COP to clinical test performances, demonstrating the importance of maintaining and increasing RFD in older adults.

Rate of force development is related to risk of fall in older adults. Rate of force development (RFD) of the lower limb muscles also has a close association with falls in older adults. In a study among thirty one older women, muscle peak torque (peak force) and rate of torque development, or RFD, was compared between fallers and non-fallers (Bento, Pereira, Ugrinowitsch, & Rodacki, 2010). Inclusion criteria for this study required that all women be over the age of 60 years, free from balance problems, and had not participated in any physical activity program within the last six months prior to testing. The women were divided into three groups: no fall history, one fall, and two or more falls. All subjects performed lower limb maximal isometric contraction tests which included: hip, knee, and ankle flexion and extension though the specific muscles assessed were not described in the study. Tests were performed from a recumbent posture with joints placed at 90 degrees and were performed either proximal to distal or distal to proximal order to avoid a training effect. Force-time curves were attained with a load cell attached to an adjustable pole that was aligned perpendicularly to the tested segment. Then the distance between the load cell and the center of the joint was measured to attain net joint torques (Bento, Pereira, Ugrinowitsch, & Rodacki, 2010). Subjects were instructed to move the limb tested as fast and hard as possible while maintaining a maximal contraction for two to three seconds. RFD was calculated from the slope of the force-time curve between 20% and 80% of the highest torque recorded.

The results did not yield statistically significant differences in RFD and peak torque between groups, however, in the non-fallers there was a trend for higher RFD in the hip, ankle, and knee extensors and flexors. However, the knee extensors and flexors RFD measurements were significantly higher ($p < .05$) in the non-fallers compared to both the one and the two or more fall groups, though specific data on RFD scores was not presented in this study. Although the RFD scores were not significantly greater in the non-faller group, these data demonstrate differences in RFD between fallers and non-fallers and how increased RFD may play a role in the prevention of falls and recurrent falls in older adults. This relationship may be further due to the association of RFD and other functional domains of muscle that decline with age, such as muscle power. It is important to consider RFD along with power in older adults because RFD is an indirect measure of muscle power (Orr, Vos, Singh, Ross, Stavrinos, & Fiatarone-Singh, 2006). This is particularly important because muscle power is related to functional performance in older adults (Miszo, Cress, Slade, Covey, Agrawal, & Doerr, 2003; Orr, Vos, Singh, Ross, Stavrinos, & Fiatarone-Singh, 2006).

Effect of muscle power on physical function in older adults. A study of older adults who participated in a strength and power training program revealed a positive relationship between power and physical function. Fifty older adults were separated into one of three groups: strength training (ST), power training (PT), or control (Miszo, Cress, Slade, Covey, Agrawal, & Doerr, 2003). All subjects underwent pre-test measurements which included: the continuous scale physical functional performance scores (CS-PFP), one repetition maximum (1RM) test for the chest and leg press, and a Wingate anaerobic cycle power test. The strength training group and power training groups trained three times per week for 16 weeks. The strength training consisted of the seated row, chest press, triceps extension, leg press, leg extension, and seated leg curl, squats, plantar flexion, and biceps curls done for three sets of six to eight repetitions. The intensity began at 50% 1RM and progressed to 80% 1RM by the last 4 weeks of training. The power training group performed the same exercises as the ST group, with the exceptions of jump squats replacing the squat. The intensity was set to 40% 1RM for three sets of six to eight repetitions. Subjects in the PT group were coached to perform the concentric action in about one second and the eccentric actions in about two seconds. The control group was instructed to maintain their regular activities, without participating in strength training or beginning any new exercise programs.

After the 16 week training period, the PT group had significantly greater improvements (P = .033) on the CS-PFP scores moving from 60.8-69.9 compared to the ST group, although the ST group did have improvements in CS-PFP scores as well moving from 54.5 to 62.8. Compared to the C group, the PT group significantly increased in CS-PFP scores (p = .016, C: 53 to 61.7). There was no significant difference between the training groups for either strength or anaerobic power, however, there were some improvements pre to post-test for anaerobic power that are worth noting. Peak power in the PT group increased from 310.2 ± 105 W pre-test to 334.7 ± 137 W post-test. Mean power in the PT group increased from 233.1 ± 80 W pre-test to 247.5 ± 119 W post-test. The ST group also had some improvements in peak power (pre-test 262.2 ± 117 W to 294.117 W post-test) and in mean power (pre-test, 216.7 ± 234.1 W ± 107 W post-test). The control group had a decline in both peak power (pre-test, 263. 0 ± 81 W to 248.4 ± 83 W post-test) as well as in mean power (pre-test, 199.8 ± 64 W to 176.0 ± 54 W post-test), coinciding with the typical finding of muscle power loss with aging in older adults (Orr, Vos, Singh, Ross, Stavrinos, & Fiatarone-Singh, 2006; Runge, Rittweger, Russo, Schiessl, & Felsenberg, 2004). In this sample of older adults, both strength and power training programs increased peak and mean power in older adults, and also resulted in significant increases on the CS-PFP test scores. The increases in the CS-PFP after either ST or PT programs is an important finding of this study as the CS-PFP encompasses physical function domains which include lower and upper body strength, flexibility, balance, and endurance. Therefore these data support the benefits of power training for the maintenance and improvement of physical function in older adults.

Effect of power on balance in older adults. For older adults, maintaining power seems to have positive effects on physical function domains (Foldvari, Clark, Laviolette, Bernstein, Kaliton, Castaneda, et al, 2000; Orr, Vos, Singh, Ross, Stavrinos, & Fiatarone-Singh, 2006; Runge, Rittweger, Russo, Schiessl, & Felsenberg, 2004), including balance. Balance is an imperative physical function for older adults, which is related to fall risk and loss of independence for this population (Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). For this reason, the association between power and balance in older adults has been explored. The dose-response of power training on balance performance was investigated in 112 healthy community dwelling older adults who had not been participating in prior resistance training programs (Orr, Vos, Singh, Ross, Stavrinos, & Fiatarone-Singh, 2006). Subjects were randomized into one of three power training dose groups: 20% (Low), 50% (Med), and 80% (High). Prior to training, balance was measured in all subjects in order to assess the dose-relationship response to power training. Balance was measured under three conditions: 1 – narrow bilateral stance on a force platform that slides back and forth at a speed of 8.3 s/cycle in the anterior/posterior directions, 2- narrow bilateral stance on a force platform that tilted up and down at zero to two degrees in the anterior/posterior direction, and the 3- unilateral stance on the preferred leg on a still platform with eyes open and then again with eyes closed. All balance conditions were done for 30 seconds and measured through a balance index (BI) which was equal to the sum of 12 sway measures plus 180 minus the sum of six time measures, and also through loss of balance scores which was the sum of the number of times balance was lost during the six testing conditions.

Muscle performance was measured in addition to balance performance. Dynamic muscle strength, power, and endurance were measured on pneumatic resistance machines for multiple exercises which included: horizontal leg press, knee extension, knee flexion, seated row, and the seated chest press. Strength was calculated as the sum of all the 1RM values measured, muscle power was assessed at 10% intervals beginning with 20% 1RM and moving to 80% 1RM for the exercises. After performing as many consecutive repetitions at 90% 1RM for each of the exercises, muscle endurance was measured by summing the repetitions performed for all five exercises divided by the five exercises performed.

The power training intervention consisted of explosive resistance training done twice a week for ten weeks. Exercises were the same as those used to measure the previously mentioned outcomes and were done for three sets of eight repetitions. The concentric movement was performed rapidly and the eccentric movement was performed slowly for each exercise. Post-test measurements revealed significant improvements across all training groups in balance performance ($p < .0001$). The low training group had significantly greater balance improvements compared to the high training group (mean difference = 9.71, $p = .003$), the medium training group (mean difference = 8.73, $p = .0001$), and the control group (mean difference = 6.51, $p = .012$). Additionally, the low training group had the greatest decrease in balance index (BI) scores (-10.8 ± 12.6) although, the medium and high groups also had decreases in BI, -2.1 ± 10.4 and -3.0 ± 9.6, respectively. Peak power increases were highest in the medium training group (15 ± 9 W) compared to low (14 ± 7 W) and high (14 ± 8 W) groups, but all groups were significantly greater compared to control group after 10 weeks ($p < 0.004$). Strength increased significantly in the high training group (20 ± 7 N) compared to medium (16 ± 7 N, $p < .05$) and low (13 ± 7 N, $p < .05$) groups, though all were significantly greater ($p < .004$) compared to control group. Endurance was significantly greater in the high training group (185 ± 126 repetitions) compared to the medium (103 ± 75 repetitions, $p < .05$) and low (82 ± 57 repetitions, $p < .05$), and all groups were significantly greater compared to control (26 ± 29 repetitions, $p <.004$). Baseline characteristics which predicated better balance after training included age ($r =.22$, $p =.034$), low peak power ($r =.20$, $P = .05$), lower average peak velocity ($r = .27$, $p = 0.10$) where lower average peak velocity contributed independently to variance in better balance ($r = .29$, $p = 0.004$). These data, especially the independent contribution of low average peak velocity to balance performance exemplifies how decreases in power seem to be associated with decreased balance performance, further elucidating the importance of maintaining muscle function in older adults.

Summary Pertaining to Data Presented

It is important to illuminate that domains of physical function (balance, lower extremity rate of force development, muscle power, and muscle strength) can be improved through resistance training (Lovell, Cuneo, & Gass, 2010Miszo, Cress, Slade, Covey, Agrawal, & Doerr, 2003; Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). It is important to address these domains as they are associated with the risk of fall and therefore independence and longevity in older adults (Hartholt et al, 2011; Rubenstein, 2006; Stevens & Olson, 2000; Todd & Skelton, 2004). While age-related sarcopenia is related to the decreases documented across these domains (Fielding et al, 2011; Rubenstein, 2006), there is some evidence of the retention of eccentric muscle action strength in this population (Frontera, Hughes, Fielding, Fiatarone, Evans, and Roubenoff, 2000; Klass, Baudry, & Dachateau, 2005). This retention of eccentric strength may be the result of physiological mechanisms involved with force production in non-contractile properties of muscle (DeVita, Helseth, & Hortobagyi, 2007; Kent-Braun, Ng, & Young, 2000; Rassier, & Herzog, 2005). These physiological mechanisms of non-contractile properties are largely at work during the eccentric action of a muscle, prior to a concentric action, and are suspected to be driving the consequent increased concentric muscle force output (Kawakami, Muraoka, Kanehisa, & Fukunaga, 2002). This evidence combined holds implications for eccentric-specific resistance training, which in emerging research has been explored in both the young and old.

Implications for Eccentric Training Programs in Older Adults

Eccentric Resistance Training in Older Adults. While resistance training programs improve muscular performance in older adults, there are only a handful of current studies that have taken advantage of the preservation of eccentric force in the prescription of exercise programs for this population. Among these studies, the ability for eccentric exercise to prevent age-related loss of muscle mass was investigated in older adults. Older adults were randomly assigned into one of three training programs: cognitive training (CT), conventional resistance training (RET), and eccentric ergometer training (EET) to be done twice a week for a duration of 12 weeks (Mueller, Breil, Vogt, Steiner, Lippuner, Popp, Klossner, Hoppeler, & Dapp, 2009). Subjects underwent functional tests and body composition tests prior to training and again post training. Functional tests included the Berg balance test and the timed up and go test. Body composition included whole body lean and fat tissue and muscle biopsies from the vastus lateralis. Additionally, maximal isometric extension of the leg was measured by having the subjects push with maximal effort against a force platform. This was repeated three times, and the highest mean force over a one second period was used for analysis. Over the 12 weeks, the EET group increased the average load from 69.6 ± 4.3 W to 314. 8 ± 27.0 W an increase of 352%. For the timed up and go test, all subjects improved significantly moving from 7.37 ± 0.16 s to 6.88 ± .16 s. Compared to the RET group, the EET group had a reduction in whole body fat (5.0 ± 1.1 %) and thigh fat (-6.9 ± 1.5 %) while the same results were not found in the RET group (-0.6 ± 1.0 % WBF and - 0.6 ± 1.9% TF). Both the RET and EET groups had a significant increase in thigh muscle mass (RET: +2.0 ± 0.3%; EET: +2.5 ± .6%), although it is important to note that the EET group had a higher average increase. The EET group had a significant improvement in maximal isometric extension of the leg (+ 7.5 ± 1.7%) while there was no significant improvement in the RET group (+2.3 ± 2.0%) nor in the CT group (-2.3 ± 2.5%). Overall the EET group had greater improvements in both physiological and functional tests compared to the RET and CT groups. The recorded increase of thigh muscle mass in the EET group is an important finding from this study as loss of muscle mass and strength with aging is largely accepted as a contributor to an increased risk of falling in older adults.

In a pilot study, the differences between conventional care and eccentric training in older cancer survivors were explored. Subjects were randomized into either the Usual-care group or a resistance exercise via negative eccentrically induced work (RENEW) group (LaStayo, Marcus, Dibble, Smith, & Beck, 2011). The RENEW group used a recumbent eccentric stepper that focused on the quadriceps muscle group. The pedals were driven in a backwards direction and the eccentric muscle contractions occurred when the subjects tried to resist the motion by pushing down on the pedals. The RENEW sessions were done three times per week for 3-5 minute sessions for the first two weeks, increased to 15 minutes by the fourth week of training, and increased to a range of 16-20 minutes for the last eight weeks of training. The Usual-care group was instructed to continue with their usual oncology follow-up care which was not specified for any of the subjects, however they did not participate in RENEW. Muscle size and lean tissue of the vastus lateralis was assessed using magnetic resonance imaging. Muscle strength (peak force) was measured through maximal voluntary isometric knee extensions and muscle power was measured with a clinical timed stair climb power test where the average of 3 trials was taken for evaluation. Mobility was measured with a six-minute walk and a timed stair descent test.

The pre to post change of quadriceps lean tissue in the RENEW group was greater than the Usual-care group, 4% increase, effect size (ES) = .16 and < 1% increase, ES = .01, respectively. There were no significant post-intervention differences between groups for muscle strength (p = 0.15), however, the RENEW group had a greater magnitude of muscle strength change (11 % increase, ES = .28) than the Usual-care group (1% increase = .04). For the stair climbing leg power test, the RENEW group had a magnitude of change that was greater (29% increase, ES = .71) than the Usual-care group (8% increase, ES = .21) from pre-posttest. The RENEW group also had a greater magnitude of change posttest, in the six-minute walk test (12 % increase compared to 2 % for Usual-care) as well as for the stair descent tests (21% increase compared to 5% for Usual-care). These data contribute evidence for the benefits that can be reaped from eccentric muscle actions and therefore eccentric training programs. Furthermore, it seems that eccentric training programs compared to conventional resistance training for older adults, result in greater increases in muscle mass, muscle power and strength, and have positive influences on performance during functional tests.

Implications for Augmenting the Eccentric Loading

Augmented eccentric loading and muscle force enhancement. Due to the growing evidence in the literature on eccentric actions of a muscle enhancing the following concentric contraction, research has turned the focus onto athletic subjects in order to investigate how to further the benefit of this phenomenon (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002; Moore, Weiss, Schilling, Fry, & Li, 2007; Sheppard & Young, 2010).

In order to capitalize on the effect eccentric muscle actions have on concentric muscle force, studies have begun to stress the eccentric muscle action by overloading it, called augmented eccentric loading (AEL) (Moore, Weiss, Schilling, Fry, & Li, 2007). The effect of additional eccentric loading on a bench press one repetition maximum (1RM) was assessed in ten moderately trained men (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002). Bench press 1RM's were established before testing. Using detaching weight hooks, each participant moved into the eccentric phase of the bench press with 105% of their 1RM and the weight was removed at the bottom of the lift immediately before lifting 100% of the 1RM (Doan, et al., 2002). After the initial 1RM attempt with additional eccentric loading, each participant was allowed to attempt a second and third 1RM bench press with respective changes to the eccentric load with increasing 1RM. In the eight men that completed the study, 1RM increased by 2.27 to 6.8 kilograms. The additional eccentric loading was reported to have significantly increased the weight lifted during the concentric phase of the bench press.

Another study found similar enhancements of the concentric muscle force following additional loading to the eccentric phase. Sheppard and Young (2010) compared barbell displacement between a 40 kg to 40 kg (equal) eccentric to concentric load, and 60 kg – 40 kg, 70 kg-40 kg, and 80 kg-40 kg eccentric to concentric loads. The study revealed the barbell displacement was significantly greater ($p < 0.05$) among the 60 kg – 40 kg, 70 kg-40 kg, and 80 kg-40 kg eccentric to concentric conditions than in the equal eccentric to concentric load condition (Sheppard, & Young, 2010). This increase in the concentric outputs was attributed to neurogenic stimulation in the eccentric phase that may involve lower inhibitory reflexes and greater tension capabilities prior to the concentric contraction (Sheppard, & Young, 2010).

