THE EFFECT OF PLANTARFLEXOR STRENGTH TRAINING ON GAIT BIOMECHANICS IN HEALTHY OLD ADULTS

by

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Locomotion is an important and inherent part of daily life and is integral in maintaining an independent lifestyle, especially in older adults whose functional capacity has declined. Physiological changes with aging, including loss of muscle mass, strength and power are manifested in walking, notably at the ankle joint. Old adults exhibit decreased power of the plantarflexors and increased power of the hip extensors. This distal to proximal shift in function could be due to plantarflexor weakness, so strengthening the plantarflexors may help reverse the negative physiological effects of aging and help preserve functional capacity in old adults. The purpose of this study was to determine the effect of plantarflexor strength training on gait biomechanics during level walking at a self-selected, a safe maximum and a standard speed of 1.5 m/s in healthy old adults.

A total of 12 healthy adults between the ages of 65 and 85 participated in this study (6 strengthening, 6 stretching). After baseline tests, the strengthening group performed resistance exercises for gastrocnemius and soleus muscles and the stretching group stretched them three times per week for 12 weeks. All subjects underwent gait assessments and maximal strength testing at the beginning and end of the 12 week training period. A 2 by 2 analysis of variance was used to determine significant interactions and main effects with an alpha level of $p<0.05$.

Plantarflexor strength increased in the strengthening group but not for the stretching group. Compared to the pretest, the subjects in the stretching group walked significantly faster, took longer strides, increased peak plantarflexor torque and ground reaction force during the self-selected walking condition, while there were no changes in the strengthening group. Based on these results, a twelve week strength training program does not affect the gait biomechanics of healthy old adults while stretching does produce some changes to the gait biomechanics of healthy old adults.

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CHAPTER 1: INTRODUCTION

According to the United States Census, in 2010 there were approximately 40 million adults, 13% of the total US population, age 65 and older. Considering the current advancements in technology and general improvements in health care, humans are living longer and the population of old adults is expected increase at progressively higher rates than younger ages. This rapid increase in the old adult population can be somewhat alarming since it is well known that functional capacity, which relies on mobility to a great extent, declines with age (Brooks & Faulkner, 1994; Christ et al., 1992; Fiser et al., 2010). Most activities of daily living depend on an individual's ability to move effectively such as when climbing stairs, walking or rising from a seated position. All of these activities require the use of lower extremity muscles such as the quadriceps, hamstrings, dorsiflexors and plantarflexors. Proper function of these components is important in maintaining an independent lifestyle, especially in old adults. With so many people facing the problems associated with aging, researching the causes of functional decline and devising ways to prevent or postpone it in old adults becomes even more urgent.

Locomotion is an important and inherent part of daily life enabling a person to move from one place to another; additionally, walking is the primary form of locomotion that humans use to perform activities of daily living in order to maintain independence and quality of life. Walking velocity is particularly interesting as it is indicative of overall health status. Studenski et al., examined the relationship between walking velocity and life expectancy and found that both men and women with faster walking velocities lived longer than those who walked slower (2011). Although it cannot be stated that increasing walking velocity will increase the number of years lived, walking velocity can be a useful measure of health and functional status in old adults. Additionally, there is a minimum walking velocity that must be maintained in order to be functional out of the home (for example, shopping for groceries and going to appointments). In order to maintain an independent lifestyle, a person must be able to walk a minimum distance and be able to walk a minimum velocity, for example crossing a crosswalk. In one study, the average walking velocity necessary to cross a crosswalk in the allotted time was 0.49 m/s and the average crosswalk length was 13.29 m (Andrews et al., 2010). A person who is unable to walk that distance or maintain that velocity over that distance would be unable to safely cross the street, limiting their function in the environment and affecting independence. This highlights the need for healthy walking capacity and its relationship to an independent lifestyle.

Increasing age is also associated with many physiological declines in human muscle. One of these changes is sarcopenia (Brooks & Faulkner, 1994; Evans, 1997). Sarcopenia results from decreases in the total number of motor units (Campbell, McComas, & Petito, 1973), decreases in the number of muscle fibers and decreases in the cross-sectional area of remaining muscle fibers (Evans, 1997; Frontera et al., 2000; Gallagher et al., 1997; Lexell, Taylor, & Sjostrom, 1988). All three of these changes contribute to muscle weakness and power loss. In addition to the changes in number of motor units, number of fibers and their sizes, there is also a neuromuscular reorganization that occurs with age. The proportion of type II muscle fibers, which are thought to be the primary fiber type responsible for strength and power production, decreases with age and this fiber type experiences the decreases in size and number more so than the type I fibers (Lexell, 1995).

These physiological declines are associated with decreased muscle strength and power in old adults. Numerous studies report decreasing strength with increasing age in both men and women (Judge, Underwood, & Gennosa, 1993; Larsson, Grimby, & Karlsson, 1979; Metter, Conwit, Tobin, & Fozard, 1997; Skelton, Greig, Davies, & Young, 1994). Reduced muscle strength and power affect one's ability to perform activities of daily living. Generally, healthy old adults require more relative effort to complete a task compared healthy young adults (Hortobagyi, Mizelle, Beam, & DeVita, 2003) but when the demand of the task relative to the old adult's capacity is low, there is no age-related difference (Zijlstra, 2004). As the demand increases, the effect of age becomes more noticeable with the old adults performing worse than young adults.

While aging affects the entire body, the physiological changes that occur with age are asymmetric. Distal muscle groups experience a greater loss of motor units compared to proximal muscle groups (Bua, McKiernan, Wanagat, McKenzie, & Aiken, 2002). Moreover, lower extremity muscles experience greater percent of strength loss versus upper extremity muscles (Christ et al., 1992). The plantarflexors fall into both categories, since they are both distal and in the lower extremity, making them most susceptible to decreased overall function. Oddly enough, the dorsiflexors which are also a distal, lower extremity muscle group do not seem to experience as dramatic a loss of function compared to the plantarflexors (Christ et al., 1992).

These neuromuscular changes occurring with age are manifested in the walking patterns of old adults. Many studies found that old adults typically chose a slower self-selected gait speed (Chung & Wang, 2010; Riley, Della Croce, & Kerrigan, 2001; Van Emmerik, McDermott, Haddad, & Van Wegen, 2005), spend more time in double limb support (Begg & Sparrow, 2006) and have decreased ranges of motion at the hip, knee and ankle compared to young adults (Cofre, Lythgo, Morgan, & Galea, 2011; Kerrigan, Todd, Della Croce, Lipsitz, & Collins, 1998). However, some literature shows that old adults choose a similar self-selected walking speed to young adults, but when asked to walk faster (increasing the demand relative to the capacity), the age-related difference in walking speed becomes apparent with the old adults walking slower than young (Zijlstra, 2004). Additionally, the lower extremity joint contributions differ between young and old when walking. Compared to healthy young counterparts, healthy old adults exhibited decreased plantarflexor power and torque at the ankle but increased hip power and torque, even when walking at a matched speed (Cofre et al., 2011; DeVita & Hortobagyi, 2000; Kerrigan et al., 1998; Silder, Heiderscheit, & Thelen, 2008). Since the plantarflexors are the primary muscle group responsible for propulsion during walking, decreased function of this group would necessitate compensation from another muscle group to accomplish the task. Aging highlights this distal to proximal shift in lower extremity function during walking. In order to match a given walking velocity, old adults increase the use of proximal muscles, such as the hip extensors, and decrease the contribution of the distal muscles, such as the plantarflexors. This could be the result of a compensatory mechanism, shifting away from the distal muscles that lose the most function with age to larger, proximal muscle groups such as the hip extensors, for propulsion during walking.

Impaired muscle function and weakness in the lower extremity limits the capacity to perform activities of daily living effectively and may result in an overall decrease in physical activity, the loss of an independent lifestyle and a decrease in quality of life. Considering this distal to proximal shift in function, increasing the function of the distal muscles, specifically the ankle plantarflexors, may reverse this shift and increase the overall function of old adults by improving walking quality. Muscular strength is a strong predictor of functional decline occurring with aging (Pendergast, Fisher, & Calkins, 1993; Rantanen et al., 1999) and functional tests, such as the chair rise and gait velocity tests, are good indicators of lower extremity function. One potential strategy to increase function is strength training. Several studies have shown that increasing lower extremity strength has a positive impact on function in older adults as measured by these functional tests (Chandler, Duncan, Kochersberger, & Studenski, 1998; Krebs, Scarborough, & McGibbon, 2007). Like young adults, old adults respond well to strength training (Chandler et al., 1998; de Vos et al., 2008; Ferri et al., 2003; Studenski et al., 2011) . Specifically, strength training programs focusing on the plantarflexors have proved to be effective in increasing strength of the plantarflexors (Caserotti, Aagaard, Buttrup Larsen, & Puggaard, 2008; Ferri et al., 2003) and may therefore change the gait biomechanics of old adults and improve walking capacity. Special attention should be given in developing ways to promote functional capacity and preserve quality of life for as long as possible.

Purpose

The purpose of this study is to determine the effect of plantarflexor strength training on gait biomechanics during level walking at a self-selected, a safe-maximum and a standardized speed of 1.5 m/s in healthy old adults.

Hypothesis

A plantarflexor strength training program will alter gait biomechanics by producing a proximal to distal shift in lower extremity joint torques and powers in healthy old adults.

Significance

Activities of daily living such as locomotion require adequate muscle function and aging involves the loss of muscle mass, strength and power particularly in the ankle plantarflexors. A plantarflexor strength training program may help reverse the effects of aging by increasing strength and power at the ankle joint. Increasing plantarflexor strength in old adults may alter gait biomechanics and potentially preserve independence, functional capacity and quality of life.

Delimitations

1. All subjects will be healthy old adults with no history of musculoskeletal problems, neuromuscular disease or cardiovascular disease.
2. Subjects will be able to function independently, performing activities of daily living without assistance or difficulty.
3. Subjects will be walking on a level surface, using a supine leg press machine and a seated calf raise machine.
4. Measurements will be taken of the left hip, left knee and left ankle joints.

Limitations and Assumptions

- Data from only the left limb can be collected due to the layout of the biomechanics laboratory.
- Symmetry between limbs is assumed.
- Anatomical marker placement is assumed to be accurate.
- Information obtained during the Telephone Health Interviews is assumed to be accurate.

Definitions of Terms

- Sarcopenia: age-related muscle loss and weakness
- Old adult: an individual 65 years old or older
- Plantarflexors: gastrocnemius and soleus muscles

CHAPTER 2: REVIEW OF LITERATURE

The aging process affects many systems in the body, especially the neuromuscular system. It is well documented that both muscular strength and power decline with age (Judge et al., 1993; Metter et al., 1997), affecting the biomechanics of gait in older adults. Additionally, it has been demonstrated that aging humans lose distal muscle function more so than proximal muscle function (Cofre et al., 2011; DeVita & Hortobagyi, 2000). Therefore, a strength training program that focuses on distal muscles such as the plantarflexors may help reverse this effect and alter gait characteristics in old adults by changing the joint torques and powers in the lower extremity. This chapter will address the following topics: physiological changes associated with aging, the effects of physiological changes on functional status, gait characteristics of old adults and the effects of strength training in old adults.

Physiological Changes with Aging

Many physiological changes are associated with aging, but one of the most influential physiological changes is the loss of muscle mass. Proper muscle function, requiring strength and coordination, is needed to produce any movement such as walking across a room or up a flight of stairs. Without adequate muscular strength and power, physical function in old adults is limited.

Strength is defined as the ability to produce a force over some distance and power is the product of muscle force and velocity of the movement. The decrease in strength seen in old adults is related to sarcopenia. Sarcopenia is the decrease in muscle mass and changes in muscle architecture such as total muscle cross sectional area, fiber cross sectional area, and motor unit changes. Larsson et al. reports a reduction in the cross-sectional area of the muscle due to a decrease in the number of fibers and also a decrease in the diameter of the remaining muscle fibers, fast-twitch muscle fibers in particular (1979). While fast-twitch muscle fibers are regarded as being responsible for high force production compared to slow-twitch fibers, a decrease in the number of either fiber type results in decreased strength. As well as the decrease in total number of muscle fibers, motor unit remodeling may also account for some of these fiber type changes. As a fast-twitch muscle fiber is dennervated, it may be reinnervated by a neighboring slow-twitch muscle fiber, creating larger but fewer motor units in old adults (Brown, Holland, & Hopkins, 1981; Campbell et al., 1973). According to Campbell et al., old adults have as much as 75% fewer motor units compared to adults younger than 58 years (1973). These changes notably impact the function of a muscle and it is clear that muscle function is compromised in old adults.