Vaverka, Jakubsova, Jandacka, Zahradnik, Farana, Uchytil, et al (2013) investigated the enhancement of vertical ground reaction forces also demonstrated an increase in performance attributed to the additional loading of the eccentric phase. Eighteen male students performed an initial countermovement jump on a force plate in order to establish a control condition (Vaverka, Jakubsova, Jandacka, Zahradnik, Farana, Uchytil, et al., 2013). The subjects then performed a series of counter movement jumps with additional loads of 10%, 20%, and 30% of their body weight and the ground reaction forces on a force plate were compared with the control jump. The magnitude of force impulse during the acceleration phase was greater in all of the loaded jump conditions compared to the control jump condition: 212.3 N/s control, 220.3 N/s with 10% additional load, 227.9 N/s with 20% additional load, and 233.1 N/s with 30 % additional load. The average forces during the acceleration phase increased significantly with increasing eccentric loads: baseline was 1543.9 N/s, 10% additional load was 1595.1 N/s, 20 % additional load 1661.8 N/s, and 30% additional load resulted in 1733.4 N/s (Vaverka, et al., 2013).

These data suggest that the enhancement from the stretch shortening cycle along with stored elastic energy can be further improved by overloading the eccentric phase of muscle actions. The use of AEL has not been investigated in the older adult population nor have the chronic effects of long-term AEL training programs in either athletic populations or older adults. However, with the identified retention of eccentric muscle force in older adults, the application of an AEL resistance training program may be beneficial for the maintenance and/or improvement of muscular function in older adults.

Summary

It is evident that age-related declines in muscle mass and function increase the risk of falls in older adults. Reducing the risk of falls in older adults is especially important as falls are associated with decreased independence, increased morbidity, mortality, and early admittance into assisted living institutions. Recent research on the function of older adults has demonstrated the preservation of eccentric muscle force production in the geriatric population. Though the mechanisms through which this phenomenon occurs are still being investigated, it is likely that age-related increases in non-contractile properties of the muscle increase muscle stiffness that may be responsible for the maintenance of eccentric force production. This is an important factor to explore as it is well established that eccentric muscle actions immediately before concentric contractions enhance the consequent muscle force output. Additionally, it is now evident that over loading the eccentric phase furthers the concentric enhancements.

In athletic populations, the augmentation of the load during the eccentric phase before a concentric muscle action has resulted in improved muscle force production. However, this has not been explored in older adult populations. It has been established that low volume with moderate intensity resistance training programs for older adults results in increased muscle functions.

When resistance training programs are focused on increasing muscle force and power output of the lower extremity muscles, older adults have increases in lower extremity rate of force development, improved center of pressure which infers improved balance, and improvement in performance on functional tests related to risk of fall. Improving performance on functional tests like the sit-to-stand tests and balance tests through the improvement of muscle rate of force development and muscle power is vital for decreasing the risk of falls in older adults. It seems that the application of augmented eccentric load (AEL) training program may be beneficial for older adults in the improvement and maintenance of muscle force development, balance, and performance on functional tests. Furthermore eccentric training programs involving dynamic resistance training exercises has not been explored in either the young or old. Therefore, the focus of this study was to investigate the effect of a six week augmented eccentric training program in older adults on the rate of force development during a STS-1, center of pressure, and performance in a STS-5.

Chapter III

Methods and Procedures

Introduction

This study tested the effect of a six-week augmented eccentric load (AEL) training program on the rate of force development during a one-time sit-to stand test (STS-1), center of pressure excursion during single-foot balance and quiet standing, and performance in a five-times-sit-to-stand test (STS-5) in older adults. Subjects were assigned to either the AEL in addition to resistance training group or the resistance training only group. This chapter includes the description of the sample, design of the study, AEL training protocol, and data collection processes.

Description of Study Sample

Twenty moderately active older adults were recruited for this study from the Western Washington University's Adult Fitness Program and from the Blaine Senior Center. Older adults were defined as being 60 years of age or older. All participants had general knowledge of resistance training techniques. Moderately active was defined as participating in at least 30 minutes a day of exercise, three times per week and having resistance trained for at least 2 days a week for the previous six months. Participants were excluded from the study if either knee or hip replacements were reported to minimize potential risk of injury.

Design of the Study

A pretest-posttest randomized group study design was used to assess the effect of an AEL training program on the rate of force development during an STS-1, center of pressure, single-foot balance test, and performance in the STS-5 test. The participants were randomly assigned into two groups. The treatment group participated in a six-week AEL training program. The resistance training group (RT) was asked to continue their regular resistance training program.

Data Collection Procedures

The Human Subjects Committee at Western Washington University approved this study (*Appendix A*). Both the risk and benefits of participating in this study were clearly explained to each subject. All subjects signed an informed consent (*Appendix B*) before the first testing day. Additionally, all subjects obtained physician clearance to participate in the study prior to the first day of training (*Appendix C)*.

Instrumentation. Rate of force development, center of pressure, and single-foot balance tests were measured with an AccuGait AMTI OR6-6 (Watertown, MA) standard sized force plate sampling at 1200 Hz. A custom computer software using LabView was used to calculate and produce the graphical format of rate of force development from the AccuGait AMTI OR6-6 force plate.

Measurement Techniques and Testing Procedures. Data collection was conducted at the Western Washington University Biomechanics Laboratory. Each subject attended a pretest familiarization session. At the familiarization session, subjects were asked to answer questions about their age, activity level, recent injuries, and hip or knee replacement to determine inclusion for the study. If they met the inclusion requirements, height and weight measurements were taken from the pre-participation packets filled out by the subjects. Subjects who met inclusion criteria were invited to come back for a measurement session (testing day) and instructed to refrain from heavy exercise which may fatigue the lower extremity for 48 hours prior to the first testing day.

During the first testing day, each subject performed a general warm-up that consisted of walking on a treadmill for three minutes at two miles per hour. Then, each subject performed a dynamic warm-up that consisted of five lunge-to-knee hugs for each leg, and were allowed to lean against a wall for support and stability. A task-specific warm-up of 10 chair rises was also performed. Then a three-minute rest period was given before beginning testing to minimize fatigue.

Center of Pressure Excursion

Subjects were asked to stand on the force plate with feet hip width apart. Subjects performed this test with athletic shoes on. Subjects stood quietly with their eyes closed with their hands comfortably at their sides for a full 30 seconds. Test administrators stood beside each subject with instruction to catch or support the subject if subject asked for help and the test was then restarted. Anterior-posterior and medial-lateral excursions of the center of pressure were measured by calculating the moment arm of the vertical force in the x and y directions; $COPx = My/Fz$ and $COPy = Mx/Fz$, respectively.

Single-Foot Balance Test

Subjects were asked to stand on a force plate with arms at their sides. Subjects were then asked to stand quietly and slowly lift one foot off the ground while keeping the other firmly in the middle of the force plate. Subjects performed this test with athletic shoes on. Center of pressure was then recorded for up to 30 seconds or until subject became unstable. Subjects were to say “HELP” if they felt unsafe. A test administrator stood beside each subject with instruction to catch or support subjects if subjects asked for help and the test was then restarted. This test was performed for each foot. Anterior-posterior and medial-lateral excursions from the center of pressure were assessed as described in previous section.

Rate of Force Development in STS-1

A chair with no arm rests was placed outside the force plate, so that the participant's heel fell completely over the force plate in a natural manner. Seat height was 40.6cm and had no arm rests, a commonly used chair type used to avoid compensation from the upper body. Participants were instructed to keep their arms crossed against the chest throughout the entire test. Then instructions were given to stand all the way up from the chair as fast as possible. A 'three, two, one, GO' countdown prompted the subjects to begin the test. Test administrators began collection of data on 1, and the subjects began the test on GO. Test administrators were trained to safely assist the subjects in the case a subject lost balance, otherwise, test administrators were instructed not assist the subjects. Subjects were instructed to say "HELP", cueing the test administrators to close their arms around the participants and lean the body weight of the participants onto themselves to support them safely. The change in force was found by subtracting the force exerted at the beginning of the movement from the peak force reached. The change in time was found by subtracting the time at which the beginning of the movement occurred from the time the peak force was reached. The rate of force development was found by dividing the change in force in Newtons by the change in time, thus, determining the slope of the vertical ground reaction force.

Five-Times Sit to Stand Protocol

All subjects performed a STS-5 test pre- and post-intervention. The STS-5 test began with the subject sitting up straight with knee and hip angles as close as possible to 90 degrees. The subject was instructed to sit down quickly after the fifth stand to conclude the test. The test time was taken when the participant was in the seated position at the end of the fifth stand. All subjects were allowed to finish the five stands, however the test was considered failed if the subject failed to stand up all the way successfully.

Augmented Eccentric Load Protocol

The augmented eccentric load (AEL) training program was implemented two days a week for six weeks with at least two days in between training sessions. An introduction to proper weight training techniques was given and continually monitored during each group training session. The training session consisted of a five minute walking warm-up, 30 minutes of six different lower extremity strengthening AEL exercises were performed and included: calf raise, unilateral lunges, task-specific chair rise exercise, step downs, and ankle eversions (*Appendix D*). Additional weight was handed to the subjects during the eccentric phase of each exercise and removed prior to the concentric phase. All subjects began with no weight and progressed by 5% body weight weekly if the subjects had good form and were able to handle the load. Resistance was then increased to 10% in the second week and up to 20% by the final week depending on the subject's individual progression. Ankle eversions were completed with two kilograms of resistance and this weight did not change throughout the six weeks because additional weight was not tolerated by the subjects. A ten minute cool down including lower body static stretches (*Appendix E)* ended each session. All exercises were performed for 3 sets of 8 repetitions in accordance with appropriate exercise prescription for older adults (ACSM, 2013).The six-week AEL program was concluded with a post-testing day following at least a two-day rest period after the final training session. The average length of time between the last training day and the post-test was four days.

Data Analysis

A two-way analysis of variance was used to assess the effect of group, (AEL) plus resistance training versus resistance training only, and time (pre-test vs. post-test) on the rate of force development during a one time sit to stand task, center of pressure excursion during quiet standing on both feet with eyes closed and in single-leg standing with eyes open, and the time to complete a five time sit to stand test. Simple effects analyses were conducted in the case of a significant group by time interaction effect. Significance for the rate of force development and the five time sit to stand test was set to $p < .05$. Significance for the center of pressure conditions was set to $p < .008$ after using the Bonferroni correction for six conditions.

Chapter IV

Results and Discussion

Introduction

This study assessed the hypothesis that a six-week augmented eccentric loading (AEL) exercise program for older adults would improve rate of force development during a one-time-sit-to-stand test (STS-1), anterior/posterior and medial/lateral center of pressure (COP) excursion in a balance test, as well as in a single-foot balance test. Additionally, it was hypothesized that AEL training would decrease the time to complete the clinical five-time-sit –to-stand (STS-5) risk of fall evaluation test. In order to measure the effect of a six-week AEL exercise program, subjects were separated into either an AEL training group or a resistance training only group (RT).

Subject characteristics

Both male (AEL n=2, RT n= 1) and female (AEL n = 8, RT n = 7) subjects aged 60 – 82 years (73 ± 5.8years) participated in this study. Twelve subjects from the Blaine Senior Center performed a six-week augmented eccentric training (AEL) exercise program and eight subjects from the Western Washington University's Mature Adult Fitness Program were assigned into (RT). Subjects were placed into either the AEL group or the RT group depending on their location, due to limited availability of the subjects to train within available trainer times. Two female subjects from the AEL group dropped out of the study after three weeks of training due to medical complications that were not associated with the training regimen. All subjects were moderately active older adults who participated in regular strength training (ST) programs at least three times per week prior to the study and continued the ST during the course of the study. At baseline, subjects' height and weight did not differ significantly between groups (*p* = .076 and *p* = .406, respectively). The group characteristics are presented in Table 1.

Table 1. Subject Characteristics

Subject Characteristics

	Mean ± SD	
	AEL	RT
Subject Age (years)	70.18 ± 5.70	76.25 ± 5.63
Subject Height (cm)	166.45 ± 6.58	160.56 ± 15.44
Subject Weight (kg)	76.48 ± 11.28	65.77 ± 9.77

Results

Data from eighteen subjects (10 AEL, 8 RT) comprised the final data set. Two subjects from the AEL group dropped out due to medical complication unrelated to the training program.

Clinical Five Time Sit to Stand Test. There was no significant group by time interaction effect on STS-5 time (F [1, 16] = 2.538, *p* = .131). Compared to baseline, results revealed a significant main effect of time difference in the time to complete the STS-5 among both group (F [1, 16] = 15.904, *p* =.001). There was no significant difference between groups (F [1, 16] = 2.538, *p* = .131) in time to complete the clinical STS-5. However, post-hoc t-tests revealed that only AEL decreased the time to complete the STS-5 significantly (t = 2.29, df = 8, p = .0004) compared to RT (t = 2.2, df = 6, p =.2). The effect size was moderate, d = .49 for the AEL group at pre- to post-test. The results for the STS-5 are presented in Table 2.

Table 2. Time to Complete STS-5

Time to Complete STS-5

Group		Mean ± SD
Pretest	AEL	11.55 ± 2.52
	RT	9.88 ± 0.84
Posttest	AEL	9.33 ± 0.72*
	RT	8.94 ± 1.87

Notes: Time measured in seconds (s); * indicates significant change within group from pre to post-test p < .05

Rate of Force Development during a One Time Sit to Stand. Results of the two-way mixed analysis of variance (ANOVA) indicated that there was a significant group by time interaction effect (Figure 1*)* on rate of force development during the STS-1 (F [1, 16] = 9.276, *p* = .008). Simple effects results for the RT group did not demonstrate a significant change, (t(13) = = 2.16, *p* = .55) in RFD during the STS-1 compared to baseline. Simple effects test results indicated that at baseline the AEL group did not differ significantly from the RT group in RFD during the STS-1 (t (18)= 2.12, *p* = .711). However, there was a significant post-test difference in RFD during the STS-1 between AEL and RT (t (14) = 2.14, p = 0.003). The effect size was large, d= .69, for post-test difference in RFD during the STS-1 between the AEL and RT. The means and standard deviations for RFD during the STS-1 are presented in Table 3.

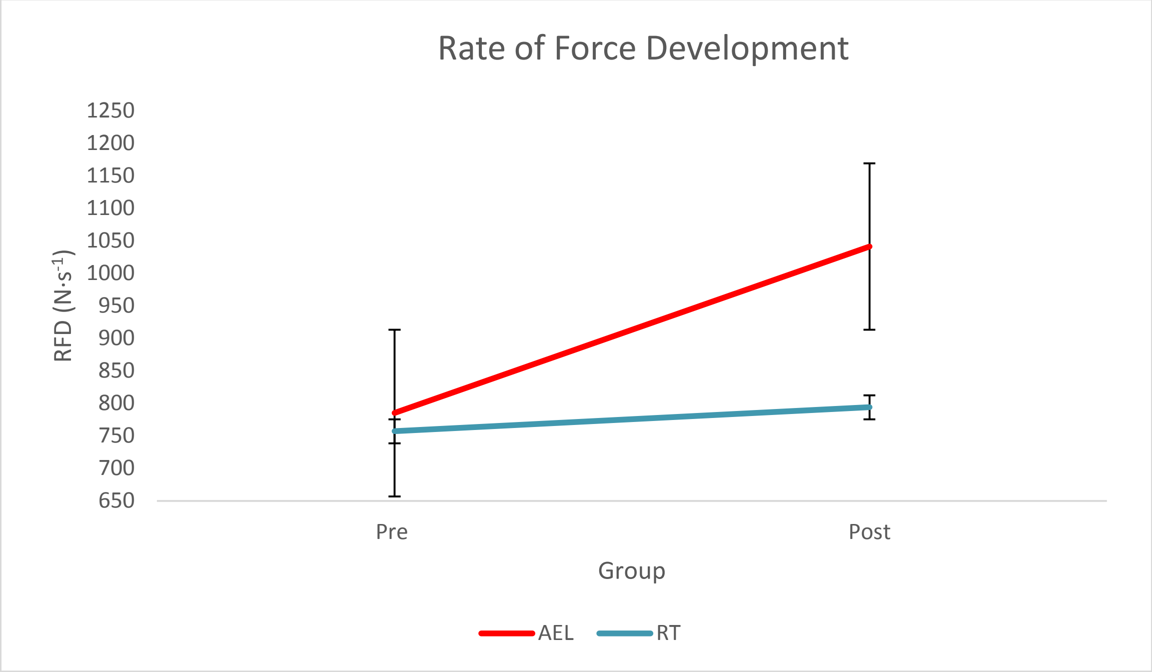
Table 3. Rate of Force Development in STS-1

RFD in STS-1

Group		Mean ± SD
Pretest	AEL	785 ± 176
	RT	757 ± 133
Posttest	AEL	1041 ± 187**
	RT	794 ± 101

Notes: STS-1= one time sit to stand, ** indicates significant change between AEL and RT and within the AEL at post test

Figure 1. Rate of Force Development at Pre- to Post-Test



Center of Pressure Excursion; Both Feet, Eyes Closed. There was no group by time interaction for center of pressure medial-lateral excursion in both feet, eyes closed condition (MLCOP) (F [1, 15] = .282, *p* = .603). Results indicate a significant difference in the main effect of time for medial-lateral COP excursion MLCOP compared to baseline (F [1, 15] = 16.661, *p* = .001). There was no significant difference in main effect of group for MLCOP (F [1, 15] = .282, p = .603). There was no group by time interaction effect on anterior-posterior COP excursion (APCOP) (F [1, 15] = 1.29, *p* =. 274). AEL had a significant difference for APCOP at post-test compared to baseline, p = .002. The effect size for AEL APCOP was large, d = 6.3. For RT, there was no significant difference for APCOP (p = .08). There was no significant difference between groups in APCOP at either test times (F [1. 15] = 1.289, p = .274). The data for MLCOP and APCOP for both groups are presented in Table 4. Data on subject 10 (RT) was not recovered for post-test analysis on center of pressure for any condition, therefore n = 7 for RT for all COP post-test analysis.

Table 4. Center of Pressure Excursion; Both Feet, Eyes Closed

Center of Pressure Excursion; Both Feet, Eyes Closed

		MLCOP(m)	**APCOP(m)**	**N**
	AEL	0.075 ± 0.07	0.157 ± .11	10
Pretest	RT	0.056 ± 0.05	0.094 ± .11	7
	AEL	0.003 ± 0.01	0.005 ± .01*	10
Posttest	RT	0.000 ± 0.00	0.005 ± .00*	7

Notes MLCOP = Medial-lateral excursion, APCOP = Anterior-posterior excursion in meters; * significant difference within groups p < .008

Center of Pressure Excursion; Right Foot, Eyes Open. There was no significant group by time interaction for center of pressure medial-lateral excursion in the right foot, eyes open condition (MLRF) (F [1, 15] = 5.45, *p* =.034). Results indicate a significant difference in the main effect of time for MLRF in both AEL and RT compared to baseline (F [1, 15] = 42.903, *p* ≤ .001). The effect size was large in both groups, d= .82 and d =. 72, respectively. There was no significant difference for the main effect of groups for MLRF at either test times (F [1, .113] = 5.455, *p* = .034). AEL and ST did not have a significant difference in APRF at post-test compared to baseline, p = 0.06 and p = .02, respectively. The data for MLRF and APRF for both groups are presented in Table 5.

Table 5. Center of Pressure Excursion; Right Foot, Eyes Open

Center of Pressure Excursion; Right Foot, Eyes Open

		MLRF(m)	**APRF(m)**
	AEL	0.457 ± 0.20	0.465 ± .15
Pretest	RT	0.243 ± 0.19	0.199 ± .16
	AEL	0.012 ± 0.00*	0.012 ± .01**
Posttest	RT	0.032 ± 0.06*	0.012 ± .01

Notes: MLRF = medial-lateral excursion of the right foot, APRF = anterior-posterior excursion of the right foot in meters; * indicates significant difference within groups p < .008, **indicates significant difference between groups p < .008.

Center of Pressure Excursion; Left Foot, Eyes Open. There was no significant group by time interaction on medial-lateral COP excursion in the left foot (MLLF). Results indicate a significant difference in MLLF in both groups compared to baseline (F [1, 15] = 31.274, *p* < .001). Results revealed that there was no significant difference between groups (F [1, 15] = 5.033, *p* < .04). APCOP excursion of the left foot (APLF) for AEL and ST indicates a significant difference (p = .002 and p = .008, respectively) in APLF in both groups compared to baseline (F [1, 15] = 35.188, *p* < .001). The effect size was large in both groups for the pre- to post-test difference in APLF, d=.89 and d= .73 respectively. Results did not indicate a significant difference between groups for APLF (F [1, 15] = 4.928, *p* = .042). The data for MLLF and APLF are presented in Table 6.

Table 6. Center of Pressure Excursion; Left Foot, Eyes Open

Center of Pressure Excursion; Left Foot, Eyes Open

		MLLF(m)	**APLF(m)**
Pretest	AEL	0.366 ± 0.14	0.438 ± .22
	RT	0.227 ± 0.19	0.211 ± .19
Postest	AEL	0.011 ± 0.012*	0.013 ± .01*
	RT	0.076 ± 0.18	0.013 ± .16*

Notes: MLLF = Medial-lateral excursion of the left foot, APLF = Anterior-posterior excursion of the left foot in meters; * indicate significant difference within groups pre to post-test p < .008

Discussion

The purpose of this study was to investigate the effect of a six-week augmented eccentric load (AEL) program on the RFD during a one-time-sit-to-stand-test (STS-1), center of pressure (COP) excursion during quiet standing and single leg standing, and performance in the clinical five-time-sit-to-stand test (STS-5) in older adults. The AEL training program consisted of six lower extremity exercises designed to minimize and prevent the risk of falling for older adults. Each lower extremity exercise targeted the eccentric muscle action of the major and minor leg and thigh muscles involved in braking a fall with the goal to strengthen those muscle groups. The lower extremity exercises were a key element in developing the AEL training program as sarcopenia, or the loss of muscle mass, as well as dynapenia, or the loss of muscle strength, are recognized as the leading causes of falls in the older adults population (Frontera, Hughes, Fielding, Fiatarone, Evans, & Roubenoff, 2000; (Joshua, Souza, Unnikrishnan, Mithra, Kamath, Acharya, & Venugopal 2014; LaStayo, Ewy, Pierotti, Johns, & Lindstedt, 2003). The nature in which the exercise movements were performed was slow loaded eccentric movement followed by quick unloaded concentric movement. The nature of the exercises was chosen in order to stimulate a neuromuscular adaptations similar to those found with the stretch-shortening cycle and could be used to aid in concentric muscle force development and therefore increase lower extremity function in older adults.

Five Time Sit to Stand. The results of this study support the experimental hypothesis demonstrating a significant effect of a six-week AEL program on performance in the clinical five-time-sit-to-stand test (STS-5). The STS-5 is an indirect measure of lower extremity muscle power, and indicates the risk of falling in older adults (Buatois, Milijkovic, Manckoundia, Gueguen, Miget, Vancon, et al., 2008). Performance in the STS-5 is a reliable predictor of falls where a time greater than 12 seconds is closely associated with increased risk of falls in older adults (Buatois, Milijkovic, Manckoundia, Gueguen, Miget, Vancon, et al., 2008). In the present study, AEL training was effective in reducing time to complete the STS-5, where the AEL group improved from 11.54 ± 2.52 s to 9.33 ± .72 s to complete the STS-5. More impressively, seven of the ten subjects in the AEL group shifted from a high risk of falling time of ≥ 12 s, improving the AEL mean time by -2.63 s. After the AEL training program, no subjects in this group were in a high risk of falling category for older adults (Buatois, Milijkovic, Manckoundia, Gueguen, Miget, Vancon, et al., 2008). Compared to AEL, RT did not demonstrate a significant change in time to complete the STS-5, 9.8 ± .83 s to 8.94 ± 1.86 s. In fact, two subjects in RT increased the time to complete the STS-5 (*Appendix I)* and of that two, one subject moved into the high risk of falling category of ≥ 12 s. These data support the experimental hypothesis and hold strong implications for AEL training to be incorporated into preventative strength training programs for older adults.

Compared to the present study, research on strength training and performance in the STS-5 involves strength training programs with heavy lower extremity resistance in order to elicit a positive effect on performance (Caserotti, Aagaard, Larsen, & Puggaard, 2008; Schlicht, Camaione, & Owen, 2001; Schlicht, Camaione, & Owen, 2001). Schlicht, Camaione, and Owen (2010) compared times to complete the STS-5 between an eight week-intense strength training group and a control-no strength training group. Compared to the present study, the strength training group performed a greater number of repetitions (10 vs. 8) at higher intensities (75% 1-repetition maximum). In the present study, the resistance exercises consisted of functional and dynamic movements, while Schlicht, Camaione, and Owen (2010) required the strength training group to perform isolated limb exercises on weight machines. The time to complete the STS-5 was measured at pre-intervention, mid-intervention, and post-intervention in both groups. Similar to the present study, the strength training group performed significantly better at mid- and post-intervention compared to pre-intervention while the control group only demonstrated significantly better performance at post-intervention compared to mid-intervention. In that study, there was no significant between groups suggesting that something other than the strength training programs may account for the observed differences. However, in the present study, post-hoc tests revealed that only the AEL group improved significantly compared to baseline. This is a key finding of this study as it seems that an AEL program may be more beneficial than a typical strength training program in improving performance in five-time-sit-to-stand test for older adults. Additionally, the AEL training program was only six weeks long and required only moderate resistance in order to elicit a significant effect that is comparable to that found in an eight week, high intensity strength training intervention. Along with the decreased time to improve STS-5, the AEL training program also elicited positive results in RFD in the STS-1.

Rate of Force Development. The results indicate that six-weeks of AEL training of the lower extremity muscles was effective in eliciting a significant increase in RFD during a one-time-sit-to-stand test (STS-1) in older adults. The AEL group increased RFD significantly at post-testing in the STS-1 compared to RT, which did not demonstrate a significant increase in RFD. These results are comparable to other studies concerned with the effect of strength training programs on RFD during a chair rising task in older adults. Lovell, Cuneo and Gass, (2010) compared RFD during a standing task between a strength training group (ST) and a non-strength training group (control) of older adult males. After 16 weeks of strength training, ST demonstrated a significant increase in the RFD (926 ± 125 $N \cdot s^{-1}$vs 1109 ± 140 $N \cdot s^{-1}$, $p <.05$) while the control group demonstrated no appreciable change in the RFD at post-testing (895 ± 87 $N \cdot s^{-1}$to 882 ± 83 $N \cdot s^{-1}$). Similar to the present study, post-test results revealed that those in the AEL demonstrated significantly greater RFD compared to RT. Compared to the present study, lower extremity strength training for 16 weeks elicited similar increases in RFD in older adults. This is an important comparison as these results contribute to the discussion of the positive benefits of strength training programs for older adults as the AEL training program was effective in eliciting a notable increase in RFD during chair rising.

In another study, RFD was compared between a control (non-fall) and hip fracture (fall) group of older adults. Similar to the present study, Houck, Kneiss, Bukata, and Puzas, (2011) measured vertical ground reaction forces (vGRF) in order to assess RFD in a sit-to-stand task. Unlike this study, the RFD values were then correlated with self-reported lower extremity functional ability among both groups. The results indicated that the hip fracture group had a significantly lower RFD compared to the control group, 12.9 Ns/kg versus 20.9 Ns/kg. The RFD was significantly correlated with self-reported functional ability (r = 0.499). Additionally, as vGRF increased, self-reported functionally ability positively increased. Although the present study did not assess correlations between RFD and self-reported functional ability, the RFD improvements demonstrated in the AEL group hold clinical implications for the development of preventative as well as rehabilitative programs for older adults. More importantly, the correlation between self-reported function and RFD observed by Houck, Kneiss, Bukata, and Puzas, (2011) along with the data presented in this study elucidate the relationship between RFD and lower extremity function in older adults (Miszo, Cress, Slade, Covey, Agrawal, & Doerr, 2003; Orr, Vos, Singh, Ross, Stavrinos, & Fiatarone-Singh, 2006).

Improvement of lower extremity RFD in older adults is important as it contributes to the retention of muscle function in this population. The present study contributes to research concerned with enhancement of lower extremity RFD with strength training due to the notable increase in RFD for the AEL compared to baseline. This is a crucial finding as it may hold implications for the development of AEL training programs for older adults.

Center of Pressure Excursion. The loss of stability with aging has revealed devastating consequences in the older adult population. The maintenance of stability is therefore imperative as stability is related to the risk of falls and independence in older adults (Foldvari, Clark, Laviolette, Bernstein, Kaliton, Castaneda, et al, 2000; Orr, Vos, Singh, Ross, Stavrinos, & Fiatarone-Singh, 2006; Runge, Rittweger, Russo, Schiessl, & Felsenberg, 2004). Research on stability among older adults has attributed the loss of stability to decreased muscle strength and overall to a decrease in muscle function (Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). Unlike the present study, stability in older adults has been mostly assessed indirectly through tandem stance times and clinical balance tests compared to this study where center of pressure excursion was directly measured.

In a study conducted by Bean, Herman, Kiely, Frey, Leveille, Fileding, and Frontera, (2004), resistance training indirectly elicited positive effects on balance and thus stability through increased stance time during single-leg stance in older adults. Similar to this study, Bean et al, (2004) used task-specific and functional movement patterns in the resistance training program with the goal to produce an increase in stability among older adults. Bean et al (2004) used weighted vests in order to provide resistance progressing by 2% body mass over the course of 12 weeks and compared excursions from COP between the training group and a control exercise group which did not use weighted body vests to perform exercises. Similar to the present study, which used augmented eccentric loads, the weighted vest group demonstrated there was significant effect of resistance training on stance time, 2.24 ± 2.71 s, and therefore stability. Although this study did not measure COP excursion, the results hold similar implications to the present study in that balance and stability may be improved through moderate augmented dynamic movements as well as regular strength training programs for older adults. However, it is important to note that despite having no AEL training, RT also had significant improvements in balance. Therefore it is possible that a training effect could have influenced the performance during the balancing tasks in RT.

Summary

This study, along with current research on stability, strength, and fall risk among older adults, elucidate the need for strength training of the lower extremity muscles in this population. Lower extremity function is important in order to maintain and improve performance on functional tests having to do with risk of falling. A six-week AEL program may be beneficial in generating improvements in lower extremity functional tests and fall-prediction tests compared to typical strength training programs. Additionally, AEL training may require a smaller amount of time as well as lower work intensities to elicit similar positive performance in functional tests compared to traditional strength training programs for older adults. Further research is required in this area as the present study is the first of its kind using augmented eccentric training program in older adults.

Chapter V

Summary, Recommendations, and Conclusion

Summary

Assessment of the risk of falls among older adults is important as falls are attributable to a decrease in longevity and independence in this population. The literature regarding the association between risk of fall and the physical characteristics of older adults reveals an association between age-related decreased lower extremity muscle function with an increased risk of falling (Frontera, Hughes, Fielding, Fiatarone, Evans, & Roubenoff, 2000; Joshua, Souza, Unnikrishnan, Mithra, Kamath, Acharya, & Venugopal 2014; LaStayo, Ewy, Pierotti, Johns, & Lindstedt, 2003). There is some research that indicates that older adults retain more eccentric muscle strength compared to concentric muscle strength with aging (Frontera, Hughes, Fielding, Fiatarone, Evans, and Roubenoff, 2000; Klass, Baudry, & Dachateau, 2005; Powers, Rice, Vandervoort, 2012). This retention of eccentric strength may be, in part, due to the accumulation of collagen fibers in non-contractile properties, which may subsequently increase muscle tendon stiffness and aid in the retention of eccentric muscle strength (Kent-Braun, Ng, & Young, 2000; Rassier, & Herzog, 2005). Eccentric strength is important because increasing muscle-tendon tension during the eccentric phase of a movement has yielded increases in the consequent concentric muscle force output (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002; Sheppard and Young 2010; Vaverka, Jakubsova, Jandacka, Zahradnik, Farana, Uchytil, et al., 2013). The mechanisms driving this phenomenon include the stretch-shortening cycle and stored elastic energy, which are presumed to be the driving force of the consequent increased concentric muscle force output and a similar effect may be take place due to AEL training.

The effect of augmenting the muscle-tendon tension during the eccentric phase of a movement has only been studied acutely in the 1RM of athletic populations. The present study is novel in that AEL was assessed over a six-week training program. Moreover, AEL training has not been studied in older adults, which according to the results presented may be able to capitalize on the inevitable increase of muscle-tendon stiffness with aging.

Conclusion

The positive effect of a six-week AEL training program on RFD in the one-time-sit-to-stand test, balance tests, and the clinical five-time-sit-to-stand test confirm the experimental hypothesis. Subjects in the AEL group improved the time to complete the clinical STS-5 fall risk assessment test by -2.21 ± 1.50 s. Those in the AEL group demonstrated a significant increase in the rate of force development (RFD) during a chair rising task compared to the strength-training group. RT improved significantly in anterior-posterior excursion from the center of pressure of the right foot as well as in quiet standing, and in anterior-posterior excursion from the center of pressure of the left foot. The AEL group also showed significant improvements in M-L and A-P excursion values from the center of pressure during the quiet standing condition, as well as in the M-L excursion values for the right foot and the A-P excursion values for the left foot compared to baseline. Therefore, a six-week AEL training program may be a beneficial exercise prescription for older adults resulting in additional enhancement to a standard weight-training program.

Recommendations

Future Research and Limitations. Until the present study, a six week augmented eccentric training (AEL) program has not been assessed in any population; more research is needed in this area. Additionally, the present study was based on a six week training program and therefore a more chronic effect would be beneficial in assessing the potential effect that AEL training could have on older adults as well as other populations. Furthermore, the present study compared the AEL training group to a resistance trained group whose exercise prescription was not controlled. In order to attain a better understanding of the effect AEL training has on functional domains among older adults, future research should strictly control both exercise groups.