Due to the changes in muscle fibers and muscle architecture with aging resulting in decreased strength, declines in power would also be expected in old adults (Cofre et al., 2011; Metter et al., 1997; Skelton et al., 1994). Not only do both strength and power decline, it has been found that power decreases at a faster rate than strength. The results from Young et al. show that power decreases at a rate of approximately 3.5% per year while strength decreases at a rate of only 1.5% per year in adults between the ages of 65 and 84 (1994). This is important since successful execution of movement depends partly on the velocity of the movement in addition to force produced.

Although strength declines with age in general, these changes are asymmetric. It has been thought that lower extremity muscles lose function more than upper extremity muscles. Hunter, Gill-Body and Portney compared handgrip, knee extensor and plantarflexor maximal voluntary isometric strength in old and young adults (2000). The lower extremity muscles such as the plantarflexors (gastrocnemius and soleus) and knee extensors (quadriceps) lost more strength compared to the upper extremity muscles in the old adults (Hunter, Thompson, & Adams, 2000). The plantarflexors and knee extensors of the old adults showed a decline of approximately 55.5% of the maximal voluntary isometric contraction compared to the young adults while the handgrip muscles only showed a decline of 38% compared to the young adults (Hunter et al., 2000). These findings agree with previous studies comparing maximal voluntary isometric strength of the upper and lower extremities in young and old adults. Compared to the maximal voluntary isometric force produced by the upper extremity muscles such as the finger flexors, thumb flexors, forearm flexors and extensors, the lower extremity muscles such as the dorsiflexors and plantarflexors declined more with increasing age (Christ et al., 1992). The ankle plantarflexors declined the most, losing approximately 45% of the maximum force produced (Christ et al., 1992). Findings such as these emphasize the decreased function of the lower extremity muscle groups, particularly the plantarflexors.

Not only do lower extremity muscle groups age differently than upper extremity muscle groups, there are also asymmetric age-related changes between the muscle groups of the lower extremity. Distal muscles lose function at a faster rate compared to more proximal muscles with increasing age (Bua et al., 2002) and these changes are expressed in tasks such as walking. Despite nearly identical support torque curves of healthy old and young subjects, DeVita and Hortobágyi found decreased joint torques and powers of the ankle plantarflexors but increased hip torque and power during normal gait at a standard speed of 1.5 m/s (2000). Cofré et al. also found that old adults had more hip power and work but less ankle power and work (2011). These findings suggest that the hip muscles compensate for the reduced function at the more distal joints of the lower extremity such as the knee and, most importantly, the ankle. Since the plantarflexors are primary muscle group responsible for propulsion during locomotion tasks, reduced function of this muscle group would demand compensation from another group in order to complete the task.

Effects of Physiological Changes on Function

Declines in muscular strength and power lead to a decrease in functional ability in old adults. Most activities of daily living require some degree of strength and power, particularly during low-velocity tasks such as walking and climbing stairs (Ferri et al., 2003). Overall mobility is dependent on being able to perform common activities of daily living such as walking, climbing stairs, descending stairs and rising from a seated position (from a bed or chair) (Judge et al., 1993). Weakness in the legs is the most influential falling risk factor and the risk of falling in older adults increases fourfold as a result of leg weakness (Rubenstein & Josephson, 2006). The risk of falling is also age dependent. Fall risk increases in frequency and severity as age increases. One in every three adults over the age of 65 and one in every two adults over the age of 80 fall at least once per year (Bogle Thorbahn & Newton, 1996; Hatch, Gill-Body, & Portney, 2003; Rubenstein & Josephson, 2006). Between 25% and 75% of older adult fallers with a hip fracture do not recover to their previous levels of function in walking or activities of daily living (Magaziner, Simonsick, Kashner, Hebel, & Kenzora, 1990). With an increased fear of falling, older adults are less likely to participate in leisure time physical activity and may result in an overall decrease in physical activity, in addition to the loss of an independent lifestyle and a decrease in quality of life (Ferreira, Matsudo, Ribeiro, & Ramos, 2010). Decreased physical activity leads to muscle atrophy, escalating the negative effects of aging such as decreased muscle strength and function which impacts overall function and independence. Ordinary tasks such as these may seem insignificant to a young healthy adult, but the same task would require greater effort from a healthy old adult. A study by Hortobágyi, Mizelle, Beam and

DeVita found that old adults needed almost twice the amount of relative effort to complete activities of daily living such as rising from a seated position, ascending and descending stairs when compared to young adults and the level of effort required was close to maximum capacity (2003). Performing at levels near maximum capacity can lead to increased fatigue, further limiting physical activity in old adults. Decreased physical activity as a result of lost muscle function leads to further decreases in muscle function. This may lead to a vicious cycle emphasizing the great need for preventative strategies in older adults to maintain adequate physical function.

Gait Characteristics of Old Adults

As demonstrated by decreases in maximal voluntary isometric contractions, decreases in strength are also manifested in the gait patterns of old adults. It is well documented that many gait characteristics differ between old adults and young adults. Some of these include self-selected gait velocity, step length, stride length, time spent in the swing and stance phases, time spent in single support and double support, lower extremity joint ranges of motion and muscle coactivation. According to Studenski et al., gait velocity is indicative of functional ability and overall well-being in old adults (2011). Old adults with faster walking velocities tended to live longer than those old adults who walked slower. Based on Studenski's findings, walking velocity can be a good indication of function and health status, even though it cannot be said that increasing walking velocity will increase longevity. Typically, old adults choose a slower gait velocity when asked to walk at their normal pace compared to young adults (Christiansen, 2008; Chung & Wang, 2010; Kerrigan et al., 1998; Riley et al., 2001; Van Emmerik et al., 2005).

In addition to slower preferred gait velocity, old adults take shorter steps (Cofre et al., 2011; Riley et al., 2001). When young and old adults walked at the same speed, it was found that the old adults took shorter steps but increased their step frequency to maintain the chosen speed (DeVita & Hortobagyi, 2000; Ortega & Farley, 2007). Most researchers agree about a slower self-selected gait velocity, step length and stride length in old adults but there is some controversy regarding cadence. Riley and colleagues reported the gait speed reduction was due to shorter step lengths but not cadence (2001) while Cofré et al. reported an increase in cadence (2011). Despite these incongruences, it is clear that there are differences between the gait patterns of healthy young adults and healthy old adults.

Another gait characteristic that differs with age is the amount of time spent in double support. Double support refers to the phase of gait in which both feet are in contact with the ground. Compared to young adults, old adults spend more time in double support (Begg & Sparrow, 2006; DeVita & Hortobagyi, 2000; McGibbon & Krebs, 1999). More time spend in double support also indicates a shorter swing phase. This increase in double support time may be used to increase or maintain stability during gait. Interestingly enough, one might presume that increasing walking velocity would decrease stability since increased velocity occurs along with increased stride length, decreased time spent in stance and double support. However as Studenski et al. found, faster walking velocities are closely related to longevity and overall well-being (2011) indicating that this decreased base of support during fast walking may not have a negative effect regardless of the decreased time spent in double support.

Possible contributing factors to reduced walking speed in old adults are the decreases in muscular strength and power due to aging. Fiatarone et al. found a strong negative correlation between leg strength and the time taken to perform a six meter walk test suggesting that reduced leg strength affects walking speed (1990). These decreases relate directly to the reduction of ankle power in late stance (push off) (DeVita & Hortobagyi, 2000; Riley et al., 2001; Schmitz, Silder, Heiderscheit, Mahoney, & Thelen, 2009). During normal gait, the push off phase is primarily accomplished by the plantarflexors (gastrocnemius and soleus) contracting to propel the body forward, generating substantial power (Graf, Judge, Ounpuu, & Thelen, 2005). Compared to young adults, old adults have demonstrated a decrease in ankle plantarflexor power (Cofre et al., 2011; DeVita & Hortobagyi, 2000; Ferri et al., 2003) which contributes to these age-related differences in walking patterns between young and old adults.

Strength Training in Old Adults

While many problems associated with aging are somewhat inevitable, some of the negative age-associated physiological changes can be remedied. It is well known that strength training increases strength in healthy young adults, but even frail older adults also respond well to strength training (Hess, Woollacott, & Shivitz, 2006). Ferri and colleagues conducted a strength training program in older men and found increases in muscular strength and power (2003). In a study by de Vos et al., subjects who underwent an explosive strength training program had increases in muscular power which was mostly due to increases in force production, demonstrating that strength training programs are effective in older adults for increasing strength and power (2008). Since most activities of daily living require some degree of strength and power, functional tests are good representations of functional status. Functional tests, such as the chair stand test, are good indicators of lower extremity function and increasing strength in the lower extremity muscles has shown a positive impact on function in older adults (Chandler et al., 1998). Because older adults display such poor gait patterns, positive changes in their gait patterns as a result of strength training is encouraging. Walking speed is also a functional indicator and predictor of overall well-being (Studenski et al., 2011) and since older adults choose slower walking velocities, programs that increase walking speed may be a step in the right direction for reversing these deficits. Pereira et al., found a 14.3% increase in walking speed after a high-speed power training program along with increased chair stand test performance (2012). These results show that strength training benefits older adults, improving strength and overall function.

Remembering that older adults are at a high risk of falling, the impact of strength training programs on the risk of falling is a good indicator of improving function and quality of life. In addition to the benefits of increased muscular strength as a result of strength training, Toraman and Yildirim demonstrated a strong relationship between strength and fall risk (2010). Those who had better leg strength also had better balance and reduced fall risk (Toraman & Yildirim, 2010). The results from these studies support a specific strength training program for the plantarflexors, especially since they are more at risk for losing function. A specific strength training program targeting the plantarflexors could help reverse this age-related decline in function, increase strength in the plantarflexors, improve walking patterns and hopefully prevent further decreases in overall functional capacity, allowing for maintenance of quality of life and independence.

Summary

Healthy old adults exhibit changes in gait characteristics compared to healthy young adults. Many of these changes may be a result of a loss of distal muscle function, strength and power. Old adults require more effort to complete the same activities of daily living compared to young adults (Hortobagyi et al., 2003) and demonstrate a decrease in ankle plantarflexor power (DeVita & Hortobagyi, 2000; Riley et al., 2001; Schmitz et al., 2009). While strength training programs have been demonstrated to be effective at increasing strength, the mechanism by which this occurs is unclear and needs further exploration. A strength training program focusing on the plantarflexors may alter the gait biomechanics in old adults by inducing a proximal to distal shift in the lower extremity joint torques and powers especially at the ankle, possibly leading to improved gait characteristics such as increased walking velocity and increased overall function.

CHAPTER 3: METHODOLOGY

Subject Characteristics

Twelve volunteers between the ages of 65 and 85 were recruited for this study. The subjects were randomly assigned to either a strengthening group or a stretching control group so that the groups were equal in number. All subjects were healthy and functionally independent, meaning they could perform their activities of daily living without assistance and did not meet any of the following exclusion criteria. The groups were similar in age, height, body mass and body mass index as seen in Table 1.

Exclusion Criteria:

- Cardiovascular pathologies (atrial fibrillation, pacemaker, coronary artery disease, congestive heart failure, peripheral artery disease)
- Neurological pathologies (stroke, Parkinson’s disease)
- Musculoskeletal pathologies and problems (arthritis, joint replacement, any orthopedic problem requiring surgery in the lower extremity)
- Pulmonary pathologies (difficulty breathing, emphysema)
- Visual pathologies that limit function
- Body Mass Index > 30.0 kg/m^2
- Unsatisfactory results from the Short Physical Performance Battery, Telephone Health Survey or SF-36

Table 1: Subject characteristics

		Age (years)	Height (m)	Mass (kg)	BMI (kg/m^2)
Strengthening	*n* = 6 (2 males)	73.2 ± 4.7	1.68 ± 0.10	74.0 ± 15.1	26.2 ± 4.0
Stretching	*n* = 6 (3 males)	73.0 ± 5.0	1.72 ± 0.09	69.7 ± 9.9	23.5 ± 2.0

Testing Procedures

All subjects participated in two testing sessions (pre-test and post-test). The initial testing was split into two days. The first day was primarily for subject familiarization and the second day was the pre-test. The post-test (at twelve weeks) was the same as Day 2.