Clinical Implications. The six-week AEL training program may be beneficial for older adults in lowering the risk of falling as predicted by the STS-5, while simultaneously increasing lower extremity power and overall function. Due to the novel and eccentric nature of the exercises, delayed onset muscle soreness (DOMS) was reported by the subjects following the first week of training. However, DOMS was only reported after the first week during the body weight phase and dissipated over the course of the six-weeks. Although the following were unexpected outcomes, subjects reported a multitude of benefits after starting the AEL training program pertaining to self-reported function and ADLs. Among those outcomes, subjects reported: dissipation of thigh and shank numbness that had been present for several years, increased ability to carry weight up and down stairs without hand rail support, ability to walk up stairs using both feet compared to having spent many years dragging the injured-side-foot behind, and diminished rising from chair compensatory efforts such as: holding table, pushing off from seat, and swinging feet off the ground in order to build moment to rise. Although the aforementioned were unexpected and not assessed findings, these reports remain a key motive for the further investigation and potential development of AEL training programs for older adults.

For those looking to prescribe a similar training program, it is important to design the exercises to match functional movements of daily living for older adults. It is also vital that the exercises are done in such a manner that movement from the slow loaded eccentric phase to the quick unloaded concentric phase is a fluid pattern. This can be established through several familiarization sessions as well as consistent and clear training instructions throughout each exercise. Though further research is needed in long-term AEL training for older adults, the present study yields a positive outlook for the development of AEL training programs as fall prevention and lower extremity function exercise prescriptions.

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Appendix A

Human Subjects Review Form and Responses

1. **What is your research question, or the specific hypothesis?**

   The experimental hypothesis states that neuromuscular adaptations due to an augmented eccentric load program will improve domains of physical function in older adults which include: lower extremity rate of force development during a chair standing task, improved center of pressure and therefore stability, and improved performance in the one-time sit-to-stand and five time sit-to-stand test.

2. **What are the potential benefits of the proposed research to the field?**

   Evidence from this study may contribute to the application of augmented eccentric training as an exercise prescription to improve performance on functional tests in older adults and therefore contribute to longevity and independence in this population. Age-related declines in muscle mass and function increase the risk of falls in older adults. Reducing the risk of falls in older adults is especially important as falls are associated with decreased independence, increased morbidity, mortality, and early admittance into assisted living institutions (Hartholt et al, 2011; Rubenstein, 2006; Stevens & Olson, 2000; Todd & Skelton, 2004).

   Declines in physical function among older adults are highly associated with decreases in lower extremity muscle function (Lovell, Cuneo, & Gass, 2010Miszo, Cress, Slade, Covey, Agrawal, & Doerr, 2003; Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). This decline in muscle function is greater in the shortening muscle action (concentric) compared to lengthening muscle actions (eccentric). Though the mechanisms through which this phenomenon occurs are still being investigated, it is likely that age-related increases in non-contractile properties of the muscle increase muscle stiffness that may be responsible for the maintenance of eccentric force production (Frontera, Hughes, Fielding, Fiatarone, Evans, and Roubenoff, 2000; Klass, Baudry, & Dachateau, 2005).. This is an important factor to explore as eccentric muscle actions immediately before concentric muscle actions enhance the consequent muscle force output (Moore, Weiss, Schilling, Fry, & Li, 2007).

   In athletic populations, loading of the eccentric phase of muscle actions prior to a fast concentric muscle action increases the muscle force produced during the concentric phase (Moore, Weiss, Schilling, Fry, & Li, 2007), however, this has not been explored in older adults. The retention of eccentric muscle force production in older adults may be beneficial in the prescription of a long term augmented eccentric training program. It seems that the application of augmented eccentric load (AEL) training program may be beneficial for older adults in the improvement and maintenance of muscle force development, balance, and performance on functional tests.

3. **What are the potential benefits, if any, of the proposed research to the subjects?**

   Augmented eccentric load training may play a role in the improvement of physical function domains for older adults. These domains include balance, by improving center of pressure stability, and improving lower extremity rate of force development, which is indicative of muscle power output needed to perform every day movements like standing up from a chair. Improvements in these domains of physical function hold promising applications for decreasing the risk of falling.

4. **Answer a), then answer either b) or c) as appropriate.**

   The subjects will be male and female older adults who are at least 60 years of age. All participants should have general knowledge of resistance training techniques because they have participated in such programs at Western Washington University and at senior centers. Moderately active will be defined as: doing resistance training 2-3 times per week for the last six months.

   B) Describe how you will recruit a sample from your subject population, including possible compensation, and the number of subjects to be recruited.

   At least thirty subjects will be recruited to participate for this study. Subjects will be recruited from the Western Washington University's Adult Fitness Program and from the Bellingham and Blaine Senior Centers. Older adults are defined as being 60 years of age or older. Inclusion for this study demands that subjects be free from either knee or hip replacements. Permission to recruit subjects will be obtained from all locations. A flyer will be posted in each location for recruitment purposes (see attached).

   C) Describe how you will access preexisting data about the subjects

   N/A

5. **Briefly describe the research methodology. Attach copies of all test instruments/questionnaires that will be used.**

   Instrumentation: Rate of force development and center of pressure will be measured with an AccuGait AMTI OR6-7 (Watertown, MA) standard sized force plate sampling at 1200 Hz. A custom computer software using LabView was used to calculate and produce the graphical format of rate of force development from the AccuGait AMTI OR6-7 force plate. Data collection will be obtained at Western Washington University, Biomechanics Laboratory.

Measurement techniques and testing procedures. Data collection will be obtained at Western Washington University, Biomechanics Laboratory. Each subject will attend a pretest familiarization session. At the familiarization session, subjects will be asked to answer questions about their age, activity level, recent injuries, and hip or knee replacement to determine inclusion for the study. If they meet the inclusion requirements, height and weight measurements will be taken with a Cardinal Detecto Physicican's scale and stadiometer. Subjects who meet inclusion criteria will be invited to come back for a measurement session (testing day) and instructed to refrain from heavy exercise for 48 hours prior to testing. During testing, each subject will perform a general warm up that consists of cycling on a cycle ergometer for three minutes. Then, each subject will perform a dynamic warm up that consists of five knee hugs for each leg, and may either lean against a wall for support and stability or lie on ground. A task specific warm up of 10 chair rises will also be performed. Then a three minute rest period will be given before beginning testing to minimize fatigue.

Center of pressure protocol Subjects are asked to stand on a force plate with arms at their sides. Subjects then stand quietly and slowly lift one foot off the ground while keeping the other firmly in the middle of the force plate. Center of pressure will then be recorded for 30 seconds. Subjects are to say "HELP" if they feel unsafe. A test administrator will stand beside each subject with instruction to catch or support subjects if the subjects asks for help or if the subject becomes unstable, and the test will be restarted. This test will be performed for each foot.

Rate of force development during STS-1

A chair with no arm rests will be placed outside the force plate, so that the participant's heel falls completely over the force plate in a natural manner. Seat height will be 16 inches, a commonly used chair height in current literature (Janssen, Bussman, Stam, 2002; Mourey, Grishin, Athis, Pozzo, & Stapley, 2000; Yoshioka, Nagano, Hay, & Fukashiro, 2009). Participants will be instructed to keep their arms crossed against the chest throughout the entire test. Then instructions will be given to stand all the way up from the chair as fast as possible. A three, two, one, GO countdown prepares the subjects to begin the test. Test administrators will begin collection of data on 1, and the subjects will begin the test on GO. Test administrators will be trained to safely assist the subjects in the case a subject loses balance, otherwise, test administrators will be instructed to not assist the subjects. Subjects will be instructed to say "HELP" cueing the test administrators to close their arms around the participants and lean the body weight of the participant onto themselves to support them safely.

Five-times sit to stand test protocol. All subjects perform a STS-5 test pre and post intervention. The STS-5 test will begin with the subject sitting up straight with knee and hip angles as close as possible to 90 degrees and ends when the participant will be in this seating position at the end of the fifth stand. The same procedures used for theSTS-1 will be followed for the STS-5. Three practice trials will be done to familiarize the participants with the sit to stand movement with the arms crossed.

Augmented Eccentric Load Training Protocol. The augmented eccentric load (AEL) training program will be implemented two days a week for six weeks with at least two days in between training sessions. An introduction to proper weight training techniques will be given and continually monitored during each group training session. All trainers assisting in this protocol are CPR and First Aid certified. The training session will consist of a five minute walking warm up, 30 minutes of six different AEL exercises that included: calf raise, unilateral lunges, task-specific chair rise exercise, step downs, and ankle eversions. Additional weight will be handed to the subjects during the lengthening phase of each exercise and removed prior to the concentric phase. All subjects will begin with no weight and increase by 5% progression during the first week if the subjects have good form and are able to handle load. Progression will then be increased to 10% in the second week and up to 20% by the final week depending on the subject's individual progression. Ankle eversions will be completed with 0.9 kg sand-bells and increase to 1.8 kg sand-bells. A ten minute cool down including lower body static stretches will end each session. The six week AEL program will be concluded with a post-testing day following at least a two day rest period after the final training session. All exercises will be performed for three sets of eight repetitions in accordance with appropriate exercise prescription for older adults (ACSM, 2013).

6. **Give specific examples (with literature citations) for the use of your test instruments/questionnaires, or similar ones, in previous similar studies in your field.**

   The rate of force development during a task like standing up from a chair gives insight into how fast an older adult can produce the necessary muscle force to stand up. A greater rate of force development indicates generally stronger and healthier older adults and is also associated with maintained muscle power (Houck, Kneiss, Bukata, & Puzas, 2011). Center of pressure can be used to assess how well older adults have maintained stability with aging (Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). Both rate of force development (RFD) and center of pressure (COP) are variables that can be used as assessment tools for risk of fall and frailty in older adults and are commonly measured using a force plate sampling at 1200 Hz (Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). The PEHR department has a standard size AccuGait AMTI OR6-7 force plate (Watertown, MA) that is reliable and readily available in the Biomechanics Laboratory that will be used for this study.

7. **Describe how your study design is appropriate to examine your question or specific hypothesis. Include a description of controls used, if any.**

   A pretest-posttest randomized group study design will be used to assess the effect of an AEL training program on the rate of force development during an STS-1, center of pressure, and performance in the STS-5 test. The participants will be randomly assigned into two groups. The treatment group participates in a six week AEL training program. The control group will be asked to continue their regular resistance training program. This study will employ a 2-way ANOVA to assess the difference in means pre and post-test between control and treatment group for rate of force development, center of pressure, and time to complete the five-times-sit-to-stand test. Significance will be set at $P \leq 0.05$. This study design is appropriate to examine the specific hypothesis investigating the effect of augmented eccentric training on lower extremity rate of force development, center of pressure, and performance in the five time sit to stand test.

Give specific examples (with literature citations) for the use of your study design, or similar ones, in previous similar studies in your field.

This study design has been heavily used in research examining the effect of interventions with a goal to increase lower extremity muscle function on the performance in functional tasks in older adults (Lovell, Cuneo, & Gass, 2010; Miszo, Cress, Slade, Covey, Agrawal, & Doerr, 2003; Stel, Smit, Pluijim, & Lips, 2003; Shubert, Schrodt, Mercer, Whitehead, & Giuliani, 2006). This is novel research as there is no long-term augmented eccentric training program that has been employed on older adults. However, the acute effects of augmented eccentric training have used a similar protocol in the athletic population (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002; Moore, Weiss, Schilling, Fry, & Li, 2007; Sheppard & Young, 2010). Common clinical tests of function and risk of falling in older adults include the one-time and five-time sit-to-stand-test (STS-(Zech, Steib, Freiberger, & Pfeifer, 2011).

8. **Describe the potential risks to the human subjects involved.**

With any exercise and/or resistance training program there is a risk of injury to the muscles, tendons, ligaments, spine, and bones. Some of the measurement protocols and exercise from the training program may lead to instability and therefore loss of balance that may also lead to injuries.

9. **If the research involves potential risks, describe the safeguards that will be used to minimize such risks.**

In order to minimize the potential risk of injury, special precautions will be taken to monitor exercises. Subjects will perform familiarity and technique sessions prior to adding weight to the exercises. All subjects will have a test administrator who is trained in properly providing safety maneuvers when and if they are needed. To minimize fatigue and overtraining, exercises sessions will be two days apart to allow for proper rest time. Additionally, an activity harness may be used in order to provide optimal prevention of injuries due to the risk of falling from instability during dynamic movements. This harness will provide additional safety for the subjects involved in the study and will allow subjects to perform maximal and forceful movements with minimal risk of injury.

10. **Describe how you will address privacy and/or confidentiality.**

    Any and all data pertaining to individual characteristics will be stored safely and confidentially by subject number only on an external hard drive owned by the primary researchers and in a locked cabinet in the biomechanics lab. Only the primary researchers will have access to these records.

11. **If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), please attach a clearance letter from an administrator from your research site indicating that you have been given permission to conduct this research. For pre-kindergarten to grade 12 level schools, an administrator (e.g. principal or higher) should issue the permission. For post-secondary level schools the class instructor may grant permission. For Western Washington University, this requirement of a clearance letter is waived if you are recruiting subjects from a scheduled class. If you are recruiting subjects from a campus group (not a class) at Western Washington University, you are required to obtain a clearance letter from a leader or coordinator of the group.**

12. **If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), and you plan to take still or video pictures as part of your research, please complete a) to d) below:**

    N/A

In addition, please attach the following information:

1. **A bibliography relevant to the subject matter of the proposed research.**

   See attached

2. **A copy of the informed consent form (a checklist is attached for you to use as a guide).**

   See attached

3. **A current curriculum vitae.**

   See attached

4. **A copy of the Certificate of Completion for Human Subjects Training from the online human subjects training module, for each person involved in the research who will have any contact with the subjects or their data.**

See attached

5. If your subjects are required to turn in a physician clearance form prior to participation, include a copy of the blank form.

See attached

Appendix B

Informed Consent for Exercise Testing

You are invited to participate in a research study conducted by the Department of Physical Education, Health, and Recreation at the Western Washington University. This study involves augmented eccentric training which is an exercise method in which additional weight is added to an exercise movement during the lengthening phase (when the muscle is stretching) and removed during the shortening phase (when the muscle is contracting). The purpose of this research is to investigate the effect of augmented eccentric training on lower extremity physical function in older adults. In order to participate in this study your age must be at least 60 years or older.

The benefit of this research is that the augmented eccentric training program is designed to improve lower extremity muscle function and therefore may decrease the risk of falling. This is important because falls are among the leading cause of long term disability and loss of independence among older adults.

Given your participation, you will meet for a familiarization session and two testing sessions and at Western Washington University, in the Biomechanics Laboratory, and for twelve exercise sessions over six weeks at one of three locations: lower weight room in Carver Gym at Western Washington University, Blaine Senior Center, or Bellingham Senior Center.

Testing sessions: Both sessions will involve the same procedures. You will do a standard warm up that consists of five knee hugs for each leg, and may either lean against a wall for support and stability or lie on ground. A task specific warm up of 10 chair rises will also be performed. Then a three minute rest period will be given before beginning testing to minimize fatigue. This will be followed by a few familiarization and practice movements of the tasks required. Then you will perform a balance test where you will stand on one foot with eyes closed for up to 30 seconds then again on the other foot, a five times sit to stand test where you will rise from a seated position in a chair and be timed, and a single sit to stand test to be done where you will rise so that you are standing on a force plate in the floor to measure rate of force development. You will perform three trials for each test.

Exercise sessions: All exercise sessions will last a total of 45 minutes from warm up to cool down. All sessions will begin with a standard warm up followed by a 2 minute rest period. Then a series of exercises will be performed that include: lunges (which are long step forwards), chair rising task, calf raises (where you lift your heels off the ground), step downs (where you will step backwards off of an aerobic step), and an ankle strengthening exercise. All exercises will be done for three sets of eight repetitions. All exercises will be done along with two trainers. One trainer will hand you additional weight during the appropriate times of the exercise movement and the other will be there for safety precautions. All exercise sessions will end with a series of stretches for arms and legs that you will hold for 20 seconds.

As with any exercise or resistance training program, there is risk of muscle, tendon, ligament, or spinal injury. Some discomfort may manifest especially with resistance training. In order to minimize these risks, two trainers will always be present to assist during exercise movements. Additionally, all participants will attend a familiarization session which will help you learn proper technique for all of the exercises.

You may withdraw from participation in this study at any time, without penalty. Any questions you may have regarding the study protocol, benefits, and risks can be answered by the primary researcher (Jennifer Estep) who can be contacted at estep.jennifer5@gmail.com or 253-495-9123 or Lorrie Brilla who can be contacted at lorrie.brilla@wwu.edu or 360-650-3056. Further, all of your personal information will be stored safely in a locked cabinet and only the primary researcher will have access to sensitive information.

Any questions about your rights as a research subject should be directed to: Janai Symons at WWU Human Protections Administrator (HPA) 360-650-3220. Additionally, if any injury or adverse effects arise from this research, you should contact your health provider first, along with Jenifer Estep, Lorrie Brilla or the HPA.

HPA Contact

Office of Research and Sponsored Programs
Western Washington University
Old Main 530
516 High Street
Bellingham, WA 98225-9038
Voice: (360) 650-3220
Fax: (360) 650-6811

Any and all data collected will be stored safely and confidentially by subject number only and only the primary researchers will have access to your records.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal claims, rights or remedies.

______________________________ ____/____/____

Participants Name (Printed) Date

____

Participant Signature

____ ______/______/______

Witness Name (Printed) Date

____

Witness Signature

Appendix C

Permission Forms to Contact Mature Adults for Testing

PERMISSION FORM TO CONTACT MATURE ADULTS FOR TESTING (WWU)
Letter of permission:

As the director of the Mature Adult Training Program of the Western Washington University, I, ______________________________, consent to allow Jennifer Estep's thesis research to recruit the WWU Mature Adult Training Program participants. I understand that the thesis research includes measurement of lower extremity rate of force development during a standing from chair task, the five times sit to stand test, a center of pressure test to be done, and a six week augmented eccentric training program will take place, twice a week for 45 minutes sessions in the WWU Biomechanics Laboratory.

____ ____/____/________

Program Director's Name (Printed) Date

____

Program Director's Signature

PERMISSION FORM TO CONTACT SENIORS FOR TESTING
Letter of permission:

As the manager of the Blain Senior Activity Center, I, ______________________________, consent to allow Jennifer Estep's thesis research to recruit the WWU Mature Adult Training Program participants. I understand that the thesis research includes measurement of lower extremity rate of force development during a standing from chair task, the five times sit to stand test, a center of pressure test, and a six week augmented eccentric training program. Additionally, I understand that the augmented eccentric training program intervention may be implemented in the Blain Senior Activity Center.

____ ____/____/________

Director's Name (Printed) Date

____

Director's Signature

Appendix D

Exercise Pre-Participation Packet

Dear Participant,

We are excited that you have chosen to participate in this study. Before we begin the following forms need to be completed so we can provide the safest conditions for you during your participation.

To be completed before any data collection or exercise sessions:

- Physical Activity Questionnaire
- Health History Questionnaire
- Physical Activity Readiness Questionnaire (PAR-Q)
- Medical Release Form
- Informed Consent Form

It is recommended that all participants see their medical doctor prior to participating in any rigorous exercise.

Physical Activity Questionnaire

To help us get an idea of how familiar you are with resistance training:

1. Have you ever performed resistance training exercises in the past? (Movement against a resistance such as dumbells, weight machines, bands, or bodyweight)

   Yes ______ No _______

2. How often do you participate in physical activity?

   ___ Never ___ 1-3 times/month ___ 1-2 times/wk. ___ 4-5 times/wk.

3. How often do you participate in resistance training exercise?

   ___ Never ___ 1-3 times/month ___ 1-2 times/wk. ___ 3-5 times/wk.

4. When doing physical activity, for how long do you remain active?

   ____NA ____ 20 Minutes ____ 30 Minutes ____ 1 Hour _____ > 1 Hour

5. At what intensity are you physically active? Choose your ability to talk during exercise.

   ___NA ___Able to talk ___Able to talk but not sing ___Not able to say more than a few words.

6. Did you know that people who schedule activity are more likely to be active?

   Yes/No ____

   What time of day works for you to be active?

   ____

Health History Questionnaire

Participant

Name: ____ Date: ________________________

Address:

____

Local Phone: ______________________________Email: ____________________________

Date of Birth: ____________________ Age: __________ Sex: __________

OCCUPATION:

____

Primary Health Care Provider

Doctor: ____Phone: _______________________

Address:

____

When were you last seen by a physician?

____

Present/Past History

1. Have you had surgery within the last 2 years? Yes ______ No _______

Explain:

____

____

2. Do you have any past or present orthopedic injuries? Yes ______ No _______

3. Are you taking any medications (prescribed or not)? Yes ______ No _______

Please List:

____

____

5. Do you follow or have you recently followed any specific dietary intake plan and, in general, how do you feel about your nutritional habits?

____

____

6. Please check all conditions that you currently have or have had in the past.

☐ Heart attack

☐ Diabetes

☐ Stroke

☐ Chest discomfort

☐ Heart murmur

☐ Trouble sleeping

☐ Migraine or headache

☐ Broken Bone

☐ Shortness of breath

☐ Anemia

☐ Asthma

☐ Epilepsy

☐ Anxiety Depression

☐ Fatigue

☐ Hernia

☐ Arthritis

☐ Limited range of motion /pain

☐ Use of assisted walking device

Explain any conditions that you checked (i.e. treatment, symptoms, and restrictions):

____

I acknowledge that I am in good health, have answered the previous questions truthfully, and have no known medical problems that would preclude safe participation in this exercise program.

Signed: ______________________________________ Date: _____________

Physical Activity Readiness Questionnaire (PAR-Q)

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

Y N Has a physician ever said you have a heart condition, and you should only do physical activity recommended by a physician?

Y N When you do physical activity, do you feel pain in your chest?

Y N When you were not doing physical activity, have you had chest pain in the past month?

Y N Do you ever lose consciousness or do you lose your balance because of dizziness?

Y N Do you have a joint or bone problem that may be made worse by a change in your physical activity?

Y N Is a physician currently prescribing medications for your blood pressure or heart condition?

Y N Do you have insulin dependent diabetes?

Y N Do you know of any other reason you should not exercise or increase your physical activity?

Yes to one or more questions: It is strongly recommended that you have a **Medical Clearance Form** completed BEFORE you become significantly more physically active.

Note: If your health changes so that you then answer YES to any of the above questions, tell your fitness instructor, and ask whether you should change your physical activity plan. **I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.**

Participant’s signature: ______________________________________Date:______________

Signature of Primary Researcher ______________________________Date:________________

Appendix E

Medical Release Form

Medical Release Form

Your Patient, ______________________________, wishes to participate in an augmented eccentric training program study. It is necessary to have this form completed before the participant can enroll in this study. Participants will be tested in lower extremity rate of force development during a standing from chair task, center of pressure (balance test), and in the five time sit to stand test (descriptions of these tests are attached). Participation also includes a six week augmented eccentric training program that involves: lunges, calf raises, rising from chair task, ankle eversions, and step downs. Proper warm-up and cool downs will also be performed by the participants. Please read all testing procedures and explanation of training protocol.

Have you read the testing procedures and explanation of training protocol?

Yes No

If your patient is taking medication that will affect his/her heart rate response to exercise, please indicate the manner of the effect (raises, lowers, or has no effect on heart-rate response):

Type of medication ____

Effect ____

Please identify any other recommendations or restrictions for your patient in this exercise program:

____

____

_________________________ (Participants Full Name), has my approval to begin an exercise program with the recommendations or restrictions stated above.

Printed name ________________________

Signed _________________________ Date __________ Phone_____________

Appendix F

Testing Procedures and Training Protocol (for primary physician)

Subject inclusion criteria.

All subjects must be at least 60 years of age or older. All participants should have general knowledge of resistance training techniques because they have participated in such programs at Western Washington University and at senior centers. Moderately active will be defined as: doing resistance training 2-3 times per week for the last six months.

Measurement techniques and testing procedures.

Each subject will attend a pretest familiarization session. At the familiarization session, subjects will be asked to answer questions about their age, activity level, recent injuries, and hip or knee replacement to determine inclusion for the study. During testing, each subject will perform a general warm up that consists of cycling on a cycle ergometer for three minutes. Then, each subject will perform a dynamic warm up that consists of five knee hugs for each leg, and may either lean against a wall for support and stability or lie on ground. A task specific warm up of 10 chair rises will also be performed. Then a three minute rest period will be given before beginning testing to minimize fatigue.

Center of pressure protocol Subjects are asked to stand on a force plate with arms at their sides. Subjects then stand quietly and slowly lift one foot off the ground while keeping the other firmly in the middle of the force plate. Center of pressure will then be recorded for 30 seconds. Subjects are to say “HELP” if they feel unsafe. A test administrator stood beside each subject with instruction to catch or support subjects if subjects asked for help and the test was then restarted. This test was performed for each foot.

Rate of force development during STS-1

A chair with no arm rests will be placed outside the force plate, so that the participant’s heel falls completely over the force plate in a natural manner. Participants will be instructed to keep their arms crossed against the chest throughout the entire test. Then instructions will be given to stand all the way up from the chair as fast as possible. A three, two, one, GO countdown prepares the subjects to begin the test. Testadministrators will begin collection of data on 1, and the subjects will begin the test on GO. Test administrators will be trained to safely assist the subjects in the case a subject loses balance, otherwise, test administrators will be instructed to not assist the subjects. Subjects will be instructed to say “HELP” cueing the test administrators to close their arms around the participants and lean the body weight of the participant onto themselves to support them safely. If the subject becomes unstable, then the test administrators will follow the same procedures to support the subject safely.

Five-times sit to stand test protocol. All subjects perform a STS-5 test pre and post intervention. The STS-5 test will begin with the subject sitting up straight with knee and hip angles as close as possible to 90 degrees and ends when the participant will be in this seating position at the end of the fifth stand. The same procedures used for theSTS-1 will be followed for the STS-5. Three practice trials will be done to familiarize the participants with the sit to stand movement with the arms crossed.

Augmented Eccentric Load Training Protocol. The augmented eccentric load (AEL) training program was implemented two days a week for six weeks with at least two days in between training sessions. An introduction to proper weight training techniques will be given and continually monitored during each group training session. The training session will consist of a five minute walking warm up, 30 minutes of six different AEL exercises that included: calf raise, unilateral lunges, task-specific chair rise exercise, step downs, and ankle eversions. Additional weight will be handed to the subjects during the lengthening phase of each exercise and removed prior to the concentric phase. All subjects will begin with no weight and increase by 5% progression during the first week if the subjects have good form and are able to handle load. Progression will then be increased to 10% in the second week and up to 20% by the final week depending on the subject's individual progression. Ankle eversions will be completed with 0.9 kg sandbells and increase to 1.8 kg sandbells. A ten minute cool down including lower body static stretches will end each session. The six week AEL program will be concluded with a post-testing day following at least a two day rest period after the final training session. All exercises will be performed for three sets of eight repetitions in accordance with appropriate exercise prescription for older adults.

Appendix G

Description of Exercises and Stretches

Calf Raise was performed on a stable surface. Additional weight at approximately 20% of body weight was handed to the subject as they reached the top of the calf raise. Subjects held on to the extra weight as they moved into the lowering phase. Subject then handed weight back to test administrator before moving into the concentric phase. Test administrators stood in front of the subjects and kept arms slightly to the left and right sides of the subject for safety.

Lunges were done unilaterally, in place with the additional load of approximately 20% body weight given during the rising phase of the lunge. This was defined as the movement prior to knee extension. Test administrators stood behind the subjects and placed arms by the left and right of the subject's sides while moving with them into the lunge for safety.

Chair rise was performed with the weight held across the chest while slowly sitting down. The subject then handed the weight to the test administrator and stood up quickly with no weight. Test administrators placed arms on the left and right sides of subjects as they moved from sitting to standing for safety.

Step downs were done on an aerobic step. Subjects were handed the additional weight (approximately 20% body weight) when they had their feet firmly on top of the aerobic step and then stepped backwards and down off of the step. Test administrators stood behind the subject in order to support the subject if they lost their balance. The subjects then stepped back onto the aerobic step without weight. Test administrators stood behind the subject with arms at left and right sides of the subjects to provide safety during this movement.

Ankle eversions were customized exercises done with two kilograms of resistance. The subject would sit in a chair and bring the opposite ankle to opposite knee. The subject then performed an eversion of the ankle. Then the weight was removed prior to moving the ankle into inversion quickly and forcefully. Test administrators were prepared to remove weight from the subject's ankles if they asked for help.

All stretches were static, and were held for 20 seconds

Quadriceps Stretch: Subjects stood next to a chair for support, with feet shoulder-width apart. The chair was held with the left hand. The right leg was bent back until the thigh was perpendicular to the ground. The right ankle is held with the right hand and this pose is held for 20 seconds. This was repeated on left leg.

Hamstring Stretch: Subject sat forward in a chair with the knees bent and feet flat on the floor. The right heel was extended out and subjects slowly leaned forward at the hips, bending toward the toes. This position was held for 20 seconds and repeated on left leg.

Calf Stretch: Standing back from a wall, hands were placed on the wall until arms were straight. The right foot was placed behind with toes pointing forward. Keeping the right heel on the ground, subjects leaned forward until they could feel a stretch and this position was held for 20 seconds and repeated on the left leg.

Appendix H

Research Protocol Checklist

Subject #		**Date:**		**Age**	
Height		Weight			

MANDATORY PAPERWORK	**SIGNED BY ALL PARTIES**	**GROUP ASSIGNMENT VIA COIN TOSS**
Physical Activity Questionnaire	Yes / No	**Circle One:** HEADS TAILS
Health History Questionnaire	Yes / No	
Physical Activity Readiness (PAR-Q)	Yes / No	
Medical Release Form	Yes / No	
Informed Consent	Yes / No	
Subject received copy of informed consent	Yes / No	

WARM UP		**INITIAL**	**INSTRUMENTATION**	**INITIAL**
1.	Treadmill 3 minutes at 2MPH		Force plate and computer on	
2.	Five knee hugs each leg		Force plate zeroed	
3.	10 chair rises		Chair	
4.	3 minute rest period		Stop watch	

CENTER OF PRESSURE		**INITIAL**
Subject familiarized with task		
1.	Feet together eyes closed	
	File saved: Estep_Subject_#_COP	
2.	Right foot eyes open	
	File saved: Estep_Subject_#_COP_RF	
3.	Left foot eyes open	
	File saved: Estep_Subject_#_COP_LF	
RFD (STS-1)		**INITIAL**
Subject familiarized with task		
1.	Force plate zeroed	
2.	Force plate armed	
	Practice movement 3 times	
3.	3, 2, 1 … Go	
4.	File Saved: Estep_Subject_#_RFD	
STS-5		**INITIAL**
Subject familiarized with task		
1.	Recorded Time: __________	

Appendix I

Raw Data

Table 1.

Raw Data for Subject Characteristics.

Subject Characteristics			
Subject Information			
Subject #	**Age(yrs.)**	**Ht. (cm)**	**Wt. (Kg)**
1	68	N/A	57.7
2	72	N/A	77.3
3	67	N/A	78.6
4	70	172.21	71.7
5	80	161.54	61.2
6	72	167.64	78.5
7	80	155.45	86.6
14	67	161.54	68
15	66	167.64	98.9
16	64	169.16	63.5
17	72	173.74	77.1
18	72	176.78	82.8
Mean	70.83	167.30	75.16
± SD	5.06	6.76	11.61

*AEL

Subject Characteristics			
Subject Information			
Subject #	**Age(yrs.)**	**Ht. (cm)**	**Wt. (Kg)**
C8	81	169.16	64.1
C9	75	167.64	68.2
C10	74	N/A	N/A
C11	67	161.54	68.2
C12	79	124.97	50
C13	69	155.45	57.7
C19	83	164.59	68.6
C20	82	173.74	84.1
Mean	76.25	159.58	65.84
± SD	6.02	16.34	10.59

*RT

Table 2.

Time to Complete STS-5

Five Time Sit to Stand Test (seconds)			
Subject #	**Pretest**	**Posttest**	**Change**
1	14.47	10.62	3.85
2	10.94	8.29	2.65
3	11.53	9.12	2.41
4	15.03	11.67	3.36
5	Dropped Out		
6	12.8	9.12	3.68
7	11.89	10.51	1.38
14	6.93	8.38	-1.45
15	12.28	9.53	2.75
16	8.02	5.53	2.49
17	Dropped Out		
18	11.56	10.6	0.96
Mean	11.55	9.34	2.21
± SD	2.52	1.72	1.58

*AEL

Five Time Sit to Stand Test (seconds)			
Subject #	**Pretest**	**Posttest**	**Change**
8	9.09	8.7	0.39
9	9.48	8.06	1.42
10	9.65	8.61	1.04
11	11.25	12.41	-1.16
12	11.16	7.1	4.06
13	9.25	7.01	2.24
19	9.54	10.99	-1.45
20	9.65	8.61	1.04
Mean	9.88	8.94	0.95
± SD	0.84	1.75	1.78

*RT

Table 3.

Rate of Force Development in STS-1

Rate of Force Development (Ns)			
Subject #	**Pretest**	**Posttest**	***Change***
1	718.00	884.24	166.24
2	458.08	949.77	491.69
3	949.84	991.13	41.29
4	796.55	879.77	83.22
5	Dropped out		
6	958.00	833.00	-125.00
7	650.10	1160.90	510.80
14	841.30	1309.30	468.10
15	1065.90	1249.80	183.90
16	699.00	1276.00	577.00
17	Dropped out		
18	717.19	878.51	161.32
Average	785.40	1041.24	255.86
± SD	176.66	187.45	221.13

*AEL

Rate of Force Development (Ns)			
Subject #	**Pretest**	**Posttest**	***Change***
C8	821.60	804.90	-16.70
C9	836.30	833.10	-3.20
C10	502.80	847.20	344.40
C11	873.70	739.30	-134.50
C12	606.50	628.50	22.00
C13	771.90	768.10	-3.80
C19	870.81	978.50	107.69
C20	780.39	993.36	212.97
Average	758.00	824.12	66.11
± SD	133.66	120.75	150.94

*RT

Table 4.