Day 1

Upon arrival, the subject provided informed consent before beginning testing. Next, the subject confirmed the answers on the Telephone Health Survey and completed the Short Form-36 as a measure of physical and mental health (Ware, Kosinski, Keller, QualityMetric Inc., Lincoln, RI) (Ware et al., 1994). The subject's blood pressure was measured and recorded. Height and weight were measured and recorded; from these values, the body mass index was calculated. Balance and functional status were assessed by the Short Physical Performance Battery (SPPB) (Sayers et al., 2004). The subject warmed up on a cycle ergometer (Monark 818E, Auburn, MI) for five minutes and was instructed to walk across a walkway and to get comfortable with the testing area. Lastly, the subject was introduced to the leg press machine (Cybex International Inc., Medway, MA). The subject performed several left leg ankle presses at a light load to get familiar with the exercise and then tested to determine the one repetition maximum value to be used during the torque-velocity tests. From this value, 20%, 40%, 60%, and 80% of the one repetition maximum were also calculated. Subjects in the strengthening group were also tested to determine the one repetition maximum for the bilateral ankle press and bilateral seated calf raise (Powerline USA, Body Solid, Forest Park, IL) to be used during the strengthening sessions. Subjects in the stretching group were introduced to the stretching routine. Subjects were allowed to rest if needed.

Day 2 (Pre-test and Post-test)

On Day 2 and the post-test, the subject changed into form-fitting clothing. Blood pressure, height and weight were taken and recorded. The subject warmed up on the cycle ergometer for five minutes and performed the gait and torque-velocity ankle press tests.

Gait and Torque-Velocity Tests

To collect motion capture data, the subject was outfitted for standard biomechanical 3D motion analysis data collection similar to that used in other studies (DeVita & Hortobagyi, 2000). Passive reflective markers were placed on the right and left posterior superior iliac spines (PSIS), right and left iliac crests, right and left anterior superior iliac spines (ASIS), belly button, right and left greater trochanters, medial and lateral epicondyles of the left knee, medial and lateral malleoli of the left ankle, the first metatarsal head and the fifth metatarsal head. A thigh plate, shank plate and foot plate were also secured to the left limb. A static trial on the force plate was taken and the calibration markers were removed (knee, ankle and malleoli markers) as seen in Figure 1.

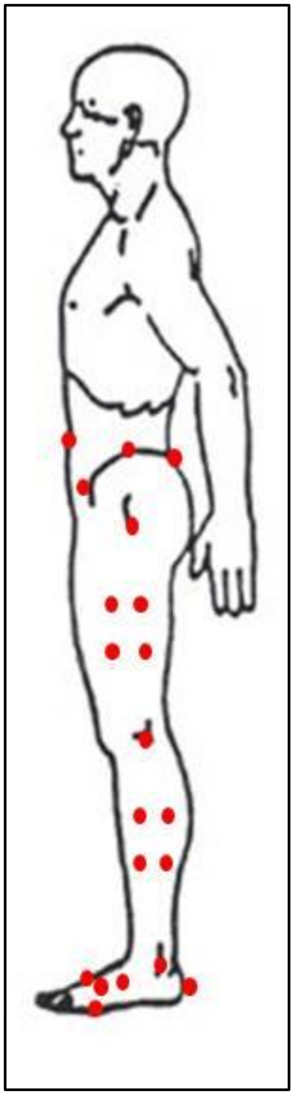

Figure 1: Diagram of marker placement for motion capture.

The subject performed five acceptable trials for three walking conditions. The walking conditions were: self-selected velocity ("walk like you're going to an appointment"), safe-maximum velocity ("walk as fast as you can without feeling like you are going to run or fall") velocity) and the third condition was walking at a standardized velocity of 1.5 m/s. An infrared timing system was used to ensure subjects walk at the standardized velocity (Brower Timing System, Salt Lake City, Utah). Marker-position data was collected using an 8-camera (ProReflex) motion capture system at 120 Hertz (Qualisys Track Manager (QTM), Qualisys AB, Gothenburg, Sweden). Ground reaction forces were collected at 960 Hertz using a force platform (0.61 by 1.22 meter) (Advanced Mechanical Technology Inc., Watertown, Ma) embedded in a raised walkway. A walking trial was considered acceptable when no obvious gait alterations were observed and speed was maintained throughout the trial (e.g., the subject did not make a special attempt to step on the force platform or to avoid it).

The torque-velocity relationship for the ankle plantarflexors was measured using the motion capture system and a (0.47 by 0.51 meter) force platform (Advanced Mechanical Technology Inc., Watertown, Ma) mounted to the leg press machine. The marker setup was the same as for the gait trials with the exception of the removal of the PSIS markers. Five load conditions for the unilateral ankle press (left leg only) were used to determine the torque-velocity relationship. The loads were set at 20%, 40%, 60%, 80% or 100% of the subject's one repetition maximum and were randomized to eliminate an order effect. The subject was instructed to lie supine on the leg press machine and get into proper position for the test. While maintaining the knee in extension (close to 0° of flexion), the subject allowed the ankle to move to the most dorsiflexed position, paused and pushed as hard and as quickly as possible, paused at the most plantarflexed position and then returned to the dorsiflexed position. This was repeated twice for each load.   Instructions were repeated for each trial and the subject rested for one minute between conditions, controlled using a stopwatch. For some of the subjects, a sixth load condition was added to the torque-velocity ankle press tests. The one repetition maximum was retested for the left ankle press for all subjects but only those who's one repetition maximum increased performed the sixth load condition. Figure 2 depicts the subject's position on the leg press machine for the torque-velocity test.

Figure 2: Subject setup on the Cybex Leg Press Machine used for torque-velocity tests and strength training.

Strength Training Protocol

All subjects in the strengthening group followed this protocol. The training took place three times per week for twelve weeks, usually with at least one day of rest in between each exercise session. Exercise sessions began with a five-minute warm up on the cycle ergometer. Next, the subject did bilateral ankle presses on the leg press machine. Two sets of ten repetitions were performed at a percentage of the subject’s one repetition maximum (starting at 50% and progressing to 80% in later weeks). This was repeated on the seated calf raise machine. The subjects rested for one and a half minutes between sets, and for two minutes between machines, controlled using a stopwatch. Whether the subject did the ankle press or seated calf raise first varied from session to session. Every two weeks the subject’s bilateral one repetition maximum was retested on both machines and the loads were adjusted accordingly for the subsequent training sessions. This strengthening protocol and progression is consistent with the American College of Sports Medicine Position Stand for strength training in an old adult population (Chodzko-Zajko et al., 2009) and similar to protocols in other strength training studies for old adults (Caserotti et al., 2008; Judge et al., 1993; Kalapotharakos, Michalopoulos, Tokmakidis, Godolias, & Gourgoulis, 2005; Persch, Ugrinowitsch, Pereira, & Rodacki, 2009; Skelton, Young, Greig, & Malbut, 1995).

Stretching Protocol

All subjects in the stretching group followed the stretching protocol. The stretching sessions took place three times per week for twelve weeks. Stretching sessions began with a five-minute warm up on the cycle ergometer. For the static gastrocnemius stretch, the subject faced a wall with hands positioned shoulder height and shoulder-width apart on the wall. The subject took a step back with the leg to be stretched, keeping the foot flat on the floor and aligned perpendicular to the wall. The front knee was bent so that a stretch was felt in the calf muscles of the back leg while keeping the feet in the same positions as seen in Figure 3A. The set up for the dynamic gastrocnemius stretch was the same as the static stretch except the subject leaned closer to the wall, increasing the stretch, paused then returned to the original stretched position. This movement was repeated throughout the duration of the stretch.

Gastrocnemius Stretches

- Static: 2 sets of 40-second stretches on each leg
- Dynamic: 2 sets of 40-second stretches on each leg

The static soleus stretch was performed in a seated position with the balls of both feet resting on the flat side of a half-foam roller, shoulder-width apart. The subject rocked the foam roll so that the ankle was forced into a dorsiflexed position, creating a stretch in the soleus muscles as seen in Figure 3B. The dynamic soleus stretch was the same set up but the subject gently rocked the foam roll so that the soleus stretch was increased and then decreased throughout the duration of the stretch. Whether the subject did the gastrocnemius stretches or the soleus stretches first varied from session to session. This stretching protocol is consistent with the American College of Sports Medicine Position Stand for flexibility exercise in an old adult population (Chodzko-Zajko et al., 2009) and similar to protocols in other stretching studies for old adults (Christiansen, 2008; Feland, Myrer, Schulthies, Fellingham, & Measom, 2001; Gallon et al., 2011).

Soleus Stretches

- Static: 2 sets of 40-second stretches (both legs stretched simultaneously)
- Dynamic: 2 sets of 40-second stretches (both legs stretched simultaneously)

Figure 3: Examples of the gastrocnemius stretch (A) and soleus stretch (B).

Data Processing

Once 3D position and force data were collected, they were processed using Qualisys Track Manager and Visual 3D (C-Motion Inc., Germantown, MD) software. Unidentified markers were identified as anatomical landmarks and leg segments for each of the ankle press and walking trials allowing the software to know where the landmark or body segment was in space at a moment in time using the Global Coordinate System. QTM also filtered the tracking of the markers and filled any gaps that may have been caused by a temporary disappearance of a marker. The labeled, filtered and gap-filled trials were then exported to Visual 3D for further reduction.

A 3D, virtual model was created with Visual 3D using the marker placements, anthropometrics (Dempster, 1955), the subject’s height in meters and mass in kilograms. The model created by Visual 3D depends on the assumption that the components of the lower extremity are a rigid and connected system. Based on the static calibration model from QTM, the virtual joint centers of the pelvis and left lower extremity were determined from the midway point between the medial and lateral markers of each joint. The subject's center of mass was also derived from the static calibration trial, along with the center of mass for each segment. Visual 3D calculated the positions and velocities of the pelvis, leg, shank and foot segments of the left leg as well as the angular positions of the hip, knee and ankle joints of the left leg. Using the ground reaction forces (collected from the AMTI force platforms), Visual 3D calculated torques and powers for the hip, knee and ankle joints of the left leg.

To determine joint kinetics, the ground reaction forces, torques, center of mass accelerations for each segment, moment arms, center of pressure of the left foot, gravitational forces on each segment and joint centers were used for the calculations. Inverse dynamics were used to calculate the joint torques and powers. The torque at the ankle was calculated first since the foot contacted the force platform and the measured total ground reaction force was applied through the ankle, knee and hip joints, respectively. Once the unknown forces at the ankle were determined, the process was repeated for the knee and lastly the hip. To calculate the joint reaction forces for the ankle, knee and hip, the following equations were used:

$$\Sigma F_x = ma_x \tag{1}$$

where ΣF_x is the sum of the forces in the horizontal plane, m is the mass of the segment and a_x is the linear acceleration.

$$\Sigma F_y = ma_y \tag{2}$$

where ΣF_y is the sum of the forces in the vertical plane, m is the mass of the segment and a_y is the linear acceleration.

To calculate the joint torques for the ankle, knee and hip, the following equation was used:

$$\Sigma T = I\alpha \tag{3}$$

where ΣT is the sum of the torques, I is the segment's moment of inertia and α is the angular acceleration.

The mass (m) and moment of inertia (I) for each segment were determined beforehand while the accelerations were derived from the data captured by the cameras.

The processed data from QTM and Visual 3D were further processed using QuickBasic proprietary laboratory software to identify peak hip extensor torque and power, peak knee extensor torque and power during early stance as well as peak plantarflexor torque and power during late stance.

Data Analysis

Strength and gait data were analyzed using a 2 by 2 analysis of variance. The first set of factors was the strengthening group versus the stretching group. The second factor was testing time: pre-test and post-test for each of the walking conditions: self-selected speed, safe-maximum speed and standard speed. A simple t-test was used to determine significant differences between the averaged peak values for the torque-velocity and torque-power relationships on the ankle press. The alpha level was set at 0.05 *a priori*.

CHAPTER 4: RESULTS

The purpose of this study was to determine the effect of plantarflexor strength training on gait biomechanics during level walking at a self-selected, safe-maximum and a standardized speed of 1.5 m/s in healthy old adults. We hypothesized that a plantarflexor strength training program would alter the gait biomechanics of healthy old adults by producing a proximal to distal shift in lower extremity joint torques and powers during level walking. This chapter is divided into the following sections: 1) Subject Characteristics, 2) Strength Measurements, 3) Ankle Press Kinetics, 4) Gait Kinematics, 5) Gait Kinetics and 6) Summary.

Subject Characteristics

Physical function and health status were measured by the Short Physical Performance Battery (SPPB) and the Short Form-36 Health Survey. All of the subjects in the current study were healthy and physically functional as indicated by the SPPB and SF-36. The scores were similar between groups (Table 2).

Table 2: Mean scores for the SPPB, SF-36 Physical Component Summary (PCS) and SF-36 Mental Component Summary (MCS) ($p>0.05$).