Center of Pressure Excursion; Both Feet, Eyes Closed

COP – Both Feet, Eyes Closed (meters)				
	M-L		A-P	
Subject #	**Pretest**	**Posttest**	**Pretest**	**Posttest**
1	0.057	0.021	0.015	0.010
2	0.053	0.001	0.309	0.005
3	0.125	0.001	0.303	0.003
4	0.254	0.004	0.284	0.006
5	Dropped Out			
6	0.070	0.002	0.124	0.008
7	0.034	0.001	0.088	0.004
14	0.018	0.001	0.092	0.002
15	0.054	0.001	0.052	0.006
16	0.009	0.001	0.075	0.003
17	Dropped Out			
18	0.072	0.002	0.227	0.007
Mean	0.075	0.003	0.157	0.006
± SD	0.071	0.006	0.112	0.003

*AEL

COP – Both Feet, Eyes Closed (meters)				
	M-L		A-P	
Subject #	**Pretest**	**Posttest**	**Pretest**	**Posttest**
8	0.018	0.002	0.042	0.008
9	0.017	0.002	0.016	0.003
10	Data Not Recoverable			
11	0.038	0.001	0.027	0.003
12	0.013	0.001	0.044	0.011
13	0.069	0.002	0.013	0.005
19	0.106	0.001	0.274	0.004
20	0.133	0.001	0.239	0.004
Mean	0.056	0.001	0.094	0.005
± SD	0.048	0.000	0.112	0.003

*RT

Table 5.

Center of Pressure Excursion; Right Foot, Eyes Open

Center of Pressure Right Foot (meters)				
	M-L		A-P	
Subject #	**Pretest**	**Posttest**	**Pretest**	**Posttest**
1	0.242	0.009	0.422	0.013
2	0.541	0.007	0.564	0.009
3	0.363	0.010	0.338	0.011
4	0.567	0.016	0.349	0.011
5	Dropped Out			
6	0.230	0.012	0.601	0.014
7	0.725	0.018	0.783	0.006
14	0.821	0.007	0.471	0.006
15	0.262	0.014	0.410	0.017
16	0.375	0.014	0.287	0.024
17	Dropped Out			
18	0.444	0.010	0.425	0.009
Mean	0.457	0.012	0.465	0.012
± SD	0.204	0.004	0.148	0.005

*AEL

Center of Pressure Right Foot (meters)				
	M-L		A-P	
Subject #	**Pretest**	**Posttest**	**Pretest**	**Posttest**
8	0.619	0.009	0.390	0.009
9	0.052	0.011	0.033	0.031
10	Data Not Recoverable			
11	0.062	0.009	0.056	0.009
12	0.230	0.174	0.011	0.008
13	0.183	0.006	0.305	0.009
19	0.301	0.008	0.266	0.009
20	0.257	0.007	0.337	0.010
Mean	0.243	0.032	0.200	0.012
± SD	0.191	0.062	0.161	0.008

*RT

Table 6.

Center of Pressure Excursion; Left Foot, Eyes Open

Center of Pressure Left Foot (meters)				
	M-L		A-P	
Subject #	**Pretest**	**Postest**	**Pretest**	**Postest**
1	0.517	0.013	0.783	0.013
2	0.282	0.012	0.222	0.010
3	0.312	0.009	0.386	0.007
4	0.432	0.018	0.805	0.009
5	Dropped Out			
6	0.637	0.014	0.409	0.016
7	0.265	0.036	0.393	0.026
14	0.241	0.007	0.226	0.014
15	0.415	0.007	0.307	0.010
16	0.202	0.008	0.243	0.008
17	Dropped Out			
18	0.362	0.012	0.615	0.024
Mean	0.366	0.014	0.439	0.014
± SD	0.136	0.009	0.221	0.006

*AEL

Center of Pressure Left Foot (meters)				
	M-L		A-P	
Subject #	**Pretest**	**Postest**	**Pretest**	**Postest**
8	0.302	0.488	0.110	0.049
9	0.051	0.004	0.042	0.006
10	Data Not Recoverable			
11	0.029	0.009	0.069	0.010
12	0.053	0.009	0.059	0.008
13	0.247	0.009	0.211	0.007
19	0.454	0.006	0.512	0.007
20	0.454	0.010	0.445	0.007
Mean	0.227	0.076	0.207	0.013
± SD	0.187	0.182	0.195	0.016

*RT

Appendix J

Statistical Analysis Tables

Table 2.

Time to Complete STS-5

Within-Subjects Factors

Measure: STS5Time

Test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1.00	AEL	10
	2.00	RT	8

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest	AEL	11.5450	2.51717	10
	RT	9.8838	.83816	8
	Total	10.8067	2.08931	18
Posttest	AEL Training	9.3370	1.72230	10
	No AEL Training	8.9363	1.86714	8
	Total	9.1589	1.74582	18

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Test	Pillai's Trace	.498	15.904[b]	1.000	16.000	.001
	Wilks' Lambda	.502	15.904[b]	1.000	16.000	.001
	Hotelling's Trace	.994	15.904[b]	1.000	16.000	.001
	Roy's Largest Root	.994	15.904[b]	1.000	16.000	.001
Test * Group	Pillai's Trace	.137	2.538[b]	1.000	16.000	.131
	Wilks' Lambda	.863	2.538[b]	1.000	16.000	.131
	Hotelling's Trace	.159	2.538[b]	1.000	16.000	.131
	Roy's Largest Root	.159	2.538[b]	1.000	16.000	.131

a. Design: Intercept + Group

Within Subjects Design: Test

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: STS5Time

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group
Within Subjects Design: Test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: STS5Time

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Test	Sphericity Assumed	22.127	1	22.127	15.904	.001
	Greenhouse-Geisser	22.127	1.000	22.127	15.904	.001
	Huynh-Feldt	22.127	1.000	22.127	15.904	.001
	Lower-bound	22.127	1.000	22.127	15.904	.001
Test * Group	Sphericity Assumed	3.531	1	3.531	2.538	.131
	Greenhouse-Geisser	3.531	1.000	3.531	2.538	.131
	Huynh-Feldt	3.531	1.000	3.531	2.538	.131
	Lower-bound	3.531	1.000	3.531	2.538	.131
Error(Test)	Sphericity Assumed	22.261	16	1.391		
	Greenhouse-Geisser	22.261	16.000	1.391		
	Huynh-Feldt	22.261	16.000	1.391		
	Lower-bound	22.261	16.000	1.391		

Tests of Within-Subjects Contrasts

Measure: STS5Time

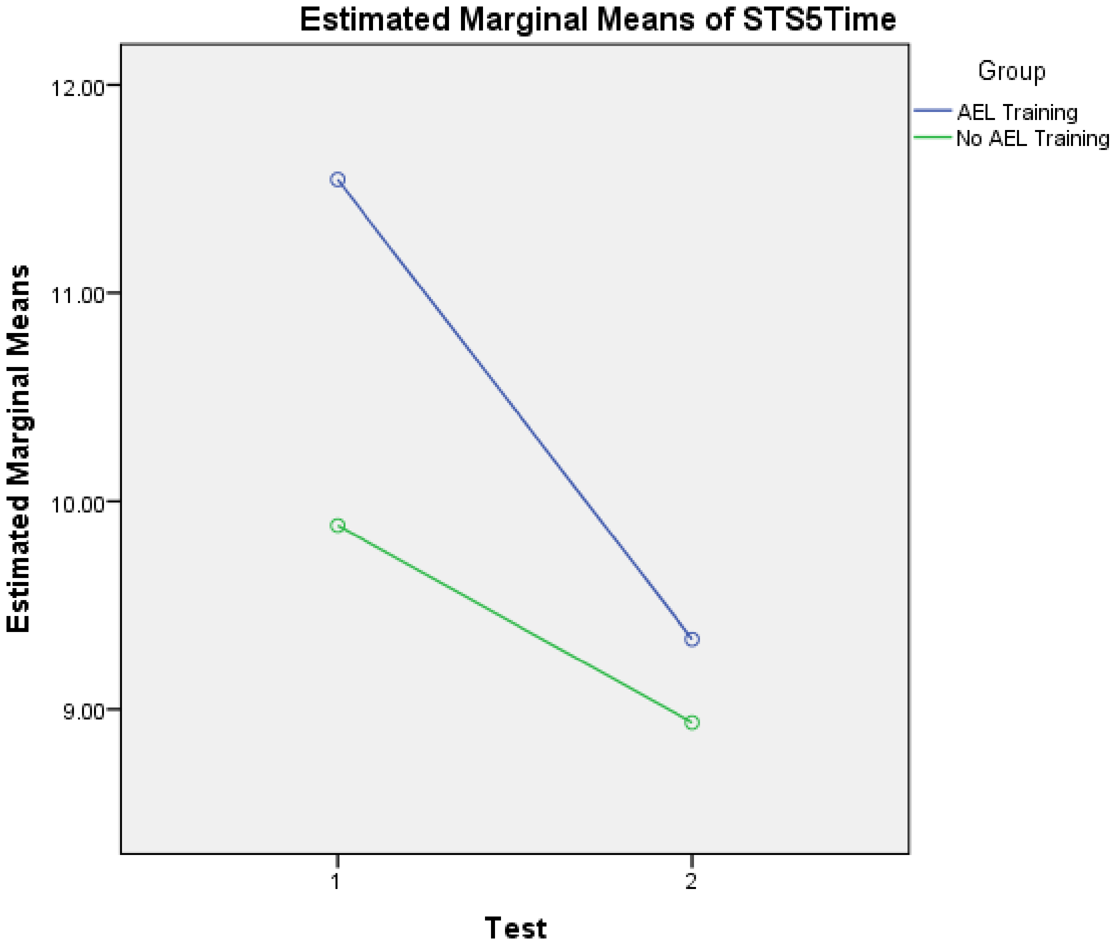
Source	Test	Type III Sum of Squares	df	Mean Square	F	Sig.
Test	Linear	22.127	1	22.127	15.904	.001
Test * Group	Linear	3.531	1	3.531	2.538	.131
Error(Test)	Linear	22.261	16	1.391		

Tests of Between-Subjects Effects

Measure: STS5Time

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	3502.775	1	3502.775	617.350	.000
Group	9.449	1	9.449	1.665	.215
Error	90.782	16	5.674		



Estimated Marginal Means of STS5Time
Group
AEL Training
No AEL Training
Estimated Marginal Means
12.00
11.00
10.00
9.00
1
2
Test

Table 3.

Rate of Force Development in STS-1

Within-Subjects Factors

Measure: RFD

Test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1	AEL	10
	2	RT	8

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Test	Pillai's Trace	.367	9.276[b]	1.000	16.000	.008
	Wilks' Lambda	.633	9.276[b]	1.000	16.000	.008
	Hotelling's Trace	.580	9.276[b]	1.000	16.000	.008
	Roy's Largest Root	.580	9.276[b]	1.000	16.000	.008
Test * Group	Pillai's Trace	.246	5.208[b]	1.000	16.000	.037
	Wilks' Lambda	.754	5.208[b]	1.000	16.000	.037
	Hotelling's Trace	.326	5.208[b]	1.000	16.000	.037
	Roy's Largest Root	.326	5.208[b]	1.000	16.000	.037

a. Design: Intercept + Group

Within Subjects Design: Test

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: RFD

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group

Within Subjects Design: Test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: RFD

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Test	Sphericity Assumed	190146.162	1	190146.162	9.276	.008
	Greenhouse-Geisser	190146.162	1.000	190146.162	9.276	.008
	Huynh-Feldt	190146.162	1.000	190146.162	9.276	.008
	Lower-bound	190146.162	1.000	190146.162	9.276	.008
Test * Group	Sphericity Assumed	106764.938	1	106764.938	5.208	.037
	Greenhouse-Geisser	106764.938	1.000	106764.938	5.208	.037
	Huynh-Feldt	106764.938	1.000	106764.938	5.208	.037
	Lower-bound	106764.938	1.000	106764.938	5.208	.037
Error(Test)	Sphericity Assumed	327980.901	16	20498.806		
	Greenhouse-Geisser	327980.901	16.000	20498.806		
	Huynh-Feldt	327980.901	16.000	20498.806		
	Lower-bound	327980.901	16.000	20498.806		

Tests of Within-Subjects Contrasts

Measure: RFD

Source	Test	Type III Sum of Squares	df	Mean Square	F	Sig.
Test	Linear	190146.162	1	190146.162	9.276	.008
Test * Group	Linear	106764.938	1	106764.938	5.208	.037
Error(Test)	Linear	327980.901	16	20498.806		

Tests of Between-Subjects Effects

Measure: RFD

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	25373377.615	1	25373377.615	870.520	.000
Group	167094.099	1	167094.099	5.733	.029
Error	466357.832	16	29147.364		

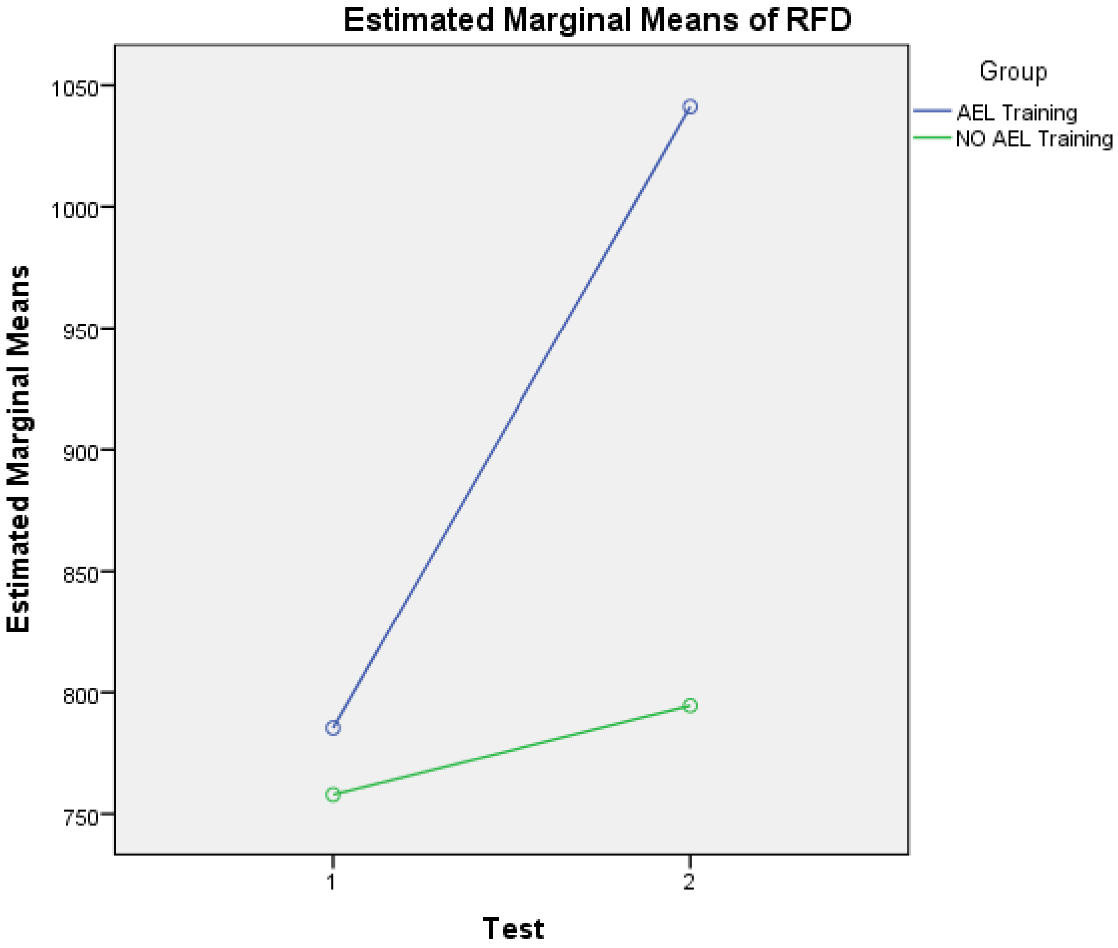

Estimated Marginal Means of RFD
Estimated Marginal Means
1050
1000
950
900
850
800
750
1
2
Test
Group
AEL Training
NO AEL Training

Table 4.

Excursion from Center of Pressure Both Feet, Eyes Closed – Medial- Lateral

Within-Subjects Factors

Measure: MLCOP

Test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1.00	AEL	10
	2.00	RT	7

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest	AEL Training	.0746	.07074	10
	No AEL Training	.0562	.04789	7
	Total	.0670	.06133	17
Posttest	AEL Training	.0034	.00616	10
	No AEL Training	.0014	.00025	7
	Total	.0026	.00474	17

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Test	Pillai's Trace	.526	16.661[b]	1.000	15.000	.001
	Wilks' Lambda	.474	16.661[b]	1.000	15.000	.001
	Hotelling's Trace	1.111	16.661[b]	1.000	15.000	.001
	Roy's Largest Root	1.111	16.661[b]	1.000	15.000	.001
Test * Group	Pillai's Trace	.018	.282[b]	1.000	15.000	.603
	Wilks' Lambda	.982	.282[b]	1.000	15.000	.603
	Hotelling's Trace	.019	.282[b]	1.000	15.000	.603
	Roy's Largest Root	.019	.282[b]	1.000	15.000	.603

a. Design: Intercept + Group

Within Subjects Design: Test

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MLCOP

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group

Within Subjects Design: Test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MLCOP

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Test	Sphericity Assumed	.033	1	.033	16.661	.001
	Greenhouse-Geisser	.033	1.000	.033	16.661	.001
	Huynh-Feldt	.033	1.000	.033	16.661	.001
	Lower-bound	.033	1.000	.033	16.661	.001
Test * Group	Sphericity Assumed	.001	1	.001	.282	.603
	Greenhouse-Geisser	.001	1.000	.001	.282	.603
	Huynh-Feldt	.001	1.000	.001	.282	.603
	Lower-bound	.001	1.000	.001	.282	.603
Error(Test)	Sphericity Assumed	.029	15	.002		
	Greenhouse-Geisser	.029	15.000	.002		
	Huynh-Feldt	.029	15.000	.002		
	Lower-bound	.029	15.000	.002		

Tests of Within-Subjects Contrasts

Measure: MLCOP

Source	Test	Type III Sum of Squares	df	Mean Square	F	Sig.
Test	Linear	.033	1	.033	16.661	.001
Test * Group	Linear	.001	1	.001	.282	.603
Error(Test)	Linear	.029	15	.002		

Tests of Between-Subjects Effects

Measure: MLCOP

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.038	1	.038	19.141	.001
Group	.001	1	.001	.431	.521
Error	.030	15	.002		

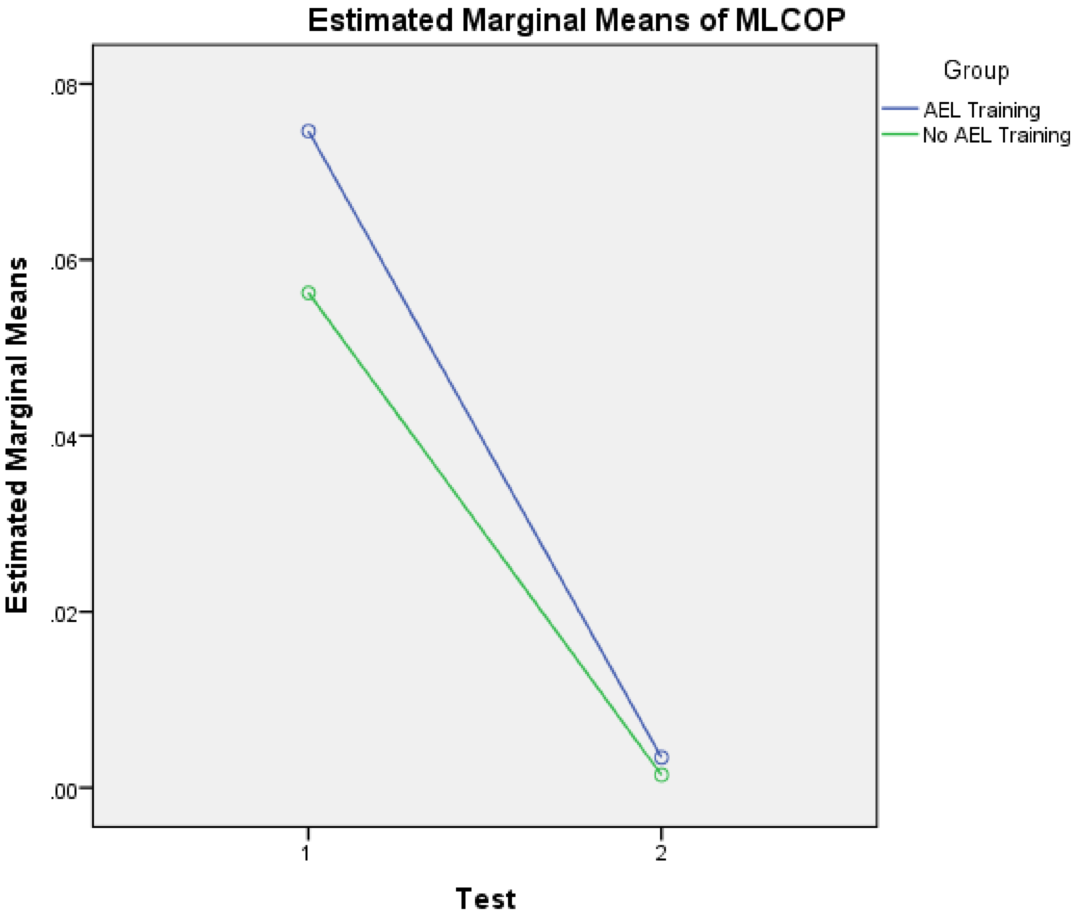


Table 4.

Excursion from Center of Pressure Both Feet, Eyes Closed – Anterior-Posterior

Within-Subjects Factors

Measure: APCOP

test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1.00	AEL	10
	2.00	RT	7

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest	AEL Training	.1569	.11218	10
	No AEL Training	.0937	.11229	7
	Total	.1309	.11329	17
Posttest	AEL Training	.0055	.00255	10
	No AEL Training	.0055	.00302	7
	Total	.0055	.00266	17

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
test	Pillai's Trace	.553	18.578[b]	1.000	15.000	.001
	Wilks' Lambda	.447	18.578[b]	1.000	15.000	.001
	Hotelling's Trace	1.239	18.578[b]	1.000	15.000	.001
	Roy's Largest Root	1.239	18.578[b]	1.000	15.000	.001
test * Group	Pillai's Trace	.079	1.289[b]	1.000	15.000	.274
	Wilks' Lambda	.921	1.289[b]	1.000	15.000	.274
	Hotelling's Trace	.086	1.289[b]	1.000	15.000	.274
	Roy's Largest Root	.086	1.289[b]	1.000	15.000	.274

a. Design: Intercept + Group

Within Subjects Design: test b. Exact statistic

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: APCOP

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group

Within Subjects Design: test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: APCOP

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
test	Sphericity Assumed	.118	1	.118	18.578	.001
	Greenhouse-Geisser	.118	1.000	.118	18.578	.001
	Huynh-Feldt	.118	1.000	.118	18.578	.001
	Lower-bound	.118	1.000	.118	18.578	.001
test * Group	Sphericity Assumed	.008	1	.008	1.289	.274
	Greenhouse-Geisser	.008	1.000	.008	1.289	.274
	Huynh-Feldt	.008	1.000	.008	1.289	.274
	Lower-bound	.008	1.000	.008	1.289	.274
Error(test)	Sphericity Assumed	.095	15	.006		
	Greenhouse-Geisser	.095	15.000	.006		
	Huynh-Feldt	.095	15.000	.006		
	Lower-bound	.095	15.000	.006		

Tests of Between-Subjects Effects

Measure: APCOP

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.141	1	.141	22.580	.000
Group	.008	1	.008	1.321	.268
Error	.094	15	.006		

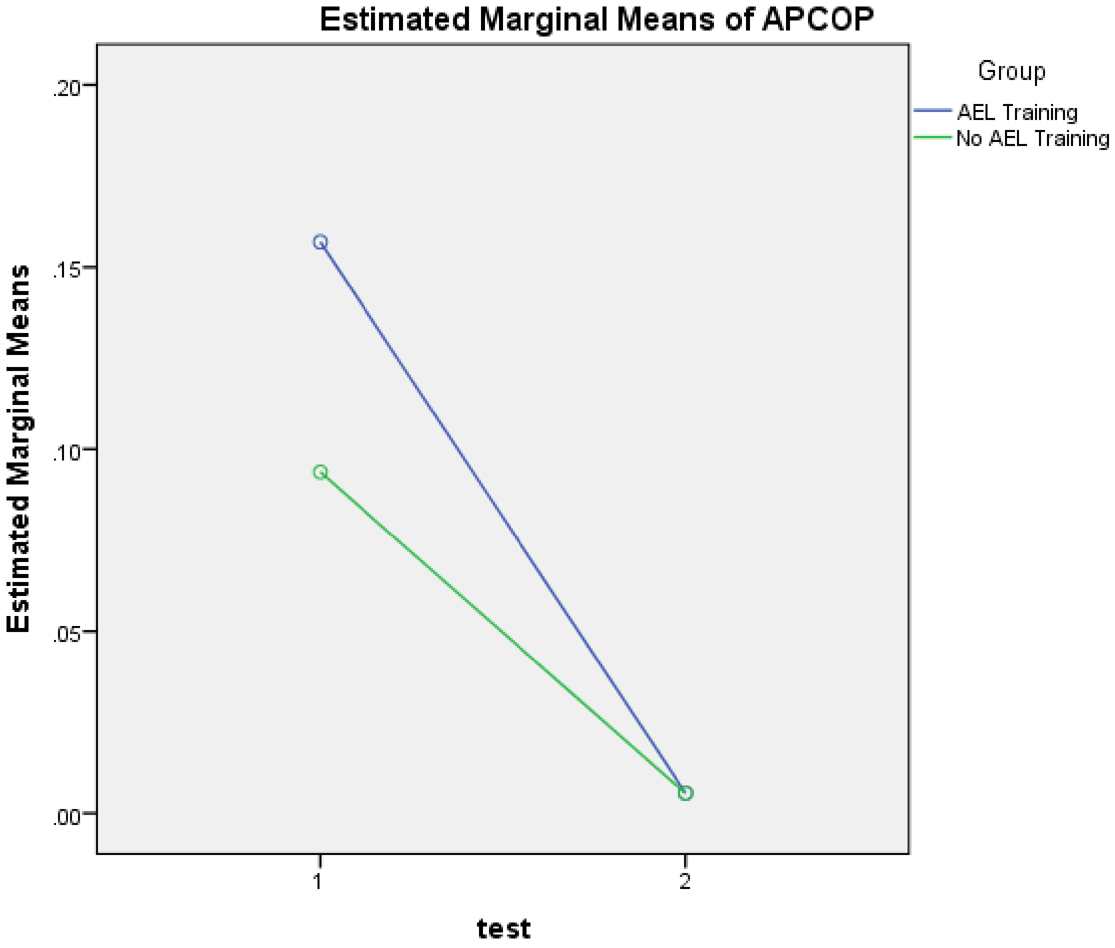

Estimated Marginal Means of APCOP
Estimated Marginal Means
.20
.15
.10
.05
.00
1
2
test
Group
AEL Training
No AEL Training

Table 5.

Excursion from Center of Pressure Right Foot, Eyes Open – Medial- Lateral

Within-Subjects Factors

Measure: MLRF

test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1.00	AEL	10
	2.00	RT	7

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest	AEL Training	.4571	.20420	10
	No AEL Training	.2433	.19056	7
	Total	.3691	.22098	17
Posttest	AEL Training	.0117	.00365	10
	No AEL Training	.0321	.06245	7
	Total	.0201	.03970	17

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
test	Pillai's Trace	.741	42.903[b]	1.000	15.000	.000
	Wilks' Lambda	.259	42.903[b]	1.000	15.000	.000
	Hotelling's Trace	2.860	42.903[b]	1.000	15.000	.000
	Roy's Largest Root	2.860	42.903[b]	1.000	15.000	.000
test * Group	Pillai's Trace	.267	5.455[b]	1.000	15.000	.034
	Wilks' Lambda	.733	5.455[b]	1.000	15.000	.034
	Hotelling's Trace	.364	5.455[b]	1.000	15.000	.034
	Roy's Largest Root	.364	5.455[b]	1.000	15.000	.034

a. Design: Intercept + Group

Within Subjects Design: test

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MLRF

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group

Within Subjects Design: test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MLRF

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
test	Sphericity Assumed	.888	1	.888	42.903	.000
	Greenhouse-Geisser	.888	1.000	.888	42.903	.000
	Huynh-Feldt	.888	1.000	.888	42.903	.000
	Lower-bound	.888	1.000	.888	42.903	.000
test * Group	Sphericity Assumed	.113	1	.113	5.455	.034
	Greenhouse-Geisser	.113	1.000	.113	5.455	.034
	Huynh-Feldt	.113	1.000	.113	5.455	.034
	Lower-bound	.113	1.000	.113	5.455	.034
Error(test)	Sphericity Assumed	.310	15	.021		
	Greenhouse-Geisser	.310	15.000	.021		
	Huynh-Feldt	.310	15.000	.021		
	Lower-bound	.310	15.000	.021		

Tests of Between-Subjects Effects

Measure: MLRF

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1.140	1	1.140	55.831	.000
Group	.077	1	.077	3.772	.071
Error	.306	15	.020		

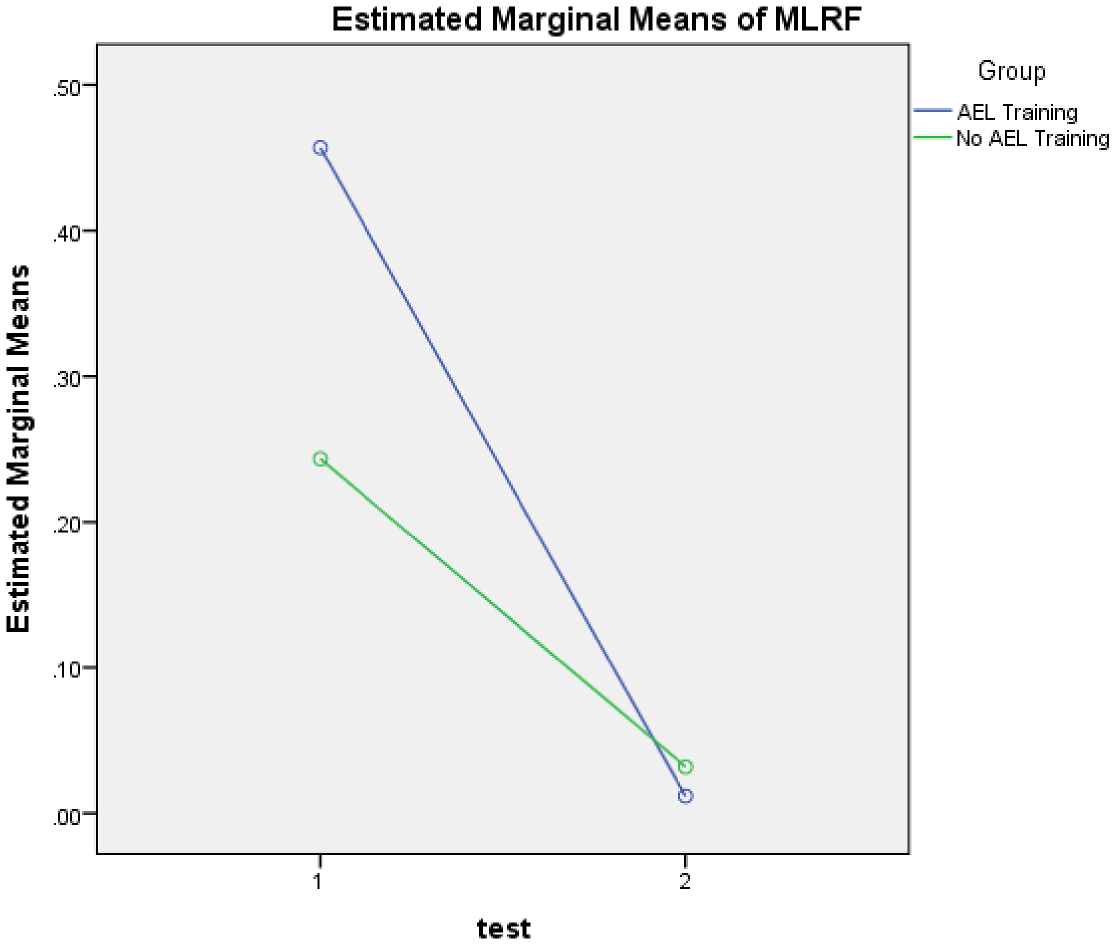

Estimated Marginal Means of MLRF
Estimated Marginal Means
.50
.40
.30
.20
.10
.00
1
2
test
Group
AEL Training
No AEL Training

Table 5.