	SPPB	**SF-36 PCS**	**SF-36 MCS**
Strengthening	11.2 ± 1.6	54.7 ± 2.2	58.2 ± 3.6
Stretching	11.0 ± 0.9	53.4 ± 3.5	55.5 ± 6.8

Strength Measurements

Strength of the plantarflexors was quantified using the one repetition maximum for the left ankle press and the peak torque value during the ankle press trial at the 100% load condition. Based on these measurements, there were significant interaction effects for both the one repetition maximum and for the peak torque value during the 100% load condition. Each group was then individually tested across time. Strength training significantly increased strength of the plantarflexors by 14%, as seen in the increase in the amount of weight lifted ($p < 0.05$), while the amount lifted by the stretching group did not change (Figure 4A).

The increase in plantarflexor strength of the strengthening group is also demonstrated in Figure 1B. There was a significant increase of 25% in peak ankle torque from the original one repetition maximum value to the retested one repetition maximum at the post-test for the strengthening group ($p<0.05$) while there was no significant change in peak ankle torque for the stretching group from pre to post.

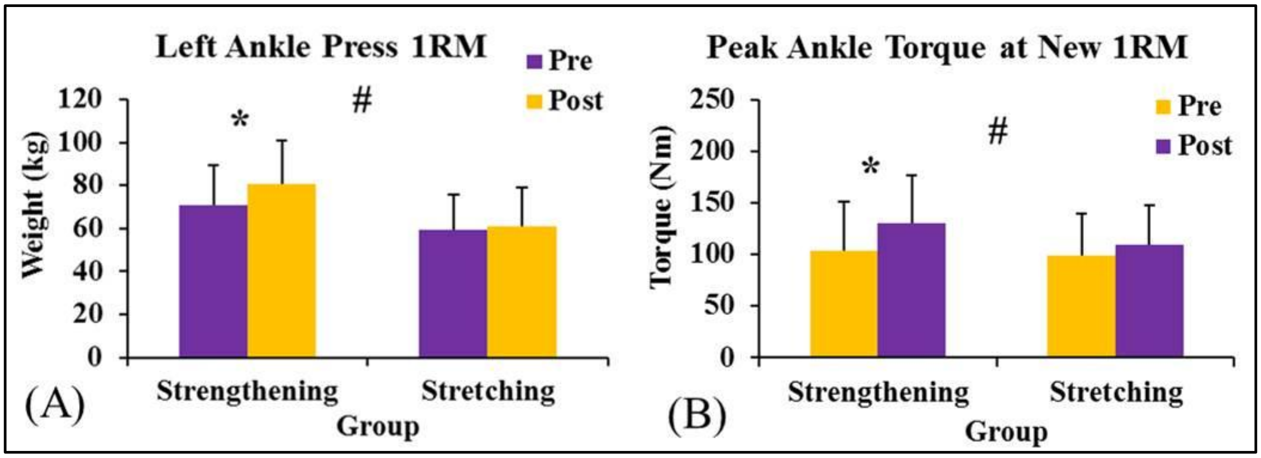

Figure 4: (A) Average 1RM values for each group before and after 12 weeks of exercise. (B) Average peak ankle torque at the re-tested 1RM value. (* p<0.05; # significant interaction effect)

Ankle Press Kinetics

Changes in the ankle kinetics were detected during the ankle press trials. The peak torque and velocity values were found during each load condition (20, 40, 60, 80 and 100% of the 1RM), for each subject during the pre-test and post-test. The peak torque values were averaged for each testing time and a t-test was used to compare the pre-test versus the post-test averages. The strengthening group significantly increased average peak ankle torque from the pre-test to post-test (Figure 5A). As seen in Figure 5B, the stretching group showed no significant changes in peak ankle torque. The relationship for peak ankle power was determined the same way as torque. Both groups significantly increased peak ankle power at the post-test (Figures 5C and 5D).

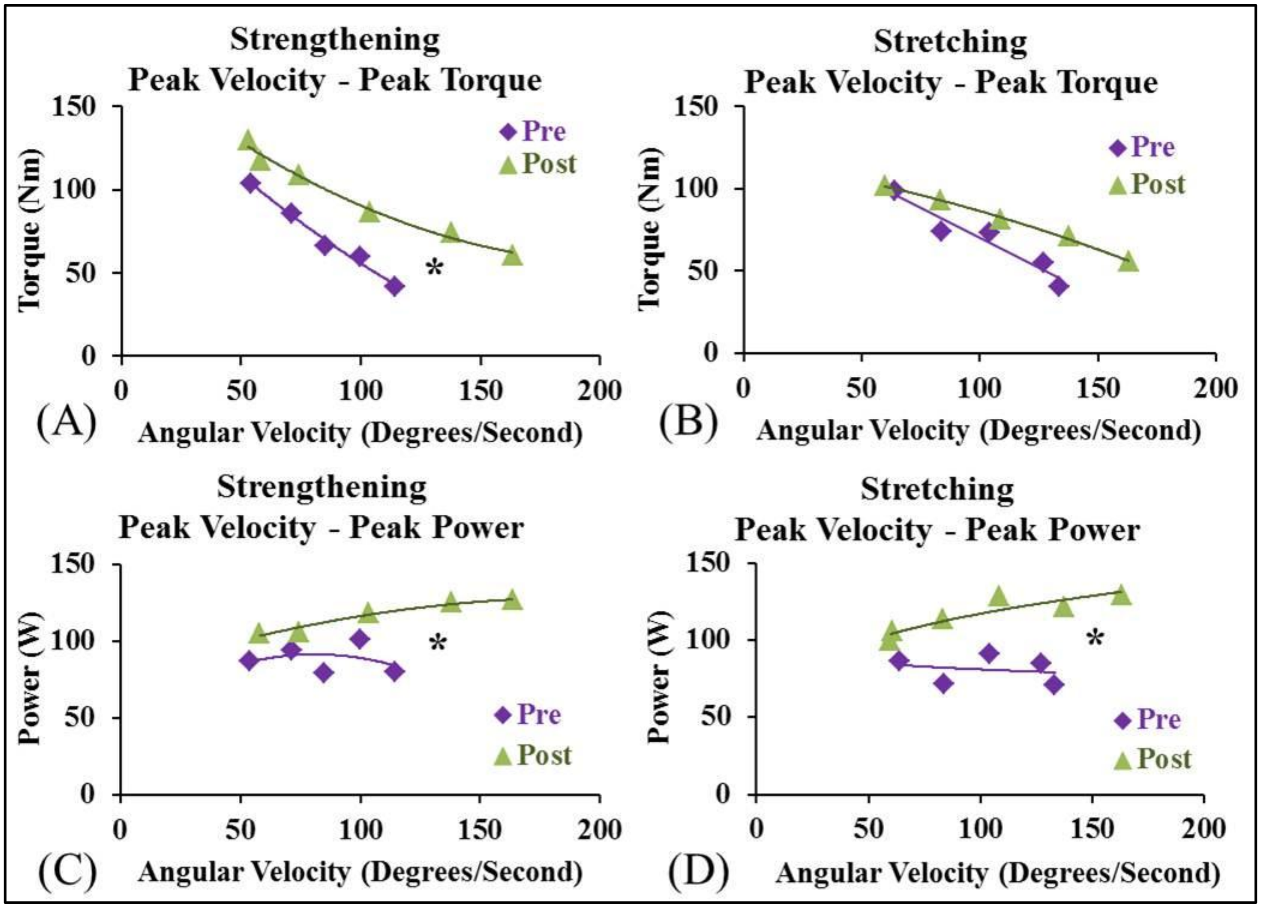

Figure 5: Peak torque (A and B) and peak power (C and D) values at each load percentage of each subject's 1RM during the pre-test and post-test. (* p<0.05)

Gait Kinematics

Few changes in the gait patterns of healthy old adults were observed. There was a significant group by time interaction for stride length for the self-selected walking speed (Figure 6A). Post hoc t-tests revealed a significant increase in stride length for the stretching group ($p<0.05$), while the strengthening group did not change (Figure 6A). There was not a significant interaction for stride length for the safe maximum (Figure 7A) or standard speed (Figure 8A) nor were the group main effects significant. The changes for walking velocity followed the same pattern as those for stride length. There was a significant group by time interaction for velocity in the self-selected walking speed (Figure 6B). Those in the stretching group walked significantly faster during the post-test ($p<0.05$) while those in the strengthening group did not change speed from the pre-test to post-test (Figure 6B). There was not a significant interaction for walking velocity in the safe maximum (Figure 7B) or standard walking condition (Figure 8B) nor were the group main effects statistically significant. There were no interaction effects for range of motion at the ankle in any of the three walking conditions nor were the group main effects significant (Figures 9A, 9B, 10A, 10B, 11A and 11B).

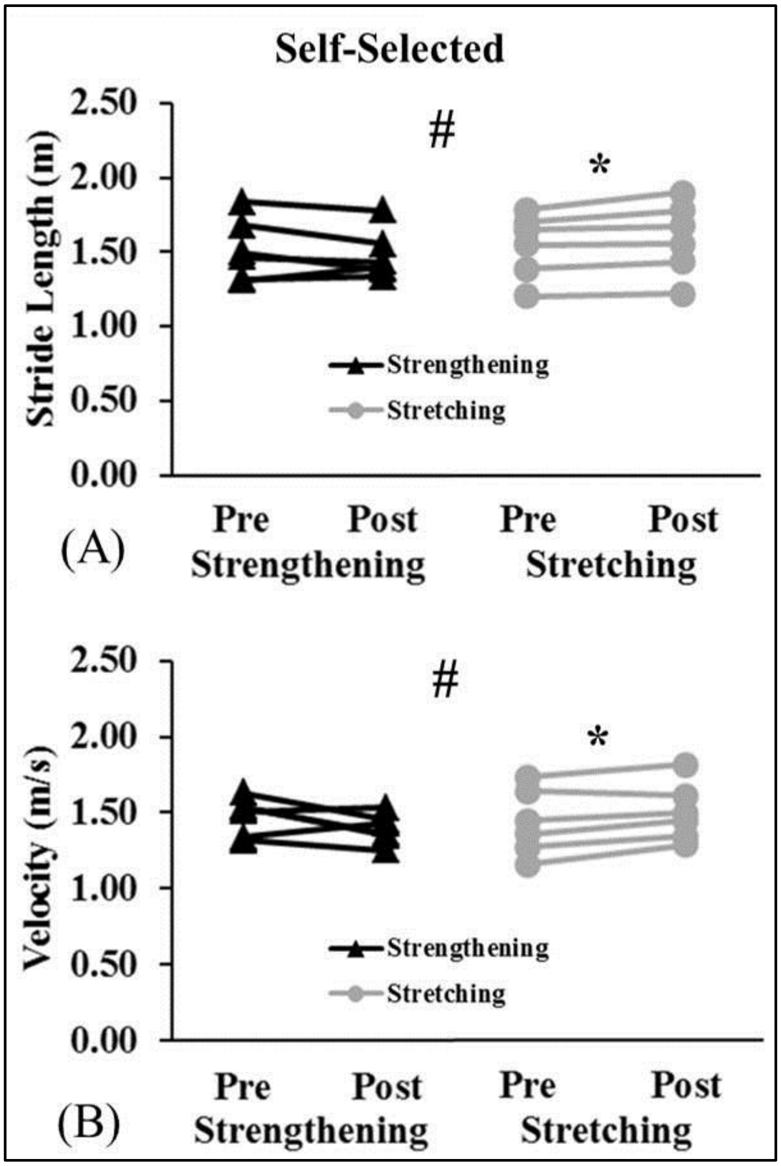

Figure 6: (A) Average stride length for both groups during the pre-test and post-test during the self-selected walking condition. (B) Average velocity for both groups during the pre-test and post-test during the self-selected walking condition. Repeated measures comparisons show single lines for each subject. (# significant interaction; * p<0.05)

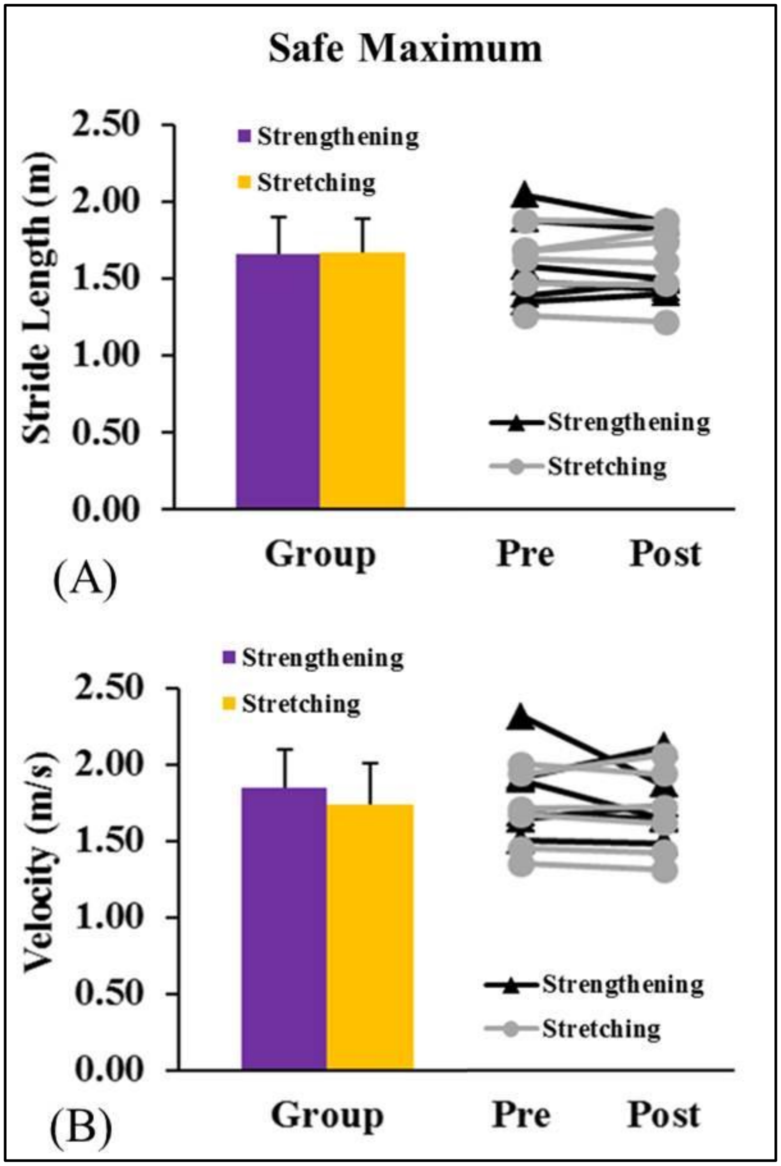

Figure 7: (A) Average stride length for both groups during the pre-test and post-test during the safe maximum walking condition. (B) Average velocity for both groups during the pre-test and post-test during the safe maximum walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject.

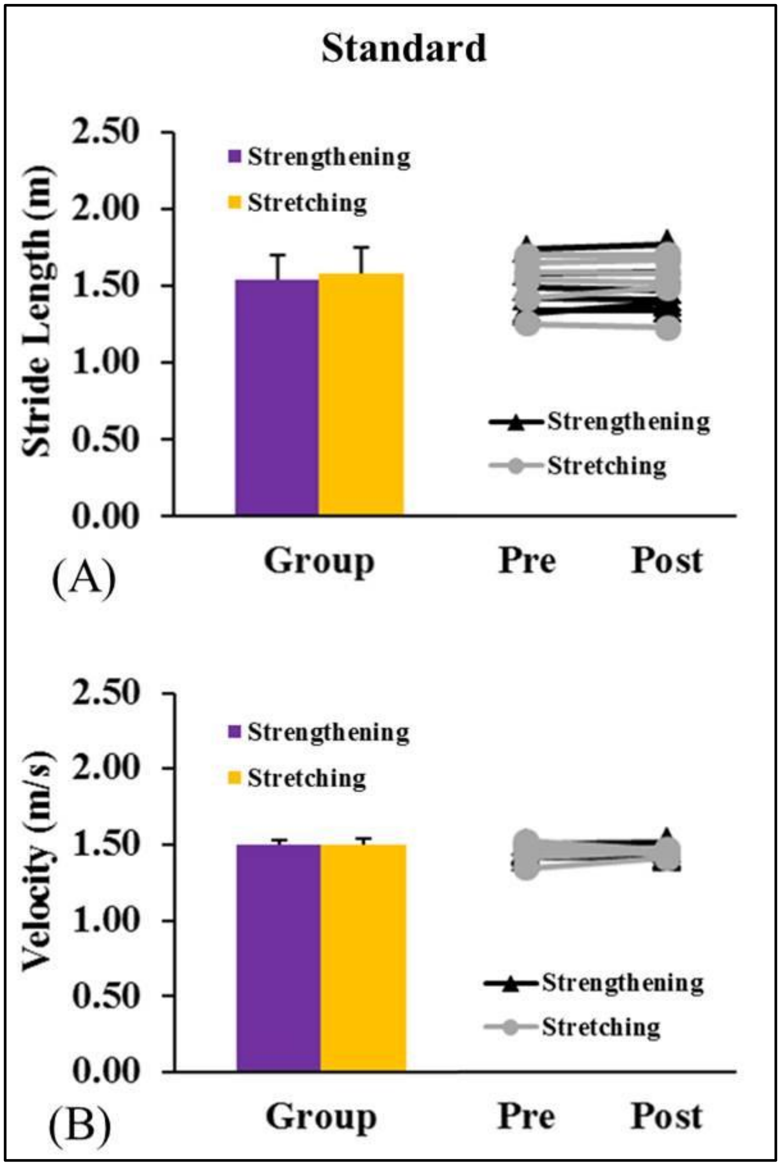

Figure 8: (A) Average stride length for both groups during the pre-test and post-test during the standard walking condition. (B) Average velocity for both groups during the pre-test and post-test during the standard walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject.

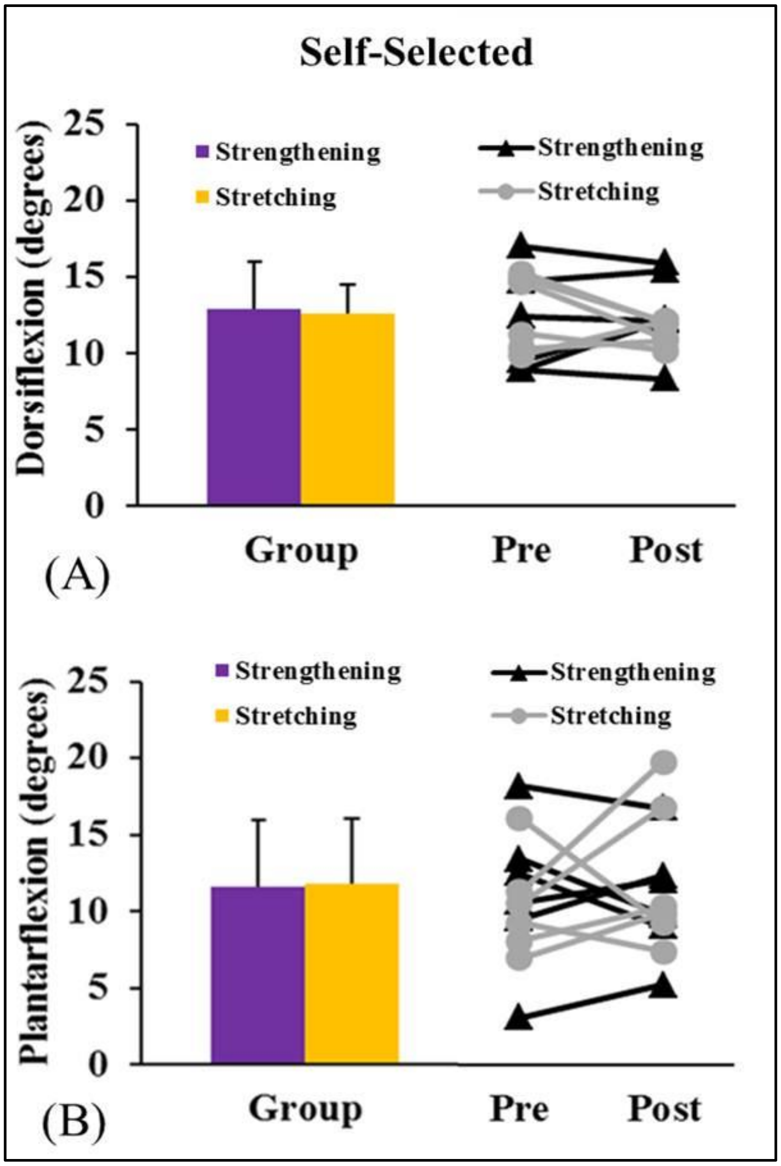

Figure 9: Peak dorsiflexion (A) and peak plantarflexion (B) during stance phase for both groups during the pre-test and post-test for the self-selected walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject.

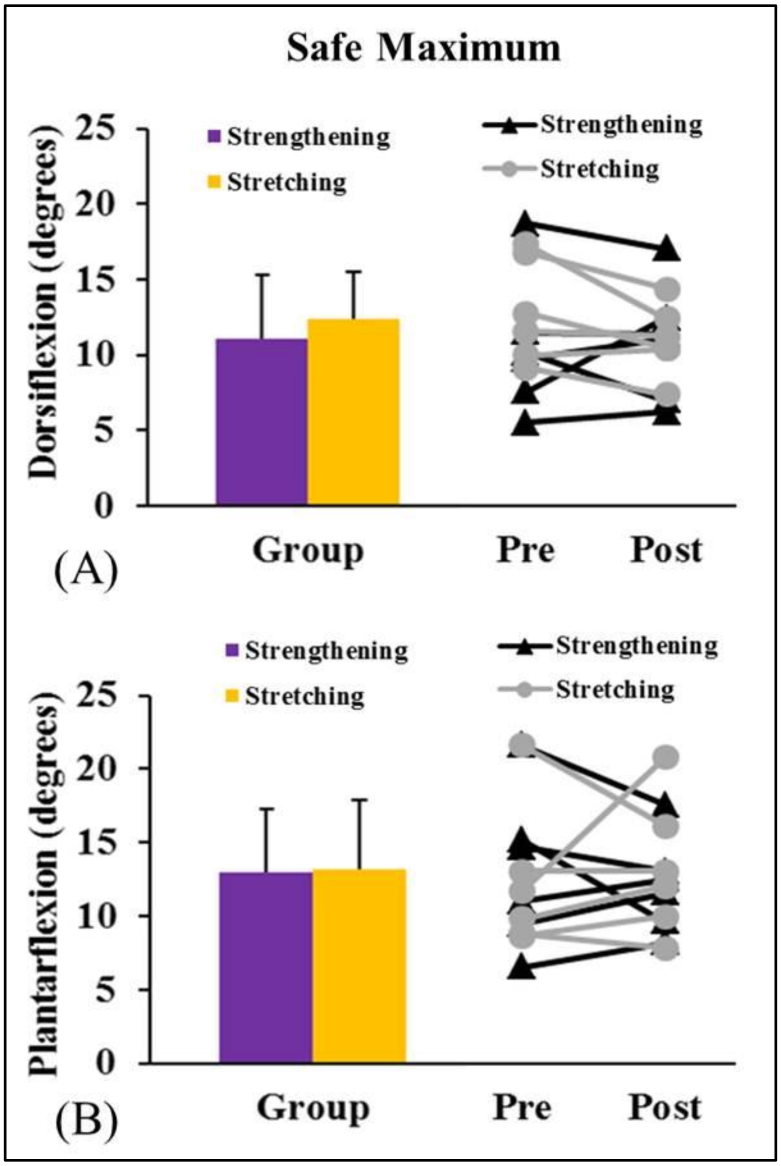

Figure 10: Peak dorsiflexion (A) and peak plantarflexion (B) during stance phase for both groups during the pre-test and post-test for the safe maximum walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject.