Excursion from Center of Pressure Right Foot, Eyes Open – Anterior-Posterior

Within-Subjects Factors

Measure: APRF

test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1.00	AEL	10
	2.00	RT	7

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest	AEL Training	.4651	.14799	10
	No AEL Training	.1997	.16069	7
	Total	.3558	.20031	17
Posttest	AEL Training	.0118	.00544	10
	No AEL Training	.0122	.00822	7
	Total	.0120	.00648	17

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
test	Pillai's Trace	.821	68.908[b]	1.000	15.000	.000
	Wilks' Lambda	.179	68.908[b]	1.000	15.000	.000
	Hotelling's Trace	4.594	68.908[b]	1.000	15.000	.000
	Roy's Largest Root	4.594	68.908[b]	1.000	15.000	.000
test * Group	Pillai's Trace	.441	11.849[b]	1.000	15.000	.004
	Wilks' Lambda	.559	11.849[b]	1.000	15.000	.004
	Hotelling's Trace	.790	11.849[b]	1.000	15.000	.004
	Roy's Largest Root	.790	11.849[b]	1.000	15.000	.004

a. Design: Intercept + Group

Within Subjects Design: test

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: APRF

					Epsilon[b]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group

Within Subjects Design: test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: APRF

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
test	Sphericity Assumed	.845	1	.845	68.908	.000
	Greenhouse-Geisser	.845	1.000	.845	68.908	.000
	Huynh-Feldt	.845	1.000	.845	68.908	.000
	Lower-bound	.845	1.000	.845	68.908	.000
test * Group	Sphericity Assumed	.145	1	.145	11.849	.004
	Greenhouse-Geisser	.145	1.000	.145	11.849	.004
	Huynh-Feldt	.145	1.000	.145	11.849	.004
	Lower-bound	.145	1.000	.145	11.849	.004
Error(test)	Sphericity Assumed	.184	15	.012		
	Greenhouse-Geisser	.184	15.000	.012		
	Huynh-Feldt	.184	15.000	.012		
	Lower-bound	.184	15.000	.012		

Tests of Within-Subjects Contrasts

Measure: APRF

Source	test	Type III Sum of Squares	df	Mean Square	F	Sig.
test	Linear	.845	1	.845	68.908	.000
test * Group	Linear	.145	1	.145	11.849	.004
Error(test)	Linear	.184	15	.012		

Tests of Between-Subjects Effects

Measure: APRF

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.977	1	.977	86.832	.000
Group	.145	1	.145	12.858	.003
Error	.169	15	.011		

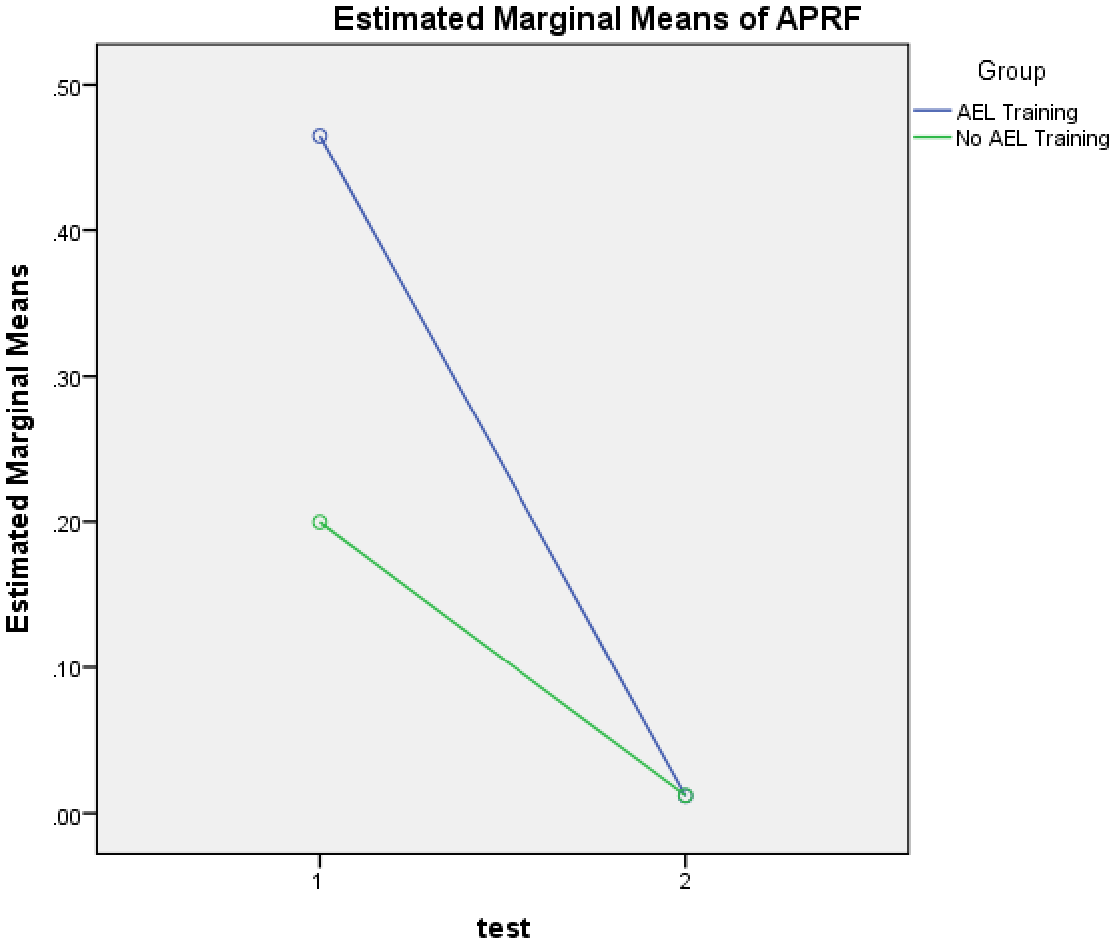

Estimated Marginal Means of APRF
Estimated Marginal Means
.50
.40
.30
.20
.10
.00
1
2
test
Group
AEL Training
No AEL Training

Table 6.

Excursion from Center of Pressure Left Foot, Eyes Open – Medial-Lateral

Within-Subjects Factors

Measure: MLLF

test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1.00	AEL	10
	2.00	RT	7

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest	AEL Training	.3664	.13557	10
	No AEL Training	.2273	.18683	7
	Total	.3091	.16855	17
Posttest	AEL Training	.0136	.00873	10
	No AEL Training	.0765	.18169	7
	Total	.0395	.11593	17

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
test	Pillai's Trace	.676	31.274[b]	1.000	15.000	.000
	Wilks' Lambda	.324	31.274[b]	1.000	15.000	.000
	Hotelling's Trace	2.085	31.274[b]	1.000	15.000	.000
	Roy's Largest Root	2.085	31.274[b]	1.000	15.000	.000
test * Group	Pillai's Trace	.251	5.033[b]	1.000	15.000	.040
	Wilks' Lambda	.749	5.033[b]	1.000	15.000	.040
	Hotelling's Trace	.336	5.033[b]	1.000	15.000	.040
	Roy's Largest Root	.336	5.033[b]	1.000	15.000	.040

a. Design: Intercept + Group

Within Subjects Design: test

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MLLF

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group

Within Subjects Design: test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MLLF

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
test	Sphericity Assumed	.522	1	.522	31.274	.000
	Greenhouse-Geisser	.522	1.000	.522	31.274	.000
	Huynh-Feldt	.522	1.000	.522	31.274	.000
	Lower-bound	.522	1.000	.522	31.274	.000
test * Group	Sphericity Assumed	.084	1	.084	5.033	.040
	Greenhouse-Geisser	.084	1.000	.084	5.033	.040
	Huynh-Feldt	.084	1.000	.084	5.033	.040
	Lower-bound	.084	1.000	.084	5.033	.040
Error(test)	Sphericity Assumed	.250	15	.017		
	Greenhouse-Geisser	.250	15.000	.017		
	Huynh-Feldt	.250	15.000	.017		
	Lower-bound	.250	15.000	.017		

Tests of Within-Subjects Contrasts

Measure: MLLF

Source	test	Type III Sum of Squares	df	Mean Square	F	Sig.
test	Linear	.522	1	.522	31.274	.000
test * Group	Linear	.084	1	.084	5.033	.040
Error(test)	Linear	.250	15	.017		

Tests of Between-Subjects Effects

Measure: MLLF

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.963	1	.963	44.673	.000
Group	.012	1	.012	.555	.468
Error	.323	15	.022		

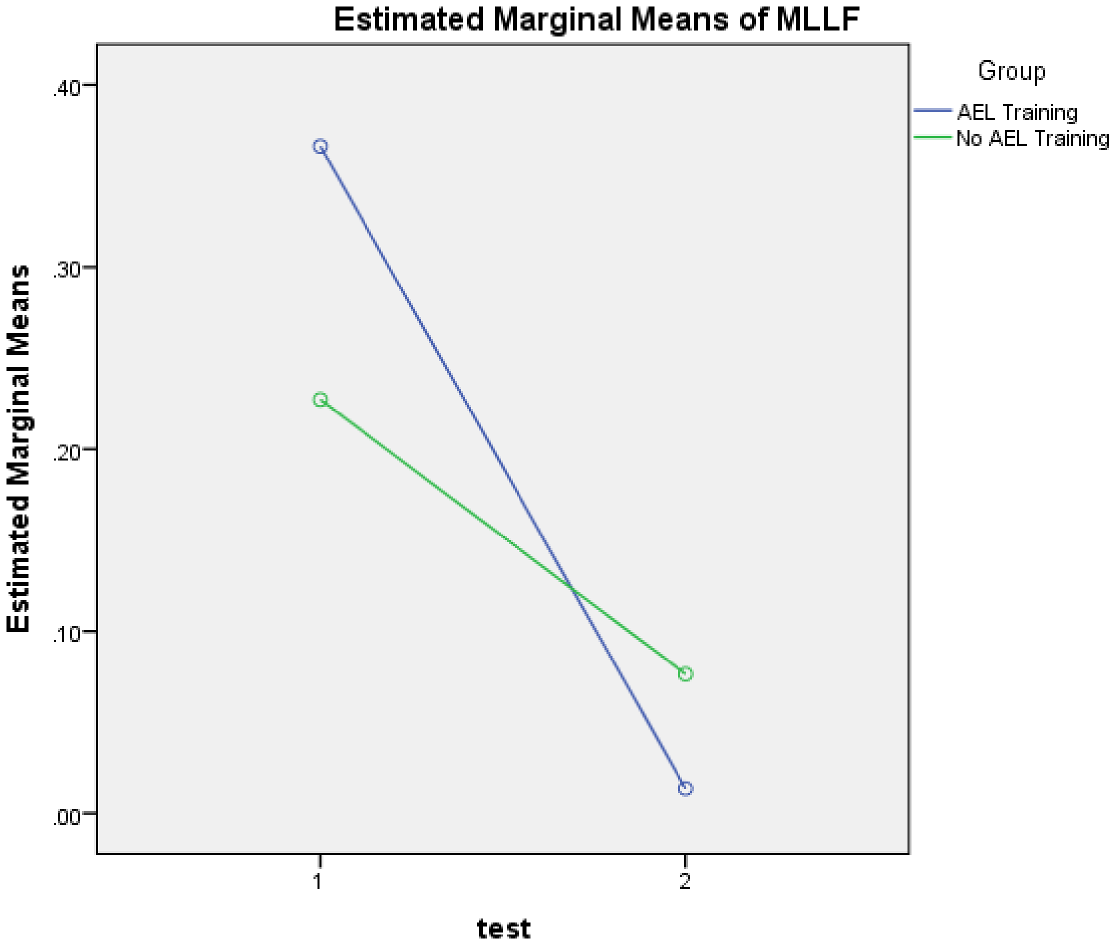

Estimated Marginal Means of MLLF
Group
AEL Training
No AEL Training
Estimated Marginal Means
.40
.30
.20
.10
.00
1
2
test

Table 6.

Excursion from Center of Pressure Left Foot, Eyes Open – Anterior- Posterior

Within-Subjects Factors

Measure: APLF

test	Dependent Variable
1	Pretest
2	Posttest

Between-Subjects Factors

		Value Label	N
Group	1.00	AEL	10
	2.00	RT	7

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest	AEL Training	.4388	.22060	10
	No AEL Training	.2069	.19457	7
	Total	.3433	.23541	17
Posttest	AEL Training	.0137	.00649	10
	No AEL Training	.0133	.01569	7
	Total	.0135	.01077	17

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
test	Pillai's Trace	.701	35.188[b]	1.000	15.000	.000
	Wilks' Lambda	.299	35.188[b]	1.000	15.000	.000
	Hotelling's Trace	2.346	35.188[b]	1.000	15.000	.000
	Roy's Largest Root	2.346	35.188[b]	1.000	15.000	.000
test * Group	Pillai's Trace	.247	4.928[b]	1.000	15.000	.042
	Wilks' Lambda	.753	4.928[b]	1.000	15.000	.042
	Hotelling's Trace	.329	4.928[b]	1.000	15.000	.042
	Roy's Largest Root	.329	4.928[b]	1.000	15.000	.042

a. Design: Intercept + Group

Within Subjects Design: test

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: APLF

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
test	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + Group

Within Subjects Design: test

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: APLF

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
test	Sphericity Assumed	.788	1	.788	35.188	.000
	Greenhouse-Geisser	.788	1.000	.788	35.188	.000
	Huynh-Feldt	.788	1.000	.788	35.188	.000
	Lower-bound	.788	1.000	.788	35.188	.000
test * Group	Sphericity Assumed	.110	1	.110	4.928	.042
	Greenhouse-Geisser	.110	1.000	.110	4.928	.042
	Huynh-Feldt	.110	1.000	.110	4.928	.042
	Lower-bound	.110	1.000	.110	4.928	.042
Error(test)	Sphericity Assumed	.336	15	.022		
	Greenhouse-Geisser	.336	15.000	.022		
	Huynh-Feldt	.336	15.000	.022		
	Lower-bound	.336	15.000	.022		

Tests of Within-Subjects Contrasts

Measure: APLF

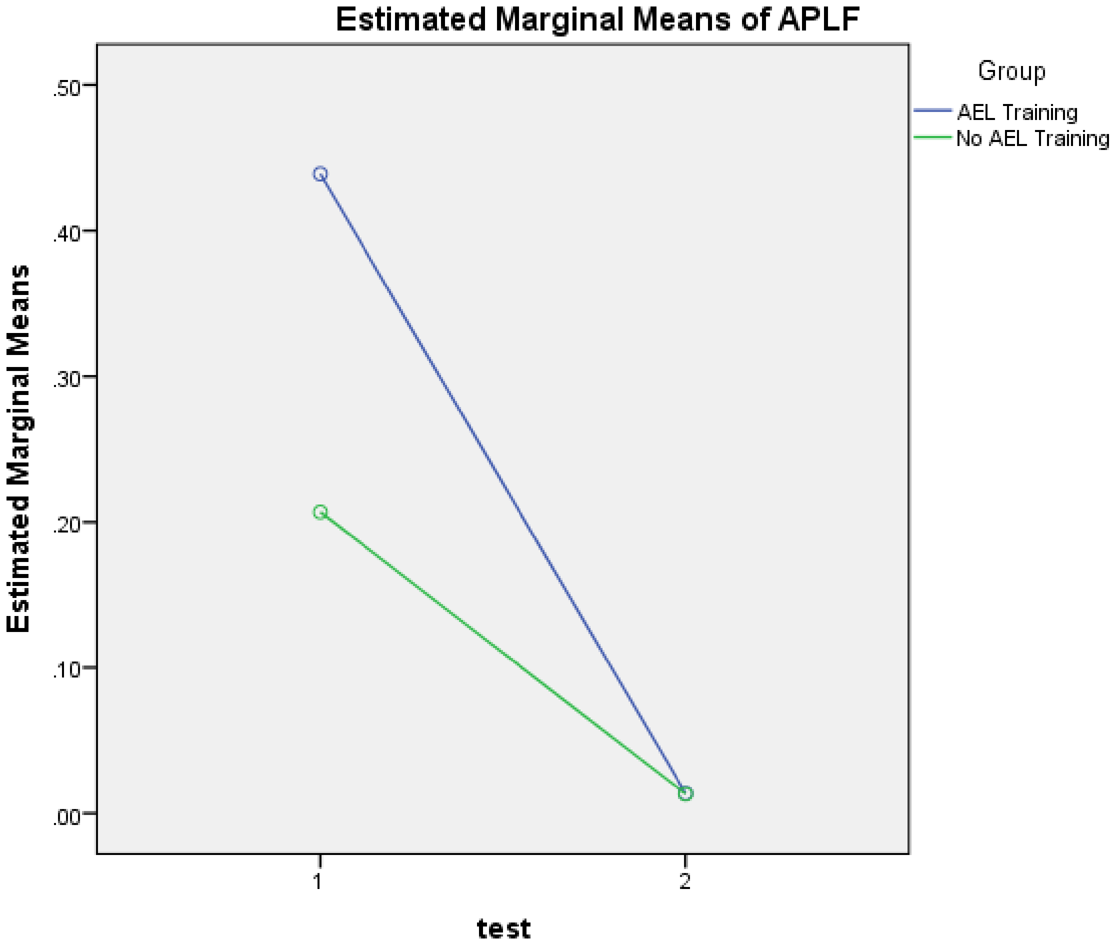
Source	test	Type III Sum of Squares	df	Mean Square	F	Sig.
test	Linear	.788	1	.788	35.188	.000
test * Group	Linear	.110	1	.110	4.928	.042
Error(test)	Linear	.336	15	.022		

Tests of Between-Subjects Effects

Measure: APLF

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.932	1	.932	42.206	.000
Group	.111	1	.111	5.037	.040
Error	.331	15	.022		


Estimated Marginal Means of APLF
Estimated Marginal Means
.50
.40
.30
.20
.10
.00
1
2
test
Group
AEL Training
No AEL Training