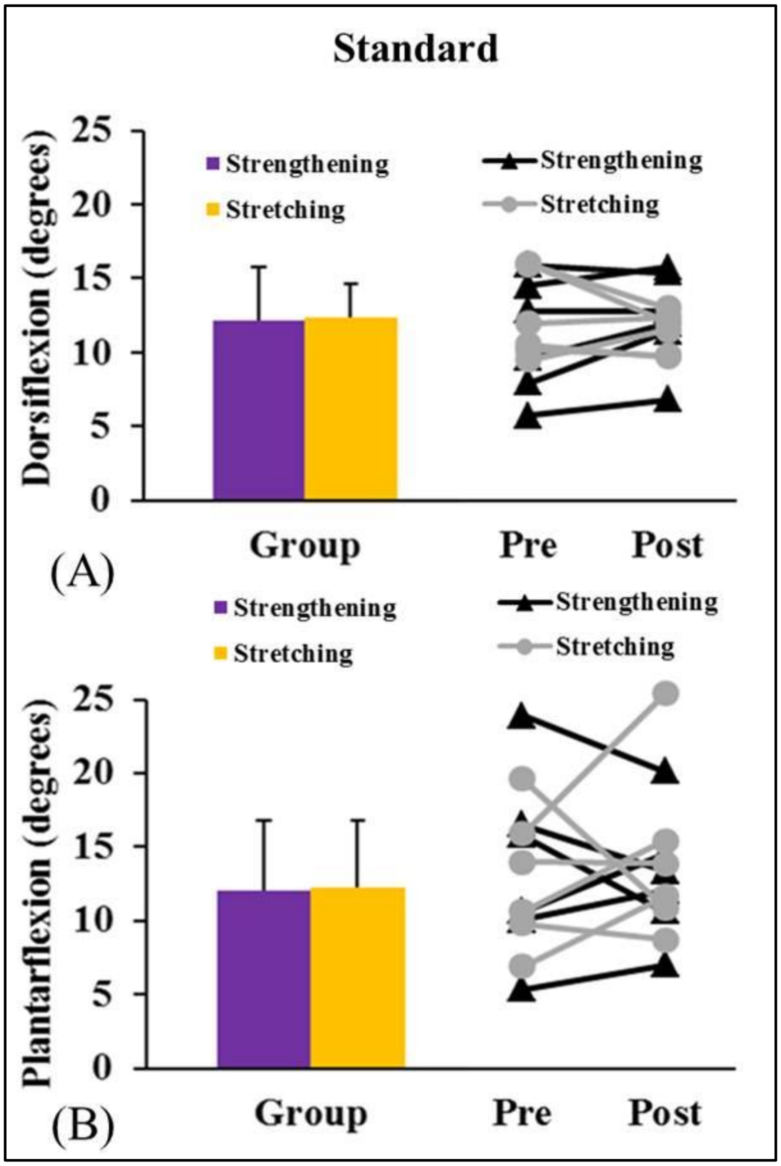

Figure 11: Peak dorsiflexion (A) and peak plantarflexion (B) during stance phase for both groups during the pre-test and post-test for the standard walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject.

Gait Kinetics

For the self-selected walking condition, there was a significant group by time interaction in peak plantarflexor torque. Those in the stretching group significantly increased peak plantarflexor torque ($p<0.05$), while the peak plantarflexor torque for those in the strengthening group did not change from the pre-test to post-test (Figure 12A). There were no interactions in peak plantarflexor torque for the safe maximum or standard walking conditions (Figures 13A and 14A). There were no interactions in peak plantarflexor power for any condition (Figures 12B, 13B and 14B).

For the second peak resultant ground reaction force, there was a significant group by time interaction in the self-selected walking condition. Post hoc t-tests revealed a significant decrease in the peak ground reaction force from the pre-test to post-test in the strengthening group ($p<0.05$), while the stretching group had a significant increase ($p<0.05$) (Figure 15A). There were no significant interactions or main effects in the ground reaction force for the safe maximum or standard walking conditions (Figures 15B and 15C).

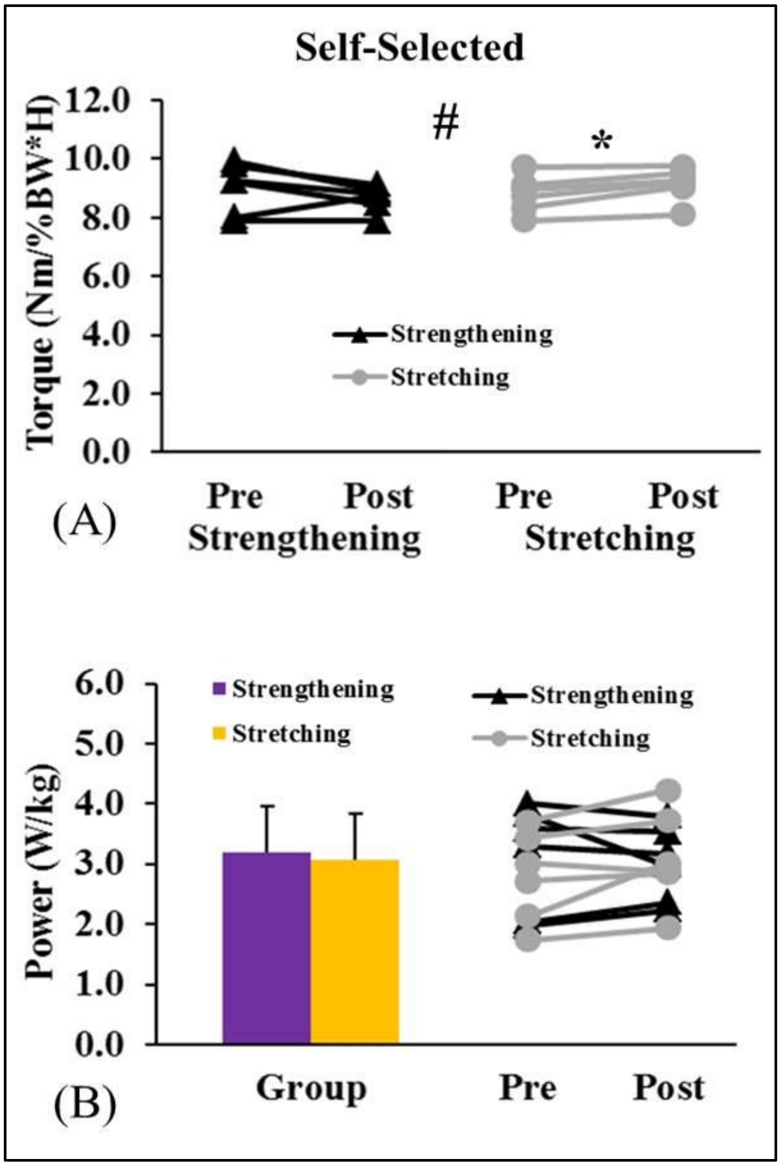

Figure 12: Peak normalized plantarflexor torque (A) and peak normalized plantarflexor power (B) during the stance phase of gait for both groups during the pre-test and post-test during the self-selected walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject. (# significant interaction; * $p<0.05$)

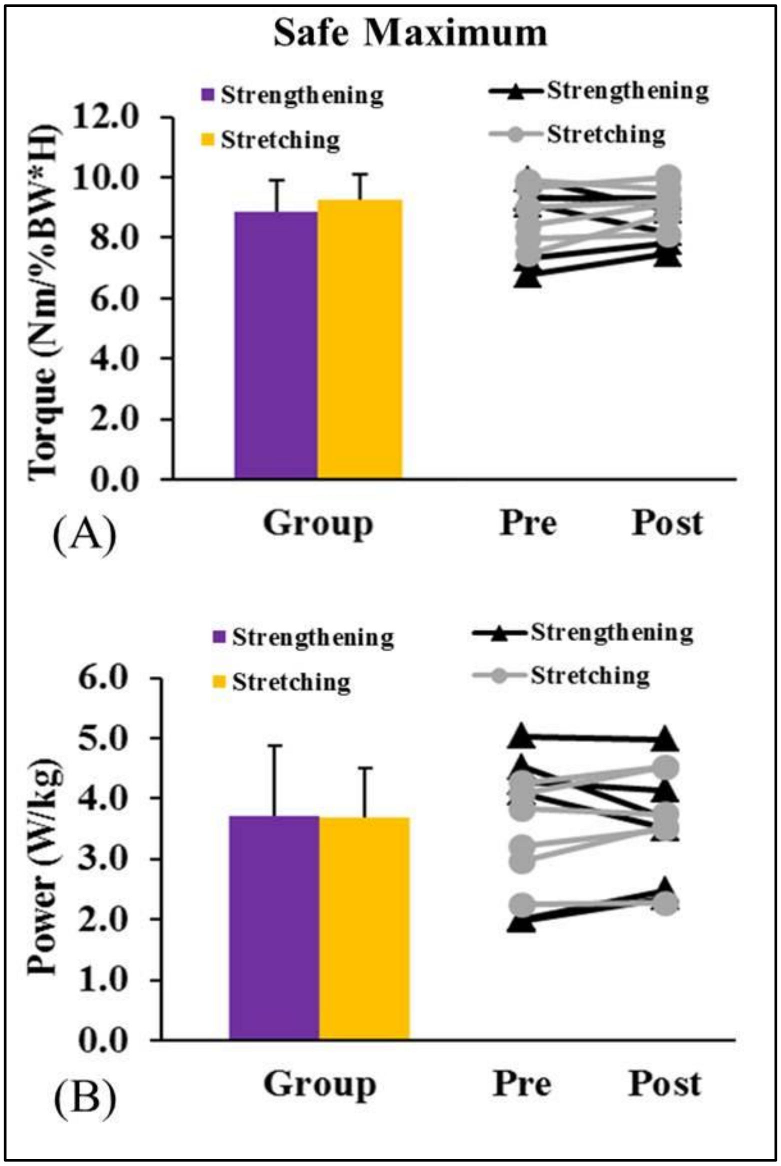

Figure 13: Peak normalized plantarflexor torque (A) and peak normalized plantarflexor power (B) during the stance phase of gait for both groups during the pre-test and post-test during the safe maximum walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject.

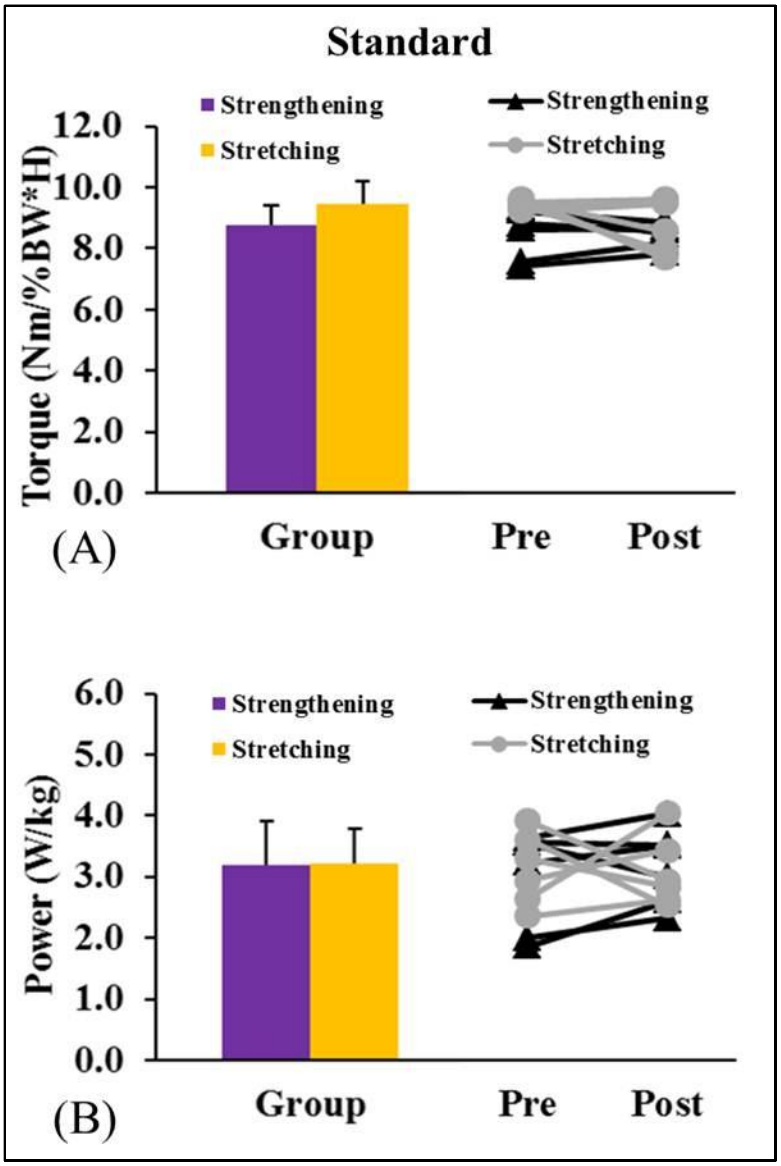

Figure 14: Peak normalized plantarflexor torque (A) and peak normalized plantarflexor power (B) during the stance phase of gait for both groups during the pre-test and post-test during the standard walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject.

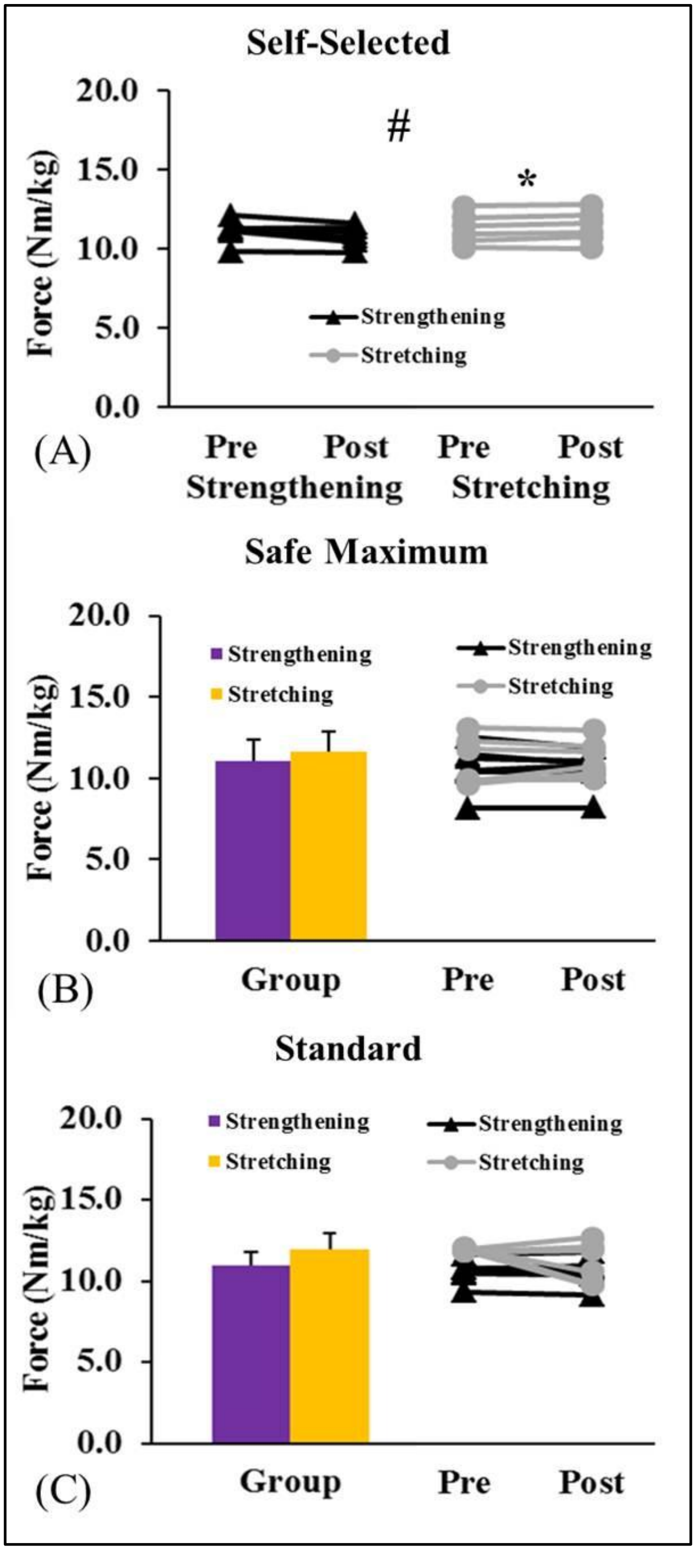

Figure 15: Peak normalized ground reaction force for both groups during the pre-test and post-test for each walking condition. Bar graphs represent whole group comparisons. Line graphs represent repeated measures comparisons with single lines for each subject. (# significant interaction; * p<0.05)

Summary

In summary, these subjects were healthy, fully functional old adults. Both groups were similar in age, height, mass, body mass index, physical function and mental function. Based on these results, a 12-week plantarflexor strength training program is effective at increasing strength of the plantarflexors. However, strength training did not affect gait kinematics or kinetics of healthy old adults during level walking while stretching does affect gait kinematics and kinetics of healthy old adults during level walking.

CHAPTER 5: DISCUSSION

The following chapter will discuss the results of this study in comparison to current literature. This chapter is divided into the following sections: 1) Subject Characteristics, 2) Strength Training, 3) Gait Kinematics, 4) Gait Kinetics, 5) The Effect of Strength Training and Stretching on Gait Biomechanics and 6) Summary.

Subject Characteristics

The subjects in the current study were very healthy and extremely mobile as indicated by their scores using the SPPB and SF-36 tests. Scores on the SPPB ranging from 10 to 12 are considered high physical function (Sayers et al., 2004). The average SPPB scores for the subjects in the current study were 11.2±1.6 for the strengthening group and 11.0±0.9 for the stretching group indicating that they have high physical function. This is consistent with previous literature testing healthy old adults, who had an average SPPB score of 10.8±1.35 (Iannuzzi-Sucich, Prestwood, & Kenny, 2002) and higher than other healthy old adults, 9.1±0.3 (Sayers et al., 2004). The high functional level of the subjects in the current study was further established with the average scores from the SF-36. According to the SF-36 manual, the population norm score is 45. The subjects in the strengthening group scored 54.7±2.2 and 58.2±3.6 for the physical and mental components, respectively. The subjects in the stretching group scored 53.4±3.5 and 55.5±6.8 for the physical and mental components, respectively. All of these scores are above the population norm, indicating that they are highly functional both physically and mentally. This is consistent with previous literature testing healthy old adults, who had an average score of 47.9±8.6 and 56.9±5.9 for the physical and mental components, respectively (Iannuzzi-Sucich et al., 2002). While all of the subjects in the current study were highly functional, there was a noticeable difference in the physical characteristics between groups. The average BMI was 26.2 and 23.5 kg/m^2 for the strengthening and stretching groups, respectively.

Strength Training

It is well accepted that strength training increases strength. Based on the results from the one repetition maximum tests and the peak ankle torque generated at the one repetition maximum load, strength training increases strength while stretching does not. The subjects in the strengthening group experienced a 13.6% increase in the one repetition maximum value for the left ankle press and a 25.0% increase in the peak ankle torque generated during the one repetition maximum load condition. This is similar to strength gains found in other strength training studies as summarized in Table 3. After 10 weeks of exercise, Judge et al. found at 30.9% increase in knee extensor one repetition maximum (1993). Subjects in a study by Carmeli et al. increased their knee extensor one repetition maximum by 11.4% after 12 weeks of strength training (2000). Caserotti et al. found a 24.8% increase in maximal voluntary contraction of a leg press after 12 weeks of heavy explosive resistance training (2008).

While there is much literature showing strength gains after strengthening exercises, many of them focus on large muscle groups such as the quadriceps and hamstrings. There are few studies that report strength changes in the plantarflexors and even fewer studies that look specifically at strength training of the plantarflexors. Chandler et al. reported a 13.6% increase in the plantarflexor torque after 10 weeks of resistance exercise (1998). Ferri et al. found a 21.6% increase in the one repetition maximum of the plantarflexors after 16 weeks of strength training. The current study demonstrates that a 12-week plantarflexor strength training program increases strength of the plantarflexors, which is consistent with previous literature.

The stretching group served as the control group for this study. Stretching exercises are often performed in conjunction with strengthening exercises; however, they do not increase strength. Four weeks of hamstring stretching had no effect on peak hamstring force (LaRoche, Lussier, & Roy, 2008) and after eight weeks of stretching the knee extensors and knee flexors, there was no increase in peak torque of either muscle group (Gallon et al., 2011). Likewise, Bird et al. found no significant increases in strength for the subjects in the flexibility program after 16 weeks of stretching (2009). The results of the current study are consistent with previous literature since the subjects in the stretching group did not significantly increase the left ankle press one repetition maximum or the peak ankle torque during the one repetition maximum load condition after twelve weeks of plantarflexor stretches.

Table 3: Percentage of strength increase after various strength training programs in old adults

	Strength Increase (%)
Current Study	**25.0**
Kalapotharakos et al., 2005	44.3
Judge et al., 1993	30.9
Caserotti et al., 2008	24.8
de Vos et al., 2005	15.0
Ferri et al., 2003	13.0
Carmeli et al., 2000	11.4
Average from previous studies listed above	*23.2*

Gait Kinematics

Gait kinematics in old adults are widely studied. Table 4 reports stride length and walking velocity from several studies of healthy old adults walking at a self-selected speed, a safe-maximum speed and a controlled walking speed condition. When walking at a self-selected speed, the subjects in the current study (both strengthening and stretching groups) took longer strides compared to subjects in previous literature. Concomitantly with increased stride length, the subjects in the current study walked faster than all of the subjects in the previous studies during the self-selected walking condition. In addition to taking longer strides and having a faster self-selected walking speed than most, the subjects in the current study also took longer strides and walked faster during the safe-maximum condition than healthy old adults in other studies. When walking at a standard speed of 1.5 m/s, the subjects in the current study took longer stride lengths than subjects in other studies as seen in Table 4.

Table 4: Stride length and walking velocity during self-selected, safe maximum and controlled walking conditions in old adults

	Stride Length (m)	**Velocity (m/s)**
Self-Selected Walking Condition		
Current Study	**1.53 ± 0.20**	**1.45 ± 0.17**
Cofré et al., 2011	1.43 ± 0.13	1.39 ± 0.14
Hartmann et al., 2009	1.38 ± 0.14	1.35 ± 0.18
Riley et al., 2001	1.21 ± 0.11	1.20 ± 0.10
Kerrigan et al., 1998	1.20 ± 0.12	1.19 ± 0.13
Lord et al., 1996	1.15 ± 0.13	1.13 ± 0.19
Graf et al., 2005	1.11 ± 0.15	1.05 ± 0.17
Judge et al., 1996	1.09 ± 0.01	1.03 ± 0.13
Averages from previous studies listed above	*1.22 ± 0.11*	*1.33 ± 0.15*
Safe Maximum Walking Condition		
Current Study	**1.67 ± 0.25**	**1.81 ± 0.28**
Cofré et al., 2011	1.49 ± 0.14	1.60 ± 0.04
Riley et al., 2001	1.35 ± 0.13	1.60 ± 0.20
Kerrigan et al., 1998	1.33 ± 0.14	1.55 ± 0.20
Cao et al., 2007	1.35 ± 0.18	1.37 ± 0.15
Averages from previous studies listed below	*1.38 ± 0.15*	*1.53 ± 0.15*
Controlled Walking Condition		
Current Study	**1.56 ± 0.16**	**1.50 ± 0.05**
DeVita and Hortobágyi, 2000	1.44 ± 0.08	1.48 ± 0.11

While overall the subjects in the current study had fast walking velocities, there were differences between groups. The subjects in the strengthening group actually performed worse during the self-selected walking condition, decreasing both stride length and velocity. Contrary to this, those subjects in the stretching group improved stride length and walking velocity during the self-selected walking condition demonstrating that a stretching intervention might be more effective at changing the gait biomechanics of healthy old adults versus a strength training program.

The range of motion at the ankle was similar between the subjects in the current study and those in previous literature at the self-selected walking speed. The average range of motion for the subjects in the current study was 24.1 ± 2.9 degrees. Other studies report ranges of 24.1 ± 9.3 (Kerrigan et al., 1998), 26.0 ± 6.0 (Graf et al., 2005) and 26.0 ± 8.0 degrees (Judge, Davis, & Ounpuu, 1996). When walking at a safe-maximum speed, the subjects in the current study had 25.3 ± 4.2 degrees of ankle motion compared to Cao, who reported 36.4 ± 5.9 degrees of motion (2007). At the standard speed of 1.5 m/s, the subjects in the current study had 24.1 ± 4.2 degrees of ankle motion compared to 26.7 ± 2.4 degrees from DeVita and Hortobágyi (2000). During level walking at three speed conditions, the ankle range of motion of the subjects in the current study did not change with twelve weeks of strength training or stretching of the plantarflexors and is consistent with measurements from previous literature. These findings are not altogether surprising. Normal gait only requires about 30° of ankle range of motion while the full passive ankle range of motion is close to 70° (Houglum, 2005). Since normal walking uses less than half of the available ankle range of motion, increasing ankle flexibility may not become apparent during normal walking tasks.

Gait Kinetics

While the only significant change detected was an increase in plantarflexor torque and the seconds peak ground reaction force during the self-selected walking condition for the stretching group, the gait kinetics overall in this study are consistent with values of previous literature. At the self-selected walking speed, the average positive ankle work of the subjects in the current study was 0.23 ± 0.07 J/kg, compared to an average of 0.23 ± 0.07 J/kg from other studies (Cofre et al., 2011; Silder et al., 2008). Average ankle power was 3.18 ± 0.79 W/kg compared to previous values of 3.79 ± 095 (Cofre et al., 2011) and 3.25 ± 0.94 W/kg (Silder et al., 2008). These patterns were similar for the safe maximum walking condition. Average positive ankle work was 0.27 ± 0.08 for the current study versus 0.25 ± 0.07 J/kg (Cofre et al., 2011; Silder et al., 2008). Average ankle power during the safe maximum condition was 3.73 ± 1.21 W/kg for the current study versus 3.64 ± 1.02 W/kg (Cofre et al., 2011; Silder et al., 2008). Overall, ankle joint kinetics were not affected by strength training or stretching and are consistent with values from previous studies.

To further explore this relationship between change in strength and walking biomechanics, we compared the peak plantarflexor torque generated during the walking conditions to that generated during the 100% load ankle press trials (Figure 10). For the strengthening group, the correlations were weak and nonsignificant, with the highest r=0.261 during the safe maximum walking condition. The strongest correlation observed was for the stretching group during the safe maximum condition with r=0.586. However, with such a small sample size, the critical value would have to be greater than or equal to 0.8114 to show significance. Based on these r values, we cannot say that these changes in plantarflexor torque are significantly different from zero and thus we did not observe a relationship between change in plantarflexor strength and gait kinetics during any of the walking conditions.

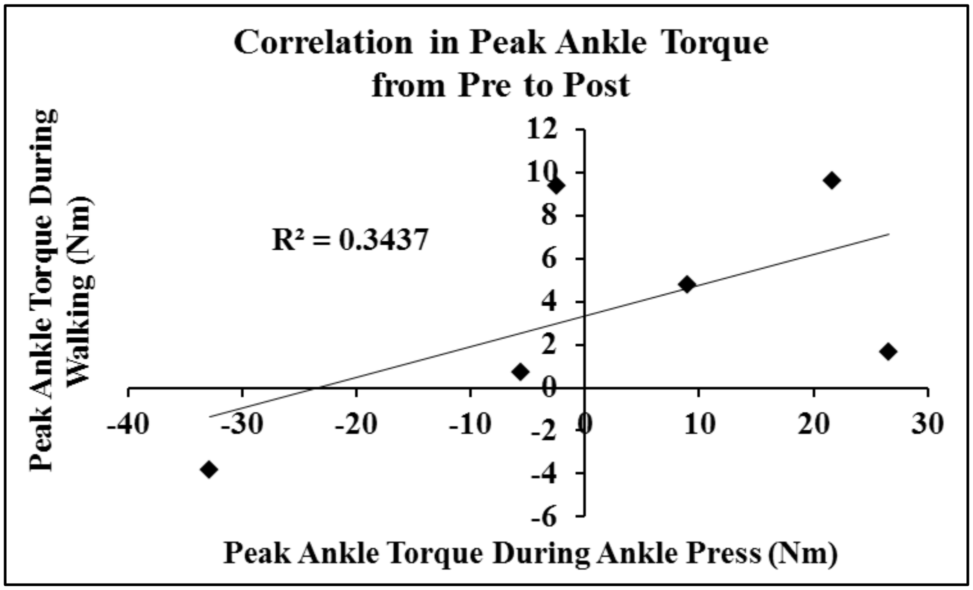

Figure 16: Correlation between the changes in peak ankle torque generated during the 100% load condition for the ankle press from the pre-test to post-test and the peak ankle torque generated during the safe maximum walking condition from the pre-test to post-test for the stretching group.

The Effect of Strength Training and Stretching on Gait Biomechanics

The effect of strength training on gait kinetics in old adults has not been widely studied. While gait kinematics such as walking velocity have been studied in old adults after participating in a strength training program, there have been no studies, to date, that examined gait kinetics in old adults after strength training (Beijersbergen, Granacher, Vandervoort, Devita, & Hortobagyi, 2013). Often, strength training is found to increase walking velocity. Judge et al., found a 7.7% increase in usual walking speed following and a 4.2% increase in maximum walking speed after twelve weeks of strength training (1993). Kalapotharakos reported a significant increase in maximum walking velocity of 31.2% after twelve weeks of strength training exercises (2005).

The current study is the first study to test the effect of plantarflexor strength training on the gait kinematics and kinetics in healthy old adults. While the current study only strengthened one muscle group and found no changes in the gait characteristics of old adults, other studies have found changes in the gait characteristics of old adults after strength training programs. The subjects in the strength training group did not walk faster in any walking condition but they did get stronger. On the other hand, the subjects in the stretching group did not get stronger but they chose a significantly higher self-selected walking speed while their safe maximum speed stayed the same. Overall the subjects in the current study were very healthy and mobile as demonstrated by their high SF-36, SPPB Scores, and fast self-selected and safe maximum walking velocities. Their initial self-selected walking speed at the baseline test was 1.45 m/s and is much faster than the average self-selected walking speed from previous literature (1.22 m/s). Additionally, their safe maximum walking speed was much faster than those speeds reported from previous studies (1.81 m/s versus 1.53 m/s). Perhaps the old adults who participated in the current study were at such a high level of functional capacity that the level of strength training gained in this study simply was not enough stimuli to create gait adaptations. Although the changes observed were not statistically significant, the lowest functioning subject increased stride length for all three walking conditions, increased velocity for the self-selected and safe maximum walking conditions as well as and peak plantarflexor torque and peak plantarflexor power for all three walking conditions after twelve weeks of plantarflexor strength training. This could suggest that a frailer population might experience more noticeable changes in their gait patterns after a plantarflexor strength training program. Additionally, it is possible that the strength gains needed to be much greater for it to have an effect on gait patterns. The length of the study may have also been a constraint. Unfortunately, the length of this exercise study was limited by the university’s schedule, so twelve weeks was long enough to increase strength but perhaps not long enough to increase strength to levels sufficient for gait adaptations. A third possibility is that strength training alone is not enough stimuli to cause changes in gait. Strategies such as gait retraining have been successfully used in the past to change the way healthy adults run. Crowell and Davis found that gait adaptations in runners persisted one month after the end of the gait retraining program to reduce the impact on the tibia (2011). Gait retraining has also been effective at decreasing step length asymmetry in a stroke patient and was maintained one month after the end of the program (Reisman, McLean, & Bastian, 2010). Since gait retraining can be effective in altering the gait patterns of healthy adults and those who are limited, perhaps is can be used in a healthy old adult population. A gait retraining program emphasizing the pushoff during gait coupled with a plantarflexor strength training program may be enough of a stimulus for gait adaptations to occur in healthy old adults.

Additionally it is interesting that the significant changes in walking biomechanics were detected in the stretching group. The stretching group was designed primarily as the control group in this study as it is well documented that stretching does not increase strength (Bird, Hill, Ball, & Williams, 2009; Gallon et al., 2011; LaRoche et al., 2008). However, since the ranges of motion in the lower extremity decrease with age (Cofre et al., 2011; Kerrigan et al., 1998), perhaps a stretching intervention would be beneficial at maintaining or increasing flexibility during walking. The results of the current study showing a significant increase in walking velocity, stride length and plantarflexor torque during the self-selected walking condition for the stretching group but not in the strengthening group suggest this as a possibility. Perhaps stretching increased the full range of motion available at the ankle or decreased the resistance of the ankle joint within the range of motion, making it easier to move. At this point, however, the relationship between stretching and these changes in gait biomechanics can only be suggested since ankle range of motion was not directly measured in this study (for example, passive ankle range of motion measurements using a goniometer). A future study could further explore the effect of stretching interventions on the gait biomechanics of healthy old adults.

Summary

Like in any research study, there were limitations. As expected, strength training increases strength while stretching does not. Old adults in the strengthening group significantly increased plantarflexors strength while no change in plantarflexor strength was observed in the stretching group. Despite the increase in strength of the plantarflexors, there were few changes in ankle kinematics during any of the self-selected, safe maximum and standard speed walking conditions. Additionally, there were no changes in plantarflexor torque or power during any of the walking conditions. Overall, there were no changes in the gait biomechanics of old adults walking at a self-selected, safe maximum or standard speed following twelve weeks of plantarflexor strength training. Therefore, the hypothesis of this study is not supported. Previous studies have reported increases in walking velocity following strength training which is contrary to the findings in the current study. It is possible that the old adults participating in the current study were already at such a high level of function that strength training alone was not enough of a stimulus to induce gait adaptations such as increased walking velocity. Furthermore, it is possible that twelve weeks of strength training is not long enough to affect the gait patterns of healthy old adults or that training just the plantarflexors is not an important factor in changing gait patterns. Further research is needed to explore the mechanism by which strength training affects walking velocity as seen in previous literature but not in the current study. Additionally, the effects of stretching interventions on gait biomechanics should be more closely investigated since the subjects in the stretching group displayed some changes from the pretest to posttest in the self-selected walking condition.

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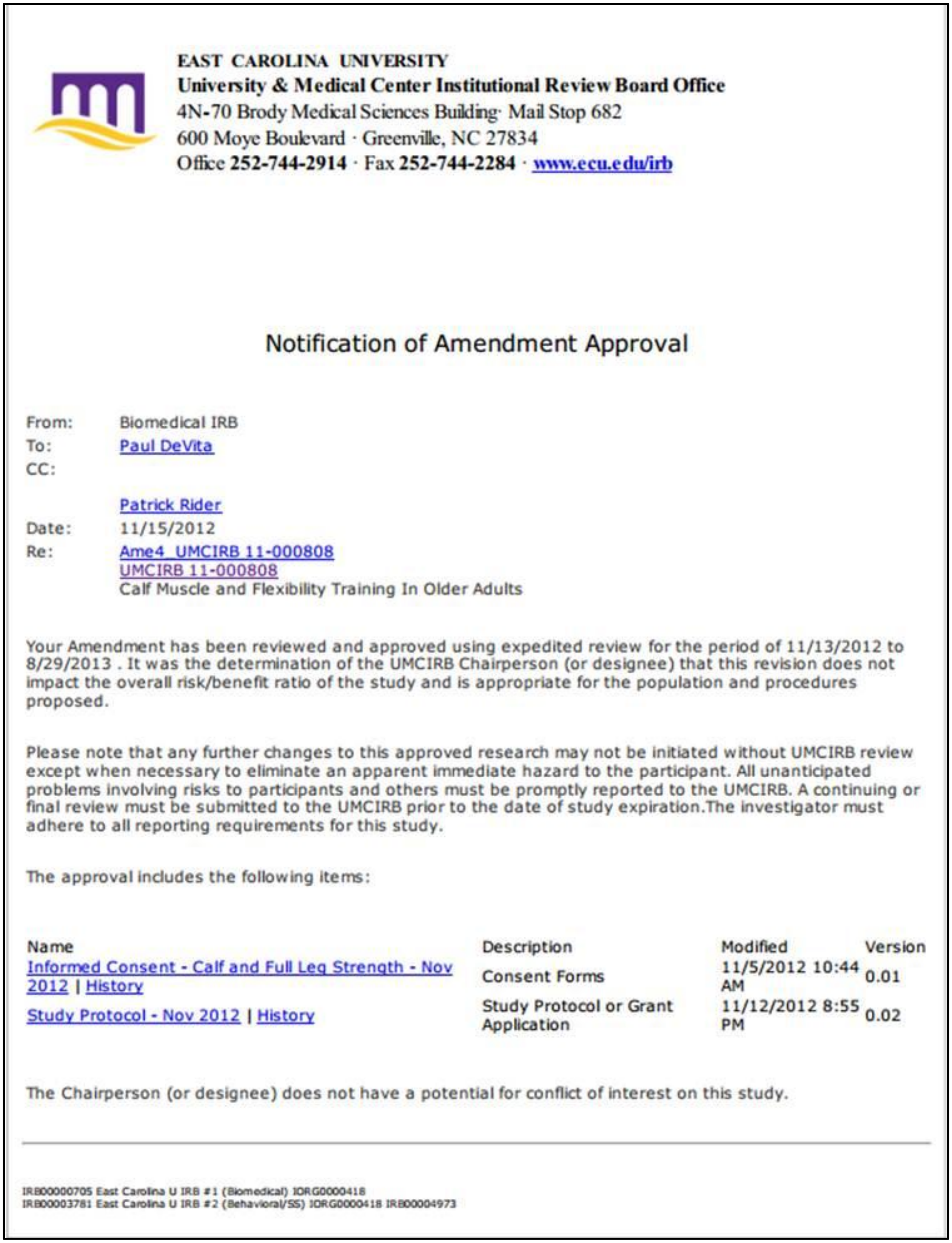
APPENDIX A



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Notification of Amendment Approval

From: Biomedical IRB
To: Paul DeVita
CC:
Patrick Rider
Date: 11/15/2012
Re: Ame4_UMCIRB 11-000808
UMCIRB 11-000808
Calf Muscle and Flexibility Training In Older Adults

Your Amendment has been reviewed and approved using expedited review for the period of 11/13/2012 to 8/29/2013 . It was the determination of the UMCIRB Chairperson (or designee) that this revision does not impact the overall risk/benefit ratio of the study and is appropriate for the population and procedures proposed.

Please note that any further changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. A continuing or final review must be submitted to the UMCIRB prior to the date of study expiration.The investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description	Modified	Version
Informed Consent - Calf and Full Leg Strength - Nov 2012 | History	Consent Forms	11/5/2012 10:44 AM	0.01
Study Protocol - Nov 2012 | History	Study Protocol or Grant Application	11/12/2012 8:55 PM	0.02

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418 IRB00004973